Combating Micronutrient Deficiencies: Food-based Approaches

Edited by

Brian Thompson and Leslie Amoroso

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Contents

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Foreword

The importance of food-based approaches for the prevention and control of micronutrient deficiencies as well as for the improvement of nutrition in general is fully recognized by the Food and Agriculture Organization of the United Nations (FAO). FAO, a specialized UN agency, has as its mandate the raising of levels of nutrition and ensuring humanity's freedom from hunger by promoting sustainable agricultural and rural development. Focusing on the unique relationship between agriculture, food and nutrition, FAO works actively to protect, promote and improve established food-based systems as the sustainable solution to ensure food and nutrition security and, by doing so, to achieve the nutrition-related Millennium Development Goals (MDGs). FAO is committed to supporting the promotion of the production and consumption of micronutrient-rich foods as the sustainable solution to micronutrient malnutrition. This activity clearly falls under the Organization's mandate, and the Nutrition and Consumer Protection Division, under whose direction this publication has been prepared, plays an important role in its implementation.

Inadequate attention has so far been paid to food-based approaches in achieving sustainable improvements in the micronutrient status of vulnerable populations. The Nutrition and Consumer Protection Division has therefore undertaken the preparation of this publication to provide more emphasis on these strategies. For the first time in one volume, *Combating Micronutrient Deficiencies: Food-based Approaches* brings together available knowledge, case studies on country-level activities, lessons learned and success stories showing that food-based approaches are the only viable and sustainable solution to micronutrient malnutrition.

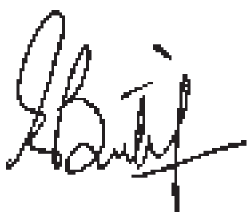
The purpose of this publication is to provide policy makers, agronomists, food and nutrition security planners, programme implementers and health workers with the information needed to better understand, promote, support and implement food-based strategies to combat micronutrient deficiencies in their respective countries. This book will appeal to professionals in the sectors of food security, nutrition, public health, horticulture, agronomy, animal science, food marketing, information, education, communication, food technology (preservation, processing and fortification) and development.

The book is designed as a useful supplementary source for Bachelor, Master and PhD courses on public health; human nutrition (including nutrition education and communication courses); micronutrient deficiency interventions, programmes and policies, and food and nutrition security policy interventions and programmes; and food and agriculture in agricultural research.

A varied diet is the key to solving micronutrient deficiency problems. The elimination of micronutrient deficiencies on a sustainable basis will only be possible when the diets of vulnerable populations provide all required nutrients in adequate amounts. Programmes in several countries show that comprehensive, well-designed food-based strategies can improve the diets of vulnerable populations in a relatively short period of time and that these improvements can be sustained. A number of countries demonstrate that problems of micronutrient deficiencies can be resolved when government policies and programmes are directed to the goal of increasing production of and access to vitamin- and mineral-rich foods, in combination with marketing and education activities to improve the consumption of such foods. FAO support to food-based approaches also extends to fortification where it is seen as part of an overall strategy for a total food and total diet approach.

Currently, the combined effects of prolonged underinvestment in nutrition, food and agriculture, the recent food price crisis and the economic downturn have led to increased hunger and poverty, jeopardizing the progress achieved so far in meeting the MDGs. According to FAO, there were 105 million more hungry people in 2009 than in the previous year; the number of malnourished people now stands at 1.02 billion. This book shows how food-based approaches can not only reduce the prevalence of micronutrient malnutrition, but also improve the nutritional status of all populations and mitigate one of today's greatest public health problems.

It is hoped that *Combating Micronutrient Deficiencies: Food-based Approaches* will be a catalyst for continuing the process of dialogue and information exchange to support, promote and implement food-based strategies to reduce micronutrient deficiencies.



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Preface

We are proud to bring you the first edition of the publication *Combating Micronutrient Deficiencies: Food-based Approaches*. This book aims at documenting the benefits of food-based approaches, particularly of dietary improvement and diversification interventions, in controlling and preventing micronutrient deficiencies. The focus of the publication is on practical actions for overcoming micronutrient malnutrition in a sustainable manner through increasing access to and availability and consumption of adequate quantities and variety of safe, good-quality food. The book is unique in this area as it is the first to gather a variety of relevant articles under one cover to encourage and promote further attention, importance and investment in food-based strategies to combat micronutrient deficiencies.

Although the most severe problems of micronutrient malnutrition are found in developing countries, people of all population groups in all regions of the world can be affected by micronutrient deficiencies. Approximately two billion people – about a third of the world's population – are today deficient in one or more micronutrients. This is one of the most serious impediments to socio-economic development, contributing to the vicious cycle of malnutrition, underdevelopment and poverty. Micronutrient malnutrition has long-ranging effects on health, learning ability and productivity, leading to high social and public costs, reduced work capacity in populations due to high rates of illness and disability and tragic loss of human potential. Therefore, overcoming micronutrient deficiencies is a precondition for ensuring rapid and appropriate development.

National, regional and international efforts to improve micronutrient status worldwide have been guided by recommendations made during international meetings and high-level conferences. At the International Conference on Nutrition (ICN), jointly convened by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) in Rome in 1992, delegates of participating countries pledged 'to make all efforts to eliminate … iodine and vitamin A deficiencies' and 'to reduce substantially … other important micronutrient deficiencies, including iron' before the end of the decade. Linked to the World Declaration was the Plan of Action for Nutrition which recommended that governments give priority to food-based approaches to combat micronutrient malnutrition.

The Plan of Action of the World Food Summit 1996 re-affirmed the ICN goals 'governments, in partnership with all actors of civil society … will implement the goals of preventing and controlling specific micronutrient deficiencies as agreed at the ICN'. Furthermore, the Declaration of the World Food Summit: *five years later* in 2002 recognized 'the importance of interventions to tackle micronutrient deficiencies which are cost-effective and locally acceptable'. Addressing micronutrient deficiencies will also help bring the international community closer to achieving the Millennium Development Goals by 2015.

Food-based approaches promote the consumption of foods that are naturally rich in micronutrients or are enriched through fortification. To be successful they require a sound scientific basis and need to be built on practical experiences in nutrition; agricultural sciences, including horticulture, agronomy, animal science and food marketing; information, education and communication; food technology related to preservation, processing and fortification; and in problem assessment, programme management and monitoring and evaluation.

FAO strongly emphasizes that food-based approaches, which include food production, dietary diversification and food fortification, are sustainable strategies for improving the micronutrient status of populations. Increasing access to and availability and consumption of a variety of micronutrient-rich foods not only have a positive effect on micronutrient status but also contribute to improved nutrition in general. In addition to its intrinsic nutritional value, food has social and economic significance which, for many people, especially those living in developing countries, is commonly mediated through agriculture and agriculture-related activities that sustain rural livelihoods. The multiple social, economic and health benefits associated with successful food-based approaches that lead to year-round availability, access and consumption of nutritionally adequate amounts and varieties of foods are clear. The nutritional well-being and health of individuals is promoted, incomes and livelihoods supported, and community and national wealth created and protected.

However, progress in promoting and implementing food-based strategies to achieve sustainable improvements in micronutrient status has been slow. They were often overlooked as governments, researchers, the donor community and health-oriented international agencies sought approaches for overcoming micronutrient malnutrition that had rapid start-up times and produced quick and measurable results. Much effort to control the three major deficiencies of public health concern – i.e. vitamin A, iron and iodine deficiencies – has focused on supplementation. Although supplementation has saved many lives and much suffering has been avoided as a result of these efforts, and while supplementation remains necessary for groups at high risk and as a short-term emergency measure, it fails to recognize the root causes of micronutrient malnutrition and to assist communities and households to feed and nourish themselves adequately. Supplementation simply cannot provide the overall long-term economic benefits of economy and sustainability that food-based approaches can deliver.

The idea for this publication originated during the First International Meeting of the Micronutrient Forum held in Istanbul, Turkey, in April 2007. With very few posters and little discussion on food security and dietary diversification, the Istanbul meeting highlighted the lack of attention to and information on this important aspect of the fight against micronutrient malnutrition. On that occasion, FAO discussed with interested individuals the possibility of putting together this publication for which support was received.

Subsequently, a 'call for papers' was prepared and widely circulated through different Internet sites and web forums. Expertise from the nutrition community, including programme managers and researchers from universities, research institutions, food industries and enterprises at various levels and disciplines, non-governmental organizations (NGOs) and international organizations were invited to submit articles. Papers were welcomed from a wide diversity of relevant disciplines including nutrition, agriculture, horticulture, education, communication and development.

The publication has been as inclusive as possible and has benefited from the contribution of 100 authors. We have captured and included many different views and analyses and created an interesting and rich combination of knowledge and experience.

Effective correspondence and communication with the authors was maintained throughout the preparation process of the publication. A peer review panel was established to provide technical inputs to, comments on and suggestions for the papers. The hard work of the reviewers and their dedicated efforts in providing feedback to the authors was critical in ensuring the high quality of the contributions.

Many developing countries, international agencies, NGOs and donors are beginning to realize that food-based strategies that promote diet diversity are a viable, cost-effective and sustainable solution for controlling and preventing micronutrient malnutrition. We hope that this book will serve as the basis for future dialogue, debate and information exchange and facilitate wider support for an international movement committed to the implementation of effective, long-term food-based solutions to undernutrition and for combating micronutrient deficiencies, thus allowing the world population to achieve its full human and socio-economic potential.

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Introduction

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This publication contains 19 chapters, each of which, with a diverse and unique emphasis and focus, shows the benefits – and in some cases the limitations – of food-based approaches for preventing and controlling micronutrient malnutrition. The purpose of this introductory chapter is to set the scene for the publication, briefly synthesizing the crucial aspects of each article. One hundred authors with different backgrounds have contributed to this volume, which brings together for the first time under one cover available knowledge, success stories and lessons learned on country-level activities that help to demonstrate that food-based approaches are viable, sustainable and long-term solutions to overcoming micronutrient malnutrition. Furthermore, the book is an exceptionally rich source of references on the subject.

Chapters 1 and 2 present an *overview* of current developments in food-based approaches and examine some of the studies and programmes applying these strategies. Chapter 1, 'Strategies for Preventing Multi-micronutrient Deficiencies: A Review of Experiences with Food-based Approaches in Developing Countries' by Rosalind Gibson, observes the importance of coexisting multiple micronutrient deficiencies is gaining recognition prompted by disappointing outcomes frequently found with single micronutrient supplements. Concerned about the feasibility and sustainability of supplementation in poor resource settings, the chapter discusses the growing emphasis on food-based approaches including fortification, dietary diversification and modification, and biofortification. A summary is provided of new developments in food-based approaches, their advantages and limitations, and some of the efficacy studies and programmes utilizing food-based strategies to combat micronutrient malnutrition are examined. Chapter 2, 'Addressing Micronutrient Malnutrition to Achieve Nutrition Security' by Prakash Shetty, shows that combating micronutrient deficiencies requires short-, intermediate- and long-term sustainable approaches. The article emphasizes that, in addition to micronutrient supplementation and fortification, we need to promote sustainable food-based approaches to enable adequate intakes of micronutrients by much of the population including through dietary diversification strategies and agriculture-based approaches. By ensuring food and nutrition security and reducing the widespread problem of micronutrient malnutrition, the Millennium Development Goals may be

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reached. While agricultural approaches have the potential to significantly impact nutritional outcomes in a sustainable way, Chapter 3, 'Agricultural Interventions and Nutrition: Lessons from the Past and New Evidence' by Mary Arimond *et al*., notes that there is insufficient understanding of the evidence base on how best to achieve this potential. Looking at the available evidence linking agricultural interventions to nutrition outcomes, the chapter describes the pathways through which agricultural interventions impact nutrition and reviews the types of studies that have provided insights on the links between agriculture and nutrition. Two case studies are presented that show how well-designed interventions can successfully diversify diets and/or impact on micronutrient intakes and nutritional status outcomes and can have impact at scale. Finally, lessons for the design of future interventions are provided including cost-effectiveness, scaling up and sustainability.

Chapters 4 and 5 show how *multi-sectoral programmes* with food-based approaches components can alleviate undernutrition and micronutrient malnutrition. The impact of a comprehensive multi-sectoral approach in reducing morbidity and mortality tends not to be as well documented as single interventions and hence evidence for the effectiveness of this approach remains inconclusive. Chapter 4, 'A 3-year Cohort Study to Assess the Impact of an Integrated Food- and Livelihood-based Model on Undernutrition in Rural Western Kenya' by Jessica Fanzo *et al*., aims to correct this by evaluating the impact of an integrated food- and livelihood-based model on nutrition-related outcomes in rural western Kenya. A 3-year prospective cohort study was conducted collecting data on wealth, socio-economic status, health, food and nutrition security, food consumption and dietary diversity, anthropometry and blood chemistry. Encouraging evidence is presented that a multi-sectoral food- and livelihood-based model can improve diet quality, enhance food security and positively affect childhood nutritional outcomes. The wider application of this approach to a diversity of agro-ecological zones in sub-Saharan Africa is currently being assessed. Chapter 5, 'Food-based, Low-cost Strategies to Combat Micronutrient Deficiencies: Evidence-based Interventions in Lesotho and Malawi' by Juliet M. Aphane *et al*., shows it is possible to enable resource-poor, HIV- and drought-affected communities to combat micronutrient deficiencies through food-based approaches. The project carried out interventions in food and nutrition security, health, education and social welfare but mainly the food and nutrition security component is discussed. Several strategies were used including institution building, human resource development, participatory approaches, bio-intensive methods of agriculture, and crop and diet diversification. Communities produced more and had greater access to a variety of micronutrient-rich foods, including animal-source foods, all year round. Nutrition education and improved techniques in food production, processing, preservation and storage and preparation increased the consumption of micronutrient-rich foods.

Increased intake of *animal-source foods* improves nutritional status in populations with high levels of nutrient deficiencies. However, the identification of effective strategies to increase access to and consumption of animal-source foods by vulnerable populations has proven challenging. The benefits of animal-source foods in combating micronutrient deficiencies are discussed in Chapters 6 to 8. Chapter 6, 'Animal-source Foods as a Food-based Approach to Address Nutrient Deficiencies and Functional Outcomes: A Study among Kenyan Schoolchildren' by Charlotte G. Neumann *et al*., shows how food-based approaches, particularly utilizing animal-source foods, offer potentially sustainable solutions to multiple deficiencies. Looking at school feeding, a causal link was found between intake of animal-source foods and micronutrient nutrition, growth and cognitive and behavioural outcomes, including physical activity, initiative, arithmetic test and leadership behaviours. Differences in meat versus milk consumption and between animal-source foods and plant-based snacks on children's functional outcomes were found. Chapter 7, 'Small Animal Revolving Funds: An Innovative Programming Model to Increase Access to and Consumption of Animal-source Foods by Rural Households in Malawi' by A. Carolyn MacDonald *et al*., looks at a community-based intervention to increase household access to and consumption of animal-source foods, implemented as part of a comprehensive, 9-year nutrition and health programme in Malawi. Small animals were given to poor households accompanied by training on animal husbandry and intensive nutrition education to promote consumption of the animal products as part of a broader anaemia-control strategy which included iron supplementation and malaria control. The intervention increased access to and consumption of animal-source foods and the prevalence of anaemia in women decreased. However, the authors admit that the potential contribution of animal-source foods in the diet cannot be separated from the potential impact of the integrated programme. Chapter 8, 'Aquaculture's Role in Improving Food and Nutrition Security' by Brian Thompson and Rohana Subasinghe, describes the benefits of aquaculture, which provides almost half of the total worldwide food fish supply, for improving the diets of even the very poor through increased consumption of protein, fatty acids, vitamins and minerals. The authors argue that aquaculture policies and plans need to ensure that the small-scale fisheries sector in developing countries benefits from improvements in this sector, as aquaculture is not only an essential source of nutrition, but also a key sector that can decrease poverty and alleviate malnutrition, including micronutrient deficiencies. They conclude that small-scale aquaculture has to be developed as a responsible and sustainable entrepreneurial activity that is financially viable so as to assure its efficacy in poverty reduction and nutrition improvement, including the increase in the micronutrient status of vulnerable populations.

Fruits and vegetables are a fundamental part of a balanced diet and a good source of vitamins and minerals. Chapters 9 to 13 describe the benefits of vegetables and fruits in preventing and combating micronutrient malnutrition. Chapter 9, 'A Home Gardening Approach Developed in South Africa to Address Vitamin A Deficiency' by Mieke Faber and Sunette Laurie, describes a home garden strategy that integrates gardening activities with nutrition education, using community-based growth monitoring as an entry point in South Africa. A positive effect on maternal knowledge of vitamin A nutrition, dietary intake of provitamin A-rich vegetables, child morbidity as reported by the caregiver and vitamin A status of children is reported. Non-participating households within the project area were exposed to the promotion activities and benefited from the spill-over effect. Provitamin A-rich vegetables and fruits contributed significantly towards achieving the recommended dietary intake of vitamin A and other micronutrients. The chapter concludes that home gardening is a long-term strategy that contributes to combating vitamin A and other nutritional deficiencies. Constraints experienced with vegetable gardens and their possible solutions are discussed. The World Vegetable Center (AVRDC) conducts research and development activities to increase access to and improve consumption of diverse and nutrient-rich vegetables, particularly in areas where malnutrition is prevalent. In Chapter 10, Madan L. Chadha *et al*. describe 'AVRDC – The World Vegetable Center's Approach to Alleviate Malnutrition', which focuses on increasing vegetable productivity, availability and consumption; improving the nutrient content and phytochemical density of vegetables; and enhancing the bioavailability of nutrients from vegetables. The impact of vegetable consumption on health and economic development, as well as the health benefits of consuming vegetables high in bioactive compounds, are discussed. Schools are increasingly recognized as important settings for promoting healthy nutrition and eating practices in children. Chapter 11, 'Introducing Vegetables into the India Mid-day Meal (MDM) Programme: The Potential for Dietary Change' by Ellen Muehlhoff *et al*., reviews current literature on school-based fruit and vegetable initiatives. The chapter describes the process and the results of a pilot intervention in urban Indian schools to promote increased vegetable consumption through the Mid-day Meal (MDM) programme and to create awareness among teachers and children on the health benefits of vegetables. Adequate nutrition is crucial during childhood and a diet rich in micronutrients is vital for good physical growth, mental development and prevention of infectious diseases. The chapter shows that the introduction of vegetables into MDM is feasible and sustainable if adequate funds are allocated. The authors conclude that, if used effectively, the MDM has the potential to become a major tool for improving vegetable consumption among school-age children both in urban and rural areas of India. Poor maternal micronutrient status resulting from poor-quality diets before and during pregnancy impairs fetal growth and development. Chapter 12, 'Developing Micronutrient-rich Snacks for Pre-conception and Antenatal Health: the Mumbai Maternal Nutrition Project (MMNP)' by Devi Shivashankaran *et al*., describes how the development of locally produced food supplements improves the quality of the diet of young women living in Mumbai slums, India. A cooked snack of green leafy vegetables, fruit and milk which could be distributed daily to women was developed. The authors conclude that it is possible to develop palatable, culturally acceptable and safe micronutrient-rich food supplements using a low-technological approach and locally available fresh and dehydrated ingredients. The Pacific island state of Pohnpei, Micronesia, has experienced much change in diet and lifestyle since the 1970s: traditional local foods have been neglected and there has been a shift to rice and imported processed foods which, at the same time, have been accompanied by the emergence of serious micronutrient deficiencies and non-communicable diseases. Chapter 13, 'Approaches and Lessons Learned for Promoting Dietary Improvement in Pohnpei, Micronesia' by Lois Englberger *et al*., describes an awareness campaign on the benefits of growing and consuming local food, especially carotenoid-rich bananas, for nutrition. As yellow-fleshed carotenoid-rich foods (banana, taro, pandanus and breadfruit varieties) were identified and promoted, banana and taro consumption increased as did the number of the varieties consumed. The awareness campaign was considered a success and the authors suggest its application in other Pacific Islands.

Chapters 14 and 15 describe the benefits of food-based approaches for *overcoming single specific micronutrient deficiencies*. Chapter 14, 'A Food Systems Approach to Increase Dietary Zinc Intake in Bangladesh Based on an Analysis of Diet, Rice Production and Processing' by Anne-Marie B. Mayer *et al*., suggests that an understanding of the zinc content of rice at different stages of the process from field to fork may be used to identify and plug 'nutrient leaks' in the food system. In villages in Bangladesh, the potential for intakes of zinc increases if soil zinc is above the critical level and adjustments are made to milling, cooking and local variation in the zinc content of rice varieties, in that order. It is suggested that if all these changes are implemented, dietary zinc could increase by more than 50%. Iron deficiency is the most prevalent dietary deficiency worldwide affecting almost two billion people. Chapter 15, 'Combating Iron Deficiency: Food-based Approaches' by Brian Thompson, describes the requirements for iron and related micronutrients and the prevalence and geographic and socio-economic distribution of anaemia. The chapter outlines the public health consequences of anaemia on both the individual and society and discusses the determining factors that can lead to or hinder their alleviation. The chapter describes policies and intervention programmes that can effectively alleviate micronutrient deficiencies and highlights the commitment of the Food and Agriculture Organization of the United Nations to place food-based strategies for preventing micronutrient deficiencies high on the development policy agenda. The chapter concludes that increasing the availability and consumption of a nutritionally adequate diet is the only sustainable long-term solution, not only for combating iron-deficiency anaemia, but also for preventing and controlling other micronutrient deficiencies.

Chapters 16 to 18 discuss *food fortification*. Chapter 16, 'Human Micronutrient Deficiencies: Linkages with Micronutrient Deficiencies in Soils, Crops and Animal Nutrition' by Maarten Nubé and Roelf L. Voortman, discusses the connection between micronutrient deficiencies in soils, crops, animal and human nutrition. The chapter asks whether the application of micronutrients as fertilizer is realistic and feasible for addressing human micronutrient deficiencies. Evidence for direct quantitative relationships between micronutrient deficiency in soils and human nutrition is clearly available for iodine and selenium, and possibly also for zinc. Addition of these micronutrients to soils can substantially increase crop micronutrient content and thus contribute to ameliorating human micronutrient deficiencies. While recognizing the potential for developing new crop varieties through plant breeding and genetic manipulation (genetically modified organisms), for some micronutrients there appears to be evidence that micronutrient fertilization in some cases may be an alternative approach. For example, worldwide the element selenium is unequally distributed in the soil. For climatic and geochemical reasons Finland is one of the low-selenium regions in the world. To improve the quality of Finnish foods and animal health and to increase the selenium intake of the population, it was decided in 1984 to supplement compound fertilizers with selenium. Chapter 17, 'Nationwide Supplementation of Sodium Selenate to Commercial Fertilizers. History and 25-year Results from the Finnish Selenium Monitoring Programme' by Georg Alfthan *et al*., describes the effects of the supplementation of selenium in commercial fertilizers on soils, feeds, basic foodstuffs, dietary selenium intake, human tissues and environment. In Finland, where the geochemical conditions are relatively uniform, the nationwide supplementation of fertilizers with selenium has proved to be an effective, safe and controlled way of bringing selenium intake of populations up to the recommended level. Chapter 18, 'Leaf Concentrate and Other Benefits of Leaf Fractionation' by M.N. Glyn Davys *et al*., describes the nutritional qualities of leaf concentrate, providing the technical details of leaf fractionation at domestic and intermediate scales of production. It reviews the evidence for the effectiveness of leaf concentrate in improving human nutritional status and the factors that have slowed down its adoption on a larger scale. The authors propose how these may be overcome and argue the possible wider role of leaf concentrate in combating human malnutrition, including its use as a locally produced ready-to-use therapeutic food.

In conclusion, Chapter 19 describes how the *disability-adjusted life years (DALYs) methodology* can be a useful approach for economically assessing cost-effectiveness in terms of the nutritional impact of interventions. The development of biofortification programmes, for example in Nicaragua, can complement traditional food-based strategies, but their applicability and continued development ought to be strengthened with an accurate assessment of cost-effectiveness and their economic impact. The DALYs methodology could be a good approach for this. Chapter 19, 'Disability-Adjusted Life Years (DALYs): a Methodology for Conducting Economic Studies of Food-based Interventions such as Biofortification' by Salomón Pérez Suárez, describes the DALYs methodology which is used to evaluate interventions in health and nutrition (biofortification) in economic terms, and then applies it in the case of iron-biofortified beans in Nicaragua. The DALYs are a useful approach for the economic assessment of nutritional interventions such as biofortification, but the author points out that the principal constraint is the availability and quality of the information required for its application.

The chapters have been selected and the publication compiled to showcase and document the impact of food-based approaches on nutrition, drawing as much as possible on evidence-based experiences. This has been achieved with the contributions from this diverse and learned group of researchers and experts who all point to the need for viable, long-term and sustainable interventions and programmes for the alleviation of micronutrient deficiencies among vulnerable population groups. What the chapters also point out is the need for better documentation of the impact of agricultural development programmes and food-based interventions on people, and specifically on their ability to produce, acquire and consume better diets in terms of quantity, quality and variety of nutrient-rich foods for improving nutrition in general and for alleviating micronutrient deficiencies in particular. We need to keep in mind that Ministries of Finance, investment banks and donors all require firm evidence from development strategists and agricultural planners that the approach proposed has an impact, and that this impact can be measured in a way that can lend itself to analysis of its cost-effectiveness. Consequently, we need to make further efforts to better document and collect the scientific evidence to demonstrate the impact and effectiveness of food-based approaches for preventing and controlling micronutrient malnutrition.

1 Strategies for Preventing Multi-micronutrient Deficiencies: a Review of Experiences with Food-based Approaches in Developing Countries

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Abstract
The importance of coexisting micronutrient deficiencies in developing countries is gaining recognition, prompted by the disappointing responses often observed with single micronutrient supplements. Further, of concern is the feasibility and sustainability of supplementation as a mode of delivery in poor resource settings. Consequently, there is increasing emphasis on food-based approaches: fortification, dietary diversification and modification, and biofortification. Novel delivery approaches exist for fortifying complementary foods in the household using tablets, sprinkles and fat-based spreads. These are all designed to supply micronutrients without any changes in feeding practices, and irrespective of the amount of food consumed. A version of the fortified spread is also used as a ready-to-use therapeutic food for treating malnourished children. Dietary diversification and modification, in conjunction with nutrition education, focus on improving the availability, access to and utilization of foods with a high content and bioavailability of micronutrients throughout the year. The strategies are designed to enhance the energy and nutrient density of cereal-based porridges; increase the production and consumption of micronutrient-dense foods (especially animal-source foods); incorporate enhancers of micronutrient absorption; and reduce the phytate content of cereals and legumes through germination, fermentation and soaking.

In the future, biofortification via processes such as agronomic practices, conventional plant breeding or genetic modification holds promise as a sustainable approach to improve micronutrient adequacy in the diets of entire households and across generations in developing countries. This review summarizes new developments in food-based approaches, their advantages and limitations, and examines some of the efficacy studies and programmes utilizing food-based strategies to alleviate micronutrient deficiencies.

Key words: complementary food supplements, fortification, household dietary strategies, biofortification

Introduction

The existence of multiple micronutrient deficiencies in developing countries is gaining increasing recognition (1). Their aetiology is multi-factorial: inadequate intakes and genetic, parasitic and infectious diseases may all play a role (2,3). Inadequate intakes of certain micronutrients such as iodine, selenium and zinc can also be exacerbated by environmental factors, as their content in plant-based foods is dependent on soil trace element levels (4).

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Micronutrient deficiencies can have major adverse health consequences, contributing to impairments in growth, immune competence, mental and physical development, and poor reproductive outcomes (1,5) that cannot always be reversed by nutrition interventions.

Clearly, there is an urgent need for programmes to alleviate micronutrient deficiencies in developing countries. Strategies commonly used are supplementation and food-based approaches, preferably in conjunction with public health interventions such as promotion and support of breastfeeding and control of infectious and parasitic diseases. Several efficacy trials employing multi-micronutrient supplements have been conducted on selected population groups in developing countries. Results have been mixed, depending on the combination of micronutrients included, age or life-stage group, baseline nutritional status of the subjects (including HIV status), study setting and duration, and the outcomes measured (6–12). Such discrepancies have highlighted that a cautious approach is needed with regard to routine use of micronutrient supplements, especially when they contain large doses of iron taken in a single dose in malaria-endemic areas (13). Distribution and sustainability of supplementation programmes are additional concerns in poor resource settings. As a consequence, increasingly, food-based approaches involving fortification, improving dietary quality through diversification/modification and nutrition education, and biofortification are being pursued. Some of these new developments, especially appropriate for poor resource settings, are discussed below.

New Approaches for Fortifying Complementary Foods

Inadequacies in several micronutrients, notably iron, zinc and calcium, and sometimes vitamin A, vitamin B_6 and riboflavin, have been reported in complementary foods in many developing countries (14–16). Such deficits arise in part because unrefined cereals are often used as a basis for complementary foods in poor resource settings. These staples contain high levels of phytic acid and/or polyphenols, components known to inhibit absorption of iron, zinc and calcium (15). Unfortunately, addition of animal-source foods, especially red meat and organ meats which are rich sources of absorbable iron and zinc, vitamin B_6, riboflavin, vitamin B_{12} and in some cases vitamin A, is often not feasible in complementary foods given to infants living in poor resource settings.

Use of complementary food supplements

In an effort to reduce risk of these micronutrient inadequacies during the complementary feeding period, complementary food supplements (CFSs) have been developed. At present, three types of CFS are available: (i) crushable or water-soluble micronutrient tablets – termed foodlets; (ii) micronutrient powders – termed sprinkles; and (iii) micronutrient lipid-based fortified spreads – termed lipid-based nutrient supplements (LNSs). They have been summarized in detail by Nestel *et al*. (17). The CFSs have been designed to supply vitamins and minerals at the level of one or two recommended dietary allowances, without any changes in feeding practices and irrespective of the amount of complementary food consumed. A modified version of micronutrient sprinkles containing a lower amount of iron per serving is now available for use in malaria-endemic areas in an effort to avoid the potential adverse effects of a large bolus of iron taken in a single dose. This modified sprinkles formulation also contains lower amounts of zinc, vitamin A and iodine, copper and added vitamin K, and can be added to family foods as well as home-prepared complementary foods (13).

Unlike the foodlets or sprinkles, the LNSs also provide a source of energy, protein and essential fatty acids – linoleic acid and α-linolenic acid. A modified version of the fortified spread – termed ready-to-use therapeutic food (RUTF) – is used for treating acutely malnourished children in health centres and home-based care. RUTFs do not have to be cooked before consumption and have a low water content, so that risk of interactions among micronutrients, as well as bacterial contamination during home storage, is low (18).

Typically, malnourished children consume the RUTF directly from the jar, without diluting it or mixing it with other foods, although it can also be added to a traditional cereal- or legume-based porridge when used for feeding infants aged 6 to 12 months, who may find the thick paste difficult to swallow. Acceptable clinical outcomes have been achieved among malnourished children in Malawi using either imported (18,19) or locally produced RUTFs (19,20).

LNSs have also been used for the prevention of malnutrition in infants and young children. Efficacy trials in sub-Saharan Africa have reported improvements in linear growth and a reduction in the incidence of severe stunting among 6- to 18-month-old breastfed infants provided with small daily doses of complementary LNS (21,22). There is some evidence that this positive impact on stunting may be sustained post intervention (23), although more studies are needed to confirm these findings. In the future, it is anticipated that specially formulated LNSs designed to meet the needs of infants and young children and pregnant and lactating women will be incorporated in the food packages supplied in emergency settings; more details are available in Chaparro and Dewey (24).

Some concern has been raised about possible antagonistic interactions that might occur in complementary foods fortified with multi-micronutrients, arising from competition for a common absorptive pathway. However, some data suggest that these risks are low in fortified foods because the dietary ligands released during digestion of the fortified foods chelate the trace minerals, which are then absorbed by different pathways (25). Nevertheless, the bioavailability of iron, zinc and calcium fortificants may still be compromised if the complementary foods are based on cereals and legumes high in phytic acid, polyphenols and oxalates (26).

Several efficacy trials of CFSs mixed with home-prepared complementary foods have been completed; details are summarized in Dewey *et al*. (27). Significant positive effects on haemoglobin concentrations and/or iron status have been observed in most of these studies (28–32). In contrast, of the four trials that have measured serum/plasma zinc (29,30,32,33) only the South African study (30) observed a significant decrease ($P < 0.05$) in the incidence of low plasma zinc concentrations in those receiving a daily micronutrient crushable foodlet mixed with the porridge compared with the placebo group.

The effects of the CFSs on growth have been inconsistent, and dependent on the type of CFS consumed. Significant gains in length and/or weight have been reported in Ghanaian (21) and Malawian (33) infants fed fortified spreads, but not in those receiving micronutrient sprinkles (21,29,31) or foodlets (21,30). The essential fatty acid content of the fat-based fortified spreads may account for the improved length gain, whereas the increased energy intake may be associated with greater weight gain (21).

Consuming all three types of CFS for 6 months has been reported to result in a higher proportion of Ghanaian infants walking independently by 12 months compared with non-intervention infants (21), but no positive effects on morbidity. Indeed, only one multi-micronutrient sprinkles study among 6- to 12-month-old Pakistani infants at high risk for diarrhoea has shown a significant reduction in morbidity (34). Future studies of CFSs should include an assessment of biomarkers for all micronutrients and functional health outcomes such as growth, body composition, morbidity, motor milestones and cognitive function. Consideration should also be given to the addition of acid-resistant phytase enzyme to the fortificant premixes to hydrolyse phytate in high-phytate complementary foods; these enzymes hydrolyse phytic acid during digestion in the stomach.

Effectiveness studies of CFSs are limited. World Vision has been involved in two large-scale effectiveness programmes of micronutrient sprinkles, one in conjunction with nutrition education in Mongolia (35) and a second with fortified wheat/soy blend in rural Haiti (36). In both programmes, significant reductions in anaemia were reported among those children receiving sprinkles, which in Haiti were sustained 7 months after completion of the 2-month sprinkles intervention period; growth outcomes were not reported. To date, there have been no effectiveness trials of foodlets or LNSs mixed with complementary foods for the prevention of malnutrition.

Use of centrally processed, micronutrient-fortified cereal-based complementary foods

There have been several efficacy trials of centrally processed micronutrient-fortified complementary foods based on cereal blends; results have been summarized by Dewey and Adu-Afarwuah (37). Some biochemical and/or functional health outcomes, most notably growth, have been investigated, but again results have been mixed. In some of these studies, results of the fortified group have been compared with a control group receiving the same product but unfortified with micronutrients (38,39), whereas in others (40,41) the comparison children have consumed their usual home diets, making comparisons among the studies difficult. Two of the randomized controlled trials (38,39) reported a significant and positive effect of the fortified complementary food on haemoglobin and/or iron status. However, there has been no significant increase in serum/plasma zinc observed, perhaps attributed to the low bioavailability of zinc in high-phytate-based complementary foods. Moreover, no significant effects on weight or length gain were reported in three of the studies (38–40), although in India weight but not linear growth improved significantly compared with the comparison group during the 8-month intervention (41). Of the other functional outcomes investigated in some of these efficacy trials (i.e. morbidity, psychomotor and/or motor development), only the South African study by Faber *et al*. (39) reported significantly higher motor development in the fortified compared with the unfortified group. No reductions in morbidity from infections have been observed. Indeed, in the study in India (41), morbidity increased in the group receiving the fortified complementary food, possibly in part due to contamination during the preparation of the food, a decrease in breastfeeding rates and/or differential over-reporting of morbidity in this group.

A few large-scale effectiveness programmes have included a micronutrient-fortified cereal-based complementary food, notably the Food and Nutrition Program (PANN) in Ecuador (42), which distributed *Mi Papilla* (with education) for families, and the National Fund of Development and Social Compensation (FONCODES) Project in Peru in which children received *Ali Alimentu*, a pre-cooked (extrusion) instant fortified food (43). Only the PANN programme in Ecuador showed a significant increase in haemoglobin ($P < 0.0001$) and ponderal growth ($P = 0.03$), with a marginally significant improvement in linear growth ($P = 0.08$) compared with the control group, although improvements in micronutrient intakes were reported in the FONCODES Project in Peru (43).

Use of other micronutrient-fortified food products by young children

The effects of micronutrient fortification of other food products such as biscuits, spreads, milk and other beverages consumed by young children have also been investigated, in some cases in schools (44–46). Results of several of these efficacy studies have been promising. Reductions in anaemia (47–50), biochemical micronutrient deficiencies (45,47–51) and morbidity (46,47,52) have been reported. Improvements in some aspects of cognitive function (short-term learning and memory and attention span) (46,47,51) and sometimes in body weight (48–50) and height (49) have also been observed.

Effectiveness trials with fortified food products are limited. In an effectiveness programme in Mexico, children aged 10 to 30 months from low-income families were supplied (400 ml/day) with Nutrisano – distributed as whole cow's milk powder fortified with iron (ferrous gluconate), sodium ascorbate, folic acid and zinc oxide. Significant reductions in anaemia prevalence and improvements in iron status after 6 months were noted in the children receiving the fortified versus unfortified milk, but there were no differences in mean serum zinc concentrations (53). Powdered whole cow's milk is also fortified with iron, copper, vitamin C and zinc in Chile and used for feeding children aged >6 to 18 months of age. Although studies have shown increases in the amount of absorbed iron and zinc from this fortified milk, and improvements in iron status among 18-month-old male children (n = 42) receiving the fortified powdered cow's milk for at least 6 months, no comparable effect on their biochemical zinc status has been reported; growth was not measured in this study (54). Such inconsistencies may be associated, at least in part, with the form and/or dose of the fortificants and the composition of the food vehicle, as well as the earlier factors discussed in relation to micronutrient supplementation. Additionally, constraints on growth may be linked to infection, poor child feeding practices (55,56), long-term effects of prenatal malnutrition and/or intergenerational effects of maternal malnutrition. The impact of the latter emphasizes the critical need for sustainable strategies to enhance both energy and micronutrient adequacy of the plant-based diets of the entire household in developing countries and across generations; some of these dietary strategies are outlined below.

Household Dietary Strategies

Use of CFSs and processed fortified foods may have limited lasting benefits in poor resource households in developing countries because of problems with accessibility, affordability and their reliance on continuing donor support. In such circumstances, dietary diversification and modification, designed and implemented through a formative research process, may be the preferred strategy. The approach involves changes in food selection patterns and traditional household methods for preparing and processing indigenous foods, with the overall goal of enhancing the availability, access to and utilization of foods with a high content and bioavailability of micronutrients throughout the year. Factors that must be considered when designing and implementing effective dietary strategies include knowledge of dietary patterns, availability and cost of foods, data on their nutrient and anti-nutrient content, information on food beliefs, preferences and taboos, impact on cooking time and workloads of the caregivers, and the inclusion of nutrition education and social marketing to foster behaviour change.

Dietary diversification and modification have the potential to prevent multiple micronutrient deficiencies simultaneously without risk of antagonistic interactions, while at the same time being culturally acceptable, economically feasible and sustainable, even in poor resource settings. The strategies have the added advantage of enhancing the micronutrient adequacy of diets of the entire household and across generations. Several additional non-nutritional benefits may also be achieved through the community-based nature of dietary diversification/modification. These may include empowerment of women in the community, training and income generation. To be successful, a multidisciplinary team of specialists in nutrition, epidemiology, agriculture, rural extension, adult education, psychology and community health is essential to assist with the design, implementation, monitoring and evaluation of dietary diversification/modification strategies.

Possible household dietary strategies include: (i) increasing the energy and nutrient density of cereal-based porridges; (ii) increasing the production and consumption of micronutrient-dense foods; (iii) incorporating enhancers of micronutrient absorption in household diets; and (iv) employing germination, fermentation and/or soaking to reduce the phytate content of unrefined cereals and legumes by enzyme-induced hydrolysis of phytate and/or passive diffusion of water-soluble phytate. Each of these strategies is discussed briefly below; the reader is referred to the following reviews for more details (26,57–59).

Increasing the energy and nutrient density of cereal porridges for infant and young child feeding

The energy (and micronutrient) density of porridges used for infant and young child feeding can be increased by using thicker porridges prepared with 20–28% dry matter, a practice that can be facilitated by the addition of small amounts of germinated cereal flours to the cooked porridges. The α-amylase in the germinated cereals hydrolyses amylose and amylopectin to dextrins and maltose, reducing the viscosity of thick porridges to an easy-to-swallow semi-liquid consistency suitable for infant and child feeding, without dilution with water (26).

Five efficacy trials have employed the addition of amylase (either produced industrially or by traditional methods) to enhance the energy density of complementary foods; details are given in Dewey and Adu-Afarwuah (37). Of these, only two significantly enhanced ponderal and/or linear (60,61) growth. Only the trial in the Congo collected morbidity data (61), and reported significantly greater ($P < 0.05$) rates of cough and rhinitis (but not diarrhoea or fever) in the intervention compared with the control group. Differences in breastfeeding practices did not account for this finding. Instead, although not confirmed, the intervention group may have had a greater intake of microbial-contaminated complementary food. No effectiveness studies or programmes employing the addition of amylase have been reported.

Increasing the production and/or consumption of micronutrient-dense foods

To increase the micronutrient content of diets, small livestock production and aquaculture can be promoted, and consumption of meat, poultry, fish and eggs encouraged ensuring they are not sold for cash but targeted to those household members at high risk of micronutrient deficiencies. Incorporation of some animal-source foods, especially cellular animal protein, into predominantly plant-based porridges used for infant and young child feeding has several advantages. Cellular animal foods have a high energy density and are good sources of high-quality protein, readily available haem iron and zinc, as well as vitamins B_6, B_{12}, B_2, and in liver, vitamin A, all micronutrients frequently limiting in plant-based diets (62). Incorporation of dried meat and fish has the added advantage of not requiring refrigeration. Further, dried fish can be consumed in countries where religious and/or cultural beliefs prohibit the consumption of meat, and when prepared from small, whole, soft-boned fish, provides a good source of readily available calcium.

At least six studies have either supplied or vigorously promoted the consumption of animal-source foods such as chicken livers (63) and/or eggs (63–65), red meat (65–67) or fish (38,65) among infants and/or young children; details are summarized in Table 1.1. Increases in weight (63–65), length (63,64), head circumference (67) and behaviour index score (67) have been reported but no reductions in morbidity (38,66), perhaps because of small sample sizes. Results of the studies conducted in Peru (63) and China (64), in which stunting was significantly reduced, emphasized the beneficial effects of including key educational messages to promote the consumption of animal-source foods together with enhanced feeding and caring practices.

The addition or promotion of animal-source foods in the diets of schoolchildren and women of reproductive age in developing countries also has the potential to have a positive impact on micronutrient status, growth and cognitive function. In a 2-year randomized controlled efficacy study among Kenyan schoolchildren, despite no significant increase in biochemical indices except for plasma vitamin B_{12} concentrations (68), improvements in weight (69) (but not height) and certain domains of cognitive functioning (70) were reported in those receiving a meat-based snack compared with the control group. An increase in height was also observed in those children who received a milk-based snack and had a lower baseline height-for-age Z score (≤ -1.4) compared with their counterparts in the control group (69). In two later reports, growth among all the children was shown to be positively predicted by average daily intake of energy from animal-source foods and those nutrients provided in high amounts and in a readily available form from meat and milk (i.e. haem iron, calcium, vitamin B_{12}, vitamin A) (71). Improved cognitive test scores were significantly related to intakes of available iron, available zinc, vitamin B_{12} and riboflavin, after controlling for potential

Table 1.1. Studies that have supplied or promoted the consumption of animal-source foods among infants and toddlers.

	Intervention strategies					Outcomes	
Country (reference)	Supplied ASFs	Nutrition education	Target groups	Design	Methods	KAP and dietary intake	Nutritional status
Ghana (38)	Yes	No	Healthy breastfed infants ≥2.5 kg at birth (Efficacy study)	RCT for 6 months, with 4 treatments: Weanimix (W); W plus vitamins & minerals (WVM); W plus fish powder (WF); koko with fish power (KF); compared with non-intervention group (NI) ($n = 464$)	Monthly 24-h recalls for 3 days (6 to 12 months); 12-h weighed records for 50% of subjects; morbidity; anthropometry; Hb, Hct, CRP, plasma Zn, serum retinol, serum ferritin, TIBC, RBC B-2	• No differences in intakes between W, WF and KF groups except at 7 months when Zn and Fe intakes higher in KF than W group ($P < 0.05$)	• No significant differences in morbidity outcomes, weight, length, HC, MUAC, skin folds, AFA or AMA, or plasma Zn, Hb, Hct, transferrin saturation or RBC B-2, between 4 groups at any time • WAZ and LAZ scores of NI group were lower ($P < 0.05$) than combined intervention group at 6 and 9 months of age • Significant increase in percentage with low ferritin between 6 and 12 months in W, WF and KF groups but not in WVM group ($P < 0.05$) • Change in plasma retinol was significantly greater in WVM between 6 and 12 months than in other 3 groups combined (0.14 ± 0.3 versus −0.04 ± 0.3 µmol/l, $P = 0.003$) • No effect on morbidity after 3 months

Continued

Table 1.1. Continued.

Country (reference)	Intervention strategies: Supplied ASFs	Intervention strategies: Nutrition education	Intervention strategies: Target groups	Design	Methods	Outcomes: KAP and dietary intake	Outcomes: Nutritional status
Bangladesh (65)	No	Yes	Malnourished children (WAZ 61–75% of NCHS median) aged 6–24 months (n = 189) (Efficacy study)	RCT for 3 months, with 2 treatments: Grp 1 (n = 93) received supplemental food for 6 days/week) (cereal blends) plus intensive nutrition education that promoted inclusion of egg, meat or fish in CFs; Grp 2 (n = 90) was control, received normal services	Anthropometry, morbidity		• Greater change in WAZ and WLZ but not LAZ in intervention versus control (P < 0.05) after 3 months
USA (67)	Yes	No	Exclusively breastfed, healthy, infants followed from ~6 to 12 months (Efficacy study)	RCT: puréed beef (n = 46) versus iron-fortified infant rice cereal (n = 42) as first CF at ~6 months; plus fruits and vegetables as desired. 9 months follow-up	2 × 3-day diet records/month for 4 visits); rating scale of infant's acceptance to CF; anthropometry; developmental testing (Bayley scores); Hb, Hct, serum ferritin, somatomedin, plasma Zn	• Mean protein and Zn intakes higher but Fe intake lower in meat than cereal group at 5 and 7 months (P < 0.001) • No difference in mean energy intakes • Tolerance and acceptance for beef and cereal comparable	• Greater increase in HC for meat than cereal group; Zn and protein significant predictors of head growth • No biochemical differences in Fe or Zn status between groups • Trend for higher behaviour index at 12 months in meat than cereal group (P = 0.08)

Denmark (66)	Yes	No	Healthy, term, partially breastfed infants, aged 8 months ($n = 41$) (Efficacy study)	Randomized trial; low meat group (LMG) 10 g meat/day ($n = 20$) versus high meat group (HMG) 27 g meat/day ($n = 21$). 2 months follow-up	Food records: 24-h weighed food record 1/wk; anthropometry; Hb, serum ferritin, TfR; morbidity (frequency of illness)	• Despite higher meat intakes, NSD in total Fe intakes: HMG 3.1 (0.4–6.2) mg/day versus LMG 3.4 (1.4–6.1) mg/day, $P > 0.05$ • Zn intakes not measured	• Change in Hb: LMG –4.9 (–12.9, 5.6) g/l versus HMG –0.6 (–12.1, 7.3) g/l, $P = 0.008$ • NSD in change in serum ferritin or TfR • No differences in serum Zn at follow-up or morbidity between LMG and HMG
China (64)	No	Nutrition education and counselling visits to increase BF and quality plus quantity of CFs from 4 months of age, e.g. give egg yolk daily after 4–6 months	Infants aged 4–12 months from rural China (Efficacy study)	Quasi-experimental design with non-equivalent controls. Pre/post intervention, 1-year follow-up; intervention group ($n = 250$) versus control group ($n = 245$)	Weight and length; single 24-h recall; FFQ; KAP (infant feeding and health-related behaviours); Hb measures	• Intervention group had greater nutrition knowledge, higher BF rates (83% versus 75%, $P = 0.034$) and better reported infant feeding practices versus controls ($P < 0.05$) • Greater number eggs fed/day to children 4–9 months in intervention versus controls	• NSD in growth between 2 groups before age of 12 months • At 12 months, WAZ in intervention group was –1.17 versus –1.93 for controls ($P = 0.004$), HAZ was –1.32 versus –1.96 for controls ($P = 0.022$) and prevalence of anaemia was 22% versus 32% for controls ($P = 0.008$)

Continued

Table 1.1. Continued.

	Intervention strategies					Outcomes	
Country (reference)	Supplied ASFs	Nutrition education	Target groups	Design	Methods	KAP and dietary intake	Nutritional status
Peru (63)	No	Nutrition education to increase intake of thick purées and ASFs and increase practice of responsive feeding. Demonstrations of CF preparation. Accreditation system in government health facilities	Birth cohort: infants from a poor, peri-urban area, followed from 0 to 18 months (Efficacy study)	Cluster-randomized trial (non-blinded), pre/post intervention; intervention (n = 187) versus control (n = 190). 18-month follow-up	Home interviews and observations for SES, hygiene and feeding practices; weight and length; 24-h recalls on intake of CFs at 6, 9, 12, and 18 months; morbidity (over past 24 h) at same visits	Intervention versus control group: • more caregivers received nutrition education (16/31 (52%) versus 9/39 (24%); P = 0.02) • more infants were fed nutrient-dense thick purées at 6 months (31% versus 20%, P = 0.03) • higher intake of energy from ASFs at 15 months (P = 0.082) and 18 months (P = 0.001) • fewer children failed to meet requirements for energy (8 and 12 months), Fe (8 and 9 months) and Zn (9 months) (P < 0.05)	• Intervention group had higher housing and hygiene scores, education level and body weight than controls at baseline: analysis performed without and with adjustment • Stunting at 18 months: intervention 5% versus control 16% (P = 0.02; adjusted OR = 3.04; 95% CI, 1.21, 7.64) • Adjusted mean changes in WAZ and LAZ better in intervention than in control group at 18 months (P < 0.05)

AFA, arm fat area; AMA, arm muscle area; ASF, animal-source food; BF, breastfeeding; CF, complementary food; CI, confidence interval; CRP, C-reactive protein; FFQ, food-frequency questionnaire; HAZ, height-for-age *Z* score; Hb, haemoglobin; HC, head circumference; Hct, haematocrit; KAP, knowledge, attitudes and practices; LAZ, length-for-age *Z* score; MUAC, mid-upper arm circumference; NCHS, National Center for Health Statistics; NSD, non-significant difference; OR, odds ratio; RBC B-2, red blood cell B-2 (riboflavin) concentration; RCT, randomized controlled trial; SES, socio-economic status; TfR, serum transferrin receptor; TIBC, total iron-binding capacity; WAZ, weight-for-age *Z* score; WLZ, weight-for-length *Z* score.

confounders (72). Among women of childbearing age, promotion of consumption of animal-source foods has also resulted in improvements in iron status (73) and/or haemoglobin (73,74); no data on functional health outcomes were reported in these studies.

Orange/yellow fruits (e.g. mangoes, papayas) and vegetables (carrots, pumpkin, orange-fleshed sweet potatoes), and to a lesser extent dark-green leafy vegetables, provide food sources of provitamin A carotenoids (75) which can also contribute effectively to improving vitamin A intakes on a year-round basis, provided appropriate preservation strategies are adopted (76). The carotenoids in orange and yellow fruits and vegetables are dissolved in oil droplets in chromoplasts and are more readily extracted during digestion, so that the efficiency with which they are absorbed and converted to their active form is much higher than that from dark green leafy vegetables, where the β-carotene is bound to proteins in the chloroplasts. Several studies have confirmed the use of yellow vegetables, orange-red fruits and/or orange sweet potatoes with or without fat supplementation to be efficacious in improving the vitamin A status of children (57,77,78).

Incorporating enhancers of micronutrient absorption in household diets

Besides providing a rich source of micronutrients often limiting in plant-based diets, cellular animal protein also enhances the absorption of non-haem iron and zinc from plant-based foods (26,79). Even small amounts of meat (≥50 g) can significantly increase non-haem iron absorption from meals low in vitamin C and rich in phytate (80). The mechanism of this effect in different types of meals remains uncertain (81).

Plant-based foods rich in ascorbic acid including certain fruits (e.g. citrus fruits and other fruits: guava, mango, papaya, kiwi, strawberry) and vegetables (e.g. tomato, asparagus, Brussels sprouts, spinach, etc.) have long been known to be enhancers of non-haem iron absorption (26). Nevertheless, in a study in rural Mexico, no improvement in biochemical iron status was observed among iron-deficient women receiving 25 mg ascorbic acid from fresh lime juice twice daily, 6 days/week, for 8 months, compared with those receiving a placebo (82), despite a twofold increase in iron absorption, based on earlier stable isotope results (83). Ascorbic acid may also enhance the bioavailability of folate by increasing its stability during food processing and digestion. Other organic acids (e.g. citric and lactic acid) produced during fermentation may also enhance non-haem iron and possibly zinc absorption to some degree, possibly by forming soluble ligands in the gastrointestinal tract, thus preventing the formation of insoluble compounds with phytate (26), while simultaneously generating an optimal pH for the activity of any endogenous phytases in cereal or legume flours (84). However, the magnitude of the enhancing effect, if any, of organic acids on iron and zinc absorption is uncertain. Improvements in protein quality have also been documented after fermenting some blended mixtures of plant-based complementary foods (85,86). Such improvements may be associated with the destruction of protein inhibitors that interfere with nitrogen digestibility by microbial enzymes, or from the ability of starter cultures to synthesize certain amino acids. Oilseeds and nuts provide a source of fat necessary for enhancing absorption of the fat-soluble vitamins and provitamin A carotenoids in plant-based diets.

Reducing inhibitors of micronutrient absorption in plant-based diets

The adverse effect of some of the organic components in plant-based diets on micronutrient bioavailability can be reduced by certain household food preparation and processing practices; they are summarized in Gibson *et al*. (26).

The strategies involve inducing enzymatic hydrolysis of phytic acid by endogenous cereal and/or microbial phytases through germination and fermentation, respectively, or soaking to reduce the phytic acid content of some cereal and legume flours by passive diffusion because their phytic acid is stored in a relatively water-soluble form; some polyphenols that inhibit iron absorption may also be lost via soaking. Several *in vivo* isotope studies in adults have reported improvements in both iron (87) and zinc (but not copper) (88) absorption in cereal-based porridges with a reduced phytate content.

Only a few efficacy trials have been undertaken to assess the impact of these phytate-reducing strategies on zinc absorption (89,90), nutrient adequacy (91,92) and biochemical and/or functional outcomes in infants and children (93–97). In a small hospital-based study in Malawi, phytate reduction of a corn-plus-soy porridge via commercial phytase enzyme (*Aspergillus niger*) increased fractional zinc absorption and decreased endogenous zinc losses only in children recovering from tuberculosis but not in the apparently well children (89). Restriction of this response to the children experiencing catch-up growth suggests that zinc absorption may be up-regulated by Zip4 in response to the high zinc requirements for catch-up growth. Zip4 is the principal zinc transporter responsible for regulation of zinc absorption across the apical membrane of the enterocyte.

In a large community-based, double-blind randomized controlled trial in Tanzania in which a processed complementary food, based on soaked and germinated finger millet and kidney beans, with roasted peanuts and mango purée, and an identical unprocessed blend were fed to 6-month-old infants (n = 309) for 6 months, there were no significant differences between the two groups at the end of the study in anaemia, iron status as measured by haemoglobin and zinc protoporphrin, hair zinc concentrations, or growth (95,96). Failure to observe any positive response may be in part because there was only a 34% reduction in the phytate content of the processed complementary food (95).

Results of these efficacy trials emphasize the importance of an integrated approach that combines a variety of the strategies discussed above to improve the energy, micronutrient content and bioavailability of plant-based diets. We have undertaken two such community-based efficacy trials among infants and young children in rural Malawi; details of the strategies used and their implementation have been published earlier (59,91,92,94,97). The efficacy of these dietary strategies was evaluated by determining knowledge, trial and adoption of the new practices, and by comparing dietary quality and adequacy of the energy and nutrient intakes of the intervention and control groups post-intervention (91,92,94,97). In the study of young children, changes in growth and body composition, morbidity, and haemoglobin and hair zinc concentrations were also investigated (94). In both trials, improvements in the adequacy of energy, protein, calcium and available zinc were observed in the diets of the intervention compared with the control group, associated with significantly higher intakes of animal-source foods (mainly fish). In the children, however, the adequacy of iron intakes did not differ between the intervention and control groups post-intervention, in part because fish, rather than meat, was the major source of cellular animal food consumed and the estimates of iron bioavailability did not take into account the impact of the phytate-reduction strategies on non-haem iron absorption. These findings were also accompanied by a significantly enhanced anthropometric index of lean body mass and a lower incidence of both anaemia and common illnesses in the intervention compared with the control group (97). Our results indicate that a combination of household food-based strategies can be designed to be feasible and acceptable to caregivers of infants and children in subsistence farming settings, although ongoing nutrition education and social marketing efforts are essential to enhance their adoption and to empower the community to sustain them. In the future, a new technique based on goal programming may become available to health professionals for the development of realistic and sustainable complementary feeding recommendations for interventions in developing countries, based on habitual dietary practices (98).

An integrated food-based approach has been adopted by programmes implemented by Helen Keller International (HKI) and World Vision (WV) Malawi, although strategies to reduce the phytate intakes were not included in these programmes. The Homestead Food Production (HFP) programme of HKI integrates animal husbandry with home gardening and nutrition education, with the aim of enhancing the production, availability and consumption of animal-source foods by women and children (99). This integrated HFP programme was implemented first in Bangladesh, but has now been expanded into Nepal, Cambodia and the Philippines. Results of the evaluation for the HFP programme in Bangladesh showed significantly higher intakes of animal-source foods, specifically eggs, poultry, other meat, milk or milk products, and dark green leafy vegetables at end point compared with baseline among children aged 6 to 59 months from target households, whereas intakes in the control group were almost unchanged (99). In addition, more of the target households earned income from gardening and poultry activities, showed improvements in poultry-rearing practices and a higher involvement of women in decision making than control households. A decline in the prevalence of anaemia among non-pregnant women and children from HFP households compared with controls was also reported in Nepal and Bangladesh, but not in Cambodia (100,101).

The Micronutrient and Health Programme (MICAH) of WV Malawi is another example of an integrated programme that included public health interventions (e.g. promotion and support of breastfeeding; control of infectious diseases, malaria and parasites), vitamin A and iron supplementation for young children, nutrition and health education, and dietary diversification strategies. As a result of a small animal revolving fund set up by World Vision (102), increases in both production and consumption of guinea fowl, chickens, rabbits, eggs and goat's milk were observed in the MICAH intervention households compared with the comparison group (102). Modest but significant reductions in stunting and anaemia among the children and anaemia in the women from the MICAH households were also achieved compared with the trends observed in the comparison group households (103).

Biofortification

In the long term, biofortification of staple cereals, involving strategies to enhance both their micronutrient content and bioavailability, may become a feasible option for improving the micronutrient status of the entire household and across generations in poor resource settings. Unlike fortification at the national level, biofortification does not depend on a food vehicle being centrally processed. Hence, biofortification has the potential to fill the gap in coverage left by mass fortification because it can be more accessible to the rural poor who consume staple foods from local or self-production. Biofortification can be achieved by three processes: (i) agronomic practices; (ii) conventional plant breeding; and (iii) genetic modifications involving gene insertions or induced mutations.

Minimum target levels have been set for increasing the micronutrient content of biofortified staple food crops, taking into account the usual daily intake of the staple food crop, the loss of micronutrients from the seed, root or tuber during processing (e.g. milling) and cooking, and the bioavailability of the micronutrient from the staple food as consumed in the habitual diet (104). Adoption rate estimates for these new crop varieties in Africa and Asia have been made, and range from 20–40% for Africa, where seed systems are less well developed, to 30–60% for Asia which has more developed seed systems (105).

Agronomic practices

Fertilizers can be applied to the foliage to enhance its iron content and to the soil to improve the content of zinc, selenium and iodine content of staple food crops (e.g. wheat, maize, rice, sorghum, beans) when grown in trace-element deficient soils, as has been practised for low-zinc soils in Turkey (106) and India (107) and low-selenium soils in Finland (108). Nevertheless, care is needed because too high amounts can have negative effects on plant growth and soil microorganisms (109). Further, the response to the application of fertilizer varies, depending on the crop, genotypes of the same crop and environmental conditions, making it difficult to extrapolate to all situations.

Conventional plant breeding

Conventional plant breeding can also be used to increase iron and zinc concentrations in seeds of common beans (*Phaseolus vulgaris* L.), rice (especially aromatic varieties) and wheat (especially *Tritium dicoccum* Schrank species), with no negative correlations between grain yield and iron and zinc density in the seeds and grains. The effect of processing on the content and bioavailability of iron and zinc in these seeds is under investigation.

Research is also underway to produce varieties of cassava roots, sweet potatoes, maize and bananas that are high in β-carotene using selective plant breeding. Genotypes containing the highest amount of β-carotene have been found in the Amazonian regions of Brazil and Columbia. However, processing techniques influence the final β-carotene content of these foods, with some genotypes being more stable to various types of processing than others. Hence, any effects of processing must also be taken into account in any breeding programme.

So far, efficacy studies employing conventional plant-breeding methods of biofortification are limited. A stable isotope study in Mexican adult women compared the amount of zinc absorbed from tortillas prepared with biofortified (4.0 mg Zn/100 g) and control (2.3 mg Zn/100 g) wheat flours. Zinc absorption from the tortilla meals prepared with biofortified wheat flour was significantly higher (0.5 mg Zn/day; $P < 0.05$) than from the control wheat, confirming that increases in zinc absorption can be achieved from biofortification of wheat with zinc (110). The efficacy of consuming high-iron rice (3.21 mg Fe/kg) compared with a local variety (0.57 mg Fe/kg) has been assessed in a 9-month randomized, double-blind, controlled feeding trial involving 192 religious sisters living in ten convents around Metro Manila, the Philippines (111). A modest increase in serum ferritin ($P = 0.10$) and total-body iron ($P = 0.06$) was reported among the subjects overall, but no increase in haemoglobin. For non-anaemic subjects, the corresponding responses were significantly greater: serum ferritin, $P = 0.02$ and total-body iron, $P = 0.05$. These results confirm the efficacy of biofortified rice in enhancing iron stores of women consuming habitual diets with a low content and bioavailability of iron. The efficacy of orange-fleshed sweet potato, developed by selective plant breeding, for increasing intakes of vitamin A and serum retinol among young children in rural Mozambique has also been confirmed (112), emphasizing that such an approach has the potential to enhance the vitamin A status of young children in other similar areas of sub-Saharan Africa.

Genetic modifications

For some crops (e.g. oilseed rape and rice), genetic engineering is the only way to enhance the content and in some cases the bioavailability of β-carotene (113,114). Indeed, in the Philippines, 5000 ha of a new variety of genetically modified Golden Rice containing a yellow daffodil gene that is rich in β-carotene were planted in 2004 (115). Genetic modification can also be used to alter simultaneously the amounts of absorption modifiers in plant foods. Possible approaches include producing new varieties of cereal grains with an increased content of methionine and cystine to promote zinc absorption; and a reduced phytic acid content (116). *In vivo* stable isotope studies have demonstrated increases in both iron (117) and zinc (118,119) absorption when adults were fed tortillas or polenta prepared from low-phytate hybrids of maize compared with those with their native phytate.

Transgenic approaches are also being used to express microbial-source, heat-stable phytase from *Aspergillus fumigatus* into the endosperm of wheat, and to introduce a gene that codes for a sulfur-rich metallothionein-like protein into rice (*Oryza sativa*), a protein that increases the resorption-enhancing effect of iron from the small intestine (120).

Conclusions

More attention is urgently required to develop sustainable multiple micronutrient interventions suitable for poor resource settings. In such circumstances, dietary deficits in energy and multiple micronutrients often coexist together with infections, especially among infants (>6 months) and young children, so that provision of micronutrients alone is unlikely to prevent growth faltering during childhood. As a result, an integrated approach that combines a variety of public health, nutrition education and dietary strategies is probably the best strategy to overcome the dietary deficits and improve the growth and development of infants and young children. In settings where inclusion of animal-source foods is especially difficult, fortification of complementary foods, either at the household level using CFSs or at the national level, should be explored, provided the energy densities of the fortified complementary foods are adequate. Care must be taken to ensure that the fortificants selected are bioavailable, effective, and added at levels that do not induce any adverse micronutrient interactions or influence the organoleptic qualities and shelf-life of the food vehicle. In the future, biofortification may be the most sustainable approach to improve the micronutrient adequacy of plant-based diets of entire households and across generations in developing countries, especially if a full range of bioavailable micronutrients can be achieved in a single staple plant species. Finally, to maximize their effectiveness, attention must always be given to the delivery and utilization of any programme based on food-based strategies.

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2 Addressing Micronutrient Malnutrition to Achieve Nutrition Security

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Abstract
The poor quality of the habitual diet and the lack of dietary diversity in much of the developing world contribute to deficiencies of micronutrients. Micronutrient malnutrition is a global problem much bigger than hunger and imposes enormous costs on societies in terms of ill health, lives lost, reduced economic productivity and poor quality of life. Addressing the global challenge of micronutrient malnutrition requires the need for many strategies – both short- and intermediate-term and long-term sustainable approaches. In addition to the conventional approaches of micronutrient supplementation and fortification, promoting sustainable food-based approaches to enable adequate intakes of micronutrients by much of the population includes dietary diversification strategies and agriculture-based approaches. Dietary diversification is possible by the promotion of homestead food production, which includes home gardening, small livestock rearing and fishing as well as the processing and preservation of food. Agriculture and agricultural biotechnology offer the opportunity of increasing crop yields and have the potential to improve the micronutrient content of staple foods and cereal crops, thus contributing to better nutrition of populations and thereby helping to achieve nutrition security. By ensuring food and nutrition security and by reducing the widespread problem of micronutrient malnutrition we may hope to achieve the targets set for the Millennium Development Goals.

Key words: nutrition security, food security, micronutrient deficiencies, dietary diversification, home gardening, homestead food production, agricultural biotechnology

Introduction

While the objectives of food security are focused on increasing agricultural production and the availability and access to food, nutrition security has emphasized more the physiological needs for nutrients and the role of health and the environment in determining good health and nutrition of communities. Nutrition security is thus broader than food security as it incorporates additional aspects such as biological utilization, which refers to the ability of the human body to ingest food and metabolize nutrients and meet the needs of essential nutrients required by the body (1). Nutritious and safe diets, an adequate biological and social environment, and proper nutrition and health care ensure adequate utilization of food in order to promote health and prevent disease. Consequently, good nutrition or nutritional status, i.e. nutrition security, is a function of both food intake and health status.

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Food and water are what people eat and drink to achieve an adequate nutritional status, i.e. maintain life and physical, cognitive and social development. It has to meet physiological requirements in terms of quantity and quality, and be safe and socially and culturally acceptable. Accordingly, nutrition security has been defined as 'adequate nutritional status in terms of protein, energy, vitamins, and minerals for all household members at all times' (2). The necessity to incorporate nutrition into food security evolved over time and food and nutrition security is said to have been achieved 'if adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for and satisfactorily utilized by all individuals at all times to achieve good nutrition for a healthy and happy life' (3,4). Food and nutrition security are fundamental to the achievement of the Millennium Development Goals (MDGs) (5) and incorporating nutritional goals alongside the goals of food security provides a holistic approach towards achieving the targets set out in the MDGs (6).

Micronutrient Malnutrition

Micronutrient malnutrition or 'hidden hunger' is an important dimension of food and nutrition security from a global perspective and is caused by the lack of adequate micronutrients (vitamins and minerals) in the habitual diet. Micronutrient deficiencies are common in populations that consume poor-quality diets lacking in dietary diversity, as their habitual diet is often deficient in these nutrients. Diets deficient in micronutrients are relatively high in intakes of staple food and cereal crops, but low in the consumption of foods rich in bioavailable micronutrients such as animal and marine products, fruits and vegetables.

Deficiencies of micronutrients are therefore common in developing country populations that habitually consume largely cereal-based, monotonous diets. For example, for iron, the amount of bioavailable iron is dependent on the content and source of iron in the diet and on iron absorption during the digestive process. The absorption of iron of plant origin into the body is relatively low and is considered to be a major factor in the causation of iron-deficiency anaemia. The exception is soybean, which is a good source of dietary iron (7). Cereals also contain high concentrations of phytic acid, a potent inhibitor of iron (and zinc) absorption. Foods that enhance non-haem iron absorption such as fruits and vegetables, which are rich in ascorbic acid, are often not consumed in adequate amounts in developing countries. Haem iron, which is relatively well absorbed by the human intestine, is found primarily in animal products such as meat, but animal sources of food are usually limited in the diets of the poor in developing countries owing to cost and availability. Widespread infections such as malaria and hookworm infestation also contribute to the risk of iron deficiency (8). In general, cereal grains contain low concentrations of carotenoid compounds which are precursors to vitamin A. Consequently, vitamin A deficiency often occurs where the diet is predominantly cereal-based and individuals have poor and irregular access to foods rich in provitamin A carotenoids. The bioavailability of vitamin A also varies with the source of the carotenoids in the diet (9). Zinc and iodine deficiencies are the other major micronutrient deficiencies in the developing world and are essentially caused by the low levels of these micronutrients in the diet.

Globally, there are nearly two billion people who suffer deficiencies of micronutrients such as iron, iodine, zinc and vitamin A (10). Micronutrient deficiencies are therefore important from a public health perspective and exceed current estimates of global hunger and food insecurity. Micronutrient deficiencies impair cognitive development and lower resistance to disease in children and adults (11). They increase the risk of morbidity and mortality of both mothers and infants during childbirth and in early childhood, and impair the physical ability and economic productivity of adults. The costs of these deficiencies in terms of lives lost and reduced quality of life are enormous, not to mention the economic costs to society. They lower school performance of children, while in adults they compromise work output, productivity and earning capacity (12). They impair immunity and increase susceptibility to infectious diseases and mortality, particularly among vulnerable groups such as pregnant women and children. Deficiencies of vitamin A and zinc together are estimated to contribute to one million deaths of children while iron deficiency as a risk factor for maternal mortality adds an additional 115,000 deaths. The analysis of co-exposure to these nutrition-related factors shows that, together, they are estimated to be responsible for about 35% of child deaths and 11% of the total global disease burden (13).

Intervention Strategies to Tackle Micronutrient Malnutrition

The global prevalence of vitamin and mineral deficiencies is remarkably high and it is estimated that a third of the world's population does not meet its physical and intellectual potential because of micronutrient deficiencies (11), in addition to having increased risk of morbidity and mortality related to infectious disease. The most vulnerable groups are infants and children, women in their reproductive age and the elderly. Micronutrient deficiencies are sufficiently widespread to warrant action as they cause enormous health, economic and social costs. As the problem is worldwide and poses numerous challenges, several intervention programmes have been initiated in developing countries in order to improve the current situation with regard to micronutrient malnutrition of their populations. The time-tested strategies universally promoted to combat micronutrient malnutrition have hitherto focused on supplementation and fortification of commonly consumed foods with micronutrients.

Supplementation of specific nutrients helps to meet the immediate deficits of vulnerable groups; an example is the provision of iron and folate supplements to all pregnant mothers attending antenatal clinics in primary health care centres in several developing countries. Despite iron deficiency being a major public health problem, there has been very little progress in its control in the developing world (13). This is attributable to the low compliance with iron supplementation, insufficient targeted interventions for infants and young children, and lack of integration of nutritional interventions with other national programmes. The recent controversies regarding the safety of iron interventions related to the interaction between malaria and iron metabolism, and those pertaining to the role of iron in oxidative damage, have not helped (13). On the other hand, there has been a lot of progress with vitamin A supplementation with a threefold increase in effective coverage over the last 10 years and it has been estimated that 70% of all pre-school children receive at least one mega-dose of vitamin A (14). However, shortfall of the supplement and sustainability of vitamin A supplementation programmes are major challenges. Zinc supplementation to young children in at-risk populations is expected to have a high impact and a course of zinc supplements in conjunction with oral rehydration solution is currently recommended by the World Health Organization/United Nations Children's Fund for the treatment of acute diarrhoea (15). Recent evidence from Bangladesh shows, however, that few eligible children are receiving zinc in response to diarrhoeal attacks. Despite the well-documented benefits of zinc supplementation of high-risk groups, there are currently no formal recommendations for programmes for the preventive supplementation for zinc.

Fortification of food items in the daily diet is another successful intervention strategy that has been widely adopted to deal with specific nutritional problems or nutrient deficiencies. A good example is the fortification of common salt with iodine (iodized salt) to tackle the problem of iodine deficiency and goitre; one of the most successful strategies that has helped reduce the burden of iodine deficiency disorders globally. Success in prevention of iodine deficiency rests on the effectiveness of universal salt iodization and currently approximately 80% of the 130 countries with a significant problem have implemented legislation on salt iodization since the late 1990s. Iron fortification programmes have usually been poorly designed with largely ineffective forms of iron used, and their success has been limited. Zinc fortification of staple foods and of special foods targeted at specific subpopulations is being implemented.

Zinc fortification of complementary foods is expected to have an impact on the health of young children. While there appear to be no technical barriers to including zinc in existing food fortification programmes, there is a need for well-designed trials to determine their efficacy.

Food fortification is increasingly recognized as an effective means of delivering micronutrients, with the objective being to deliver micronutrients to remote and impoverished populations in an affordable and sustainable manner. Commercially marketed fortified complementary foods and home-based fortification of complementary foods, as well as the fortification of staple foods such as cereal flours, cooking oils and dairy products, have made a positive impact (16). Proper choice of the fortificant and processing methods can ensure the stability and bioavailability of the nutrient in the food vehicle. The level of fortification needs to take into account variations in food consumption and ensure safety for those at the higher end of the scale while having an impact on those at the lower end. Fortification requires food regulations and labelling, quality assurance and monitoring to ensure compliance and the desired impact. A growing number of large-scale fortification programmes in different parts of the world are beginning to demonstrate impact towards eliminating several micronutrient deficiencies; however, food fortification continues to be an underutilized opportunity in many developing countries where micronutrient malnutrition remains a public health problem (16).

Supplementation and fortification are intervention strategies that have been aimed at the immediate or short-term amelioration of the situation and often address the symptoms and not the underlying causes of micronutrient deficiencies. Other complementary interventions include public health measures such as water and sanitation, and treatment of parasitic infestations, which often are important contributors to micronutrient deficiencies such as that of iron. While both these strategies have been tried with varying degrees of success and continue to play an important role in improving the nutrition of communities, increasingly more emphasis is being placed by international agencies on food fortification strategies (16) since they can be categorized as food-based approaches and hence probably sustainable in the long term.

Food-based Approaches to Combat Micronutrient Malnutrition

The International Conference on Nutrition (ICN) Declaration (17) advocating a strategy to combat micronutrient malnutrition stated: '… ensure that sustainable food-based strategies are given first priority particularly for populations deficient in vitamin A and iron, favouring locally available foods and taking into account local food habits'. Food-based intervention strategies include attempts to improve the nutrition of households by enabling families to have access to and to consume a diversified diet rich in micronutrients. Food-based strategies to address micronutrient malnutrition encompass a wide variety of interventions that aim to increase the production, availability and access to micronutrient-rich foods, promote the consumption of foods rich in micronutrients and enhance the bioavailability of these micronutrients in the diet. Strategies, which are food-based and are sustainable, alter behaviour and include nutrition education and the promotion of dietary diversity through investment in access to a diversified diet.

Food-based strategies to address micronutrient malnutrition pose their own set of challenges. Food-based approaches aimed at improving vitamin A status by increasing the intake of fruits and vegetables have been shown to improve vitamin A status in many studies. However, the challenge posed relates to the bioavailability of dietary carotenoids and their conversion to retinol, which appear to be influenced by a host of other factors (18). The availability of dietary iron is low in populations consuming monotonous plant-based diets with little meat, since most dietary iron is non-haem and its absorption is usually less than 10% (19). The absorption of non-haem iron is increased by meat and ascorbic acid, but inhibited by phytates, polyphenols and calcium. Because iron is present in many foods, and its intake is directly related to energy intake, the risk of iron deficiency is highest when iron requirements are greater than what can be met by meeting the energy needs. Zinc deficiency, now recognized as a micronutrient malnutrition of significant importance in developing countries, is related more to the role of inhibitors of zinc absorption such as phytates in the largely cereal-based diets rather than inadequate intakes in the diet (20).

Dietary diversification and modification

Food-based strategies focusing on dietary modification and diversification to enhance intakes and bioavailability of micronutrients at the household level have been summarized elsewhere (21) and are dealt with thoroughly in Chapter 1 of this book. While promoting the addition of animal and marine foods to the predominantly cereal- or plant-based diets of populations in developing countries may be the ideal, recognizing the socio-economic circumstances and being sensitive to the cultural and religious beliefs of those who live there is important. Gibson and Hotz (21) have enumerated strategies that do not involve substantial changes in habitual diets.

Home gardening, horticulture and homestead food production have been promoted for a long time in order to provide low-cost variety in the diet. Although home gardening as an activity has been extensively promoted in developing countries by international agencies such as the Food and Agriculture Organization of the United Nations (FAO) and non-governmental organizations like Helen Keller International, it is only now that they are being evaluated for their impact; and there are a few evaluations of its proven benefits and sustainability (22). A study in rural South Africa has shown how effective home gardening can be and provides insights into what activities ensure success and sustainability in the community (23). These include the integration of community-based monitoring of children's growth, the active participation and involvement of women and their consequent empowerment. It also facilitates maternal awareness of vitamin deficiencies through nutrition education. This study showed that locally produced vegetables and promotion of the consumption of vitamin-rich foods, such as orange-fleshed sweet potatoes, can provide households with direct access to foods rich in β-carotene and that home gardens can make a valuable contribution towards vitamin A intake and, ultimately, the alleviation of vitamin A deficiency (24).

Evaluation of the promotion of homestead gardening programmes in Bangladesh revealed that the active households on the gardening programmes improved the production and consumption of vegetables year-round (25). Over a 3-month period, these households produced a median of 135 kg and consumed a median of 85 kg of vegetables, while the control households produced a median of only 46 kg and consumed a median of only 38 kg. The active-participant households also generated a higher garden income which was spent mainly on food compared with the control households. It was also shown to be sustainable over several years while increasing the economic contribution and empowerment of women in the households with the predictable increase in the use of health care facilities and schooling, especially for female children. The development and expansion of the Bangladesh homestead gardening programme has successfully increased the availability and consumption of foods rich in vitamin A and has been expanded nationally (26). Several reviews have highlighted the effectiveness of home gardening interventions, especially when combined with promotional and education interventions, in improving vitamin A intake and nutrition (27). Food-based approaches to addressing malnutrition and food and nutrition security should necessarily include educational inputs and the promotion of the awareness of nutrition-related health problems.

Interventions that promote small animal husbandry and fishponds can promote and ensure the increased intake of cheap sources of animal products. They also have a positive impact by helping to control iron deficiency in communities (27). Thus, alongside the promotion of home gardening aimed at dietary diversification are other related household or community strategies broadly considered as homestead food production. These include the promotion of small livestock production, encouragement of integration of aquaculture into farming systems, and the investment at community level in village-based technologies for refrigeration, drying and preservation of food (21). The contribution of foods from animal sources by the promotion of small livestock production in the homestead can help to combat micronutrient malnutrition and provide the range of micronutrients that are deficient in a wholly cereal or plant-based diets. Such foods diversify the diet and enhance its nutritional quality by providing a good source of protein, fat and a number of key micronutrients like iron and zinc that are more readily bioavailable from these sources. Homestead food production is of particular benefit to vulnerable segments of the population such as infants and children, pregnant and lactating women, female-headed households and the elderly.

Several intervention and community development programmes have used livestock promotion to achieve improvements in nutrition and health (28). FARM-Africa promoted livelihoods projects, the objectives of which included the improvement of family welfare through the generation of increased income and diversified food consumption. Goats need less space than cows and goats' milk is highly nutritious. Through breeding goats and selling the milk, households can increase their income and these are activities that women traditionally undertake. The Dairy Goat Project in Ethiopia and Kenya adopted an integrated approach and increased the productivity of local goats managed by women. It demonstrated an increase in milk and meat products in local diets, and a considerable improvement in the nutritional status and family welfare of participant households (29). The VAC programme (V = *Vuon*, i.e. garden; A = *Ao*, i.e. pond, C = *Chuong*, i.e. cattle shed) in Vietnam is another homestead food production intervention whose aim was to provide diversified agricultural products to meet the range of nutritional needs of communities (30). V has been extended to mean all kinds of land farming; A involves all activities consisting of intensive exploitation of water areas; and C refers to all animal husbandry activities including raising cattle and poultry. Subsequent nutritional surveys showed that the population's dietary intake had improved in terms of both quality and quantity and the consumption of foods such as meat, fish and fruit was much higher than before the VAC was introduced. The prevalence of child malnutrition and chronic energy deficiency in women of reproductive age decreased and there was a remarkable increase in incomes and the health and nutrition of the rural populations in Vietnam (30). The Vietnamese government now considers this to be an effective solution for the alleviation of poverty, dietary improvement and the prevention of malnutrition. National programmes in Thailand have also prioritized the production of livestock by the poor, resulting in improvements in the quality of their diets and better nutrition and health. Integration of these programmes with national policies for poverty alleviation is now recommended to ensure long-term sustainability (31).

The Nutrition Collaborative Research Support Programme (NCRSP) reported on three parallel longitudinal studies in disparate ecological and cultural parts of the world, i.e. Egypt, Kenya and Mexico. Strong associations between the intake of foods from animal sources and better growth, cognitive function and physical activity in children, better pregnancy outcomes and reduced morbidity due to illness were found (32). Access to foods of animal origin through the promotion of small livestock is thus considered a strategic intervention for avoiding the poverty–micronutrient–malnutrition trap (33).

Fish is considered a good source of animal protein although its role as a source of vitamins and minerals in the diet of populations in developing countries is often overlooked. In poor, rural households, mean fish intake was between 13 and 83 g raw, whole fish per person per day; the frequency of intake of small fish was high and made up 50–80% of all fish eaten during the fish production season in rural Bangladesh and Cambodia (34). Many small fish are eaten whole and therefore are a rich source of calcium; some are also rich in vitamin A, iron and zinc. However, the results of randomized control trials using small fish in Bangladesh have been disappointing, showing no changes in biochemical indicators of vitamin A status in children following a 9-week feeding trial (35), but may reflect the short timespan of the study, or more likely the type of fish consumed. Where fish is consumed, use of small dried whole fish eaten with the bones is encouraged. As fish flour or relish they can be used to enrich cereal-based foods for infants and children.

Gibson and Hotz (21) identify food-based strategies more specifically targeted at infants and children such as the use of soaking to enhance micronutrient availability; the use of fermentation which decreases phytate – an inhibitor of mineral absorption – and thus enhances micronutrient availability; and the use of germinated cereals and legumes to increase nutrient density and bioavailability of nutrients in prepared foods. Hence a variety of home-based food processing techniques can be used to either increase the bioavailability of micronutrients or to ensure their retention during preparation, cooking, processing or preservation, while in the case of others the challenge is to extend the availability of micronutrient-rich foods beyond the season in which they are in abundance (27). This can be achieved through solar drying or the production of concentrates. In the case of iron from plant sources (non-haem iron) the objective is to increase its bioavailability.

Home processing techniques such as germination, fermentation and amylase treatment are effective in reducing the amount of inhibitors like phytates and in promoting the absorption of iron. Avoiding tea and coffee during the meal and the addition of citrus fruits (rich in ascorbic acid) are other effective approaches to improve non-haem iron bioavailability. It has also been suggested that cooking in iron pots increases the intake of bioavailable iron in the foods and improves iron status. However, it is unsure whether there are benefits to the use of cooking in iron pots as a strategy as some studies have shown (36), while others have not (37) and some others indicate that while the iron added to foods cooked in iron pots is bioavailable, the amount obtained through this process is insufficient to replenish depleted iron stores (38).

Role of agriculture and agricultural biotechnology

A sustainable solution to the problem of micronutrient malnutrition can only be achieved when their concentration in the major staple crops is adequate (39) and the agricultural approaches to increase quantity also attempt to improve the quality of the food at the same time. This is particularly true of cereals given that a major proportion of the diet of vulnerable populations in the developing world is cereal-based. For example, rice alone contributes 23% of the energy consumed worldwide and countries that rely on rice as the main staple often consume up to 60% of their daily energy from this cereal (40).

Agricultural approaches to improve the nutrient content of crops have included *field fortification strategies*, which enhance the micronutrient and trace element content of crops by applying enriched fertilizers to the soil. There is good evidence that deficiencies and excesses of micronutrients and trace elements in soils have a profound impact on the well-being of plants and animals that depend on soil to thrive. Increase in the micronutrient and trace element content of cereal grains has been attempted by enrichment of soil with fertilizers fortified with these minerals and trace elements. This appears to influence the selenium, iodine and zinc content in the cereal grain and, in the case of iron, to enhance the iron content of the leaves. However, the best studies showing this to be an effective strategy have been with the soil fortification of zinc through fertilizers. Gibson and colleagues (41) have demonstrated an increase of almost double the zinc intake of children in north-east Thailand achieved through the application of zinc fertilizer to rice fields deficient in the element.

The advent of modern biotechnology has generated new opportunities in agriculture to address the global problem of micronutrient malnutrition. *Agricultural biotechnology strategies* can help improve the amount and availability of a range of nutrients in plant crops and provide an important opportunity to do so in a sustainable manner. The strategies include simple plant selection for varieties with high nutrient concentration in the seeds, cross-breeding for incorporating a desired trait within a plant, and genetic engineering to manipulate the nutrient content of the plant (42). In agriculture, biotechnological or molecular-biology-based approaches are used primarily in one of two ways: (i) genetic engineering to create transgenics or genetically modified organisms by manipulating, deleting or inserting genes in order to change the organism; and (ii) marker-assisted selection to speed up conventional crop and animal breeding. Both can and have played a part in providing biotechnology-based solutions to improve the nutritional quality of agricultural products and can thus address the challenge of micronutrient malnutrition.

Genetic engineering

The production of Golden Rice was a major event involving the transfer of the genes necessary for the accumulation of carotenoids (vitamin A precursors) in the endosperm that are not available in the rice gene pool. As the endosperm of rice does not contain any provitamin A, the initial objective was to introduce the entire biochemical pathway for its synthesis. The transgenics developed were based on daffodil genes which resulted in substantial increases in provitamin A, visible as a 'golden' colour of different intensities in different lines (43,44). The best provitamin A line had 85% of its carotenoids as β-carotene. Other lines had less β-carotene, but high levels of lutein and zeaxanthin, both substances of nutritional importance because they have other positive nutritional effects (43). The first-generation Golden Rice with a gene from daffodil and a common soil bacterium drew considerable criticism as a technological solution to a problem associated with poverty and hunger. It was argued that Golden Rice would encourage people to rely on a single food rather than the promotion of dietary diversification. Detractors also noted that a normal serving of Golden Rice contained only a small fraction of the Recommended Daily Allowance (RDA) of β-carotene. However, the development of Golden Rice 2 by replacing the daffodil gene with an equivalent gene from maize increased the amount of β-carotene by about 20-fold, resulting in about 140 g of the rice providing a child's RDA for β-carotene (45). It has also been recently demonstrated that β-carotene from Golden Rice is effectively converted to vitamin A in humans (46).

Another approach with similar objectives was to increase the availability of iron while reducing the inhibitor content or adding a resorption-enhancing factor. Only 5% of the iron in the rice plant is in the seed and hence an attempt was made to create a sink for iron storage within the endosperm by expressing a ferritin gene from *Phaseolus* which resulted in a 2.5-fold increase in iron content of the endosperm. Feeding studies with peptides from muscle tissue showed that cystein-rich polypeptides enhance iron resorption. A metallothionein-like gene achieved a sevenfold increase in endosperm cystein (47). Since interference with the phosphate storage may affect germination, expression of a phytase gene had to be achieved in such a manner as not to interfere with germination. The enzyme was hence excreted into the extracellular space and one transgenic line that was developed expressed the phytase to levels 700-fold higher than endogenous phytase. However, the transgenic enzyme in this line had lost its thermo-tolerance and did not refold properly after cooking and was therefore ineffective. New transgenic plants aimed at targeting the enzyme-to-phytase storage vesicles to reduce the phytate content directly were developed to overcome the loss of the enzyme during cooking. These three genes, which influence iron availability and absorption, are combined with the provitamin A genes by crossing (47). The addition of provitamin A genes was justified by the observation that vitamin A deficiency indirectly interferes with iron metabolism (48) and higher intakes of β-carotene (converted to retinol after ingestion) may promote absorption of iron.

Work supported by FAO and the International Atomic Energy Agency, as well as by other investigators, has approached this problem in a different manner, aimed at agricultural improvement by induced mutation using nuclear techniques (49). The aim here is to produce strains of cereals with higher concentrations of micronutrients and improvement of their bioavailability by reduction in the concentration of phytic acid. Raboy (50) has developed low phytic acid (or lpa) mutant varieties of maize, rice and barley using these techniques. The phytic acid content of lpa seeds was reduced by 50–80% compared with non-mutant seeds, but the total amount of phosphorus remained the same as the phytic acid was replaced by inorganic phosphorus. This does not bind trace minerals, thus allowing them to be potentially available for absorption. Unfortunately, unless the phytate levels are reduced below 5% of that of the wild type, the strong inhibitory effect on absorption of iron persists (51).

Marker-assisted selection

The composition of nutrients in a range of food crops such as rice, cassava, beans and maize shows wide variations. Kennedy and Burlingame (52) have shown a wide range in the micronutrient content of rice varieties grown throughout the world. There is substantial useful genetic variation in the germplasm of key crops which may be exploited by conventional plant breeding but this takes a long time. Using molecular markers associated with specific traits, i.e. marker-assisted selection, the process can be speeded up. A strategy of breeding plants that contain a high concentration of minerals and vitamins in their edible parts has the potential to reduce substantially the recurrent costs associated with fortification and supplementation. But this will be successful only if farmers are willing to adopt such varieties, if the edible parts of these varieties are palatable and acceptable to consumers, and if the incorporated micronutrients can be absorbed by the human body (53). According to Bouis (53), for a plant-breeding strategy to combat micronutrient deficiency to work and to be universally adopted, particularly in developing countries, five crucial questions need to be addressed. They are: (i) Is it scientifically feasible to breed micronutrient-dense staple food varieties? (ii) What are the effects on plant yields and will farmers adopt such varieties? (iii) Will micronutrient density change the characteristics of the staple for the consumer? (iv) Will the extra micronutrients in staple foods be bioavailable to humans? (v) Are there other cheaper or sustainable strategies for reducing micronutrient malnutrition?

Thus the ICN goal of promoting sustainable ‘food-based strategies’ to enable adequate consumption of micronutrients in the developing world can be achieved by the introduction of ‘biofortified’ crops, which are varieties bred for their qualitative aspects and not merely to improve yields. The feasibility of plant-breeding approaches for improving the micronutrient content of staple crops is real (54). This is an approach that uses both classical plant breeding and modern biotechnology. Breeding programmes can readily manage nutritional quality traits, which for some crops are highly heritable, simple to screen for and offer the possibility of increasing the content of several micronutrients in the same variety. The desirable traits are sufficiently stable across a wide range of growing environments and, in addition, these traits for quality and high nutrient content can be combined with the traits for which staples are specifically bred e.g. superior agronomic characteristics and high yields. Biotechnology enables the identification of markers and thus facilitates marker-assisted selection that will enable transfer of these desirable traits through conventional plant breeding.

There is considerable progress in this new area of biofortification of staple food crops (55). Good examples are iron-rich rice (International Rice Research Institute (IRR), Philippines), maize with improved quality protein (International Maize and Wheat Improvement Centre (CIMMYT), Mexico), high-carotene orange-fleshed sweet potato (International Potato Center (CIP), Peru) and high-carotene cassava (International Center for Tropical Agriculture (CIAT), Colombia) (56). Orange-fleshed sweet potato has been shown to be an efficacious source of vitamin A both in Mozambique (57) and South Africa (58). Studies in Mozambique have not only shown that biofortified orange-fleshed sweet potatoes are adopted by farmers and consumed by children (57), but also that their integrated promotion is an effective food-based approach to improving the vitamin A status of children (59).

It is important to note that, while the potential for the breeding of biofortified crops by the agricultural community is high, it is quite some way from establishing the efficacy and sustainability of the nutritional benefits of many of these crops. The major advantage of the biofortification approach is that this strategy does not depend much on the change in behaviour of the producer (farmer), although there may be implications for acceptability of these staple foods on the part of the consumer (53). Already existing high-yielding varieties can be used and these are widely consumed. The increase in nutrient content is a natural variation and hence breeding specifically for these qualities need not necessarily alter appearance, taste, texture or cooking qualities, which influence consumer behaviour. Combining nutritional quality traits with those for high yield or pest or drought resistance ensures ready adoption by the farmer and market success. An added advantage is the increasing recognition that high levels of trace minerals in seeds also aid plant nutrition and may thus contribute to better growth and yields of staple crops. Because trace minerals are important not only for human nutrition but also for plant and animal nutrition, plant breeding has great promise for making a significant, low-cost, sustainable contribution to reducing micronutrient deficiencies even among livestock and other agricultural food products (60). It may thus have other important spin-off effects for environmentally beneficial increases in farm productivity for developing countries and may thereby contribute to agricultural trade from the South.

Conclusions

Promoting sustainable 'food-based strategies' to promote nutrition security and enable adequate consumption of micronutrients to reduce the global problem of micronutrient malnutrition can be achieved by micronutrient supplementation and fortification, dietary diversification and modification strategies and the introduction of biofortified crops. Dietary diversification strategies, which include home and homestead gardening, small livestock production, aquaculture and other related activities such as nutrition education, are sustainable strategies that provide rural employment and active participation of women, furthering their empowerment as well as contributing to increase awareness of nutrition and health.

Another sustainable long-term approach to reducing micronutrient malnutrition among vulnerable populations in developing countries is to enrich major staple food crops with micronutrients through plant-breeding strategies assisted by biotechnology, which can offer direct and indirect benefits to producers and consumers in developing countries (61). Breeding nutrient-dense staple foods can make a major contribution to reducing the global problem of micronutrient deficiencies and, at the same time, to achieving food and nutrition security. Improving the micronutrient composition of plant foods may become a sustainable strategy to combat deficiencies in human populations, complementing or even replacing other strategies such as food fortification or nutrient supplementation (62). Plant breeding has thus a great potential to emerge as a long-term sustainable agricultural strategy for improving not only the quantity but also the quality of the daily diet, thus contributing to achieving nutrition security for all.

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3 Agricultural Interventions and Nutrition: Lessons from the Past and New Evidence*

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Abstract

Globally, many poor households rely on agriculture for their livelihoods, and this remains true even when livelihoods are diversified. Poor households are also most vulnerable to undernutrition, including lack of micronutrients. Over the last decades, a variety of organizations have aimed to harness agriculture for nutrition. Agricultural approaches have the potential to substantially impact nutritional outcomes in a sustainable way, but there is insufficient understanding of the evidence base for this potential impact and of how best to achieve this potential. This chapter aims to consolidate the available evidence linking agricultural interventions to nutrition outcomes. First, the chapter describes five pathways through which agricultural interventions can impact nutrition: consumption of own production; increases in income; reductions in market prices; shifts in consumer preferences; and shifts in control of resources. Second, we review four types of studies that provide insights about links between agriculture and nutrition: early studies of agricultural commercialization; studies of women in agriculture; studies of horticultural interventions; and studies of livestock and aquaculture interventions. Consistent themes include the importance of integrating well-designed behaviour-change communications and careful consideration of gender dimensions. Third, we present two case studies that show how well-designed interventions can successfully diversify diets and/or impact micronutrient intakes and nutritional status outcomes; the second case study illustrates impact at scale. The review yields lessons for design of future interventions and for evaluation design, and identifies critical areas for future work, which include investigations of cost-effectiveness, scaling up processes and sustainability.

Key words: nutrition, agriculture, micronutrients, gender, interventions

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Background

International development agencies, governments and non-governmental organizations (NGOs) have been designing strategies and interventions[1] linking agriculture and nutrition since the 1960s. Initially, efforts to harness agriculture for nutrition were focused on increasing agricultural production and smallholder incomes to improve food security, with food security narrowly defined as food availability and household-level access to sufficient food energy. Late in the last century definitions of food security evolved to incorporate new knowledge about the wide prevalence and public health importance of micronutrient deficiencies, and the following definition was adopted at the World Food Summit in 1996 (1):

> Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Inclusion in the definition of *sufficient, safe, and nutritious food* broadened the focus beyond food energy. The emphasis on *all people* implicitly recognized that food security is determined by distribution both within communities and within households. For young children – a vulnerable group targeted by many nutrition interventions – access to sufficient, safe and nutritious food is contingent on their receiving adequate care and feeding. In most societies this is conditional on the power of women within households and, specifically, their control over resources to both secure sufficient quality food and give it to children according to need.

Despite consensus around this broad definition of food security, outside the nutrition community dialogues about food security often remain focused on household-level access to sufficient food energy, indicating a need for increased communication between nutritionists, agriculturalists, advocates and policy makers. At the same time, and supported by several international agencies and donors, a number of agricultural approaches to improving diet quality and micronutrient intakes have emerged (2,3). These agricultural approaches have the potential to substantially impact nutritional outcomes (as well as food security) in a sustainable way, but there is insufficient understanding of the evidence base for this potential impact and of how best to achieve this potential.

Objective, Scope and Conceptual Framework

This review summarizes and integrates lessons learned from a range of past agricultural interventions that provide evidence about nutrition outcomes. The aim was to identify lessons that can inform the design of future interventions. Although much of this material has been previously reviewed, we build on this work by bringing together and integrating information from these reviews, describing a wide range of interventions and synthesizing lessons learned for design and for future evaluations. We supplement previous reviews with two case studies of well-designed interventions. These case studies highlight the potential of agriculture to improve micronutrient nutrition.

Several different types of literature are included in the review. The primary focus is on studies linking agricultural change or intervention to individual-level nutrition outcomes (dietary intakes and/or nutritional status indicators). Current best practice in

[1] We define 'agricultural interventions' broadly to mean changes purposefully introduced into an existing agricultural system to promote new crops, technologies, management practices, production and marketing methods and other innovations. Such interventions usually include an implicit objective of behaviour change; some interventions address this explicitly with programme elements. Commonly, sets of activities in the agriculture sector are referred to as 'projects', while 'programme' is more commonly used in the public health and nutrition sectors. For the purposes of this document we use both 'interventions' and 'programmes' interchangeably to refer to planned sets of activities undertaken by an organization or organizations in order to achieve defined results.

designing agricultural interventions for nutrition is also informed by decades of research regarding the role of women in agriculture; therefore, we provide a selective review of this research. Women perform most of the work of food production in the developing world, and have been shown to spend a large proportion of their income on food and health care for children and on household consumption goods (4,5). They therefore play a key role in translating available household resources into nutrition improvement for vulnerable household members. While studies of women in agriculture do not necessarily provide information on nutrition outcomes per se, they do provide critical insights into how the benefits of agricultural interventions are distributed and whether it is possible to achieve nutrition gains.

Agricultural interventions have the potential to influence nutrition, including micronutrient intakes and status, through a variety of pathways. The evidence summarized in this review illustrates five main pathways toward impact:

1. Increases in *food availability and access* at the household level through production for the household's own consumption – this can also include filling seasonal gaps.
2. Increases in *income* through production for sale in markets, and hence potential to increase food purchases and/or purchases of higher-quality food as well as acquire other goods and services that influence nutrition.
3. Reductions in real food market *prices* associated with increased agricultural production (again impacting potential to purchase more or different types of food).
4. Shifts in consumer *preferences*, for example when intervention programmes include elements of behaviour-change communication (BCC).
5. Shifts in *control of resources* within households and communities – in particular, interventions that shift resources (income, time, other) towards women provide an additional pathway towards impact on nutrition.

These pathways are not mutually exclusive. For example, even in areas with poor market access, subsistence-oriented households are likely to sell part of their crop production to meet other needs. This is particularly true for high-value micronutrient-rich fruits, vegetables and animal products. Which pathway dominates in determining impacts on nutrition depends on a variety of factors, including market access and integration, potential for surplus production within a given agro-ecological setting, pre-existing nutrition knowledge, and consumer preferences and demand.

In addition, impacts on nutrition through the first pathway depend on the types (i.e. nutrient content) of crop/livestock produced. Impacts through the second pathway depend on who controls any new income generated. For all pathways, the extent to which nutrition improvement for any particular individual actually occurs depends on a series of intra-household factors and processes, including women's status, education, knowledge, practices and decision making, as well as access to and use of health and sanitation services and other key inputs into nutrition.

Methods

The review is based on systematic searches of recently published literature and a limited search of unpublished documents, as well as personal contacts with project officers and international agency staff. The searches primarily aimed to identify studies of agricultural interventions that had evaluated individual-level nutrition outcomes, such as child nutritional status, individual food or nutrient intakes and diet quality. Some studies also documented household-level impacts on food consumption. In most cases, these interventions had explicitly included nutrition improvement among their objectives. We did not exclude studies lacking such objectives, however, so long as nutrition outcomes were measured. Details about search methods and results are published elsewhere (6). Several thousand published articles were reviewed for relevance.

We drew on previous reviews (7–16) with the purpose of synthesizing them. Much of the analysis related to interventions promoting animal production was taken from

Leroy and Frongillo (17). No primary search was done to identify studies of women in agriculture. Rather, key lessons regarding women in agriculture already identified in previous reviews (4,17–21) are summarized here as these inform current thinking about intervention design.

Results

Overview

Most of the studies identified in this review documented nutrition impacts of agricultural interventions along the first two pathways described above, i.e. through increased household production and own consumption and/or through increased income. Some studies described interventions that included an explicit BCC strategy. In addition, some studies took gender into account and disaggregated results according to gender roles in production and in the control of new resources generated by the interventions.

Studies in this review are divided into the following categories:

- Agricultural commercialization (early 'cash crop' studies).
- Women in agriculture.
- Horticultural interventions.
- Livestock and aquaculture interventions.
- Case studies with impact on micronutrient nutrition.

The order of presentation is roughly chronological. Studies of agricultural commercialization were among the first to examine links between agriculture and nutrition. Key insights from these early studies still influence current thinking and intervention designs. Notably, these studies were among the first to highlight differential nutrition outcomes depending on women's control of new resources. In the years that followed, a large number of studies focused on women in agriculture. While these generally did not include examination of nutrition outcomes per se, they yielded many critical insights for programme design and policies, which remain relevant. Concurrent with this evolution in general knowledge about optimal design, agricultural interventions specifically aiming to improve nutrition also evolved. With recognition of the widespread prevalence of micronutrient deficiencies, more recent agricultural interventions have focused on nutrient-dense horticultural crops and/or animal-source foods (ASFs) from livestock and aquaculture production interventions. Finally, some recent interventions have built on the existing knowledge base and have demonstrated success in impacting micronutrient malnutrition; the results of two such interventions are presented here as case studies.

Agricultural commercialization

Studies of agricultural commercialization were motivated by early conceptual reviews, which had suggested the potential for negative impacts of commercialization on nutrition through reduced household-level access to food (see e.g. Fleuret and Fleuret (22)). One early review showed mixed impacts on nutrition, but also identified methodological issues that constrained interpretation and comparison (7). Given these uncertainties, von Braun and colleagues designed and undertook a series of micro-level case studies that included assessment of nutrition outcomes as an explicit objective (10). The case studies assessed the impact of commercialization on energy intakes rather than on diet quality or micronutrient intake, consistent with the then-prevailing idea that energy intakes were the primary constraint in the diets of the poor (23,24). In addition, young child nutritional status (anthropometry) was assessed in most of the studies. These studies also reported results disaggregated by income group and examined the role of control of income by women as opposed to men.

Results from these and closely related studies were synthesized in previous reviews (8–10); results of individual studies are summarized in Table 3.1. In sum, the case studies documented fairly consistent positive impacts on focus crop production,

Table 3.1. Summary of findings from selected studies of agricultural commercialization.

Country crop (reference(s)) (publication date(s))	Intervention or technological change	Study design	Key findings: Production, income, marketing/sales[a]	Key findings: HH energy consumption[a]	Key findings: Individual energy intakes and/or nutritional status	Key findings: Gender dimensions
West Kenya Irrigated rice (25,26)[b,c] (1988, 1994)	Two rice irrigation schemes. Irrigated land was expropriated and redistributed to smallholders for rice production only. Initially, all tenants lived on scheme but eventually some moved off scheme. No livestock and only small rainfed plots on scheme	Cross-sectional survey comparing: (i) resident tenants; (ii) non-resident tenants; (iii) individual rice growers; and (iv) non-rice growers	• Total incomes were similar across all four groups but sources of income were least diverse for resident tenants and most diverse for individual rice growers	• HH energy consumption increased with increasing diversity of income sources	• Child energy intakes were lowest and nutritional status (height-for-age) was substantially worse among resident tenants. Other groups fared better and were similar	• In-depth follow-up study among resident tenant HHs revealed higher per capita food expenditures from income controlled by women
Rwanda Potatoes (27,28)[b,d] (1994, 1991)	Expansion of potato production in former forest reserve, allowing access to additional land for food production. During reforestation, potato production was allowed to keep weeds down. However, potato cultivation expanded rapidly and uncontrollably	Cross-sectional survey comparing: (i) farms with access to and (ii) farms without access to 'extra' forest reserve land under potato (monocropped)	• Potatoes grown on 'extra' land were the only crop marketed to a significant degree but the amount sold varied from 8% to 45% based on wealth quartile; potato production expanded rural wage labour market	• A 10% increase in income was associated with a 5% increase in energy consumption • A lower degree of commercialization raised energy intakes over and above price and income effects	• Increases in HH energy consumption were associated with better child nutritional status (height-for-age and weight-for-age) but this effect was very small • Child anthropometry was more strongly related to health and sanitation	• Female-headed HHs consumed more energy (per unit); this effect was strongest in poorest HHs and did not hold in wealthiest

Continued

Table 3.1. Continued.

Country crop (reference(s)) (publication date(s))	Intervention or technological change	Study design	Key findings: Production, income, marketing/sales[a]	Key findings: HH energy consumption[a]	Key findings: Individual energy intakes and/or nutritional status	Key findings: Gender dimensions
Zambia Hybrid maize (29)[b] (1994)	Introduction of hybrid maize. A number of different varieties were introduced over a 1-year period	Repeated HH surveys comparing: (i) HHs in high- and low-adopting areas; and (ii) adopters and non-adopters	• Incomes were 33–45% higher in high-adoption areas whether HH adopted or not; incomes of adopters were 25% higher than non-adopters	• Per capita consumption of energy and other nutrients followed same pattern as income (higher intakes among adopters and in high-adoption areas)	• Results for child nutritional status were mixed. Higher weight but lower height in high-adoption areas (young children) and lower weight among older children. In adopting HHs, young child height was slightly higher but weight and height were lower among older children	
The Gambia Irrigated rice (30,31)[b,c] (1988, 1994)	Large-scale rice irrigation scheme. Explicit attempt to maintain traditional use rights of women farmers through giving women priority during registration of plots. Production technology in the scheme was heterogeneous with varying levels of water control	Repeated HH surveys in area of new state-owned large-scale rice irrigation scheme, with 4 production systems: (i) traditional swamp rice; (ii) small pump irrigation; (iii) partial water control (rain or tide); and (iv) central irrigation drainage	• New technology resulted in substantially increased yields and allowed a second crop, but did not have large impact on marketed surplus • Substitution effects in labour allocation meant that increased rice production was accompanied by decreases in other cereals and groundnuts (– $0.64 per $1.00 rice)	• Consumption (energy) increased with expenditure quartile in both wet (hungry) and dry seasons. A 10% increase in expenditure was associated with a 5% increase in energy (wet season) • Consumption was not correlated with HH cereal production, but was correlated with women's share of cereal production	• Women's seasonal weight fluctuations were buffered in HHs with greater access to new rice land • Child height was lowest in the lowest expenditure quartile (Q1) but similar across Q2–Q4 • Child weight increased with HH energy intakes; access to new rice land did not have other independent effects, positive or negative	• Traditional swamp rice was grown on 'women's land'. The scheme sought to assure women's access to new project rice land; however, the men changed the HH classification resulting in the land and crop being controlled by men • Women's control of production and income was decreased for new higher-input and higher-yielding rice

Mexico Sorghum (32)[c] (1990)	Adoption of sorghum production in areas formerly dominated by subsistence agriculture (maize and beans); sorghum production increased to meet increasing demand for livestock feed	Ethnographic methods (participant observation and informal interviews) followed by a HH survey in 4 communities where sorghum was produced as a cash crop. Communities represented range of ecological conditions, landholding size, irrigation, and access to credit, technical assistance and markets	• Incomes were highly diversified • Access to good-quality and irrigated land determined income, rather than participation in cash cropping	(Neither food consumption nor dietary intake was measured)	• There was no relationship between sorghum production and child nutritional status (height-for-age, weight-for-age or weight-for-height) • Income was associated with child nutritional status (weight-for-age), but only weakly

HH, household.
[a]Income and HH consumption expressed per adult equivalent unit.
[b]Included in von Braun and Kennedy (10).
[c]In DeWalt (9).
[d]In Kennedy *et al*. (8).

household income and food expenditures, but no substantial impacts on young child anthropometry.

In relation to the original stimulus for exploring impacts of commercialization on nutrition – i.e. the hypothesized negative impacts – DeWalt (9) concluded that a focus on commercialization per se was misplaced and that impacts on food consumption and child nutrition were determined by control of production and income, allocation of household labour, maintenance of subsistence production, land tenure and pricing policies for both food and non-food crops.

Overall, review authors made the following nutrition-relevant conclusions:

- Participation in cash-crop schemes generally resulted in increased household income.
- Increases in income were accompanied by increases in food expenditures, but impacts were also dependent on changes in relative prices.
- Household dietary energy intakes increased in most cases but decreased in some, as food expenditures shifted to more expensive items such as meat and fruits – potential improvements in diet quality were suggested but not documented.
- Increases in women's income were documented in some studies and were generally linked to increases in household energy consumption – this effect was most pronounced among the lowest-income groups.
- Overall, commercialization did not have a significant impact – negative or positive – on young child nutritional status.

Kennedy *et al*. (8) attributed the lack of impact on child nutritional status to the generally high levels of morbidity observed in intervention areas. In addition to this factor, we also note that the commercialization schemes were not designed as nutrition interventions and consequently did not include any BCC relevant to nutrition objectives. As demonstrated in subsequent sections, this may have contributed to limited impact on nutrition.

Finally, many of the studies in Table 3.1 were weakly designed. Most were observational studies and randomization was not possible. This is often the case, but a number of these studies also lacked adequate control groups and compared groups that had been 'self-selected'. Some authors addressed this analytically and explored differences between adopters and non-adopters and, in one case, between high- and low-adoption areas. Some studies also lacked baseline information. Overall, design constraints limited the strength and/or generalizability of some conclusions. However, these early studies began to illuminate links between agriculture and nutrition and, in particular, the key role of women.

Women in agriculture

Several of the commercialization studies highlighted the role of women, and specifically the positive effect of women's control of income on household energy intakes. Following on this work, additional studies confirmed the positive association between women's income and food expenditures and also demonstrated strong positive associations between women's income/other resources and child health and nutrition outcomes; this evidence is summarized in Quisumbing *et al*. (4), Peña *et al*. (19), Quisumbing and Maluccio (33) and Kurtz and Johnson-Welch (34).

In addition to documenting links between women's resources and positive nutrition outcomes, studies of women in agriculture have described a series of problems and constraints faced by women agriculturalists in many contexts. These constraints include: weak land rights; limited access to common property resources; lack of equipment and appropriate technology; limited contact with agricultural extension; lack of access to financial services, markets and information; and lower levels of education (4).

These constraints have conspired to substantially lower the productivity of women farmers compared with male farmers even from the same socio-economic bracket, resulting in high opportunity costs for households and communities (18,20). In addition to affect-

Box 3.1. Characteristics of agricultural interventions targeting women farmers. (Adapted from Peña *et al.* (19).)

Failed interventions often:
- did not take into account women's needs, livelihoods or their context-specific constraints;
- did not consult participants regarding their preferences for new activities;
- lacked needed staff expertise;
- focused on traditional women's activities with low economic returns; and
- provided inadequate training and technical inputs.

Successful interventions often:
- 'mainstreamed' gender in the intervention rather than treating it as a separate project or component;
- incorporated assessments of women's pre-existing livelihood assets;
- considered women's incentives to undertake new activities;
- considered women's time constraints and multiple roles;
- listened to participants and their own assessment of needs;
- worked with groups of women;
- employed female extension specialists or trained male extension specialists to work with women;
- disaggregated monitoring data by gender;
- monitored participation and could adjust intervention to address identified constraints as needed;
- provided leadership training to participants; and
- integrated well multiple components of intervention.

ing productivity, these constraints have limited women's share of benefits flowing from adoption of new technologies and have limited the share of household resources that they can command and control.

The evidence suggests that specific intervention strategies aimed at addressing these constraints must be carefully designed. Past experience is rich in examples of incomplete or failed attempts to address gender dimensions (19,26,35), including examples of interventions where new technologies for 'women's crops' have shifted control of the focus crop to men (10,17,36). Past studies have also identified characteristics likely to be associated with successful and failed interventions (Box 3.1). Because of the proven importance of women's access to and control of resources for food security and child nutrition outcomes, these same characteristics are relevant for the design of any agricultural intervention aimed at improving nutrition.

However, note that the constraints identified above operate at many levels and involve many institutions; in some situations the legal and institutional context in which programmes operate may limit their potential to increase women's access to and control over resources.

Horticultural interventions

Concurrent with the recognition of the role of women in agriculture, new nutrition knowledge generated recognition of the prevalence and importance of micronutrient malnutrition. This motivated new efforts to impact micronutrient malnutrition through agricultural interventions involving fruit and vegetable production. Despite the existence of a wide variety of fruit and vegetable production systems, however, only homestead garden production systems have been implemented and evaluated with explicit nutrition objectives. These interventions generally have been designed to impact nutrition via the first pathway described above (i.e. own production for consumption) and sometimes, secondarily, via increased income from sales.

Homestead gardens take a wide variety of forms, in backyards, farmyards, kitchens, containers, small patches of available land, vacant lots, on rooftops and tabletops, and along roadsides and the edges of fields. They are generally close to a house and source of water, and are managed by family members using low-cost inputs. Their products include fruits, vegetables, herbs, condiments and sometimes secondary staples like legumes and sweet potatoes, most of which are grown for household consumption. The nutrition impacts of homestead gardens have been relatively well documented in previous reviews (12–16).

In 1990 and 1991 the United States Agency for International Development-funded Vitamin A Field Support Project (VITAL) carried out an assessment of past and then-current household garden interventions and their impacts on nutrition outcomes. The aim was to inform the planning of future research and initiatives. Focusing on the effects of homestead gardens on the intake of vitamin A-rich foods and improving vitamin A status, the review yielded a number of recommendations on design, targeting and evaluation of homestead gardens as a means of strengthening their nutritional impact. The main recommendation was that interventions should focus on women and provide nutrition education to promote appropriate processing, storage and cooking techniques for vitamin A-rich foods. They should also promote a diverse variety of vitamin A-rich foods to meet both subsistence and marketing needs, and take into account cultural preferences when selecting which foods to introduce (13).

Gillespie and Mason (14) considered 13 programmes aimed at improving diet quality, seven of which included homestead gardening. Four of these were combined with social marketing activities and all four exhibited a number of indirect benefits such as increased women's income and social status. Yet only one intervention, in Bangladesh, showed a positive effect on vitamin A status in addition to increased energy intakes and improvements in the economic status of women.

Studies included in more recent reviews are summarized in Table 3.2, which details impacts on diets, nutritional status, knowledge, practices and other outcomes. Table 3.2 includes a number of intervention studies that reported increases in production and consumption of fruits and vegetables. In summarizing, Ruel (15) found that interventions that did not include explicit BCC strategies (Box 3.2) (generally those conducted prior to the mid-1990s) failed to achieve significant impacts on nutritional outcomes. Subsequent interventions that incorporated well-designed BCC elements did demonstrate impacts. The review also emphasized that using a gender-sensitive approach to agricultural interventions could strengthen their impact on nutrition.

Berti *et al*. (16) used a Sustainable Livelihoods Framework and assessed whether agricultural interventions had invested in different types of capital: human, physical, social, environmental and financial. Interventions that invested more broadly in various types of capital, as was usually the case with homestead gardening programmes, tended to have a greater impact on nutrition than did those that focused more narrowly on production. Interventions with a strong gender focus were classified as having made investments in social capital; those with BCC components were classified as having made investments in human capital.

Although they employed different theoretical frameworks, the two reviews by Ruel (15) and Berti *et al*. (16) led to a common conclusion that homestead gardening interventions after the mid-1990s succeeded in improving diets, nutrient intakes and/or child nutritional status if they incorporated communication and nutrition education activities targeting behaviour change among their audiences and if they incorporated gender considerations in their design.

As noted with regard to the cash crop studies, both reviews also reported that many of the studies of horticultural interventions had weak designs, which limited the strength of conclusions and generalizability. While a number of studies included control groups, selection of appropriate comparison groups remained challenging and/or poorly described and inter-group differences were not always accounted for in analyses. Baseline information was also often unavailable.

Livestock and aquaculture interventions

Like homestead gardening interventions, livestock and aquaculture interventions have the potential to improve diet quality and increase micronutrient intake. Livestock and aquaculture interventions could impact nutrition through any of the five pathways

Table 3.2. Summary of findings from horticultural interventions with nutrition objectives.

Country (reference(s)) (publication date(s))	Intervention(s)	Study design	Key findings: Diets, nutrient intakes and/or nutritional status	Key findings: Other: Food production, KAP, morbidity, gender dimensions
Bangladesh (37)[a,b] (1995)	Homestead gardening with provision of seeds, farming education, nutrition education	Pre/post, with control	• Slight decrease in night blindness indicating improved VA status	• Increase in % of HHs growing vegetables and fruit in both intervention and control areas • Increased knowledge of function of VA
Bangladesh (38)[a,b] (1993)	Homestead gardening with vegetables, training on agriculture, provision of seeds, nutrition education.	Pre/post, with control	• Increase in vegetable consumption per capita and children's vegetable intake • Improvements in stunting and in underweight	• Increase in vegetable production, size of plot cultivated, year-round availability of vegetables and income • Intervention children had fewer respiratory infections • Increase in women's control over income
Bangladesh (39)[a] (1998)	Vegetable production or polyculture fish production in HH-owned or group-managed ponds, and credit and agricultural training; some nutrition education but primary objective was not better nutrition	Pre/post, with 3 groups: (i) adopters; (ii) potential adopters (in non-intervention villages); and (iii) random selection of HHs not in (i) or (ii)	• No increase in consumption of fish in fishpond group. Shift in consumption from smaller to larger fish, with possible negative impact on micronutrient intakes • Increase of vegetable intake in vegetable group • No change in Hb in any group, implying no change in Fe status	• Increased production of fish and vegetables; modest increase in income for adopters, compared with potential adopters • Demands on women's time relatively small
Ethiopia (40)[a,b] (1999)	Training on agriculture, food preparation sessions, provision of seeds; health and nutrition education	Participants compared with non-participants	• More diversified diets, higher VA food frequency scores among participants • Lower prevalence of clinical signs of VAD among participants	• More gardens • Better KAP for VA

Continued

Table 3.2. Continued.

Country (reference(s)) (publication date(s))	Intervention(s)	Study design	Key findings: Diets, nutrient intakes and/or nutritional status	Key findings: Other: Food production, KAP, morbidity, gender dimensions
Guatemala (41)[b] (1996)	Provision of seeds, extension services and nutrition education for the promotion of VA-rich foods	Pre/post, with control	• Control children without gardens with VA-rich vegetables had more VAD	
India (42)[a] (2000)	Homestead gardening and nutrition and health education	Pre/post	• Weekly intake of VA-rich garden produce more than doubled • Decrease in ocular signs/ symptoms of VAD	• Increase in % of HHs growing vegetables • 40% of HHs sold 10–25% of produce • Increased KAP on VA
Indonesia (43)[a] (1998)	Social marketing with mass-media and 1-on-1 communication to increase intake of targeted VA-rich foods	Pre/post	• Increase in % of children and mothers consuming at least 1 egg in previous week; increase in amount of vegetables prepared/ person per day • Increased VA intakes from both eggs and plants. • Increased serum retinol with increased egg consumption; dose–response relationship indicating improved VA status	
Kenya (44)[a,b] (2001)	Introduction of new varieties of yellow- and orange-fleshed sweet potatoes and training in food-processing techniques; nutrition education	Pre/post, with control	• Higher VA food frequency scores for children in intervention (nutrition education plus agricultural component) versus control group (agricultural component only)	• Unfamiliar yellow and orange flesh colour did not constrain adoption
Nepal (45)[a,b] (1995)	Homestead gardening, irrigation, agriculture extension, seeds	Pre/post	• Insufficient VA intake for mothers and children both pre- and post-intervention	• Increase in % of HHs producing vegetables

Niger (46)[a] (1996)	Promotion of home production; multimedia education campaign promoting consumption of VA-rich foods	Pre/post	• Increased intake of VA-rich vegetables (children), purchase and consumption of liver (a food targeted by the intervention to increase VA) by women and children	• Increase in VA knowledge of women
Peru (47)[a] (1998)	Nutrition education in community kitchen with capacity building	Pre/post members/non-members	• Increased quality of diet and intake of Fe-rich foods • Increased intakes of VA, haem Fe and proportion of absorbable Fe • Reduction in prevalence of anaemia	
Philippines (48–50)[b] (1979, 1980, 1991)	Promotion of production of VA-rich fruits and vegetables with provision of seeds and seedlings and advice on agricultural practices	Paired pre/post	• Increase in children's VA intake • Improved weight-for-height and decrease in severe wasting • No change in serum retinol or clinical eye signs of severe VAD, implied no change in VA status	
Philippines (51)[b] (1996)	Promotion of homestead gardens with some target vegetables; provision of seeds and cuttings; mass media campaigns, social marketing and nutrition education	Pre/post, with control	• Increased vegetable consumption • Increased VA intake in intervention group; 48% *decrease* in VA intake in control group	• Increased production of five types of vegetables
Senegal (52)[b] (1989)	Promotion of homestead gardens and sale of produce; nutrition education and agriculture education	Survey of those with and without homestead gardens (baseline; 10–12 years later)	• Consumption increased for some nutrients, decreased for others	
Tanzania (53)[a,b] (2000)	Agriculture, promotion of home production, consumption and storage of VA-rich foods; health and nutrition education	Intervention/control; post	• Higher 7-day frequency of intake of VA-rich foods • Lower serum VA and higher helminths in intervention area • Higher intake of VA-rich foods associated with higher serum VA (both areas)	• Higher % of HHs with homestead gardens and producing VA-rich vegetables in intervention area • Better KAP for VA, higher % using solar driers for VA foods

Continued

Table 3.2. Continued.

Country (reference(s)) (publication date(s))	Intervention(s)	Study design	Key findings: Diets, nutrient intakes and/or nutritional status	Key findings: Other: Food production, KAP, morbidity, gender dimensions
Tanzania (54)[a] (2000)	Promotion of solar driers; nutrition and health education	Pre/post, with control	• VA food frequency score higher in intervention group and among adopters with increased intake of animal products	• 8% women adopted solar driers in intervention area • No significant increase in % selling or income from selling dried vegetables
Thailand (55–57)[a,b] (1993, 1999, 1999)	Seed distribution, training of women farmers, promotion of gardens, fishponds and raising chickens; nutrition education and social marketing	Pre/post, with control	• Increased VA intake; no change in fat intake; increased Fe intake in some targeted groups; increase in vitamin C intake in lactating women • Increased serum retinol, decreased VAD (in school girls). Increased mean Hb, decreased anaemia and low serum ferritin (NS) implied improved Fe status	
Vietnam (58,59)[a] (1997, 1998)	Homestead gardens, fishponds, animal husbandry; nutrition education	Intervention/control; post	• Higher fruit and vegetable intake in intervention group • Higher energy, protein and VA and vitamin C intakes for children in intervention areas • Better growth in intervention group	• Better KAP in mothers of intervention group • Lower severity and incidence of respiratory infections in intervention group
Vietnam (60)[b] (1994)	Promotion of homestead gardens with a focus on VA-rich crops; nutrition education for mothers	Pre/post	• Increase in intake of energy, protein and fat • Clinical eye signs of severe VAD decreased to almost zero implying improved VA status	• Per capita vegetable production increased five-fold

Fe, iron; Hb, haemoglobin; HH, household; KAP, knowledge, attitudes and practices; NS, not significant; VA, vitamin A; VAD, vitamin A deficiency.
[a]Included in Ruel (15).
[b]Included in Berti *et al.* (16).

Box 3.2. Behaviour-change communication. (Adapted from Linkages (61) and United Nations Children's Fund (62).)

Behaviour-change communication:
- bridges the gap between information, knowledge, attitudes and subsequent behaviour;
- requires listening, understanding and then negotiating with individuals and communities for long-term positive behaviour change;
- involves the use of an appropriate mix of communication channels, including interpersonal, group, community and mass media; and
- recasts the role of 'communicator' as 'facilitator' rather than 'expert'.

(i.e. consumption of own production, new income from sales, changes in prices, shifts in preferences or shifts in control of resources, including women's time). Animal production interventions also have the potential to impact nutrition through negative health effects (i.e. via exposure to zoonoses), but information on this link is scarce (17). Impacts through the first pathway are potentiated because certain micronutrients (e.g. iron and vitamin A) are found in more bioavailable forms in animal-source, as compared with plant-source foods. However, unlike homestead gardens, livestock and aquaculture interventions have often focused on income generation through the sale of products, rather than on own consumption. Also unlike homestead gardens, which are often the domain of women, resources from aquaculture and large livestock are frequently controlled by men.

A range of livestock and aquaculture interventions have been evaluated with respect to their impacts on nutrition (among other outcomes). Leroy and Frongillo (17) reviewed fifteen intervention studies, including four on aquaculture, five on dairy production, three on poultry and three in which livestock production was one component of a larger integrated intervention. The findings concerning the impacts of these studies on production, income and expenditure, dietary intake, nutritional status and women's income and time use are summarized in Table 3.3.

Most of the studies showed a positive impact on production of ASFs, despite the large variety of promotional interventions. Similarly, most interventions that measured income or expenditures also reported increases in these (Table 3.3).

Impacts on diets, nutrient intakes and nutritional status, however, showed mixed results. For aquaculture interventions, one intervention may have actually decreased dietary quality because it led to a switch from consumption of small fish (which are consumed whole and contain high levels of calcium and vitamin A) to greater consumption of larger fish with poorer micronutrient density (39). In another, there were no differences in total fish consumption between the fish-producing and non-fish-producing households (63). In a third study, intervention households appeared to have consumed more fish, but the analyses were not subject to statistical testing (64).

Similarly mixed results were found for dairy interventions. In one intervention in India, households in villages with milk cooperatives actually consumed less milk than households in villages without cooperatives. The overall nutrient consumption of households with cows in intervention villages did rise, however, whereas nutrient consumption among non-producing households fell (65). In another intervention in India, children in households that produced more than 5 litres of milk daily had higher protein intakes than those from non-producers (or smaller producers) (66). A third intervention in East Africa found that households with cross-bred cows consumed more energy, fat, protein, retinol and iron than non-adopters (68). Finally, a study in Kenya introducing cross-bred cows and promoting fodder production found that participating women increased their milk consumption relative to baseline (69).

Poultry interventions in Bangladesh and Egypt saw higher intakes of a range of nutrients among participating households than

Table 3.3. Summary of findings from animal-source food interventions. (Adapted from Leroy and Frongillo (17), including notes to table.)

			Key findings		
Country (reference(s)) (publication date(s))	Intervention (s)	Design	Production, income, expenditures	Diets, nutrient intakes and/or nutritional status	Gender dimensions
AQUACULTURE					
Bangladesh (39) (1998)	Polyculture fish production in HH-owned or group-managed ponds (or vegetable production) to improve income; some nutrition education was provided, but primary objective was not better nutrition	Three groups: (i) adopters; (ii) potential adopters (in non-intervention villages); and (iii) random selection of HHs not in (i) or (ii)	• Positive but very modest increase in income in adopters compared with potential adopters	• No effect on fish consumption; shift to larger fish, i.e. speculated that effect on certain micronutrient intakes may be negative • Pre-schoolers favoured, particularly boys • Programme effect on anthropometric indicators not estimated	• Demands on time relatively small
Bangladesh (63) (2003)	Poor farmers trained in carp culture. HH ponds were stocked with carp and either *mola* (species very rich in VA) or other small indigenous fish species	Intervention/control; post	• No difference in production between *mola* and small indigenous fish species ponds	• No difference in fish intake between producing and non-producing HHs • 47% of the *mola* was consumed in the HH, covering 21% of the recommended VA intake	
Bangladesh (64) (2000)	Aquaculture extension (pond aquaculture). HHs expected to adapt monoculture of tilapia or silver barb or polyculture of native and exotic carp species using on-farm resources	Intervention/control with 2 control groups: (i) neighbouring HHs in same village; and (ii) others from other area	• Both extension recipients and neighbours had higher yields than control farmers • Returns on investments higher in extension HHs	• Intervention and neighbouring HHs seemed to consume more fish	

DAIRY					
India (65) (1987)	Integrating rural HHs into a market economy by increasing the use of purchased inputs and increasing the marketed surplus. Dairy cooperatives were set up in the villages	Intervention/control; pre/post comparisons of HHs in villages with and without dairy cooperatives	• Villages with cooperatives produced twice the amount of milk as control group (result of > number of cross-bred cows) • Income and expenditure increased in the cooperative villages	• HHs in villages with cooperatives consumed *less* milk • Nutrient consumption of milk-producing HHs in intervention villages rose, that of non-producing HHs fell	
India (66) (1994)	Dairy Development Project of the Indian government; formation of dairy cooperatives	Intervention/control; post; 3 groups within intervention: (i) large (LP) (>5 l/day), (ii) medium (MP) (2.5–5 l/d) and (iii) small producers (SP) (<2.5 l/d)	N/A	• Only children in the LP met protein RDA • LP children had the highest energy intake too (did not meet RDA) • Overall, protein and energy requirements best met in LP and worst in MP	
Ethiopia (67,68) (1999, 2000)	Market-oriented dairying for smallholder mixed-crop and livestock farmers; use of cross-bred dairy cows for milk production and traction; farmers with cross-bred cows encouraged to grow fodder and received training on improved hygiene and restricted grazing; also veterinary and breeding services	Intervention/control; post	• Income of intervention HHs 72% higher • Higher income associated with higher food and non-food expenditures	• Energy intake 19% higher in participating HHs • Intake of fat, protein, retinol and Fe also higher • Increase in maternal income	• No apparent increase in women's labour input • Men's incomes benefited significantly more from intensified dairying than women's

Continued

Table 3.3. Continued.

			Key findings		
Country (reference(s)) (publication date(s))	Intervention (s)	Design	Production, income, expenditures	Diets, nutrient intakes and/or nutritional status	Gender dimensions
Kenya (69) (1996)	National Dairy Development Project: intensive dairy technology through introduction of cross-bred cows, fodder production	Pre (recall)/post	• Increase in HH income • Increases in food purchases, school fee payments and book purchases	• Increased milk consumption	• Higher workload for women • Increase in maternal income
POULTRY					
Egypt (70) (1987)	More and Better Food Project: combined activities promoting plant production with animal production (poultry). 47% of poultry farmers were women	Intervention/control (adopters/non-adopters)	Increase over time in poultry production (and in maize, groundnut and wheat production) (not clear whether for adopters only)	• Fe, total protein and animal protein intake higher in adopting HHs • Prevalence of Fe-deficiency anaemia dropped in school-aged children during the same time period (in community)	
Bangladesh (71) (2003)	Saving schemes, technical training for poultry rearing and credit programmes; project beneficiaries were all women	Pre/post	• Chicken production increased • All reported improved economic conditions • Both food and non-food expenditure increased • % of income spent on food decreased	• HH consumption of eggs, chicken, fish, meat and milk increased • Frequency of vegetable consumption did not change • Grain consumption increased	• Women gained influence in deciding on the use of income

Bangladesh (72) (1996)	Participatory Livestock Development Project supporting semi-scavenging poultry production; loans and technical assistance provided through women's groups	Intervention/control; post	• Egg production significantly higher in adopting HHs • No difference in chicken production • Egg and chicken sales significantly higher in adopting HHs	• Egg and chicken consumption not different • Women and girls in adopting HHs ate more fish
MIX OF INTERVENTIONS				
Ethiopia (40,73) (1999, 2003)	Women-focused goat development project without impact on nutrition was expanded to include interventions to promote VA intake, including nutrition and health education, training in gardening, food preparation and distribution of vegetable seeds; school garden clubs	Intervention/control; 2 intervention groups: (i) local goats or (ii) cross-bred goats	• All of the newly started vegetable gardens during intervention period in participating HHs • Participation significantly associated with vegetable garden ownership • No other data on production	• Goat-owning HHs consumed all produced milk • 87% by adults as *hoja*[b]; children in participating HHs had slightly more diversified diet; more likely to consume milk >4×/week • Participating HHs consumed egg at low rate (0.46/week) but significantly more than controls (0.29) • No impact on child anthropometry; clinical VAD lower in intervention children
Vietnam[a] (58) (1997)	Fishponds; livestock; home gardens; nutrition education	Intervention/control; post; only 1 intervention and 1 control, village, no randomization	• Larger production of fish, eggs, vegetables and fruits in intervention community	• Children in intervention group had greater intakes of vegetables, fruits, energy, protein, VA and Fe, and better child growth

Continued

Table 3.3. Continued.

Country (reference(s)) (publication date(s))	Intervention (s)	Design	Key findings: Production, income, expenditures	Key findings: Diets, nutrient intakes and/or nutritional status	Key findings: Gender dimensions
Thailand (56) (1999)	Promotion of poultry and rabbit-raising and home gardens through a community-based intervention; nutrition education; school-based nutrition programme targeted to 10- to 13-year-old schoolgirls; girls received weekly iron supplement of 60 mg ferrous sulfate; improved school lunches; poultry raising, fishponds	Intervention/control; pre/post	N/A	• Increased intake of VA in both intervention and control groups, but greater in intervention group • Inconsistent findings for Fe intake • No increases in fat intake • Schoolgirls had improved serum retinol and serum ferritin (double difference: changes over time compared between t_x and control)	

Fe, iron; HH, household; N/A, not applicable; RDA, Recommended Dietary Allowance; VA, vitamin A; VAD, vitamin A deficiency.

[a]Could not obtain original report: Tilden, R. (1993) *Impact of the FAO Vitamin A Nutritional Improvement Project in Rural Vietnam on: Rates of Xerophthalmia, Nutritional Status, Maternal Attitude and Practices, Household Production and Consumption Patterns, and Children's Dietary Practices.* Food and Agriculture Organization of the United Nations, Rome.

[b]Traditional tea made of coffee pulp and leaves and preferably drunk with milk (73).

among non-participating households (70,71). Another poultry intervention in Bangladesh did not lead to increased egg or chicken consumption, but participating households did eat more fish, suggesting that the intervention led to increased income and subsequent positive dietary changes (72).

Three of the interventions focusing on animal production incorporated nutrition education and were combined with fruit and vegetable production (see 'mix of interventions' in Table 3.3). In Ethiopia, children in participating households had slightly more diverse diets and were significantly more likely to drink milk four or more times weekly (40,73). In Vietnam the intervention group had higher intakes of vegetables, fruits, energy, protein, vitamin A and iron, and exhibited higher growth rates among children (58). It is not clear whether the animal production per se caused the positive effects, as the interventions were complex. In Thailand, vitamin A intake increased in both intervention and control groups, but the increase was greater in the intervention group (56).

Leroy and Frongillo (17) also assessed the impact of livestock and aquaculture interventions on maternal income and/or women's control over income. The results were quite mixed. For example, an intervention involving intensified dairy farming in Kenya (69) showed that an important share of the additional income was controlled by women, whereas in Ethiopia men's incomes increased significantly more than women's (67).

Overall, the authors concluded that women's control over income from livestock production activities has been very site-specific, depending on the livestock or aquaculture production system, the nature of the intervention, and pre-existing cultural beliefs and practices relating to gender. Even when the intervention has been targeted to women's livestock and aquaculture activities, women have sometimes lost control over the income generated by those activities.

The results relating to women's control of income serve as a cautionary note for programme planners, but some interventions did have positive impacts on nutrition. Leroy and Frongillo (17) concluded that the interventions associated with marked improvement in dietary intake and nutritional status had two key characteristics: women played a critical role in the intervention and/or the interventions included a BCC component. The conclusion was entirely consistent with the earlier reviews of horticultural interventions (15,16).

The review also concluded that uncertainties remain regarding which pathway towards nutrition impact dominates in livestock and aquaculture interventions, i.e. direct consumption, new income, changes in prices or changes in control over resources. The answer is likely to depend on a range of contextual factors and the studies reviewed did not provide a systematic way to assess this.

Concerns with design limitations add a final cautionary note and limit the strength of the conclusions that can be drawn from these studies. As with studies of cash cropping and homestead gardening, many evaluations of livestock and aquaculture interventions had weak designs. Self-selection was an issue in a number of studies, as was lack of baseline information, small sample size and lack of appropriate control for confounders in analyses. As noted, few studies captured information on unintended consequences related to zoonoses. Taken together, the studies provide sufficient information to suggest the potential of well-designed animal production interventions; in future, well-designed interventions with equally well-designed evaluations may confirm this potential.

Case Studies: Recent Agricultural Interventions with Impact on Micronutrient Nutrition

The studies summarized above yielded a range of lessons for design of interventions. Key and consistent conclusions include: careful design around gender issues is crucial; integrating BCC is necessary for ultimate impact on nutrition outcomes; and grounded understanding of livelihoods is more likely to lead to successful interventions.

Recent interventions aiming to harness agriculture for nutrition have benefited from past experience, and programme planners have incorporated many of these lessons. Two case studies – not included in the previous reviews – illustrate the potential for success when interventions are carefully designed to meet local needs. The first summarizes results of a small-scale intervention in rural Mozambique. Unlike the horticultural and animal production interventions described above, the Mozambique intervention focused on a secondary staple food, sweet potato, in an effort to improve vitamin A intakes and decrease deficiency. The second case study, of mixed homestead gardening and livestock production in Asia, provides a rare example of an agricultural intervention aimed at improving nutrition that has gone to scale.

Case study 1: Introducing orange-fleshed sweet potato production in rural Mozambique[1]

Background and context

Unlike fruits, vegetables and ASFs, staple food crops are generally not viewed as rich sources of micronutrients. In fact, monotonous diets heavily dominated by one or few staple foods generally are associated with high risk for a variety of micronutrient deficiencies among vulnerable groups. Recently, efforts have been undertaken to 'biofortify' staple food crops. Biofortification is the process of breeding food crops that are rich in bioavailable micronutrients. Orange-fleshed sweet potato (OFSP) is the first biofortified staple crop with fairly wide dissemination in several countries (primarily in sub-Saharan Africa).

OFSP has been selected as a focus crop in a number of efforts to improve vitamin A intakes, including the Vitamin A for Africa (VITAA) partnership[2] and the HarvestPlus biofortification programme.[3] OFSP is promising for a number of reasons. It contains very high levels of carotenoids (vitamin A precursors), is well accepted by the young children who are usually targeted, is easy to cultivate, propagates vegetatively and is fairly drought-resistant once established. It is also a good source of energy for children and adults. Sweet potato is less labour-intensive than most other staple crops and this is particularly helpful to labour-constrained households, such as those affected by HIV/AIDS. It can be planted over a broad range of time without considerable yield loss, and can fill some seasonal gaps in energy and vitamin A intakes. These qualities also make sweet potato an excellent food security crop.

Finally, root production varies in size and quality. Usually a significant amount of production is 'unmarketable', resulting in roots available for home consumption during the production season and drying of chips for consumption in the off-season. Therefore, OFSP has the potential to improve micronutrient intakes directly in producing households, through the first pathway towards impact of agriculture on nutrition. To the extent that marketing of OFSP roots and processed products occurs and is affordable, other community members may also increase intakes.

In many developing countries, however, and including sub-Saharan Africa, dominant sweet potato varieties are white-fleshed (WFSP) and contain no carotenoids. Hence, breeding and adaptive testing of OFSP varieties have been undertaken to ensure that new orange-fleshed varieties can compete agronomically and meet local consumer preferences.

This case study reports on the results of a 2-year intervention research project, the 'Towards Sustainable Nutrition Improvement Project' in rural Mozambique (74–76). The intervention was implemented in drought-prone areas of Zambezia Province. The area is characterized by very high levels of young child malnutrition, a monotonous diet with cassava as the primary staple and a very poor resource base. Vitamin A deficiency is prevalent in rural Mozambique and in the study area (58% at baseline). WFSP varieties were already widely cultivated (69% of households) and consumed in the area. The primary aim

[1] Information for this case study was drawn from the following sources: Towards Sustainable Nutrition Improvement webpage, http://www.aec.msu.edu/fs2/tsni/index.htm (accessed 27 February 2007); Low *et al*. (74–76).

[2] VITAA website: http://www.cipotato.org/vitaa/.

[3] HarvestPlus website: http://www.harvestplus.org/.

of the research was to establish whether a food-based, integrated agriculture–nutrition intervention, with OFSP as the key 'entry point', could lead to improvements in young child nutrient intake and serum retinol.

Intervention design, elements and scope

The theoretical model underlying design of the intervention held that three elements – each necessary and none sufficient alone – would need to be addressed to achieve sustainable impact:

- Increase farmers' access to improved OFSP vines and roots.
- Increase nutrition knowledge and create demand for OFSP.
- Ensure sustainability through market development.

The intervention purposefully built on lessons learned from an earlier OFSP intervention in Kenya (77). The Kenya experience, like others reviewed above, had focused on women and had underscored the critical importance of inclusion of BCC. Accordingly, the Mozambique intervention included integrated agriculture and nutrition extension by pairs of male and female extension specialists who lived in study areas for the duration of the intervention. The BCC component did not present OFSP as a 'magic bullet' to solve malnutrition among young children, but rather used the OFSP intervention as an opportunity to deliver a range of nutrition messages. For example, the nutrition extension package included strong support for breastfeeding, another key source of vitamin A for infants and young children.

To design and implement the intervention, partnerships were developed between researchers (led by Michigan State University); the implementing NGO, World Vision Mozambique; the Nutrition Division of the Ministry of Health and Helen Keller International (HKI), for BCC strategies and materials; and the National Institute for Agronomic Investigation (Mozambique) and the Southern African Root Crops Research Network. World Vision had extensive prior experience and pre-existing relationships in Zambezia Province.

Intervention activities included:

- Varietal trials and 'taste testing' of products with farmers and their children.
- Distribution of free OFSP vines via farmers' associations (as per government extension practice at the time).
- Stimulation of demand through BCC using multiple communication channels – community theatre and radio spots and a visible presence at local markets – as well as nutrition extension.
- Agricultural extension services supporting production, storage, processing, commercialization and marketing.
- Nutrition extension aimed to improve infant and young child feeding practices.
- Development of a grading/pricing scheme in partnership with a trader, rewarding quality.
- Development and marketing of processed products ('golden bread', doughnuts and OFSP juice).

Approximately 1000 farmers participated in 53 groups; 70% of participating farmers were women. Men, women and older household members (grandparents) were all encouraged to participate in nutrition extension activities.

Assessing impact: evaluation design and data collection

The evaluation employed a prospective, quasi-experimental design. The objective was to measure the impact of the intervention on children's vitamin A status (using serum retinol) and to document changes in the intermediate factors leading to nutritional impact, i.e. changes in knowledge, OFSP production and consumption, and vitamin A intake. Two intervention districts and one control district were purposively selected.[4] Within districts, villages were stratified by distance to services

[4] Districts were selected if they: (i) were within the implementing partner's area of operation; (ii) had high levels of malnutrition; (iii) had a common dominant language; (iv) were outside major flood plains; and (v) allowed reasonable distances between sites (i.e. feasible for research activities).

and other characteristics and randomly selected within strata. Intervention villages were selected first, and control villages were then selected to match as closely as possible on agro-ecological conditions. Within villages, all households with age-eligible children were invited to participate; in intervention areas, study participation also entailed participation in local farmers' groups. A series of nine surveys was undertaken. Information was gathered on socio-economic and demographic characteristics of households, agricultural production, child morbidity, adult and child anthropometry, parental nutrition knowledge, food frequency, dietary intakes and biochemical indicators. In addition, sweet potato plots were measured annually and market prices were monitored monthly.

Evaluation results[5]

There was a marked decrease in the prevalence of low serum retinol (an indicator of vitamin A deficiency) among children in intervention households (60 to 38%); prevalence remained unchanged in control communities. This was accompanied by large changes in every step along the pathway towards impact. There were large differences in production of OFSP (90% of intervention households compared with 11% of controls) and increases in sales (30% of households compared with 13% at baseline, among producers). Mean sweet potato plot size increased more than tenfold in intervention households and agronomic performance was acceptable, with yields similar to WFSP. Both women and men showed positive changes in nutrition knowledge, relative to baseline and relative to controls. Intervention children were ten times more likely to eat OFSP frequently. Vitamin A intakes among intervention children were eight times higher than in controls; energy intakes and intakes of several other micronutrients were also higher. Finally, by the end of the study, OFSP was the cheapest source of vitamin A (per retinol unit) in local markets.

[5] Evaluation results are reported in Low *et al.* (75).

Strengths and limitations of the evaluation

The primary strengths of the evaluation component included its prospective design and the comprehensive series of surveys, which documented a wide range of intermediate as well as final outcomes. One design limitation was that participation in intervention areas was restricted to those willing to join farmers' groups, which precluded a full exploration of determinants of adoption. This also raised the possibility of a self-selection bias, but this threat to internal validity was addressed in the analysis. A second limitation was that the time frame for the study did not allow an assessment of sustainability; the authors identified several issues of relevance to sustainability (below). Finally, this pilot intervention was relatively small. Nevertheless, the study results have provided 'proof of concept' and support the relevance and the potential for impact of the larger VITAA, biofortification and other efforts.

We also note that because the agriculture and nutrition extension activities were delivered as a full package to all participants, it is not possible to attribute results to any one component or to assess the necessity of the full package. This was by design; based on evidence from the past, the intervention model assumed that both agricultural and nutrition extension, as well as market development, were necessary elements to achieve desired impacts.

Lessons for intervention design

Key features of intervention planning and implementation, which are believed to have contributed to success, include the following:

- Careful selection of a focus crop (agronomic characteristics, role/potential role in diet, gender considerations).
- Integration of agriculture and nutrition components at every stage of planning and implementation.
- Links established between researchers and communities, through implementing partners.
- Identification, selection and adaptive breeding of nutrient-dense varieties that

also addressed the needs of farmers and the preferences of consumers.
- Grounding in thorough knowledge of context.
- Consideration to the roles of women and the constraints they face as farmers.
- Strong BCC and demand creation components, using multiple channels and targeting multiple audiences.
- Development of local markets for OFSP, to increase the likelihood of sustainability.

The project also identified several issues and questions for follow-up. First, distribution of free vines reduced farmers' incentives to preserve vines for planting the next season; sustainability will depend on future ability and willingness of farmers to invest in improved vine conservation and multiplication, and/or their willingness to pay for vines. Also related to sustainability, further research is needed to determine if adoption of OFSP is maintained without continual input on the demand creation side. Finally, the extension package was relatively intensive; more operational research is needed to identify the lowest cost and most cost-effective package of interventions that can achieve public health impacts.

Case study 2: Homestead gardening in Asia[6]

Background and context

Unlike the newer approach of biofortification, interventions with fruits, vegetables and livestock have been promoted for some time for their potential to improve nutrition. The review of past interventions showed mixed results, but confirmed the potential. This case study examines one of the largest efforts to date to use homestead gardening integrated with livestock production to improve nutrition for poor and vulnerable households. The approach was developed, documented and scaled up to national level in Bangladesh, and has since been replicated elsewhere in Asia. This has been a multi-decade programme; early published results were included in previous reviews. Additional monitoring and evaluation results have subsequently been published (79–84).

Homestead gardening in Bangladesh is a seasonal activity, and vegetable and fruit production satisfies less than 30% of national demand. To gain a better understanding of pre-existing gardening practices, HKI conducted an assessment in north-west Bangladesh in 1988. Based on the findings, HKI developed a pilot programme among 1000 households between 1990 and 1993. The aims were to: (i) explore the feasibility of promoting low-cost vegetable gardens combined with nutrition education; and (ii) identify constraints that might prevent increased production and consumption of vitamin A-rich foods among poor households.

The pilot programme provided a wealth of information on successes and challenges and gave HKI both justification and necessary information for scaling up. Encouraging results suggested that household production of fruits and vegetables could be possible throughout the year with some technical assistance and support. A mid-term evaluation in 1992 (38) confirmed that the integrated homestead gardening and nutrition education programme, targeted to women, had had a very positive impact on vegetable consumption among women and young children.

The evaluation also identified constraints and information needs, which were addressed when the pilot was scaled up. In the pilot, households were unable to sustain change without a regular supply of quality seeds and other inputs. It was also noted that scaling up would require greater understanding of cultural beliefs about child feeding, maternal food intake during pregnancy, intra-household food distribution and the role women played in programme activities. Management and human resource needs for scaling up were also defined.

Based on this work and beginning in 1993, the pilot was expanded in collaboration with local NGOs and the government of Bangladesh into the 'NGO Gardening and Nutrition Education Surveillance Project' (78). Eventually, the programme was scaled up to national-level coverage, supporting

[6] Information for this case study was drawn from the following sources: Bloem *et al*. (78); Talukder *et al*. (79); Helen Keller International (38,80–82); Bushamuka *et al*. (83); Helen Keller International (84).

900,000 households (4.5 million beneficiaries), at a cost of approximately US$8/household per annum (82). In addition, based on success in Bangladesh, the intervention was replicated by HKI in Cambodia, Nepal and the Philippines, and adapted to Niger (81,83).

As new information emerged concerning the bioavailability of vitamin A from various sources and the limited bioavailability in plant sources (85), HKI developed a pilot 'homestead food production' programme, integrating animal husbandry into the ongoing homestead gardening programme in Bangladesh. The success of this 2002 pilot led to its expansion in 2003–2005 to other regions of Bangladesh.

Intervention design, elements and scope

Both gardening and nutrition education activities were linked with the ongoing development programmes of local NGOs. Strong links were established with participating communities to ensure sustainability. The NGOs' work with women's groups helped them to address the social and cultural constraints faced by women in Bangladesh. These NGOs were supported technically and financially by HKI for the first 3 years of the intervention. The establishment of village-level nurseries and homestead gardens was conducted by the NGOs in conjunction with community groups. The village nurseries served as a community support service network, where demonstrations and training on low-cost, low-risk gardening practices were conducted and where seeds, seedlings and saplings were produced and distributed. Most of the village nurseries in the programme operated as small enterprises.

Each NGO was encouraged to form 45 village nurseries per sub-district. Five to ten working groups of approximately 20 women each were linked to each nursery. A group leader was identified to develop and manage the nursery. The group leader also facilitated nutrition and health education through peer education among the women's groups. HKI provided training and technical assistance to the partner NGOs and, together with them, provided technical assistance based on the needs of the households and nursery owners.

Gender was an important focus of intervention activities. Women in rural Bangladesh have traditionally managed seasonal homestead gardening, from sowing to harvesting and storing seeds. Thus the programme actively targeted women in an effort to provide them with new income-generating opportunities related to homestead gardening.

To incorporate ASFs in the intervention, interested village nursery owners became village model farmers who provided training, demonstration and other support services to household food producers. The focus foods were poultry, eggs, milk and fish. Nutrition education focused on dietary diversity, micronutrient consumption, and maternal and child nutrition (80).

Monitoring and evaluation methods

The HKI programme had an integrated monitoring system that was an essential part of implementation and was particularly important in scaling up. Quarterly monitoring was used to identify problems and priorities and develop solutions through collaboration between programme staff and beneficiaries. Each local NGO used the quarterly monitoring system to generate information on programme progress. The data were collected using a simple questionnaire on seed production, vegetable and fruit production and consumption, and income. In addition to responding to monitoring information, HKI staff regularly supervised NGO field and management staff.

To assess economic and social impacts in Bangladesh, a cross-sectional survey was conducted in February and March 2002 (83). The survey also aimed to capture information about the potential for sustainability. The survey covered three groups of 720 households each, representing active programme participants, former programme participants and control households. Because of targeting, participants and former participants generally were landless or land-poor (<0.2 ha), with a day labourer as household head. Control households were selected from similar geographic areas within targeted sub-districts, but in sub-divisions (unions) where the programme had not yet been implemented.

The selected control households were also landless or land-poor.

Structured questionnaires were used, and the homestead caretaker estimated garden production in kilograms. Additional information was collected on the adoption of year-round production practices, consumption of garden produce, the amount of cash generated, changes in the ability of women to contribute to household livelihoods and other developments.

Monitoring results

Monitoring data showed that the programme increased the production and consumption of fruits and vegetables in the areas it covered and increased the number of varieties consumed. Between 1997 and 1998, the proportion of households without a homestead garden decreased from 25% at baseline to less than 2%. After 1 year of participation, the proportion that practised year-round (developed) gardening increased from 3% to 33%. The number of varieties and the volume of vegetables produced in developed gardens were three times higher than in traditional gardens. Seventy-three per cent of the gardens were managed by women, and women were the main decision makers regarding gardening practices and use of the income from sales of garden produce (79).

Monitoring data also showed that children in households with developed gardens consumed 1.6 times more vegetables. The risk of night blindness was lower for at-risk children[7] when their house had a homestead garden (79).

Finally, monitoring data also suggested income effects. Participating households earned, on average, the equivalent of US$8 on a bimonthly basis selling fruits and vegetables. The main uses of this income were food purchases and investments in seeds, seedlings, saplings, poultry, or other income-generating activities. Nearly 10% of households saved income generated from the garden (79).

Households with improved or developed homestead gardens consumed micronutrient-rich, non-cereal foods more frequently than other households. These foods, such as lentils and animal products, were not produced in the gardens, but were purchased using income generated from sales of garden produce (80).

Evaluation results

The cross-sectional study in 2002 confirmed monitoring results related to production, and showed that households participating in the intervention produced a median of 135 kg of vegetables and 24 kg of fruit in the preceding 3 months, compared with 46 kg of vegetables and 14 kg of fruits during the same period for control households. Three years after withdrawal of programme support, formerly participating households maintained higher production of vegetables (120 kg) and fruits (24 kg), relative to controls. Similarly, income from gardening remained more than twice as high in formerly participating households, compared with controls. Such results suggest that the approach may lead to sustainable improvements for vulnerable households, and also illustrate a role in improving food security (83).

Strengths, limitations and conclusions

Very few agricultural interventions with nutrition objectives have been successfully scaled up. The Bangladesh model, including the scaling-up process, is well documented and has been replicated in Cambodia and Nepal. As with the OFSP intervention, information on intermediary outcomes (production, participation by women, sales and use of new income) supports results, illuminating a pathway towards impact on nutrition outcomes.

While the evaluation design lacked baseline information, the presence of the rich monitoring data documenting change across the life of the intervention, in combination with the cross-sectional post-intervention survey, provides plausible evidence of impact. Efforts to identify comparable control households, in comparable environments, also strengthen the evaluation results.

[7] Children were considered at risk if they were 12–59 months of age and had not received a vitamin A capsule in the 6 months prior to the survey.

Finally, this example is also one of the few to provide information on cost and evidence of sustainability, at scale. The programme continues to expand in Bangladesh into new areas and to additional households in the current working areas. In 1997, HKI started the phase-out of technical and financial support to NGOs that had already received one year of support. Monitoring information from these areas one year later showed that households were maintaining their improved gardening practices and continued to consume fruits and vegetables more regularly. The evaluation results reported above also show evidence of sustainable impacts on production and income.

Discussion

Lessons for design of interventions

Decades of research on the nutritional benefits of agricultural interventions have yielded a number of consistent lessons for intervention design. These include: the importance of careful attention to gender dimensions; the necessity of incorporating BCC strategies and elements; and a variety of process-related lessons that enable grounded design, taking into account livelihoods and vulnerabilities. Partnerships with local NGOs and other civil society organizations can ground programmes and improve prospects for sustainability. Such partnerships, along with careful pilot studies and systematic high-quality monitoring, were also crucial to scaling up to national level in the one case study where this occurred.

Early commercialization studies identified the critical role of women in ensuring nutritional benefits from agricultural interventions, especially for vulnerable household members. This role was confirmed in the decades that followed and it is now widely accepted that gender dimensions must be addressed in agricultural interventions, both for agricultural success and to achieve improvements in food security and nutrition. Research on women in agriculture has also shown, however, that a number of attempts to target and improve the status of women have failed. One recent institutional study (86) documented constraints to integration of gender perspectives into agricultural interventions and concluded that development planners and practitioners had limited experience with actually using gender methodologies: 'everyone "knows" gender but they don't know what to do with it' (87, p. 17). Including gender in design and monitoring and evaluation systems clearly increases costs and complexity and, hence, is often dropped due to insufficient financial and human resources. But previous work has identified key elements of successful approaches (Box 3.1). Mainstreaming gender into effective programming requires continued capacity strengthening within implementing organizations but success can be achieved and tools are available (5,88,89). Successful programmes may also depend on continued advocacy to address 'higher level' constraints related to land tenure and market systems.

The early studies also documented lack of impact on young child nutritional status, even when production and household incomes (and sometimes household-level energy consumption) increased substantially as a result of agricultural commercialization. There are a number of possible explanations for the lack of impact, including the fact that agricultural interventions alone are unlikely to affect all of the proximal determinants of childhood undernutrition. These may include intra-household food distribution favouring adult males, inadequate child feeding and caregiving practices, unaddressed micronutrient deficiencies, and other constraints on child nutrition such as high infectious disease burden and poor access to health care. This last determinant can only be addressed through coordination with other sectors.

But many of the other determinants of child nutrition involve behaviours that can be changed within households. Our review has shown that agricultural interventions that seek to improve nutrition must include strong BCC strategies to ensure that increased access to food and increased income translate into changed behaviours and nutrition improvement for vulnerable individuals. This insight has been confirmed in both horticultural and animal production interventions: only those interventions that attended to gender and/or to BCC succeeded in impacting micronutrient nutrition outcomes. The case studies confirm strong potential for success when well-designed interventions attend to both.

Finally, to enable planners to design successful interventions including the elements above, thorough and grounded knowledge of context is essential. This, too, has long been recognized; the successful interventions included in this review suggest some processes for achieving it. One key strategy is investment in developing strong partnerships with local organizations and linking these upwards to relevant actors in ministries, international NGOs and agricultural research institutes. Many organizations have also found it useful to incorporate livelihoods frameworks into planning processes, in order to ensure that existing livelihoods, vulnerabilities and opportunities are identified. A wide range of tools has been developed to facilitate this.[8]

Lessons for evaluation design

Previous reviews have identified a range of problems with evaluation designs. Common problems have included absent, inappropriate or poorly described comparison groups; self-selection of participants/adopters of innovations as the study group; small sample sizes; and lack of baseline data. In addition, studies have not always been controlled analytically for differences between groups, even when this was possible. Weak designs, together with inconsistent results, have contributed to scepticism about the potential for agricultural interventions to impact nutrition.

We argue that sufficient evidence exists to document potential for impact, but the evidence base is still limited. To contribute to this evidence base, future studies of agricultural interventions should:

- Work from a conceptual framework/programme theory that articulates pathways between intervention inputs, processes and activities, intermediate outcomes and final impact objectives, and use this framework to design data collection activities.
- Gather baseline data before the intervention is implemented.
- Include appropriate control groups whenever possible, and clearly describe how groups are defined and selected – when this is not possible, include full information about the characteristics of study groups and compare these with those to the general population.
- Use statistical methods to account for inter-group differences in characteristics resulting either from inherent population differences or from differential selection into the sample.
- Design simple monitoring systems that include useful aggregation of information to support evaluations – monitoring systems must also serve programme managers' needs for timely information for trouble-shooting and programme improvement, and can inform efforts to scale up programmes.
- In monitoring systems and in impact assessment surveys, collect data on intermediate outcomes according to the programme theory – this will strengthen the plausibility of positive results and help explain negative or null results.

Future studies of agricultural interventions can also fill several other information voids. To date, very limited information is available regarding the cost of interventions. Policy makers and programme planners and managers urgently need this information for decision making. Related to this, much work remains to be done to characterize minimum cost/minimum intensity extension and BCC packages, in various contexts and for various objectives. This was identified as a critical next step following the OFSP work in Mozambique.

Next, even though it has been suggested that agricultural solutions to nutrition problems are more sustainable than some other

[8] See e.g. a range of resources at: http://www.fao.org/sd/pe4_en.htm; http://www.livelihoods.org/; http://www.ifad.org/sla/; http://www.odi.org.uk/plag/RESOURCES/sustainablelivelihoodsseries.html.

approaches (e.g. supplementation), information on demonstrated sustainability is extremely limited. Policy makers and programme planners need information on sustainability of both new agricultural practices and improved nutrition-related behaviour. Ongoing monitoring as in the HKI example and/or follow-up studies will be very valuable in this regard.

Finally, because scaling up has been extremely rare, very little information is available to inform future efforts. Therefore, when such efforts occur, partnerships, processes, failures and successes should be well documented and this information disseminated.

Agriculture for nutrition: limitations and potential

This review has documented the potential for well-designed agricultural, horticultural and livestock interventions to improve micronutrient nutrition for vulnerable individuals. The complexity of agriculture interventions may suggest that in many cases other approaches – for example, micronutrient supplements and/or fortified products – may be more cost-effective in the short run. Whether or not this is so, even in the short run, will depend on underlying levels of micronutrient deficiencies, health infrastructure, access to commercially fortified products and many other factors. For certain vulnerable groups, such as infants and young children (6–23 months of age) and pregnant and lactating women, it is very difficult, if not impossible, to meet all micronutrient needs from family foods/dietary diversification and supplements and/or fortified products may be needed to fill gaps. However, agricultural interventions can complement supplementation and fortification programmes (75,90).

Interventions that succeed in increasing intakes of fruits, vegetables and/or ASFs for the poor deliver more than one or several micronutrients. Unlike supplements and fortified products, diverse diets including fruits, vegetables and ASFs deliver a range of macro- and micronutrients, fibre and phytochemicals, all related to human health (91). For this reason, all national dietary guidelines include objectives related to dietary diversity. Diverse diets are also needed in order to truly achieve food security, in its full sense, which recognizes diet quality and preferences.

Further, although sustainability is not yet well documented, we argue that agricultural interventions do have the potential to improve diets in a sustainable way, and this has been demonstrated in the few instances where it has been examined (53,82). If long-term costs, effectiveness and sustainability are all documented and considered by policy makers, agricultural approaches may find their place in integrated strategies to improve nutrition for vulnerable individuals.

In designing agricultural interventions for nutrition, however, it is important to recognize that the simple pathway of production for own consumption does not always dominate, even when this is the intention of the intervention design. Household decision making about use of new resources is complex and planners should consider which pathway (e.g. own consumption, sale) is likely to dominate, given conditions in the intervention area. Design of effective BCC strategies and their success will depend on careful consideration of the factors involved in these household decisions.

Finally, to fulfil the potential of agriculture to improve micronutrient nutrition, partnerships across disciplines are required. Such partnerships were evident in the case studies, in which agriculture and nutrition were closely integrated. Planners of agricultural interventions are accustomed to careful consideration of the agronomic characteristics of the crops they introduce or promote. Characteristics such as drought tolerance, disease resistance, 'fit' within existing cropping patterns and role in filling seasonal food gaps are routinely considered. To impact nutrition, agriculturalists, in partnership with nutritionists, must supplement this with information about deficits in local diets and micronutrient intakes, as well as information concerning the motivations and constraints that determine household consumption decisions. Agricultural and nutrition extension and communication packages must be designed to address these realities. When they are, the potential to meaningfully impact micronutrient malnutrition can be realized.

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4 A 3-year Cohort Study to Assess the Impact of an Integrated Food- and Livelihood-based Model on Undernutrition in Rural Western Kenya

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Abstract

Reducing extreme poverty and hunger is the first Millennium Development Goal (MDG). With undernutrition contributing to one third of all child deaths, improving nutrition is a precondition for accelerating progress towards other MDG targets. While the role of technical interventions such as micronutrient fortification and supplementation in reducing morbidity and mortality has been well documented, evidence to support more comprehensive multi-sectoral approaches remains inconclusive. This chapter aims to evaluate the impact of an integrated food- and livelihood-based model on nutrition-related outcomes in rural western Kenya.

A 3-year prospective cohort study was undertaken among 300 randomly selected wealth-stratified households. Detailed socio-economic and health surveys were conducted. A nutrition module assessed household levels of food security, food consumption frequency and diet diversity. This was complemented by anthropometric measurement and assessments of serum levels of vitamin A among children under 5 years old.

The average food insecurity score decreased from 5.21 at baseline to 4.13 at follow-up ($P < 0.0001$). Average diet diversity scores for daily, weekly and monthly time periods increased from 6.7 to 7.3; from 10.7 to 11.2; and from 12.4 to 12.6, respectively ($P < 0.0001$). Daily consumption for 14 out of 16 food groups increased significantly. For children under 2 years of age, underweight and stunting decreased from 26.2% to 3.9% ($P = 0.002$) and from 62.3% to 38.3% ($P = 0.014$), respectively. Vitamin A deficiency as measured by serum vitamin A levels decreased from 70.0% to 33.3% ($P = 0.007$) for children under 5 years old.

This study presents encouraging evidence that a multi-sectoral food- and livelihood-based model can improve diet quality, enhance food security and positively affect childhood nutritional outcomes. The wider application of this approach to a diversity of agro-ecological zones in sub-Saharan Africa is currently being assessed.

Key words: diet diversity, multi-sectoral, food security, vitamin A, stunting, food-based

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Introduction

Globally, undernutrition contributes to roughly half of the 8.8 million child deaths that take place each year (1), representing nearly one-third of the global burden of disease among children (2). Micronutrient deficiencies weaken the health, growth and productivity of over two billion people worldwide, placing constraints on the development potential of households, communities and countries (3). The number of undernourished children has increased in many countries over the past decade, with reductions in levels of child mortality levelling off or increasing in a number of countries (4). This disturbing trend has been compounded recently by global food crises and an economic downturn that have compromised fragile gains and plunged many more households into a state of vulnerability and deprivation (5). Decisive action is required to address interdependent relationships between undernutrition and wider Millennium Development Goal (MDG) targets including poverty reduction, maternal mortality and child survival. Despite this urgency, international action in support of new innovations and strategic partnerships to address undernutrition has been limited (6).

The first 1000 days of a child's life (minus 9 months to 2 years) is considered the 'critical window of opportunity' where the potential exists to affect not only child growth and nutritional status, but also cognitive development (7). However, nutrition throughout the life cycle is of critical importance. Although the significance of this time period has been well documented, interventions to improve early childhood nutrition have been fragmented and narrowly focused. Prevailing approaches have generally emphasized supplementation and fortification, relying heavily on the external delivery of target nutrients (8). Broader strategies to address the complex challenges associated with the determinants and consequences of undernutrition remain poorly understood or embraced. Food- and livelihood-based models that enhance the security and quality of the diet through local production, processing and storage of foods, the promotion of agricultural biodiversity, all complemented with community education and development, which often falls outside the traditional scope of clinical nutrition, have been under-researched and under-developed. As a consequence, well-defined scalable food and livelihood interventions linked to improvements in maternal or child health outcomes have been less embraced by the development community (9).

Recent calls for greater attention to nutrition – including the United Nations' Millennium Project, the recently formed High-Level Task Force on the Global Food Security Crisis, the reform of the World Committee on Food Security and the establishment of the High-Level Panel of Experts on Food Security and Nutrition and the Policy Brief on 'Scaling up Nutrition: A Framework for Action' – highlight the importance of integrating technical interventions with wider efforts to address its underlying causes, incorporating perspectives from agriculture, water and sanitation, infrastructure, gender and education (10–14). Such approaches would build on the knowledge and capacities of local communities to transform and improve the quality of diets for better child health and nutrition. Recent research has documented potential synergies between health and economic interventions, suggesting multi-sectoral approaches may generate a wider range of benefits than approaches of a single sector acting alone (11,15). While these findings may seem intuitive, the testing of complex multi- and cross-sectoral interventions to improve child nutrition and health remains at an early stage of development. Further operational research is urgently required if the benefits of improved food security and economic development are to be expanded and channelled into conventional health and nutrition intervention programmes.

The Millennium Villages Project (MVP) involves the systematic delivery of a package of health and development interventions with the aim of accelerating progress towards the MDG targets (16,17). The project implements a concurrent package of scientifically proven interventions in agriculture, health, education, water and sanitation, and infrastructure at an annual cost of US$110 per person per year sustained over a 5- to 10-year period. The interventions were recommended as important components in achieving the MDGs by the United Nations' Millennium Project (11,12). The MVP operates in 14 sites in ten sub-Saharan African countries with project sites drawn from a diversity of agro-ecological zones in 'hunger hot-spots' where rates of child undernutrition exceed 20% (17).

The nutrition strategy adopted within the Millennium Villages centres upon an integrated food- and livelihood-based approach. The model has three main components (Fig. 4.1). Clinical interventions are introduced to prevent and mitigate macro- and micronutrient deficiencies among infants and young children. School-based interventions work to improve health, nutrition, school attendance and learning outcomes among primary-school children. Community- and household-based interventions foster increased agricultural production, greater diet diversity and enhanced livelihood security to address longer-term nutritional needs.

We conducted a prospective evaluation of the MVP site in rural western Kenya to assess effects of this multi-sectoral approach on undernutrition over a 3-year project period. Our aim was to test the hypothesis that a food- and livelihood-based model can enhance household food security and diet diversity, increase vitamin A levels, and lead to improvements in anthropometric indicators among children.

Methods

Setting

In December 2004, the MVP was launched in collaboration with the Kenyan government in the Sauri village of the western Nyanza Province. This rural community of 63,500 persons is located in the Kenya highlands, 1400–1500 m above sea level and 30 km north of Lake Victoria with annual rainfall of 1800 mm (18). The main occupations are subsistence farming, consisting primarily of maize, sorghum and cassava and animal husbandry, including goats, chickens and cattle. Before the project started, 79% of the population lived on less than US$1/day and 90% on less than US$2/day. The infant mortality rate was 149 per 1000 live births, the under-five child mortality rate was 95 per 1000 live births, and 63% of children under 5 years of age tested positive for malaria (16,18).

Integrated multi-sectoral approach to improving nutrition

The major aim of the nutrition programme is to assist communities to eliminate hunger and improve nutrition security. The three components of the strategy are outlined in Fig. 4.1. Interventions were implemented concurrently over a 3-year period with the agriculture and health initiatives being identified by community members at project commencement as the most urgent.

Clinical interventions focused on persistent macro- and micronutrient deficiencies in children, including vitamin A supplementation, treatment of severe acute malnutrition and regular growth monitoring. For cases of moderate malnutrition, families received InstaFlour (United States Agency for International Development) or locally made nutrient-rich flour consisting of millet, soybean, sorghum, cassava and groundnuts. In addition, basic maternal health interventions such as antenatal care and institutional delivery were supported by efforts to promote adequate weight gain and improve coverage with iron and folic acid supplementation.

School-based interventions included home-grown school meals, gardens and nutrition activities after school, along with deworming campaigns. Balanced school meals have been demonstrated both to increase school attendance as well as improve learning outcomes (19). Currently, 20,584 children – nearly all those of primary-school age – receive a home-grown school meal consisting primarily of maize and beans complemented with vegetables such as tomatoes and leafy greens.

Household- and community-based interventions engaged longer-term issues of food and livelihood security. Interventions include subsidized seed and fertilizer to increase

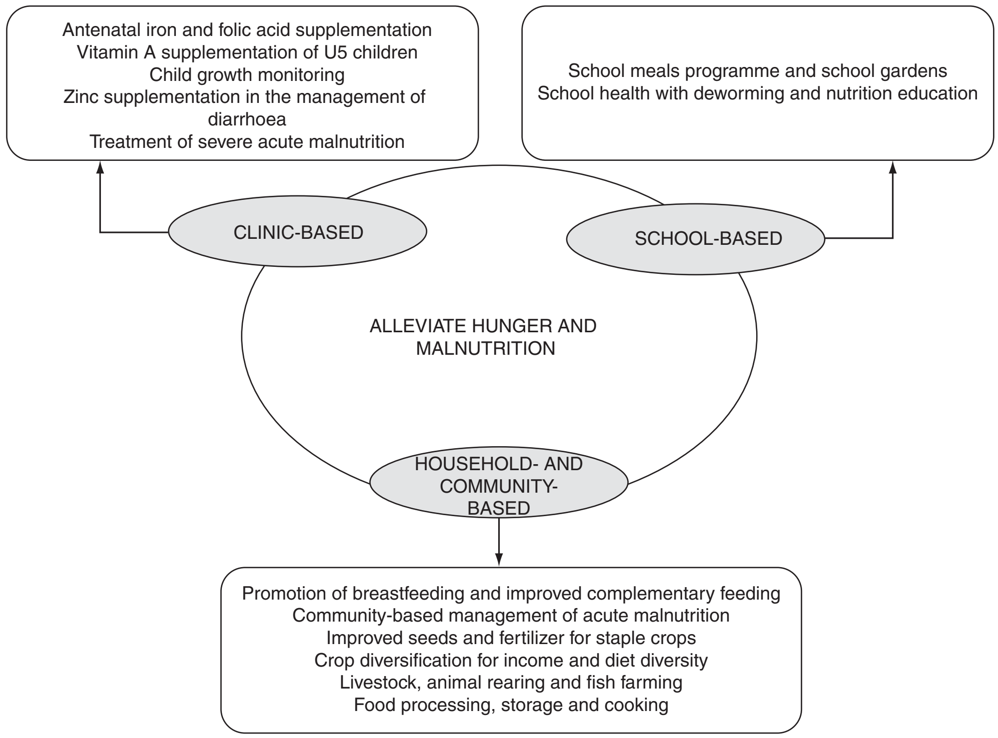

Fig. 4.1. Nutrition strategy of the Sauri Millennium Village (U5, under 5 years of age).

agricultural productivity; the introduction of high-value crops; agro-processing initiatives; and microfinance programmes to stimulate small-business development. Taken together, these efforts were an attempt to enhance nutritional intake and diet diversity, while affording households the additional income required to address nutritional needs in a sustainable fashion. This was complemented by a community health worker programme to promote exclusive breastfeeding and locally appropriate complementary feeding, home-based fortification and proper food storage techniques.

Study population

Detailed household mapping was conducted prior to the initiation of interventions. This process included a population census, Global Positioning System coordinates for most dwellings and the generation of a household wealth score. Following this process, proportional sampling was used to represent the geographic spread of the sub-administrative units within the village. From these administrative units, a total of 300 wealth-stratified households were randomly selected to undergo detailed periodic assessments. Consenting households were followed longitudinally over 3 years. In the event of refusals or household attrition, random replacement from baseline wealth strata was conducted to maintain the sample size. This chapter compares baseline data taken in June 2005 with those from an assessment conducted after 3 years of intervention exposure, in June 2008.

Within each participating household, individuals were recruited for study inclusion based on the results of preliminary demographic assessment. Household members were defined as those who have lived in the household for at least three of the past 12 months and who 'normally eat from the same pot'.

Within each household, specific demographic groups were sampled. Household heads provided information on household demography, education, employment, agricultural and non-agricultural sources of income, assets, expenditure, consumption and access to basic services including water and sanitation, energy, transport and communication. Surveys were administered to adults in the household aged 13–49 years old and assessed health-related MDG indicators, nutrition and food security, alongside common causes of child mortality including diarrhoea, pneumonia and malaria, and health-seeking behaviour. Further, biological data were collected on adults and children and anthropometry data for children under 5 years of age. A full explanation of the study procedures, purpose, risks and benefits were explained to participants during the informed consent process. The study received ethical approvals from the Institutional Review Board at Columbia University and the Kenya Medical Research Institute.

Study procedures and generation of indicators

Indicators, their definitions and sources of data within this project are listed in Table 4.1.

Food insecurity

A Food Security Questionnaire (FSQ) was administered to the head of each household and/or the person primarily responsible for preparing and serving food in the household. Surveys were administered in the same time period of the agriculture season, before the harvest of the crop from the main rainy season, which corresponds to the hunger period.

The FSQ consisted of 11 questions on food insecurity and coping aimed at assessing the household's access to food, as a measure of food insecurity. The questions were locally modified from Food and Nutrition Technical Assistance Project (FANTA) questions (20). For each of the 11 questions, the percentage of individuals answering 'yes' to that question was determined. A Food Insecurity Score (FIS) was calculated as the total number of food insecurity questions answered with 'yes', indicating that the subject had to deal with that specific food shortage situation. All questions were treated with equal weight for FIS calculation.

Consumption frequency and diet diversity

A food-frequency questionnaire (FFQ) was administered to household heads and/or the person primarily responsible for preparing and serving food at both baseline and year 3. Similar to the FSQ, surveys were administered in the preharvest period. The FFQ contained 121 locally available food items, for which frequency of consumption (times per day, week, month or year) was assessed. A Consumption Frequency Score (CFS) for each food item was calculated as the number of times the food item was consumed per week. A frequency of once weekly received a score of 1, consumption of once daily received a score of 7, with other values scaled accordingly (21).

Food items were grouped into 16 food groups based on the Food and Agriculture Organization of the United Nations (FAO)/FANTA Household Dietary Diversity Questionnaire and Guidelines (22). The 16 food categories were: cereals; vitamin-A rich vegetables and tubers; white tubers and plantains; green leafy vegetables; all other vegetables; legumes; nuts and oily fruits; vitamin A-rich fruit; all other fruit; meat; eggs; milk; fish; oils and fats; sweets; and spices and condiments. No distinction was made between organ meat and flesh meat in the list of 121 food items used for the FFQ. The CFS for each food group was calculated as the sum of CFSs of food items in the respective food group (21).

Food items and food groups were categorized for consumption frequency 'at least daily', 'at least weekly' or 'at least monthly', with criteria for CFS set at 7, 1 and 0.25, respectively, based on the CFS scoring strategy (21). For each food group, the percentage of individuals consuming the food group on a daily basis was determined.

Individual Diet Diversity Scores (DDS) were generated for daily, weekly and monthly

Table 4.1. Indicators.

	Indicator	No. of items for composite indices	Source
Food insecurity	Answered YES to Food Insecurity Question X, with X being one of 11 food insecurity questions	N/A	FSQ
	Food Insecurity Score (FIS) (total number of food insecurity questions answered with YES; possible range 0–11)	11	FSQ
Food consumption frequency and diet diversity	Consumption Frequency Score (CFS) for food item X (= times consumed per week; e.g. once weekly = 1, twice weekly = 2, once daily = 7, once monthly = 0.25), with X being one of 121 FFQ items	N/A	FFQ
	CFS for food group Y (= sum of consumption frequency scores of food items in food group Y), with Y being one of 16 food groups	N/A	FFQ
	Consumes food group Y on a daily basis (i.e. consumption frequency score of food group Y is 7 or above)	N/A	FFQ
	Food Variety Score (FVS) – day (number of food items consumed on a daily basis; i.e. CFS of food item X is 7 or above; possible range 0–121)	121	FFQ
	FVS – week (number of food items consumed on at least a weekly basis; i.e. CFS of food item X is 1 or above; possible range 0–121)	121	FFQ
	FVS – month (number of food items consumed on at least a monthly basis; i.e. CFS of food item X is 0.25 or above; possible range 0–121)	121	FFQ
	Diet Diversity Score (DDS) – day (number of food groups consumed on a daily basis; i.e. CFS of food group Y is 7 or above; possible range 0–13)	13	FFQ
	DDS – week (number of food groups consumed on at least a weekly basis; i.e. CFS of food group Y is 1 or above; possible range 0–13)	13	FFQ
	DDS – month (number of food groups consumed on at least a monthly basis; i.e. CFS of food group Y is 0.25 or above; possible range 0–13)	13	FFQ
Anthropometry	Underweight (weight-for-age *Z* score ≤–2)	N/A	Anthropometric measurements
	Stunting (height-for-age *Z* score ≤–2)	N/A	Anthropometric measurements
	Wasting (weight-for-height *Z* score ≤–2)	N/A	Anthropometric measurements
Vitamin A deficiency	Vitamin A deficient (serum vitamin A level <20 μg/dl)	N/A	Serum sample analysis
	Received vitamin A supplementation during the last 6 months	N/A	Children and Women Health Questionnaire

N/A, not applicable; FSQ, food security questionnaire; FFQ, food-frequency questionnaire.

time periods based on 13 food categories. As recommended by FAO/FANTA (22), sweets, spices and condiments, and beverages were excluded for this purpose and legumes, nuts and oily fruits were combined as one food group. DDS per day, DDS per week and DDS per month were calculated as the number of food groups (of 13 in total) consumed on a daily, weekly or monthly basis, respectively. In addition, Food Variety Scores (FVS), including FVS per day, FVS per week and FVS per month, were calculated as the number of food items (out of 121 food items) consumed on a daily, weekly or monthly basis, respectively.

Anthropometry

Body weight was obtained in two separate measures using an electronic balance (Seca, Hanover, Maryland, USA) or on a hanging spring scale (Salter Ltd, Tonbridge, UK) read to the nearest 0.1 kg. Standing height (for children aged >24 months) or recumbent length (for infants aged 0–24 months) was read to the nearest 0.1 cm on a steel tape attached to a wooden board with a foot-plate and sliding head block (Shorr Productions, Woonsocket, Rhode Island, USA). All anthropometry measures were done by standard practices (23). Anthropometric indices were calculated with Stata macros provided by the World Health Organization (WHO) with use of the new growth references (24). Underweight, stunting and wasting were defined as weight-for-age Z score (WAZ) ≤ -2, height-for-age Z score (HAZ) ≤ -2 and weight-for-height (WHZ) Z score ≤ -2, respectively. Extreme Z scores, WAZ ≤ -6 or ≥ 5 for underweight, HAZ ≤ -6 or ≥ 6 for stunting and WHZ ≤ -5 or ≥ 5 for wasting, were excluded as outliers, as suggested by the WHO protocol. In this chapter, we compare data on children under 2 years of age at follow-up, who were conceived or born during the intervention period, to the same age range at baseline.

Vitamin A deficiency

Individual serum samples were collected from children under 5 years old and women between the ages of 13 and 49 years to determine vitamin A deficiency. Aliquots of 100 μl from five individuals were pooled to represent a single sample, resulting in a total of 30 pooled serum samples (from 150 individuals) for baseline and 23 samples for year 3 follow-up. The same pooling was done for women, resulting in a total of 30 serum samples from both baseline and the year 3 analysis (25).

The levels of vitamin A were measured by high-performance liquid chromatography (Shimadzu Corporation, Kyoto, Japan). Vitamin A was de-proteinized from the serum/plasma sample using ethanol and extracted with hexane. The extract was dried, re-dissolved with ethanol and injected into the chromatograph. Retinyl acetate was used as the internal standard. This assay was standardized using calibrators from the National Institute of Standards and Technology. The minimum required volume for this assay is 150 μl. Vitamin A deficiency was defined as a level <20 μg/dl (26).

A health questionnaire was administered to adult women, above 13 years, to assess women's and children's health status and access to health care. In this questionnaire, it was asked if the child under 5 years of age received a vitamin A dose in a capsule during the last 6 months. The percentage of children for whom vitamin A supplementation was reported was determined from these data.

Statistical analysis

Data from questionnaires were entered electronically using CSPro data entry software (US Census Bureau, Washington, DC, USA) and cleaned for structural and logical errors in both CSPro and Stata version 10 (StataCorp., College Station, Texas, USA). All statistical analyses were performed with Stata. Normal distribution was checked by Shapiro–Wilk tests. Differences between means were checked by two-sample t tests. Two-proportion z tests were used to test for differences between proportions. Percentage change was calculated as the difference between year 3 and baseline divided by the value at baseline.

Results

Three hundred households were surveyed at baseline and follow-up. The study population for each component of the evaluation is detailed in Fig. 4.2. Results are summarized in Table 4.2.

Food insecurity

The decrease in average FIS at year 3 compared with baseline indicated improved food security in the community (Table 4.2). For eight of the 11 food insecurity questions, the percentage of individuals coping with the respective food shortage situation reduced significantly from baseline to year 3 ($P < 0.01$) (Table 4.3). In contrast to the results of the other food coping strategies, the proportion of the population that 'changed the family diet to cheaper or less-preferred foods in the past week' was higher at year 3 (75.2%) than at baseline (56.9%; $P < 0.0001$). The proportion of the population who borrowed food or money for food from others due to insufficient food did not change over the course of the three years. Further, the average number (95% confidence interval) of daily meals increased significantly from 2.56 (2.50, 2.62) to 2.70 (2.63, 2.77) ($P = 0.036$).

Consumption frequency and diet diversity

Higher average DDS and FVS were observed for daily, weekly and monthly time periods at year 3 as compared with baseline, indicating improved dietary diversification in the community (Table 4.2). Figure 4.3 shows changes between baseline and year 3 in daily consumption for 16 food groups. For 14 out of the 16 food groups, consumption on a daily basis increased from baseline to year 3. Most pronounced was the increased consumption of legumes, which increased from 14.6% at baseline to 44.3% by year 3 ($P < 0.0001$). This can be explained by the increased consumption frequency of common beans as a maize-and-beans dish and beans alone (data not shown).

The consumption of animal-source protein increased including fish, milk and milk products, eggs and meat ($P < 0.01$ for each of these food groups). For vitamin A-rich plant-based food products, including vitamin A-rich vegetables and tubers, vitamin A-rich fruits and green leafy vegetables, daily consumption was high at baseline (96.5%) and no change was observed by year 3 (96.1%; $P = 0.756$) (Table 4.2). Some shifts of food items within the vitamin A-rich plant group were noted, including a decrease in consumption of vitamin A-rich fruits (particularly guava and papaya) and an increase in consumption of some dark-green leafy vegetables (particularly kale, black nightshade, amaranthus and spiderweed) and vitamin A-rich vegetables and tubers (carrots, pumpkin) (data not shown). Consumption of vitamin A-rich animal-based food products increased from 55.6% to 68.2% ($P < 0.0001$) (Table 4.2).

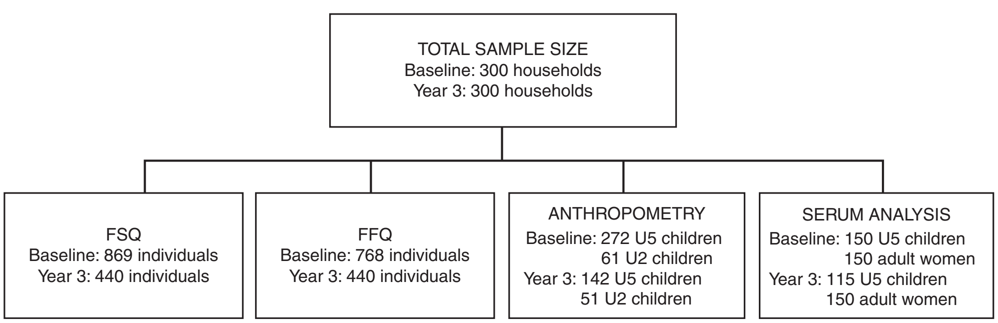

Fig. 4.2. Sampling design (FSQ, Food Security Questionnaire; FFQ, food-frequency questionnaire; U5, under 5 years of age; U2, under 2 years of age).

Table 4.2. Outcome measures.

	Indicator	Baseline	Year 3	% change	*P* value
Food insecurity	Mean FIS (95% CI)	5.21 (5.04, 5.38)	4.13 (3.92, 4.30)	–20.7	<0.0001
Food consumption frequency and diet diversity	Mean FVS – day (95% CI)	9.6 (9.4, 9.9)	11.8 (11.3, 12.3)	22.1	<0.0001
	Mean FVS – week (95% CI)	31.8 (31.1, 32.5)	35.5 (34.5, 36.5)	11.7	<0.0001
	Mean FVS – month (95% CI)	56.7 (55.8, 57.6)	63.0 (61.8, 64.3)	11.2	<0.0001
	Mean DDS – day (95% CI)	6.67 (6.54, 6.80)	7.33 (7.17, 7.50)	9.9	<0.0001
	Mean DDS – week (95% CI)	10.66 (10.56, 10.76)	11.17 (11.04, 11.29)	4.8	<0.0001
	Mean DDS – month (95% CI)	12.37 (12.30, 12.44)	12.63 (12.57, 12.69)	2.1	<0.0001
	Consuming vitamin A-rich plant products on a daily basis	741/768 (96.5%)	423/440 (96.1%)	–0.4	0.756
	Consuming vitamin A-rich animal products on a daily basis	427/768 (55.6%)	300/440 (68.2%)	22.5	<0.0001
Anthropometry	Children aged 0–2 years underweight	16/61 (26.2%)	2/51 (3.9%)	–85.0	0.002
	Children aged 0–2 years stunted	33/53 (62.3%)	18/47 (38.3%)	–38.5	0.014
	Children aged 0–2 years wasted	3/56 (5.4%)	1/45 (2.2%)	–58.5	0.386
Vitamin A deficiency	Children aged 0–5 years vitamin A deficient	21/30 (70.0%)	8/24 (33.3%)	–52.4	0.0073
	Women aged 13–49 years vitamin A deficient	1/30 (3.3%)	0/30 (0%)	–100.0	0.3132
	Children aged 0–5 years who received vitamin A supplementation during the last 6 months	168/235 (71.5%)	156/225 (69.3%)	–3.2	0.613

FIS, Food Insecurity Score; CI, confidence interval; FVS, Food Variety Score; DDS, Diet Diversity Score.

Table 4.3. Detailed outcome measures of food security from Food Security Questionnaire.

	Indicator	Baseline	Year 3	% change	*P* value
Food insecurity	*Because of insufficient food:*				
	Had a day without eating anything in the past week	289/869 (33.2%)	101/440 (23.0%)	–33.0	<0.0001
	Reduced the size and/or number of meals eaten in the past week	632/869 (72.7%)	280/440 (63.6%)	–12.5	0.0007
	Changed the family diet to cheaper or less-preferred foods in the past week	494/869 (56.8%)	331/440 (75.2%)	32.3	<0.0001
	One or more children from the HH discontinued school in order to save money or to work for additional income in the past 12 months	179/872 (20.5%)	43/440 (9.8%)	–52.4	<0.0001
	One or more of the HH went to another neighbourhood, village, town or city to find work in the past 12 months	393/872 (45.1%)	122/440 (27.7%)	–38.5	<0.0001
	Used money that was intended for investing in small business in the past 12 months	541/872 (62.0%)	204/440 (46.4%)	–25.3	<0.0001
	Sold some household possessions, agricultural tools or productive tools in the past 12 months	218/872 (25.0%)	39/440 (8.9%)	–64.6	<0.0001
	Borrowed food or money for food from relatives, friends, neighbours, bank or money lenders in the past 12 months	582/872 (66.7%)	290/440 (65.9%)	–1.2	0.7626
	Sold or consumed seeds meant for planting next season's crops in the past 12 months	486/872 (55.7%)	122/439 (27.8%)	–50.1	<0.0001
	Sold livestock in the past 12 months	643/872 (73.7%)	257/440 (58.4%)	–20.8	<0.0001
	Sold or pledged land or house in the past 12 months	78/872 (8.9%)	26/440 (5.9%)	–33.9	0.0546

HH, household.

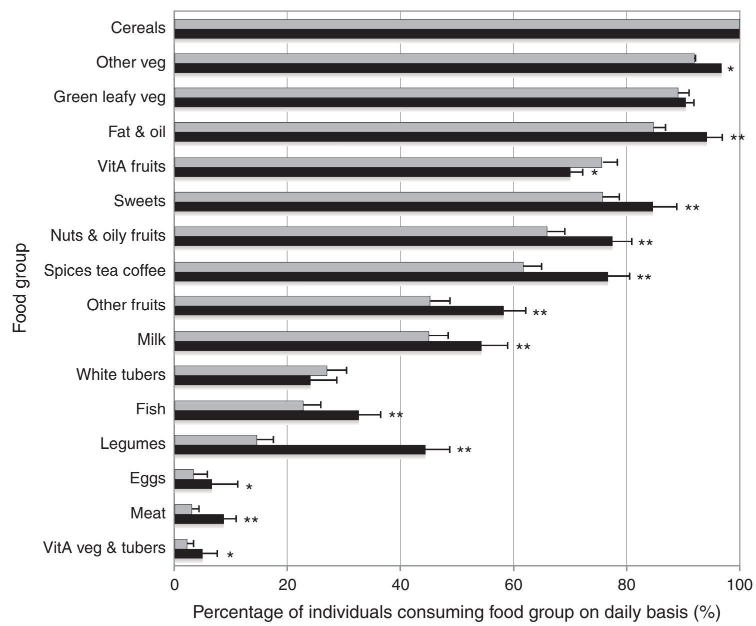

Fig. 4.3. Daily consumption of 16 food groups at baseline (▭) and year 3 (■). Bars represent percentage of the population consuming the food group on a daily basis, with 95% confidence interval represented by error bar. Number of individuals: n = 768 at baseline and n = 440 at year 3. Percentage value was significantly different from that at baseline: *P < 0.05, **P < 0.01 (vitA veg & tubers, vitamin A-rich vegetables and tubers; veg, vegetables; vitA fruits, vitamin A-rich fruits).

Anthropometry

The results of the anthropometric assessment are presented in Fig. 4.4. For children under 2 years of age, the proportion of those underweight and stunted was reduced by 85% and 39%, respectively. Levels of wasting were relatively low at baseline (5.4%) and remained unchanged by year 3 (2.2%; P = 0.431).

Vitamin A deficiency

The proportion of children under 5 years old with vitamin A deficiency was reduced by 52.4% over the study period (P = 0.0073) (Table 4.2). Compared with children under 5 years of age, vitamin A deficiency among adult women was low at baseline (3.3%) and did not change. Between baseline and follow-up, the proportion of children who received vitamin A supplementation in the past 6 months remained nearly identical at approximately 70% (Table 4.2).

Discussion

We assessed the effects of an integrated food- and livelihood-based model on nutrition-related outcomes in rural western Kenya. Over a 3-year study period, we observed improvements in diet diversity and food security, both essential for long-term nutrition gains (3). At follow-up, the number of children who were vitamin A deficient was reduced by half, and levels of stunting and underweight were reduced by 39% and 85%, respectively. These changes among children under the age of 2 years are critical for longer-term growth, cognitive development and lifetime health (7). Taken together, these

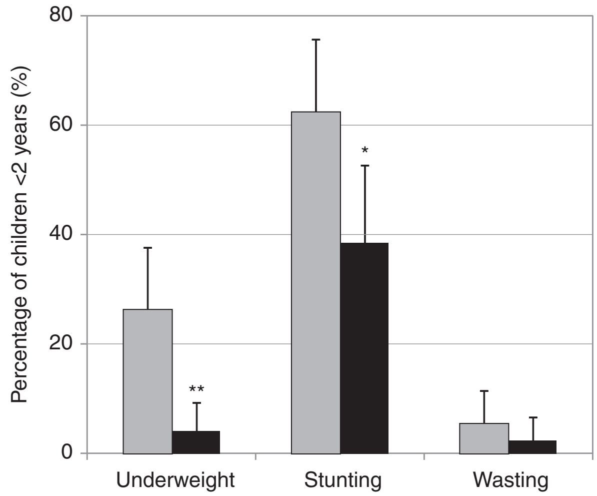

Fig. 4.4. Underweight, stunting and wasting of children under 2 years of age at baseline (▭) and year 3 (■). Bars represent the percentage of children under 2 years old with the nutritional deficit, with 95% confidence interval represented by error bar. Number of individuals: $n = 61$ at baseline and $n = 51$ at year 3. Percentage value was significantly different from that at baseline: $^{*}P < 0.05$, $^{**}P < 0.01$.

findings provide encouraging evidence that an integrated food- and livelihood-based approach can generate rapid progress towards the first MDG on reducing hunger and undernutrition.

While this assessment followed a cohort of households over a sustained period, employed previously validated tools and assessment methods, and measured changes in a series of objective pathway and outcome variables, there are also important limitations to underscore. The use of historical controls makes it difficult to separate the effect of the intervention from wider secular changes that may have taken place in the study site in the absence of the intervention. Indeed, a number of important contextual factors may have affected nutrition-related outcomes during the period of study. During 2007 and 2008, the second and third year of the intervention, the world witnessed an unprecedented increase in global food and fertilizer prices, pushing many marginal households deeper into poverty, with profound effects in sub-Saharan Africa (27). Accompanying this was a wave of post-election political violence in Kenya, from December 2007 to March 2008, which had its most direct consequences in the western region of the country where the study site is located (28,29). This instability took place several months before the follow-up surveys were conducted for this assessment. The combined effect of these factors served to exacerbate economic and food insecurity in much of the region. While further experimental research is clearly warranted, we suggest that it is likely that the programme provided an important buffer against these crisis events and that the results of our assessment are likely to underestimate the effects of the intervention package.

The results of this study point to major reductions in children stunted or underweight, which are important findings for a number of reasons. First, chronic undernutrition is a major public health challenge in Kenya and the Millennium Villages study site had substantially higher baseline levels than the national average. While levels of moderate or severe underweight (26.2%) were comparable to the 20% national figure, the levels of stunting observed at baseline (62.3%) were twice the 30% national average (30). Notably, the study was unable to detect changes in wasting, where prevalence at baseline was already low and in line with national figures. Second, the changes in stunting and underweight were observed in children under 2 years old – those conceived and born after the initiation of the intervention. As noted earlier, maximizing gains during this period has the potential to lead to longer-term nutritional and developmental benefits and make the greatest contribution to lifetime health (31). There is evidence to suggest that damage done to a child's physical or cognitive development during this period may be irreversible. Previous research in rural western Kenya has demonstrated that the prevalence of underweight and stunting was highest in children 3–24 months of age, whereas in children over 24 months of age, underweight and stunting stabilized, but they remained below the reference median (32).

In a complex multi-component approach to address undernutrition, it is difficult to make definitive statistical statements regarding the underlying mechanisms through which changes in growth outcomes were observed. However, the design of the study and results of our assessment do offer a number of potential explanations. First, changes in child growth took place alongside parallel shifts in a number of theoretically grounded pathway indicators (33), including improvements in food security, diet diversity and micronutrient levels. It has been previously demonstrated that dietary diversity predicts diet quality particularly among infants and young children (34). Second, there is an association between the diversity of a child's diet and his/her nutritional status that is independent of socio-economic factors, with dietary diversity potentially associated with diet quality (35). Our data indicate a significant positive correlation between the weight for age Z score of children under 2 years of age and the monthly DDS ($P = 0.02$) (data not shown). Other studies have confirmed this as well (36). Yet multivariate models controlling for socio-economic factors are critical to further analyse and interpret these associations. Finally, the extent to which food security results in good nutrition depends on a set of non-food factors such as sanitary conditions, water quality, infectious diseases and access to primary health care (3,37). Although not described in this chapter, other improvements in the infrastructure and health system of Sauri have taken place, perhaps contributing to the improved nutrition status.

Positive shifts in diet diversity were also likely to be the potential mechanism through which changes in vitamin A levels were observed. While the clinical component of the intervention involved vitamin A supplementation, this intervention was initiated prior to the onset of our project, with proportions of children who had received vitamin A in the past 6 months being high (70%) and nearly identical between baseline and follow-up. It is also important to note that clinical trials have not found an association between vitamin A supplementation and growth (38–40). We suggest that in this study, improvements in micronutrient deficiency may be a biological outcome of more complex changes in diet quality and diversity. Previous research has examined the association of dietary vitamin A intake with growth and the incidence of recovery from stunting, and demonstrated that dietary carotenoid intake was associated with a greater incidence of reversal of stunting, with the greatest impact on children under 2 years old (41–43).

Documentation of the portfolio of interventions undertaken during the initial study period lends further support to the potential role and importance of food- and livelihood-based approaches in contributing to changes in nutritional status. Subsidized hybrid maize seeds and fertilizers were provided in the initial stages of the project to improve food yields and boost food security. In two years, the maize yield tripled from 2.0 t/ha to 6.2 t/ha (17). Since 2006, the community worked with agricultural extension officers to diversify their crops for markets and to improve household nutrition. Farmers also engaged in other income-generating activities such as livestock for dairy production, poultry, fish farming and bee keeping. Taken together, this portfolio of interventions, when viewed alongside documented shifts in pathway variables, lends support to the contribution of food- and livelihood-based strategies to observed growth improvements among children less than 2 years old.

A recent series reviewed the evidence on mainly child-focused interventions proven to reduce stunting, micronutrient deficiencies and child mortality (9,44). The spectrum of interventions reviewed generally reflected single, stand-alone health-focused interventions that were amenable to experimental design. Little previous research has assessed the potential impact of more complex 'packages' that combine clinical with food- and livelihood-based interventions. Even less research has been done on strategies to enhance delivery systems to improve coverage.

The United Nations' commitment to ending food insecurity, as affirmed by the High-Level Task Force on the Global Food Security Crisis and the Alliance for a Green Revolution in Africa, has generated renewed attention to the need of making our world more food secure. This study suggests that integrated food- and livelihood-based models offer one potential approach. We demonstrated that such a model is feasible to deliver, with intervention components generating complementary and potentially synergistic effects. The project site in western Kenya covered 63,500 people, which is sufficiently large to extract lessons for district-wide scale up. Certainly any scale up would benefit from economies of scale and greater integration into district or national systems. More research is underway to assess the potential for similar gains to be observed in other MVP sites in sub-Saharan Africa, which will ultimately enhance the external validity and ability to generalize the findings presented here. We hope that the approach and evidence from this study can provide lessons of replicability, scale up and transfer to other contexts.

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5 Food-based, Low-cost Strategies to Combat Micronutrient Deficiencies: Evidence-based Interventions in Lesotho and Malawi

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Abstract

The combined effects of HIV infection, food insecurity and malnutrition have fuelled adult death rates across southern Africa, causing an alarming increase in the number of orphans. The long illness commonly associated with HIV infection affects productivity, drains family resources and erodes livelihoods, leaving households and communities stressed, both nutritionally and socio-economically, and vulnerable to further deterioration. Regular intake of nutritionally adequate diets, including micronutrient-rich foods, is essential for boosting the immune system and maintaining good health. Lesotho and Malawi were piloted for a food security and nutrition project that included dietary diversification, aimed at improving micronutrient intakes among HIV-affected communities.

The project's overall objectives included: protecting and promoting the nutritional well-being of HIV/AIDS-affected children; improving livelihoods and food and nutrition security among HIV-affected households; and strengthening the capacity of communities to provide support to HIV-affected households and children. This chapter restricts itself to showing it is possible to enable resource-poor, HIV- and drought-affected communities to combat micronutrient deficiencies through food-based approaches.

Multiple strategies – including institution building, human resource development, use of participatory approaches, promoting bio-intensive methods of agriculture, and crop and diet diversification – were used in the implementation process.

These strategies and technologies enabled communities to produce and access greater amounts and variety of micronutrient-rich foods all year round. Effective nutrition education and improved techniques in food processing, preservation and preparation increased the consumption of micronutrient-rich foods among target populations.

Through appropriate strategies and technologies the capacity of resource-poor, HIV-affected communities to combat micronutrient deficiencies can be strengthened.

Key words: capacity building, strengthened institutional framework, crop and diet diversification, bio-intensive agricultural methods, participatory approaches, food-based approaches, orphans and vulnerable children, HIV-affected communities, micronutrient deficiencies

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Introduction

Southern Africa has the highest prevalence rate of HIV in the world (1). In 2004, the subregion accounted for almost a third (29%) of all new HIV infections and AIDS-related deaths globally, with national adult HIV prevalence rates at 37.3% in Botswana, 28.9% in Lesotho, 21.0% in Malawi, 21.3% in Namibia, 21.5% in South Africa, 38.8% in Swaziland and 24.6% in Zimbabwe (1). The combined effects of widespread food insecurity, malnutrition and HIV/AIDS infections increase death rates in adult populations, leaving an unprecedented increased number of orphans and children in a vulnerable and compromised situation. A number of children become economically and nutritionally vulnerable even before they are orphaned because, when illness affects a household, there is often a breakdown in the family's ability to maintain its livelihood (2). The long-term HIV-related medical care takes a toll on family resources (3); productivity (as in food production and paid work) declines, family income is significantly reduced, livelihoods are eroded, and family food and nutrition security are compromised. Consequently, household vulnerability is increased and resilience in dealing with stresses is decreased.

The project 'Protecting and Improving Food and Nutrition Security of Orphans and HIV/AIDS Affected Children in Lesotho and Malawi' was developed as a pilot regional initiative to *alleviate the impact of the AIDS epidemic on affected children and their communities*. The project, funded by the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) and technically supported by three United Nations (UN) agencies – the Food and Agriculture Organization of the United Nations (FAO), the United Nations Children's Fund (UNICEF) and the World Food Programme (WFP), was implemented from November 2004 to May 2008 by the Governments of Lesotho and Malawi. The goal of the project was to improve the household food and nutrition security of orphans and other vulnerable children and families affected by HIV in the short and longer term. The immediate objectives of the project were to: (i) strengthen the capacity of local, district and national institutions to plan and undertake more effective actions to improve food and nutrition security among orphans and other children affected by HIV, and to provide support to their families and communities; and (ii) demonstrate programming models and methods for multi-sectoral action in protecting and improving food security and nutrition of orphans and HIV-affected children and their families.

The two pilot countries were selected on the basis of having high HIV prevalence, eroded livelihoods and a high number of orphans. In Lesotho, Mafeteng was selected as the pilot district for the project; and in Malawi, two districts, Mangochi and Mwanza, were piloted.

In the specific case of the piloted countries, the combined effects of malnutrition and AIDS increased death rates among adult populations. Today, in both countries, AIDS is the primary cause of the increasing number of orphans and vulnerable children (OVC). In Malawi, out of a population of 12 million people, it was estimated that there were over one million orphans countrywide, half of them resulting from HIV-related deaths (4). UNICEF's report on the state of the world's children estimated the number of orphans in Lesotho, with a population of 1.9 million inhabitants, at 180,000 (4).

Because of higher adult death rates, the number of OVC increased at a much faster rate than families and communities could cope with. In times of economic and social stresses, children, because of their vulnerability, are usually the first to succumb. Hence, the focus of the project was above all on the food and nutrition situation of vulnerable children. In both countries, for regular programmes, the majority of HIV-related interventions focused on clinical aspects of the disease and reducing adult prevalence rates.

Food always ranks high among the hierarchy of needs for poor people and indeed, in participatory community needs assessment forums organized by the project, addressing food security issues was listed as a top priority. The central importance of adequate dietary intakes for an individual's overall health and productivity, and especially for maintaining one's immune system, is well established (5,6). However, within the project's target communities, food insecurity and poor nutrition, including micronutrient deficiencies, were common. This greatly impaired the ability of both HIV-positive and HIV-negative individuals and their households to maintain their health and well-being. This dire situation was often exacerbated by poor agronomic conditions and practices in the target areas.

In Lesotho, Mafeteng, the target district, lies within the southern lowlands of the country. Compared with the other agro-ecological zones, the southern lowlands zone is semi-arid, prone to drought and has the highest incidences of chronic food insecurity. During winter months (May to August), average night temperatures are below 0°C and normally vegetable production ceases. An abundance of wild green leafy vegetables is available during the rainy season which runs from October to March. Due to poor soils and the arid condition of the district, vegetable production is a challenge. The raising of small livestock is also precarious as animals have to compete for water and food with humans. Resource-poor families depend largely on the staple food – maize – for survival. Hence an average stunting rate of more than 40% among children aged 12–59 months was registered by the Lesotho Demographic and Health Survey in 2004 (7). In view of the challenging agronomic conditions in Mafeteng and the socio-economic circumstances of the target group, two agricultural techniques of bio-intensive vegetable production, i.e. *keyhole gardening* and *double-dug method of gardening*, were introduced as part of the effort to meet the demand for increased micronutrient intakes. For the majority of the project target population, keyhole gardens, which are raised keyhole-shaped mounds of earth, were found to be more suitable as they require less labour and land size than double-dug gardens. Through keyhole gardening, all participating households – the majority of which had non-productive gardens before the project – were enabled to produce more vegetables than they could consume, in addition to attaining more variety.

Malawi, in general, has far better agronomic potential than Lesotho. The main sources of micronutrients in the diet were vegetables and fruits. However, the supply of horticultural produce was seasonal. During the rainy season, there was an abundance of a variety of wild vegetables which targeted communities relied on for relish and micronutrient intake. Due to waterlogging, not much vegetable cultivation took place at this time. Also, as there is only one main growing season, labour was mainly reserved for cultivation of major field crops, primarily maize. Both cultivated and wild fruit were also available during this period. While vegetable gardening was not operational in the rainy season, water scarcity and lack of inputs were impediments to horticultural production in the dry season. In this regard, the project assisted target communities in building two dams to support horticultural production in the dry season. Bio-intensive methods of horticulture were also introduced.

Due to a severe drought which coincided with the beginning of the project, household food insecurity in target communities was high. Food intake was so low that children could not go to school because of hunger. Through improved agricultural techniques, target communities were assisted in staple food production and crop diversification. With this intervention, from severe food insecurity, households in target communities had bumper harvests and food consumption was highly improved.

Methods

To support effective project implementation to enhance livelihoods of intended beneficiaries, ownership of the intervention and as part of capacity building, a participatory approach was used in implementing the project, i.e. stakeholders were involved in aspects of the project, from planning to implementation.

For each of the pilot districts, a district work plan for the project was first elaborated collaboratively by stakeholders from relevant sectors of government, non-governmental organizations (NGOs), voluntary community groups and the UN in a 4-day workshop. The workshops defined four specific technical areas for intervention at community level. These were food and nutrition security, health, education, and social welfare. The multi-stakeholder collaboration contributed in promoting ownership of the initiative; in ensuring that issues of real concern on the ground were addressed by the project; and in enhancing collaboration of all stakeholders in the implementation of the plan. An implementation structure was established within the existing frameworks at national and district levels to suit the inter-sectoral nature of the project. Linkages were made between national- and district-level institutions to facilitate communication and to exchange information on project activities. The national level was to provide policy guidance while obtaining information from the field for possible incorporation in programme and policy development.

Subject selection and coverage

Even though the focus of the project was to improve the food and nutrition situation and welfare of HIV-affected children, the target unit was a community, rather than individual children or families. Target communities were, therefore, selected on the basis of high HIV prevalence and the high number of OVC.

The intervention targeted three districts in the two pilot countries. In Lesotho, Mafeteng district had a total of 14,281 orphans which accounted for 16% of registered orphans in the country, as observed by the Lesotho Disaster Management Authority and WFP in 2003 (8). Project target areas covered 62 villages with a population of 6918 households.

In Malawi, the project was implemented in two districts that had high HIV prevalence rates and, consequently, high numbers of orphans – Mangochi and Mwanza, situated in the southern part of the country. The number of orphans in the two districts was estimated at 26,963 for Mangochi and 19,942 for Mwanza, accounting for about 7.2% of registered orphans in the country (9). The project targeted a total of 2886 households in both districts.

Supporting institutional framework

In both countries, committees comprising membership from existing institutions were established at national and district levels to support project implementation. The general institutional structure at central and district levels was similar for both countries. At national level, the project was guided by a National Steering Committee, with the Ministry of Agriculture and Food Security as chair and the Ministry of Health (Department of Social Welfare) as co-chair. Other members included the Ministry of Education and stakeholder institutions such as the National AIDS Commission and relevant NGOs. The committee's role was to provide overall policy guidance to the project.

Given that this project was technically supported by three UN agencies, FAO, UNICEF and WFP, a tripartite Technical Working Group (TWG) consisting of FAO as the lead agency, UNICEF and WFP was formed to provide technical advice to the Project Management Team (PMT).

The District Administration had the role of overseeing, coordinating and monitoring implementation of activities at this level. A District Coordinating Committee chaired by the office the District Administrator performed this function. The committee comprised professionals and technicians from relevant government departments and non-state institutions that were engaged in development activities of relevance to the project.

As mentioned earlier, district work plans were elaborated collaboratively by all stakeholders at project inception. Participants included staff from relevant sectors of government, NGOs, relevant volunteer groups and the UN, in order to develop ownership of the initiative and to enhance collaboration of all stakeholders in the implementation of the plan.

Community intervention activities were based on the four project focus areas of food and nutrition security, health, education and social welfare that were determined by stakeholders at the planning workshop. Activities covered in each of the focus areas were as follows.

1. *Food and nutrition security*. Depending on need, target communities were assisted in producing food at household level to combat food insecurity and improve dietary diversity to enhance health and nutritional status. In particular, improving the micronutrient content of the diets of target communities was crucial because of the high HIV prevalence. Nutrition education was central to activities in this focus area.

2. *Health*. Activities in this focus area centred on assisting target groups with basic primary health care issues through education and the provision of basic drugs and first aid supplies. Training of volunteers in home-based care, primarily to support people living with HIV, was highly appreciated by target communities. The volunteers in turn provided home-based care services to the terminally ill in their communities. Volunteers were also trained in basic nutrition principles and hygiene. In collaboration with local service providers, community education workshops and campaigns on HIV were conducted. Sanitation clubs were organized to promote hygiene messages and establishment of sanitation facilities such as pit latrines, rubbish disposal pits and dish racks.

3. *Education*. Sensitization workshops on the importance of education were conducted for community leaders and community members. Subsequently, several strategies to increase enrolment and retention of children in school, particularly OVC and girls, were developed and implemented. These included training of teachers in psychosocial care to enhance a conducive learning environment; conducting workshops for Parent–Teacher Associations to enhance their abilities in managing the schools; and introducing Mother Groups who were specifically responsible for dissuading young girls from early marriages by encouraging and monitoring them to stay in school. Out-of-school youth were taken to vocational training where they learnt income-generating skills such as plumbing, motor mechanics, brick-laying, carpentry, sewing and business management practices. In collaboration with the project partner agency, UNICEF, life skills such as good agricultural practices, crafts and food preparation were introduced in schools.

4. *Social welfare*. With project support, relevant government institutions worked together to promote, protect and support the rights and interests of OVC. Seminars to sensitize local authorities and community members on children's rights and responsibilities were conducted; volunteer groups were assisted to establish Child Welfare Forums and were subsequently trained on psychosocial support, and child protection and participation. In child care centres, caregivers were trained in child development issues, nutrition and other related subjects. With support from relevant government establishments, community members were made aware of existing laws that protect women and children against abuse, and on their property rights.

Discussions in this chapter focus primarily on the food- and nutrition-related experiences of this initiative.

For sustainability and as part of the in-built exit strategy, the project used local expertise to provide service and support to target communities in implementing activities. Implementing Partner (IP) institutions with suitable skills and capacities were identified from state and non-state institutions. Relevant government ministries assumed ownership of activities under their sector and collaborated with the IPs. Through project support, training workshops to build or fill capacity gaps for IPs were conducted. The project engaged IPs from relevant sectors, as dictated by technical skills required for the implementation of different project activities.

Community-level pre-intervention studies

Prior to community-level intervention, two studies, a baseline and a participatory community needs assessment, were carried out.

The *baseline study* was used to determine the state of primary parameters before project intervention at community level and to collect basic data for comparison with impact survey data. Three major components of the study were as follows:

- *Household survey* – designed on the basis of the project work plan, the instrument included questions on demography, nutrition, health, education, occupation, OVC, household assets and family diet, and collection of anthropometric data for children 6 to 59 months of age.
- *Focus group discussions* – these aimed at investigating major challenges faced by children and their caretakers, and coping mechanisms engaged in by families and community members in this regard.
- *Census of service providers* – this involved conducting a census of NGOs, civil society organizations, community-based organizations and volunteer groups working in the target areas on project-related interventions.

The *participatory community needs assessment* study served to engage ultimate beneficiaries; learn about their felt needs and capacities; and involve them in planning community level activities. To a large extent, existing institutional capacities and gaps in project-related areas were identified through this study. Potential IPs were also identified by the study.

Baseline Studies

Lesotho

The baseline study uncovered alarmingly high prevalence rates of stunting and wasting in children aged 6–59 months, at 40.7% and 13.1%, respectively. These results were higher than in the 2002 EPI Cluster Survey which estimated a prevalence stunting rate of 30.3% for the district (10). The high baseline rate of 32.1% chronic undernutrition for children in this age group strongly indicates some inadequacy in feeding practices for this age group, as well as poor hygiene practices. Breastfeeding alone should be nutritionally adequate for infants up to 6 months of age; and should be continued and gradually replaced with supplementary foods constituting a balanced diet by 24 months of age. With good infant feeding practices, such a high rate of chronic undernutrition is unjustifiable even among food-insecure communities. This finding indicated the need for nutrition and health education in this area.

Stunting rates peaked at 46.5% in the 12–23 months age group (see Table 5.1). Although the rates dropped in the older age groups up to 48–59 months, the prevalence was still very high at more than 40%. Boys and girls were similarly affected. Stunting rates for orphans and children in foster care were slightly higher at 44% compared with those of children living with biological parents, at 40%, although the difference was not statistically significant.

On household food production, information collected by the survey showed that although many households (72%) had vegetable gardens, they were largely unproductive, providing only an estimated 10% of the amount consumed by the household. A similar situation applied to fruit trees: most were old and bore fruit of poor quality. As dietary diversity is important for good nutritional status, this information provided direction for project emphasis at community level.

Malawi

Baseline study anthropometric results showed that the prevalence of stunting among children 6–59 months of age was 43.3% in Mangochi and 40.3% in Mwanza, just slightly lower than the national average of 48% (11). In Mangochi, the high stunting rate of 34.1% for the 6–11 months age group increased sharply to 41.0% in the 12–23 months age bracket. The sharp increase could be an indication of inadequate young child feeding practices since the rate drops (although slightly) in the next age bracket. Yet another hike (to 42.1%) was observed among older children 48–59 months of age (see Table 5.2). At this age, children should be able to consume all foods eaten by the rest of the household members. The high stunting rate could indicate both inadequate feeding practices and household food insecurity.

Table 5.1. Prevalence of stunting (low HAZ) among children in Lesotho at baseline, by sex and age.

		Stunting (%)	
	n	Moderate + severe (HAZ ≤–2)	Severe (HAZ ≤–3)
Children aged 6–59 months			
Males	266	41.5	12.8
Females	244	39.6	13.4
Male and female children			
6–11.9 months	65	31.5	0
12–23.9 months	127	46.5	19.7
24–35.9 months	121	45.3	13.9
36–47.9 months	114	41.3	15.6
48–59.9 months	84	32.1	9.0

HAZ, height-for-age *Z* score.

Table 5.2. Prevalence of malnutrition among children in Malawi at baseline, by age.

	Mangochi		Mwanza	
Age group (months)	Stunting (%)	Underweight (%)	Stunting (%)	Underweight (%)
6–11.9	34.1	21.0	22.9	13.7
12–23.9	41.0	22.6	27.8	12.5
24–35.9	37.9	23.2	54.1	19.7
36–47.9	30.6	11.4	51.4	16.4
48–59.9	42.1	17.4	47.1	19.6

For project intervention, the above findings from the two districts suggested intervention in the areas of young child feeding practices, household food security, hygiene and sanitation. Appropriate activities to address these challenges were implemented under the focus areas of health and food and nutrition as outlined above under 'Methods'.

The figures in Table 5.3 show that, due to drought at the time, for most households (58.2%) staple food stocks would be depleted six months before the next harvest period of April to June. The situation was slightly better in Mwanza, where 46.0% of households would be without food stocks six months before the next harvest period. Although most households mentioned buying as an option when food stocks were depleted, since disposable income was scarce in these communities, this situation implied a period of serious food and nutrition security challenges ahead, particularly for resource-poor households in target communities. On a larger scale, such findings would justify the declaration of an emergency. In this situation, the project was compelled to support target communities with the production of staple crops although the anticipated intervention was to assist with horticultural crops and small livestock for diet diversification.

Participatory Community Needs Assessment Studies

As indicated above, participatory community needs assessment studies were conducted primarily to ensure that target communities would be in the forefront in the planning and implementation of project activities at this level. The studies provided forums for groups in target communities to discuss and agree on their needs and priorities and how the livelihoods of OVC could be enhanced. These studies revealed views, concerns and desires

Table 5.3. Percentage distribution of availability of staple foods and stock depletion in Malawi at baseline.

	Mangochi		Mwanza	
	n	%	*n*	%
Staple food available				
Yes	91	22.9	113	29.8
No	306	77.1	266	70.2
When staple food was/will be depleted				
April–June	124	33.7	108	32.2
July–September	214	58.2	154	46.0
October–December	24	6.5	63	18.8
January–March	6	1.6	10	3.0
Source of food in time of scarcity				
Buying (Admarc, local market, vendors)	398	96.6	386	99.5
Begging/gift	12	2.9	0	–
Assisted by relatives	1	0.2	1	0.3
Food for work	1	0.2	1	0.3

of target communities on matters affecting OVC livelihoods in general.

The participatory needs assessment process entailed consultations with key informants through interviews; and focus group discussions with interest groups such as community volunteer groups, income-generating groups, agricultural groups, burial associations, primary caregivers of OVC and the youth. Community needs were identified in each discussion group and prioritized in a 'plenary' before presenting to a wider community in an open public forum for further debate. It was during the open public forum discussions that Community Action Plans were outlined for each prioritized community need. Findings and desires of target communities in relation to initiatives that would enhance OVC livelihoods are summarized below.

Lesotho

Food security

- Access to adequate, good-quality food was seen as the most central issue because it affects many other issues such as ability to learn, resistance to diseases and creativity. As such, food production, particularly horticulture, was a top priority.
- Scarcity of water in the district is a major impediment to increasing agricultural production. Therefore, low-cost irrigation techniques to enhance production should be sought.
- The area of Mafeteng has poor soils that have been ill-managed for decades. It was felt necessary to introduce agricultural methods that would also enhance the condition of the soil.
- Assistance in small livestock production (poultry and piggery) was a strong desire, as it would improve the quality of meals and serve as an income-generating activity.

Education

- Education was given the same importance as food when issues of OVC were discussed.
- Access to education by all children, from pre-school to high school, was rated as very important.
- Although primary school education is free in Lesotho, a number of OVC could still not enrol because they could not afford some of the mandatory requirements such as registration fees, uniform and books.

- Many children, in particular OVC, could not afford fees for high school education.

Vocational training

- Target communities felt that children in Lesotho were disadvantaged as they did not have access to vocational training because such schools are few.
- Due to emotional stress and other factors, some OVC were not able to attain good grades for entry into tertiary institutions and would therefore benefit from vocational training. Thus, there was a need for an exponential increase in the number of schools that can offer life skills for children who are not able to make it in the academic stream. Some of the skills mentioned which would benefit the youth included farming, carpentry, sewing and knitting.

Life skills in schools

- As OVC have fewer chances of being educated beyond free primary education, community members concluded that there was a need to incorporate life skills into the regular primary school programme.

Health

- Poor access to health care for OVC was attributed to lack of disposable income at the household level and the fact that health services were not easily accessible at the village level. While lack of financial resources impacts OVC households, they also suffer poor access to health services.
- Lack of access to psychological therapy for the population in general and OVC in particular was noted with concern. OVC are more likely to need therapy and counselling due to the trauma of the loss of loved ones and/or having to deal with terminally ill parents.
- Basic primary health care services provided by community volunteers (support groups) were appreciated. Community members recommended that support groups be supplied with first aid kits and medical kits since there was a shortage of nurses in their villages.

Access to social services

- There was variable knowledge on the rights of children among the different social groups. In some villages chiefs and other people in authority were knowledgeable and articulate about the subject while in others there was much ignorance. Therefore, efforts had to be made to increase knowledge on the rights of children among all social categories such as local authorities, teachers, support group members, the youth and priests.
- Communities knew little about services offered by the Department of Social Welfare of the Ministry of Health and Social Welfare, such as social grants (Lesotho Maluti 100/US$13.5 per month) for the elderly and destitute. In the few cases where the services offered by the Department were known, communities complained about the long, unclear and complicated bureaucracy in accessing the services. Communities suggested that members of support groups be trained so that they could assist in the rollout of social welfare services.
- Local authorities (chiefs) have the responsibility and potential to play a crucial role in the protection of the OVC. The role of the chief includes acting as guardian for OVC. It was therefore agreed that chiefs should play a more central role in ensuring that rights of OVC are protected and the needs and well-being of OVC are addressed.
- A village-level register, where births, deaths and numbers of OVC and other people with special needs are recorded, should be developed under the responsibility of the chief.

Malawi

Food security

- Relief food items were top of the list of priorities as most households had already run out of maize, the main staple, by the time of the study (August 2005), well ahead of the normal lean period (December–March). The situation was more critical for OVC primary caregivers who were mostly aged, unproductive and dependent on community support for survival.
- Agricultural inputs – fertilizers and improved seeds (open pollinated varieties) – were high on the priority list. There was limited use of low-cost technologies such as compost manure, agroforestry, marker and contour ridges, and incorporation of crop residues. These technologies were used by only a few farmers.
- Communities expressed the need for training in areas such as low-cost agricultural technologies, crop storage and food preservation, small livestock husbandry and fruit production. This training was necessitated by the weak extension service system – there was very little extension drive to adequately promote appropriate technologies.
- Access to small livestock – goats, chickens, guinea fowls, rabbits – was expressed as a strong desire by target communities. Because of poverty, there was lack of diversity in the local diet and the asset base was depleted.

Health

- Access to health facilities was minimal for all the communities covered by the study. Primary health care was constrained by lack of resources as it was almost exclusively a government-driven programme; access to and utilization of voluntary counselling and testing services was quite low; and nutrition education in the health service delivery system was weak. Target communities requested: (i) training of Support Groups and Peer Educators on HIV awareness, nutrition education and primary health care; and (ii) provision of boreholes, drugs for water purification and medication for home-based care for the chronically ill.

Education and training

- Communities expressed concern about the continuing decline in enrolment, attendance and retention of girls and OVC in primary schools. Poverty and household-level food insecurity in particular, and lack of OVC economic empowerment programmes, were regarded as the main factors for the declining trends. In addition, OVC access to secondary school education was hampered by their guardians' inability to pay school fees which, relatively, were prohibitively high. Target communities requested assistance with: (i) school feeding programmes as an incentive for increasing OVC and girls' enrolment; (ii) bursary schemes for OVC and girls selected for secondary school education; and (iii) life skills training for youth.

Welfare services

- There was limited information dissemination on women's and children's rights at community level; the few community institutions that provided awareness training were hampered by lack of resources and access to information, education and communication materials; and communities remained dependent on radio programmes for accessing information on human rights issues, yet only a few people had functioning radios.
- Community-based child care and home-based care systems at community level were underdeveloped and fragile due to resource constraints, untrained caretakers and committees, and lack of support and capacity in service delivery.
- There was no organized system for OVC vocational skills training and no promotional programmes for income-generating activities for OVC and target

communities. Communities requested assistance with: (i) women's and children's rights' awareness programmes; (ii) support on home-based care, vocational training for OVC, recreation facilities for OVC and youth; and (iii) training in psychosocial counselling.

Information from baseline and participatory community needs assessment studies was used in planning activities for intervention at community level.

Project Strategies, Activities and Outcomes

Intervention strategies at community level were largely evolved from the specific district studies carried out in relation to the project (i.e. the situation analyses, baseline and participatory community needs assessment studies) as well as information provided by the district planning workshops. Based on this information, it was clear that among the four technical project focus areas (food and nutrition security, health, education and social welfare) identified by stakeholders at the planning workshops, food and nutrition security issues were a primary concern that needed urgent attention. Strategies for intervention in this focus area (as in other project focus areas) were developed through a participatory process, taking into account the target communities' socio-economic, health and nutrition conditions, as well as the agronomic potential for each country and district. Hence, community-level activities between the two countries were similar but not necessarily identical. For instance, Malawi has a far better agronomic potential than Lesotho, and therefore had more food production activities. As such, this chapter shares project experiences by citing examples from one or both countries as appropriate.

In selecting strategies, it was also considered that livelihoods were eroded within project target communities; the high HIV prevalence had taken a toll on family financial and human resources; food and nutrition insecurity, including micronutrient deficiencies, were widespread; the general health of individuals was poor; and for many families, the asset base was depleted. Further, the majority were primarily subsistence farm families whose main food supply and livelihood were from their own production. Because of their low purchasing power, which was exasperated by increased and prolonged expenditure on health care due to high HIV prevalence, target communities could not access fortified foods even where these products were available in local markets. Therefore, low-cost, food-based strategies had to be sought to combat food and nutrition insecurity including micronutrient deficiencies and to improve the health and nutritional status of target communities.

Although food supplementation interventions play a crucial role in improving nutritional status in communities where there are specific and known nutrient deficiencies, studies to investigate specific nutrient deficiencies in target communities were not carried out, partly due to the short duration of the project period. In addition, the efficacy and sustainability of these interventions in rural, resource-poor communities are sometimes limited. This is primarily a result of several factors, including the socio-economic and logistical challenges often faced by communities in accessing such services. Sustainability of supplementation interventions is also a major concern.

This was seemingly the case in Malawi: the Government of Malawi maintained a policy of supplying vitamin A capsules every six months to all children from 6 months to 5 years old to prevent vitamin A deficiency disorders, which were a serious problem in the country. Yet, 59% of pre-school children were found to be vitamin A deficient in a study carried out in 2003 (12). Further investigation on the case of the Malawi supplementation programme would be interesting and informative for programme planning and/or redirection.

Ideally, for biological efficacy and sustainability, supplementation programmes should be implemented in parallel with food-based interventions that include an emphasis on nutrition education. In this way, the short (supplementation) and long (food-based) term approaches complement each other, assuring continued micronutrient supply even when supplementation sponsorship ceases.

To ensure regular consumption of diverse, micronutrient-rich diets among target communities, continued supply of both plant and animal food sources in all seasons was obligatory. In this regard, strategies and techniques such as crop and diet diversification, bio-intensive methods of horticultural production and production of small livestock as animal food sources were engaged. Nutrition education and practical demonstrations on improving local diets through consumption of diverse foods from plant and animal sources were incorporated and carried out throughout the duration of the project. Strategies engaged in by the project made a significantly high positive impact on the lives of target communities through improved food availability and increased consumption of highly diverse diets. The impact cannot always be concisely demonstrated as, owing to the urgency to save desperate communities from impacts of food insecurity, data were collected using both quantitative and qualitative methods.

Crop and diet diversification

As the project started in Malawi (November 2004), the country was experiencing a severe drought. Even though the project originally aimed at increasing the availability and consumption of micronutrient-rich foods primarily through horticulture and small animal production, it became apparent there was an urgent need to also promote the production of staple foods, particularly maize, the major staple. The food insecurity situation at this time was dire. For instance, based on the results of the baseline study (see Table 5.3), it was projected that food stocks would be exhausted 6 months before the next harvest for most households in Mangochi (58%) and many in Mwanza (46%).

A weakness in the production system adhered to by many subsistence farm families in much of southern Africa is monocropping, resulting in a scarce food base, particularly in the range of staple foods. Among households in target communities in Malawi, maize is the predominant staple, with barely any substantive alternative to fall back on. While maize was grown by 98% (almost all) of households in Mangochi and 90% in Mwanza, the only other staple – cassava – was cultivated by 8% of households in Mangochi and 4% in Mwanza. Sweet potato, which is used largely as a snack and to complement the staple during hunger periods, was grown by few households – 14% in Mangochi and 2% in Mwanza.

Hence, when the maize crop fails, famine ensues in the sub-region. A varied diet is known to be the key factor in preventing micronutrient deficiencies and malnutrition (13). FAO and the International Life Sciences Institute recommend consumption of varied foods from animal and plant food sources to prevent micronutrient deficiencies and malnutrition (13).

In Malawi, to assist beneficiaries improve their food base and as part of a varied diet, the project promoted drought-tolerant crops such as cassava, sweet potato and sorghum. Legumes such as soy and groundnuts were also promoted. Communities were trained in the cultivation and husbandry of these crops. Cassava and sweet potato planting materials were distributed to groups within villages for multiplication and further expansion in household fields. In addition, small amounts of soy and groundnuts were distributed among households in target communities for cultivation and multiplication. Technical support through extension services was provided for cultivation of plants throughout the harvest period by an IP institution in Mangochi and the Ministry of Agriculture in Mwanza. Communities were very active in the implementation of these activities, and established good rapport with service providers.

Staple foods are generally recognized as good sources of carbohydrates. However, given the amount and frequency of their consumption, many staple foods, especially cereal staples, can also serve as good sources of protein and several micronutrients (14,15) (see Table 5.4). For example, for an adult woman, the contribution of 100 g of orange sweet potato towards her recommended nutrient intakes is 210% of vitamin A, 33% of

Table 5.4. Nutrient content of some staples per 100 g and their percentage contribution to the Recommended Daily Allowance (RDA).

	Sorghum		Sweet potato, orange		Maize, white		Cassava		Cassava leaves	
Micronutrient	Amount	Contribution to RDA[a] (%)	Amount	Contribution to RDA (%)	Amount	Contribution to RDA (%)	Amount	Contribution to RDA (%)	Amount	Contribution to RDA (%)
Vitamin A (μg RE)	7.0	1.0	1467	210	0	0	147	2.0	5197	74.1
Vitamin D (μg)	0	0	0	0	0	0	0	0	0	0
Vitamin E (μg)	1.0	6.7	0	33.3	1.0	6.7	0	0	0	0
Vitamin C (mg)	0	0	25	33.3	0	0	72	96.0	33	44.0
Thiamin (mg)	0.3	27.3	0.1	9.1	0.4	36.4	0.3	27.3	0.1	9.1
Riboflavin (mg)	0.1	9.1	0.1	9.1	0.2	18.2	0.1	9.1	0.2	18.2
Niacin (mg)	2.8		0.6		3.6		1.4		0.9	
Vitamin B_6 (mg)	0.2	18.2	0.2	18.2	0.3	27.3	0.7	53.9	0.5	38.5
Folate (μg)	14.0		23.0		25.0		36.0		104	
Vitamin B_{12} (μg)	0	0	0	0	0	0	0	0	0	0
Pantothenic acid (mg)	0.9		0.7		0.4		0.7		0.3	
Calcium (mg)	25.0		28.0		6.0		46.0		211	
Phosphorus (mg)	222	31.7	55.0	7.9	241	34.4	168	24.0	72.0	10.3
Magnesium (mg)	171	55.2	20.0	9.5	127	41.0	24	7.7	62.0	20.0
Potassium (mg)	131		348		287		583		550	
Sodium (mg)	7.0		10.0		35.0		5.0		11.0	
Iron (mg)	4.1	22.8	0.5	2.8	3.5	19.4	1.9	10.6	3.1	17.2
Zinc (mg)	1.6	20.0	0.3	3.8	1.8	22.5	0.7	8.8	0.4	5.0
Copper (mg)	211	55.6	0.2	22.2	0.2	22.2	0.1	11.1	0.2	22.2
Manganese (mg)	0.6		0.6		0.5		0.3		0.1	

[a]Calculations for the RDA were based on Whiting and Barabash (15); where there are blank spaces, this reference did not provide the RDA and values from other sources were not used for consistency.
(Source: *Tanzania Food Composition Table* (15).)

vitamins E and C, and lesser amounts of other micronutrients. Consumption of 100 g of white maize (popular among population groups that consume maize as a staple) can contribute significantly towards dietary requirements for the B complex of vitamins: 36% for thiamin, 18% for riboflavin, 27% for vitamin B_6, as well as zinc at 23%. According to figures in Table 5.4, sorghum is a good source of thiamin, phosphorus, magnesium, iron, zinc and copper. It should be noted that many adults commonly consume at least 300 g of these foods daily, an amount which can contribute significantly towards meeting their recommended nutrient intakes.

Cassava presents an interesting case: the root is often degraded in comparison to other staples, mainly because of its low protein content (14), but cassava leaves compensate for the difference since the root is often consumed with the leaves as relish. Per 100 g, the protein content of maize is 8.1 g, sorghum 11.3 g, rice 6.5 g, cassava 2.6 g and cassava leaves 3.7 g. Figures in Table 5.4 show cassava as a good source of vitamin C (even when taking into account its sensitivity to heat and some loss during cooking), thiamin, vitamin B_6 and phosphorus. Furthermore, as mentioned above, where cassava is a staple food, the leaves are often used as relish for the root. The nutrient content of cassava leaves perfectly complements that of the root as can be observed from Table 5.4: the contribution to the recommended daily allowance of the root versus the leaves is respectively 2% versus 74% for vitamin A, 11% versus 17% for iron and 96% versus 44% for vitamin C (15). The project therefore promoted the production and consumption of cassava as part of a varied diet and not an alternative single staple. Like sweet potato, the advantage of cassava is that it can be harvested on demand, thus avoiding food or nutrient losses during storage.

Outcome

- Food diversity was greatly enhanced through crop diversification: (i) an estimated 52 t of soy was produced; (ii) 112 ha of cassava were planted by 2886 households with an estimated production of 1545 t; (iii) 144 ha of sweet potato were planted with an estimated production of 1748 t; and (iv) 246 ha of groundnuts were planted with an estimated production of 231 t. These figures are remarkable compared with the negligible amounts of these crops that were produced by only a small percentage of households before the project.
- Through nutrition education and training, communities successfully integrated soy (which was a new crop to many) into local regular recipes. Soy flour was mixed with maize meal in preparing all three meals, making the staple more nutrient-rich. In addition, soy flour was also added when preparing the regularly consumed green leafy vegetables and other foods used as relishes.
- Increased food consumption, including of micronutrient-rich foods, was enhanced in target communities through crop diversification, increased food base and nutrition education.

Ensuring continuity of vegetable supply in all seasons

Experience in Lesotho

Vegetable production was one of the strategies engaged to improve dietary diversity and increase the micronutrient intake of target communities. In Lesotho, the baseline survey showed a clear association between dietary diversity and nutritional status, where 53% of children living in households on low-diversity diets were stunted, against 39% of those whose households consumed moderate to highly diverse diets. Further, vegetables and fruit are highly recommended as good sources of micronutrients and fibre. FAO and the World Health Organization advocate a minimum daily intake of 400 g of fruit and vegetables per adult person for the promotion of good health and prevention of several micronutrient deficiencies (16). Consumption of micronutrient-rich foods is recommended in maintaining and boosting the body's immune system. As such, because of high

HIV prevalence rates, improving the micronutrient content of the diets of target communities was a key objective. HIV weakens the immune system, increasing susceptibility to opportunistic diseases and poor health outcomes. Intake of nutritionally adequate, micronutrient-rich food is important for uninfected people too, to maintain good health and strengthen their immune systems. Ensuring the availability of micronutrient-rich foods on a regular basis was therefore imperative for project target communities.

In Lesotho, however, as shown by the baseline survey, vegetable and fruit production fell far short of household consumption needs, accounting only for an estimated 10%. On average, about 70% of households in target communities had vegetable gardens and 67% had fruit trees, though these products were produced in relatively small amounts. However, since vegetable gardening was in the culture of target communities, this opportunity could be exploited by assisting the target communities to improve and increase production. The challenge was to introduce effective low-cost technologies appropriate for the conditions and capacities of the target communities.

Year-round supply and consumption of vegetables could be ensured through bio-intensive agricultural techniques of vegetable production and nutrition education, respectively. In view of the challenging agronomic conditions in Mafeteng, the pilot district and the socio-economic circumstances of the target communities, two methods of bio-intensive agricultural production techniques – keyhole gardening and double-dug methods – were introduced as part of efforts to improve and increase vegetable production. For the majority of households in project target communities, keyhole gardens were found to be more suitable (Fig. 5.1). With keyhole gardening, vegetable production could be sustained all year round, even under extreme hot or cold temperatures, enabling households to access micronutrient-rich foods in all seasons. In addition, at least five varieties of vegetables at a time can be produced in a keyhole garden, thus supporting dietary diversity; the produce from one keyhole garden is more than enough to feed a family of eight persons; the structure of a keyhole garden ensures soil fertility for 5 to 7 years; keyhole gardens retain moisture and can be maintained with disposable domestic water; there is no need for chemical fertilizers or pesticides, making it suitable for communities where disposable income is scarce; and once constructed, keyhole gardens require minimal labour and can be easily maintained by the elderly, children or sick persons. Keyhole gardens were thus well suited to HIV-affected communities.

Prior to assisting target communities to develop keyhole gardens, a core group of Peer Educators from local villages received in-depth training on the proper construction of keyhole gardens. Subsequently, in each village within target communities, training sessions and demonstrations on construction and maintenance of keyhole gardens were conducted. Thereafter, households within target communities were assisted to construct individual gardens, with close supervision by Peer Educators. For all households, the project provided inputs such as a variety of seed spinach, green beans, carrot, lettuce and onion, and nets to protect plants from hail or snow. Other inputs like poles, stones and manure were a responsibility of households themselves. Households were also at liberty to plant other vegetables and herbs they desired using their own seed.

Target communities showed a lot of enthusiasm and commitment in building the keyhole gardens. As the initial construction of keyhole gardens is labour-intensive, community members worked in groups, until the construction for all households was completed. This approach ensured that households without labour such as those headed by the elderly or children were assisted to acquire keyhole gardens. All keyhole gardens in participating communities produced a variety of lush vegetables as can be seen in Fig. 5.1. The quality of the produce was so good that it attracted a local reputable ‘chain’ supermarket, although the quantity produced was not sufficient to sustain a sales contract. In terms of sustainability, the bio-intensive keyhole approach is promising: nearby communities not targeted by the project copied the technology and

Fig. 5.1. Keyhole garden in Mafeteng in Lesotho. Through the keyhole bio-intensive method of gardening that ensures soil fertility, target communities were enabled to produce vegetables in all seasons. A keyhole garden can produce many varieties of vegetables at a time, is easy to maintain and needs very little watering.

constructed keyhole gardens without external support. Also, some target households built additional keyhole gardens without project support. This implies that the technology can be easily incorporated as a livelihood activity, and that the capacity to do so exists. Also, during the course of this project, keyhole gardens survived a drought not experienced in 30 years, hailstorms, frosts and a tornado.

Outcome

- Production of vegetables through keyhole gardening was thus a resounding success in Mafeteng, the target district in Lesotho. Indeed, in the area of food security, keyhole gardens were a flagship activity of the project in Lesotho.
- An estimated 5354 out of a total of 6918 (77%) households were assisted in starting or improving vegetable production, and were also trained in principles of nutrition and preparation of nutritious meals using produce from the gardens. These figures reflect an increase of 7% (from the initial 70% before project intervention) in households which developed vegetable gardens with project assistance. This figure is distorted by the majority of households in the peri-urban area (who largely had no vegetable gardens before the project) and who did not participate in vegetable gardening, but preferred to engage in income-generating activities with quick returns (such as brewing) to obtain funds to purchase food. Nevertheless, in rural target communities, almost all households participated in this activity.
- Communities that produced only about 10% of their vegetable requirements prior to project intervention were enabled to increase their produce by more than 100%.

Experience in Malawi

In Malawi, during the rainy season, there is an abundance of indigenous wild vegetables (e.g. amaranthus, mushrooms) that communities largely relied on as relish to consume with the staple food, maize. As elaborated earlier, during this season, cultivation of exotic vegetables was very limited due to waterlogging and unavailable manpower as household labour is primarily engaged in the production of field crops. In the dry season, because of water scarcity, vegetable production was almost non-existent. Consequently, vegetables were normally extremely scarce and therefore limiting in community diets. Interestingly, at the participatory community needs discussion forums, vegetable production was the among priority activities expressed by target groups. Construction of a dam as a source of water for vegetable irrigation was proposed as a means to overcome the water problem. To demonstrate enthusiasm and determination in this regard, with little financial and technical (on engineering) assistance from the project, beneficiaries manually constructed two dams (as shown in Fig. 5.2) by trapping water from a nearby mountain waterflow.

Communal gardens with separate plots for each household were developed near the dams. Subsequent to training in horticulture and to exploit the results of the hard labour in building the dams, beneficiaries diligently tended the gardens, with technical assistance from a local IP. At household level, bio-intensive methods of vegetable production were introduced, mainly double-dug gardening. With these two approaches, target communities had access to a variety of vegetables in the dry and rainy seasons. Marketing of produce was not incorporated in project activities as it was not envisaged that, within the short duration of one phase of an intersectoral project, poor communities could be transformed from a state of dire food insecurity to one in which they would have excess food to sell. Nevertheless, households did manage to get some cash from informal sales. Some of the excess produce was preserved.

Assistance in fruit production was another area of need expressed by beneficiaries at the discussion forums staged by the participatory community needs assessment study. Commonly grown fruit in Malawi include mango, pawpaw, orange, tangerine and banana. A challenge regarding fruit trees in a majority of target households was that many were old and yielding both lower quality and reduced quantity of fruit. Each household in target communities hence received

Fig. 5.2. Dam constructed by community members in Mangochi district, Malawi, with technical assistance sourced locally through the project.

three improved fruit seedlings of mango, pawpaw and guava. Although the newly supplied fruit trees had not yet started producing at project end, consumption and use of different varieties of fruit were included in nutrition education sessions.

Outcome

- With technical assistance and some material inputs from the project, target communities in Mangochi manually constructed two seasonal dams to ensure water availability for vegetable production in the dry season (see Fig. 5.2).
- All households in target communities (n = 2886) were provided with seed, which included spinach, cabbage, carrots, green beans, onion and tomatoes, and received technical assistance in developing vegetable gardens. Access to water from the dams enabled beneficiaries to grow vegetables during the dry season, ensuring continuity of vegetable supply in both seasons, as there was an abundance of wild indigenous vegetables in the wet season.
- All households in target communities received nutrition education and practical demonstrations on enhancing the nutritional content of local diets using vegetables, which are traditionally consumed with the staple as a relish. Beneficiaries testified that because of new methods of preparing different vegetable dishes, consumption increased, particularly by children and sick individuals.

Increased availability and consumption of animal-source foods

In rural settings, animals are kept as an indicator of wealth and are therefore a status symbol rather than production assets. However, in resource-poor, food-insecure communities, livestock is kept as a form of asset protection and used for food only when the situation becomes dire, very rarely for consumption to balance their diets. Data from the household survey in Malawi showed that although raising poultry was practised by many (88% in Mangochi and 67% in Mwanza), the numbers of chicken owned by each household were too few to make a meaningful contribution to the diet or asset base. Ownership of other types of livestock was insignificant. Overall in Lesotho, 57.3% of households kept animals of any kind, the median being five animals (cattle, sheep, goats, horses or donkeys) per household. As in Malawi, poultry-raising was popular, but mainly there were very few numbers per household. To enable target communities to have access to animal-food sources, the project promoted small livestock husbandry.

Consumption of animal-source foods on a regular basis is important to provide macronutrients such as protein and micronutrients such as vitamin A, iron and several minerals. Micronutrients from animal sources are more bioavailable than those of plant origin, which are precursors that need to be converted into the active form of the vitamin or mineral before they can be utilized by the body. For example, carotene, a precursor of vitamin A found in plants, has to be converted in the human body into vitamin A before utilization. In sick individuals it is possible that this conversion may not be efficient; hence regular consumption of animal-food sources is recommended.

Like backyard gardens, small livestock projects have been promoted for decades, but very few are sustainable for long after the project period. To avoid doing 'business as usual', the project investigated livestock management approaches and practices that could be sustained by target communities to ensure continued supply of animal-source foods. The following elements were found appropriate and incorporated in the training and management approach component introduced to target communities.

1. *Procurement of suitable livestock breeds*. Affordability, productivity and efficiency were taken into account in selecting the breed of livestock to be introduced. Management requirements for the selected breed were also considered, to ensure its suitability for the capacity and capability of target communities.

For example: (i) in both countries, the dual-purpose chicken (*koekoe*), which is a cross-breed between the traditional and hybrid chicken, was selected. This breed does not require stringent and costly maintenance like the hybrid. Like the traditional breed, the dual-purpose chicken requires basic care and management, yet its egg and meat production capacity is almost as efficient as that of the hybrid; (ii) In Malawi, imported male hybrid dairy goats were cross-bred with local indigenous female goats to increase their milk-producing characteristics. With continued, controlled breeding, the progeny will eventually inherit the milk-producing trait of the hybrids. Participating households (n = 290) were supplied with two local female goats and one hybrid male goat. Not all households received goats immediately, but the 'pass-on' arrangement, whereby the first recipient passes on the first progeny to other beneficiaries, was put in place. Poor households, particularly those that were headed by women, were given priority as first recipients of parent stock.

2. *Growing animal feed*. The project encouraged participating households to grow feed for the animals on a small piece of land and have it ready before the first stock was delivered to beneficiaries. This practice is a departure from the traditional method of feeding livestock, particularly chickens, on household leftovers. In food-insecure households, there are hardly any leftovers. If any, they are typically too meagre to sustain the animals, resulting in the failure of the livestock-raising venture.

3. *Providing animal shelter*. Before a household was supplied with the parent stock (chickens, goats or guinea fowl), a shelter for the animals/birds constructed from affordable, locally available material was prerequisite. Providing shelter facilitated monitoring of animals and easy collection of droppings to use as manure.

4. *Ensuring availability of water sources*. This was crucial, so that there was no competition for water between humans and animals, particularly in very dry or drought-prone areas. An additional pre-condition for communities, therefore, was to ensure there would be adequate water sources for both humans and animals before embarking on raising livestock.

With improved chicken production and management, participating households consumed eggs more liberally than they did when traditional methods of husbandry (where chickens were much less efficient in laying) were employed. Households also consumed more chicken than they did before. This observation applied to both countries.

Guinea-fowl raising was introduced in Malawi. The attempt was not very successful as the birds tended to be wild, poor brooders and escape frequently from the premises.

In Lesotho, only a few households were assisted (as pilot) to raise poultry. Subsequent to training in raising chickens, beneficiaries had to grow food for the birds as a prerequisite to receiving the parent stock. The same principle was applied to the piggery undertaking in Lesotho.

Dairy goats were introduced only in Malawi. In Lesotho, because of the wool industry, a zero-grazing regulation between dairy and Angora goats is in place countrywide. Therefore, dairy goats were not introduced as part of a small livestock intervention. In Malawi, goat's milk was primarily used to feed children. Households raising goats also donated some milk to Community-based Child Care Centres on a regular basis. The contribution of goat meat to local diets could not yet be confirmed, as the small livestock intervention was still in its infancy when the project ended. In both countries, the livestock intervention could only be introduced towards the end of the Phase I of the project. It should be mentioned though, that this is an intervention target communities were very enthusiastic about, as it contributes to food security, income generation and asset base. Communities participated conscientiously in training and in the initial stages of this intervention and continued to be diligent in mastering the management and husbandry of livestock.

Outcome

- One hundred and fifty-five female-headed households in Mangochi and 135 in Mwanza benefited from being the first recipients of two female goats each, and were to pass on the first progeny to other intended beneficiaries. Children's diets in recipient households were nutritionally enhanced by the goat's milk.

- Subsequent to training of target communities in chicken-rearing, 1100 dual-purpose chickens were distributed (600 in Mangochi and 500 in Mwanza) to the first recipient households, who would subsequently pass on the progeny to other intended recipients. As stipulated, all participating households (60 in Mangochi and 50 in Mwanza) had shelters built for the birds and other prerequisite tools recommended for good management.
- In Lesotho, as this activity was initiated towards project end, only a small group of 385 households was included in poultry and piggery projects. Primarily, intensive training on poultry-raising of a core group of trainers (Peer Group Trainers) from target communities, who would in turn train community members in the anticipated Phase II of the project, was conducted.
- Increased consumption of eggs and chicken was observed among households raising chickens.
- By project end, the first litter of piglets was passed on to the next recipients.

Improved food production and processing

In the two districts of Malawi, communities were trained in good farming practices and supported with inputs. For maize production, training in agricultural techniques such as the Sasakawa planting method, box ridges and constructing marker ridges using the A-frame method along with contour ridges, was provided. Inputs of fertilizer and open-pollinated maize seed were provided to all 2886 households in target communities in the two districts. This transformed beneficiaries from a situation where they fell short of food supplies six months before the next harvest season to one in which they realized a bumper crop, and were able to donate maize to village grain banks. With project assistance, beneficiary households (see Fig. 5.3)

Fig. 5.3. A woman in one of the targeted communities in Malawi, proud of her bumper harvest. Improved food production and processing entailed training target communities in improved agricultural techniques which increased production such that beneficiaries were transformed from a situation where they fell short of food supplies six months before the next harvest season to one in which they realized a bumper crop and were able to donate maize to village grain banks.

produced enough maize to feed their families (approximately one tonne per household) until the next harvest season and to provide sufficient seed for the following season. Because of the bumper harvest, each beneficiary household willingly provided a contribution of one bag (50 kg) maize to village grain banks. The contributed maize was used to support Community-based Child Care Centres as well as the old and the chronically ill who were unable to plant their own fields.

As soy (mentioned under crop diversification) was a new crop to many households in target communities, training on processing and preparation of the bean was conducted. Through nutrition education, the integration of soy into local dishes was swift. Soy flour was mixed with maize meal in preparing all three meals, making the staple food more nutrient-rich. In addition to other dishes, soy flour was also added when preparing the regularly consumed green leafy vegetables and other foods used as relishes. Women were very enthusiastic about the introduction of soy into their diets. Not only were they thrilled about incorporating soy into their everyday diets, they also learnt new recipes like making cakes from maize and soy flour. Demonstrations of these new recipes were staged in field days and other gatherings when possible.

Outcome

- All 2128 households in target communities had bumper harvests, realizing approximately one tonne each. This experience transformed beneficiaries from a situation where they fell short of food six months before the next harvest to one in which they had extra grain to give away.
- Over 400 people from target communities were trained in soybean processing by extension agents from the Ministry of Agriculture and staff from Bunda College of Agriculture. The regularly consumed maize meal and green leafy vegetables were often mixed with soy flour, enhancing the nutrient content of local diets.

Improved food preservation and storage

Through improved food preservation and storage, target communities could be assisted to have continued access to a varied diet, including micronutrient-rich foods, in all seasons. In both countries, during the dry season or winter months, when wild vegetables and fruit are not in season, maize is the predominant food, with token relishes (nutritious and non-nutritious) as complements. Yet in the summertime or rainy season when micronutrient-rich wild vegetables and fruit are in abundance, a lot of these foods go to waste because of inadequate storage facilities and rudimentary or lack of preservation practices. In addition, as discussed above, through project intervention in food production, there was abundance of micronutrient-rich foods, in excess of immediate household consumption needs. Through project intervention, households were trained and assisted in appropriate methods of food preservation and storage.

In Malawi, because of the bumper harvest, village grain banks were introduced and made operational. The project facilitated the establishment of village grain banks in all target communities in the 17 villages that constituted the project coverage area. Through demonstrations, communities were taught improved methods of grain preservation and storage. The 50 kg bags of maize that were donated by each participating household were stored in the village grain banks. Individual households also had harvested maize grain to store. At household level, the project encouraged beneficiaries to build improved storage barns using locally available material (mainly straw and bamboo) as shown in Fig. 5.3. The same material was used to construct village grain banks. However, although rodents were controlled to a large extent through these structures, the grain was still attacked by insects, mainly weevil.

FAO estimates postharvest losses in developing countries at 14–16%, with 4–6% attributable to storage. In this regard, FAO highly recommends the use of metallic silos for small and medium farmers to control losses during storage. Training of trainer courses have been conducted in several countries in collaboration with FAO, the ultimate objective being training of artisans at community or village level. Through this programme, 20 artisans from the two target districts in Malawi were trained in the construction of metallic silos which guarantee zero storage losses if used properly (17). However, the cost of these silos was a limiting factor to access by individual households and village administration. Village authorities were in the process of exploring assistance to obtain a few silos for collaborative use by the community.

Improved solar dryers to preserve excess vegetables and fruit were introduced in both countries. The technique of drying vegetables and fruit has been used by communities for generations, but the methods are rudimentary, allowing only a limited amount of food to be preserved. Much larger quantities of vegetables and fruit could be preserved using solar dryers. In training community members to use solar dryers, nutrition education sessions as well as cooking demonstrations on how to prepare palatable dishes using dried products were conducted. These training sessions were very popular among target community members, particularly women. Subsequent to training in food preservation and storage techniques, target communities were able to preserve the vegetables they produced through gardening and the wild ones that come with the summer rains. Increased availability of horticultural produce in all seasons resulted in increased consumption of these products.

During field days, women showcased dishes prepared from dried products using traditional and new recipes they acquired from training sessions. With new/improved recipes, consumption of vegetables increased, even among children. Dried fruit was very popular as a snack.

Outcome

- Village grain banks were established in all 17 villages in target communities in anticipation of maize to be donated by project beneficiaries.
- All households in target communities in Malawi were assisted to construct improved grain storage barns using locally available material, resulting in reduced postharvest losses through improved preservation and storage methods.
- Twenty artisans from target communities were trained in the construction of metallic silos which, if used properly, can result in zero storage losses.
- Through solar drying, increased amounts of vegetables and fruit were available throughout the seasons and food losses were decreased.

Conclusion

As illustrated above, this initiative has shown that it is possible to invigorate resource-poor, food-insecure communities affected by disease, including a high prevalence HIV, to attain dietary diversity and combat micronutrient deficiencies through food-based approaches. In the fight against HIV, nutrition and antiretroviral drugs are equal and complementary partners; regular intake of a diverse diet which includes micronutrient-rich foods is essential for boosting the immune system and maintaining good health for infected and uninfected individuals in a community.

This project achieved its objective of improving the food and nutrition security of HIV-affected children and their communities. Through project intervention in Lesotho, target communities increased their vegetable production from an estimated 10% of their consumption needs to more than 100%, with increased diversity. In Malawi, communities whose food stocks were depleted six months before the next harvest period had bumper yields, and testified that they had never experienced such returns. Indeed, the international project evaluation team, in its final report (May 2008) stated (18):

> One remarkable aspect of the project is the enthusiasm it could generate among beneficiary households and collaborators in the districts. It showed that a dynamic

> development is possible even in communities hit hard by drought and diseases and that local support systems can be created and/or re-invigorated.

The success of this intervention is attributable to strategies engaged in its implementation and some of the elements incorporated in the planning process.

- *Strengthened institutional framework*. To support the project implementation strategy, an institutional framework and system was established at central and district levels. However, the project did not create new structures, but rather strengthened and utilized existing ones. Where necessary, supporting structures were introduced within existing institutions. For example, in Lesotho, an inter-sectoral District Coordinating Committee to guide and oversee project activities was established within the District Administration structure. When the National OVC Coordinating Committee became operational, this committee was converted to a District Child Protection Team (DCPT) with linkages to the National Committee. DCPTs in the rest of the country were established based on the experiences of this committee, which was established for the project. Further, through the experience of the project, the structure and function of this team was strengthened. DCPTs (in both countries) have linkages to the National OVC Coordinating Committees and are supported by the Departments of Social Welfare in the Ministries of Health and UNICEF. Through this local support, some of the successes of the project at district and community levels should be sustained.
- *Participatory approaches*. The project promoted ownership of this initiative by using participatory approaches throughout the implementation process. First, the district work plan was developed by district stakeholders themselves and thus project activities were relevant to the situation on the ground. Further, through participatory community needs assessment studies, target communities were engaged and involved in the planning and implementation of activities that addressed their felt needs. Thus, service providers and target communities implemented project activities with vigour. Although this approach is time-consuming, it is worth the investment due to its returns on sustainability.
- *Capacity building*. Through the participatory community needs assessment studies, institutional capacities and gaps in skills necessary for project intervention at district and community levels were revealed and, to the extent possible, addressed. Likewise, community capacities and capabilities were revealed and, where possible, strengthened. Thus, the issue of sustainability of project interventions was partly addressed by strengthening existing structures to support communities beyond the project period; and grassroots initiatives and coping mechanisms were also strengthened and improved within the context of capacity building.

Overall, in both countries, this intervention was found to have improved the lives of beneficiaries by the impact assessment studies conducted at project end. In its report, the International Evaluation Team (18) endorsed this finding, asserting

> … the mission agrees with the statement made in the beneficiary assessments that 'there is no doubt that overall the project has had a significant impact on the lives of OVC, those who take care of them and other members of the community'. This statement is evident at the material level: e.g. in Lesotho in spite of a severe drought horticultural activities promoted by the project, particularly keyhole gardens, continued to flourish; in Malawi, harvests were increased and income generated due to project support.

Furthermore, besides the intended objectives and outputs, this project contributed towards achievement of Millennium Development Goals 1 and 6, which are eradicating poverty and hunger, and combating HIV/AIDS, respectively. Most importantly, food and nutrition security including consumption of micronutrient-rich foods in HIV-affected communities was substantially improved. It should be mentioned that the achievements of the projects could benefit from further technical and financial support to strengthen their sustainability. Respective countries are advised to incorporate successful strategies into appropriate regular programmes and similar interventions.

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6 Animal-source Foods as a Food-based Approach to Address Nutrient Deficiencies and Functional Outcomes: a Study among Kenyan Schoolchildren

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Abstract
The importance of micronutrients in growth, cognitive development and combating infection is becoming more evident. The main approaches to ameliorating micronutrient deficiencies have been non-food-based approaches. This chapter describes a randomized, controlled, school feeding study that tested for a causal link between animal-source food intake and micronutrient nutrition, growth, cognitive and behavioural outcomes. Twelve rural Kenyan primary schools were randomized to one of four groups. Standard I children received the local plant-based dish *githeri* (maize, beans and greens) as a school snack with added meat, milk or fat (the latter to equalize the energy content). Control children received no feedings but participated in data collection. Outcome measures at baseline and longitudinally were 24-hour food intake recall, anthropometry, cognitive function, physical activity and behaviours during school free play. The meat group showed the steepest rate of increase in Raven's Progressive Matrices scores and in zone-wide school end-of-term total and arithmetic test scores. The meat group showed the greatest increase in percentage time in high levels of physical activity, initiative and leadership behaviours compared with all other groups. For growth, in the milk group only younger and stunted children showed a greater rate of gain in height. The meat group showed near doubling of upper mid-arm muscle area and the milk group a smaller increase. Serum vitamin B_{12} showed significant improvement. This is the first randomized controlled feeding study to show the effect of meat- versus milk- versus plant-based snacks on children's functional outcomes. Food-based approaches, particularly utilizing animal-source foods, offer potentially sustainable solutions to multiple deficiencies.

Key words: animal-source foods, meat, milk, growth, development, micronutrients, Kenya

Introduction

Macro- and micronutrient deficiencies associated with poor dietary quantity and quality are prevalent globally, and especially in low-income countries. Children and women of reproductive age are particularly vulnerable (1,2). Limited availability, accessibility and intake of animal-source foods at the

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household level, along with a lack of knowledge about their value in the diet and role in health, contribute to poor diet quality, particularly in women and children (3). Insufficient energy and protein quality are also important coexisting problems (4). Moreover, the poor bioavailability of micronutrients, particularly iron and zinc, in high-fibre and high-phytate plant-based staple diets and the low content of some micronutrients, particularly vitamin B_{12}, in these foods contribute to deficiencies (3).

In recent years, the vital role of micronutrients in particular in promoting physical growth, cognitive development and combating infection in children has come to the forefront; mainly iron, zinc, vitamin A and vitamin B_{12} (5–9). Deficiencies of these micronutrients have a large negative societal impact. Approaches to combating multiple micronutrient deficiencies are evolving rapidly and have largely involved the utilization of multiple micronutrient distribution. Vitamin A capsules have a long history of use for prevention of vitamin A deficiency, as do iodine tablets and injections for preventing iodine deficiency. In addition, iron and folic acid preparations have long been used to prevent iron deficiency and anaemia, particularly in pregnancy. Multiple micronutrient sprinkles have been added to servings of food and used particularly in several African countries (10). Most recently, administration of zinc has been recommended for treating prolonged diarrhoeal disease and now as prophylactic treatment to prevent the development of pneumonia (11,12). The above approaches are useful for the short-term treatment of acute and severe deficiencies (13).

Food fortification has a considerably longer and successful history, especially iodization of salt, fortification of margarine, cooking oils and fats with vitamin A, and fortification of wheat with iron and occasionally B vitamins (13). Yet, quality control in developing countries has been problematic. Often, multiple micronutrient deficiencies are present rather than single deficiencies, and the problem arises if multiple tablets are needed. Possible negative interactions between iron and zinc have also been reported (14).

The above 'nutriceutical' approaches are also problematic in terms of sustainability, with reliance on often relatively expensive imported products, difficulties in reaching remote and isolated rural populations, and the need for record-keeping to prevent toxicities (as in the case of vitamin A). Moreover, as macronutrient and multiple micronutrient deficiencies often coexist, interventions with only one or two micronutrients may not alleviate all functional deficits. Intervention studies utilizing supplements such as vitamin A, iron and zinc, either singly or in combination, have had varying results (15).

As for fortified foods, many rural subsistence households deal relatively little with the cash economy, grow the bulk of their own food, rely on small transient markets for purchases and may not have access to fortified products sold mainly in shops in towns, where prices may be prohibitive. New advances have been made in biofortification, such as growing/breeding high-zinc maize and wheat, high-lysine cereals and vitamin A-rich yellow rice and sweet potatoes (16). However, except for yellow rice and perhaps sweet potato, this technology is still extremely limited in implementation and far from being accepted. Increasing the quantity of the usual diet consumed will not address diet quality and the need for multiple micronutrients.

Food-based solutions for dealing with micronutrient deficiencies, although extremely challenging, are potentially sustainable, affordable, effective and feasible approaches to addressing macro- and micronutrient malnutrition. Food-based approaches are more feasible and sustainable in rural areas of poor countries, especially with the use of locally available and familiar foods and traditional preparation and preservation methods (3,17). Meat, fish and fowl of a wide variety and type, organ meats including offal and a variety of rodents, snails, molluscs, insects and annelids offer a good source of multiple micronutrients (18,19). Meat products are energy-dense and contain relatively high amounts of iron and zinc as well as vitamin B_{12} in bioavailable (absorbable) form (19). Haem protein in meat enhances iron and zinc absorption from plant foods. Dairy products, although lacking in iron and zinc, are good sources of calcium and vitamins A and B_{12}.

Animal-source foods, particularly a broad assortment of meat and animal products, supply complete protein and readily bioavailable micronutrients (20). The fat and protein content of meat increases energy density, which is particularly relevant for young children, given their relatively small gastric volume. Milk and other dairy products, eggs, meat, fish and poultry provide high-quality, readily digestible and complete protein containing all essential amino acids (21). Moreover, meat, fish, and poultry contain haem iron, which enhances non-haem iron and zinc absorption from cereals and legumes when mixed with those foods (22–24). Although cereals and legumes may contain considerable amounts of iron, zinc and calcium, these plant foods have high content of phytate and fibre which form insoluble compounds, thereby reducing absorption of iron, zinc and calcium (25). They require large volumes to satisfy energy requirements compared with energy-dense meat-containing feedings.

In general, animal-source foods are inherently richer and contain more absorbable micronutrients than plant foods, specifically of iron, zinc, riboflavin, vitamin A, vitamin B_{12} and calcium (26). Animal foods can fill multiple micronutrient gaps at a greater concentration and lower volume of intake than can plant-source foods (19,26). For example, 100 g of beef has zinc content more than twice that of maize and beans and is up to ten times as absorbable (27). However, not all animal-source foods are of equal nutritional benefit. Meat and milk are not nutritionally equal; milk cannot be a substitute for meat, although it has similar vitamin B_{12} and protein content and more vitamin A. This is particularly important in populations where milk consumption is relatively high and meat consumption is particularly low. Red meat (beef, lamb, pork) and some small fish have consistently higher zinc and iron content than other meats such as poultry and many larger fish. Milk, eggs and fish are important sources of preformed vitamin A, and fish and milk provide calcium and phosphorus (28). Vitamin B_{12} is provided almost exclusively by meat, fish, poultry and milk, and is not found in plant foods. Other important nutrients supplied by meat, fish and poultry include copper, riboflavin, magnesium, phosphorus, chromium, lysine and selenium (21). Fish are a rich source of high-quality protein and micronutrients such as iron, selenium, vitamin C, vitamin D and preformed vitamin A (29–32). Sea fish and other sea animals are rich in iodine (33,34) and zinc, and small fish, when consumed whole, are an excellent source of calcium, vitamin A and iron (31).

The Nutrition Collaborative Research Support Program (NCRSP) reported significant statistical associations between the intake of animal-source foods and increased rates of growth and cognitive development, high levels of physical activity, positive pregnancy outcome and decreased morbidity in three parallel longitudinal observational studies in Egypt, Kenya and Mexico (20,35–37). In the NCRSP studies, it emerged that those children who consumed little or no animal products, particularly meat, performed least well on cognitive tests measuring verbal comprehension and abstract and performance perceptual abilities, as evaluated by Raven's Progressive Matrices (RPM) (38). In addition, those children consuming the fewest animal products were the least attentive in the classroom, less active physically and showed the least amount of leadership behaviour in the playground during free play (39,40). The greatest deficits in linear growth were found in those with little or no animal-source foods in their diet (41). The evidence from these longitudinal observational studies strongly suggested a positive link between the intake of animal-source foods and improved cognitive, behavioural and physical development after statistically controlling for an array of covariates (35–37,39,41).

The above findings stimulated the need for a randomized controlled intervention feeding study to test for a causal relationship between intake of animal-source foods and health, growth and cognitive function. Thus, a randomized, controlled, school feeding intervention trial – the first such study – was designed to answer whether animal-source foods, specifically meat and milk, reduce micronutrient malnutrition and promote growth, cognitive function, micronutrient status and overall health of schoolchildren in rural Kenya; and is described in this chapter. Specifically, it was hypothesized that: (i) supplementation with milk versus meat would demonstrate different benefits – the milk group would show a greater rate of growth in stature than the meat group because of the higher calcium and phosphorus content in milk; (ii) the meat group would show the greatest improvement in cognitive function, school performance and physical activity; (iii) vitamin B_{12}, iron, haemoglobin, zinc and riboflavin status would improve most in the meat group – in the milk group, improvement in vitamin A status and a moderate improvement in vitamin B_{12} and riboflavin status would also be seen compared with the group receiving a local plant-based dish and the control group; and (iv) weight gain would increase in all supplemented groups compared with the control group.

Methods

A randomized, controlled, school feeding intervention study of two cohorts of primary-school children in rural Embu District, Kenya, was designed to test for the presence of a causal link among their intake of animal-source food, rate of growth and development, and micronutrient status. We designed the school feeding intervention by adding the following foods to the traditional local plant-based dish (*githeri*): meat, milk or oil added as energy, versus a control group with no intervention feeding. As milk and meat are often thought to be equivalent, it was felt important to compare a meat and a milk intervention separately, as these differ in their content of some important nutrients (particularly iron, vitamins A and B_{12}, calcium and zinc). Extra oil was added to the *githeri* to equalize the energy content in the three intervention groups and to determine whether the same benefits could be gained by merely increasing energy intake using a common food. Based on prior findings in Embu, increasing the intake of the usual diet was not expected to show the same benefits as increasing animal products in the diet (36,42). Interventions that increased energy intake have been shown to improve developmental gains in some countries (43).

The Embu study site was uniquely suited to this intervention study as a cadre of over 100 previously trained, very experienced, local field workers from a previous study were available and able to administer all of the assessments. The methodology for data collection had been used extensively in this locale, making the acceptance and implementation much easier than starting anew elsewhere. Moreover, the community was extremely cooperative and an excellent rapport had been established with the research team.

Two sub-locations were selected in Embu District, which had approximately 2600 households and 18 schools. Twelve schools, based on their size and accessibility for daily food delivery, were randomly assigned to each of the four conditions, with three schools per condition. The total sample size of Standard I children for Cohort I was 525, and Cohort II was 375 children. Cohort II was enrolled exactly one year after Cohort I because of a prolonged teacher strike and severe drought during the early months of the Cohort I study. Cohort II students were recruited from the same schools and the same feeding groups (replicate study) as Cohort I.

Children with obvious mental retardation or other chronic handicapping conditions were excluded from data collection, and children who switched to schools with a different assigned feeding were excluded from data collection, but all were fed with their classmates when at school. Those with prolonged absences (>3 months) were likewise excluded from data collection, but not from feeding. Six children refused to eat meat, and eight children refused to drink milk. Thirty children were excluded from analyses. The children, enumerators and teachers were not blinded to the meat and milk interventions but were not aware of the hypotheses.

Ethics

Approval was obtained from the UCLA Human Subject Protection Committee, the Ethics Committee of the University of Nairobi School of Medicine, and the Office of the President before the study commenced. Verbal informed consent by parents, assent by children and community permissions were also obtained.

Design

The randomized, controlled feeding intervention study was designed with schools randomized to three feeding groups and a control group that received no feeding, and is described in greater detail in previous publications (44–46). Feeding assignments were the same for each school and classroom within each school. Each treatment group comprised three schools with children aged 6–14 years (median 7.4 years). The study continued over seven 3-month school terms (2.25 years). School feedings were provided only during the days that schools were officially open and not during school holidays.

Feeding intervention

Children received mid-morning 'snacks' every day they attended school. The control group participated in all measurements but did not receive an intervention feeding. Each control family received a milk goat at the end of data collection, a gift of the parents' choice. The snacks for all three intervention groups were based on *githeri*, a local plant dish composed of maize, beans and greens. For the meat group, finely minced beef (Farmer's Choice, Nairobi, Kenya) with 10–12% fat was added to *githeri*. The milk group was given a glass (250 ml) of ultra-heat-treated (UHT) whole cow's milk in addition to the basic *githeri*. The plain *githeri* (energy) group received *githeri* with extra oil (Kimbo, Unilever, East African Industries, Nairobi, Kenya) added to equalize the energy content of the three snacks. Fat was used in all three types of feeding, but most was added in the plain *githeri* group. Midway in the study the oil was found to be fortified with retinol (37 μg/g) but was not initially labelled. Ingredients were increased by approximately 25% after one year as children increased in size and drought continued. Feedings were designed to offer about 20% of required daily energy intake. Preparation and nutrient composition of the snacks have been described in detail previously (47,48). Snacks furnished ~1060 kJ (~250 kcal) per day (Table 6.1).

Pilot testing and retraining of field staff, and baseline observations of children, were carried out from June to August 1998 for Cohort I, before the start of feeding with the

Table 6.1. Nutrient content of school snacks.

	Githeri + meat	*Githeri* + milk	*Githeri* + extra oil
Year 1: Sept–Nov 1998			
Serving size	185 g (includes 60 g meat)	100 g + 200 ml milk	185 g + 3 g oil
Energy (kJ)	1028	1063	1032
Energy (kcal)	239	241	240
Protein (g)	19.2	12.7	7.9
Iron (mg), total	2.42	1.52	3.16[a]
Zinc (mg), total	2.38	1.46	1.35
Vitamin B_{12} (μg)	0.75	0.96	0.0
Years 2–3: Jan 1999–Mar 2001			
Serving size	225 g (includes 85 g meat)	100 g + 250 ml milk	230 g + 3.8 g oil
Energy (kJ)	1346	1346	1346
Energy (kcal)	313	313	313
Protein (g)	21.7	15.2	8.4
Iron (mg), total	2.94	1.57	3.93[a]
Zinc (mg), total	2.89	1.66	1.68
Vitamin B_{12} (μg)	0.91	1.16	0.0

[a]Total iron presented. The actual percentage absorbed would be ~5% due to high phytate and fibre in the plant *githeri*.

feeding intervention initiated at the beginning of September 1998. For Cohort II, baseline data were obtained from June to August 1999, and feeding commenced in September 1999. During the second school year of the study, the children from the first year continued to be supplemented in their Standard II classrooms and then in Standard III. To ensure the hygienic and nutritional quality of the snacks, personal medical examination of all food handlers was required and obtained periodically. Proximate analysis of the snack types was carried out every 3 months to evaluate macronutrient content and any necessary adjustments made. Micronutrient analyses were carried out at Medallion Laboratories (Minneapolis, Minnesota, USA), two to three times per year.

Baseline measures

Baseline measures of the variables to be used as outcomes and covariates were collected within 2 months before initiation of the school intervention feeding at the start of the school term. Analyses of measurements (*t* tests) were carried out to detect any statistically significant differences among the feeding and control groups at baseline.

Household census

The household census included the number and age of household members, deaths, births and identification of the household head. The definition of household membership included people who usually live in the household, who shared the food and were part of an economic unit. The biological parents of the index child, and the relationships among those who resided in the household on a regular basis (not absent over three consecutive months), were designated.

Socio-economic status

The socio-economic status (SES) score used a composite of land and house ownership and land usage for cultivation; income from any source; expenditures; ownership of household goods and implements; forms of transportation; type and structure of the house; latrine; parent's occupations and their involvement in leadership and community positions; ownership of or access to radio, television and newspapers; type of water supply; electrification; number and types of animals owned, cash crops, etc. Different weightings were assigned to possessions based on their relative importance and value. The SES score was validated by community leaders using their own criteria for ranking SES in the former NCRSP study. A statistically significant correlation between the SES scores was obtained by each method (36).

Parental information

Parental literacy testing, using Ministry of Education graded material for reading and writing, was assessed for each parent. The highest completed grade of schooling of the parents was recorded. Parental height was also obtained. Nearly 100% of mothers were measured and tested, but only about 70% of the fathers were available for data collection.

Schools

Children's attendance was assessed for each term based on teachers' reports and records. Also, the daily school feeding logs at each feeding session were a source of information on daily school attendance.

Child measures

Physical status

Baseline health histories and physical examinations of each child were carried out by nurses and physicians. Obviously retarded or chronically ill children were excluded from the study. Clinical nutritional status was assessed, and vision and hearing were evaluated. Spleen enlargement was assessed as an indicator of malaria status as well as blood smears. Stool samples were examined for intestinal ova and parasites using the formal–ether sedimentation method and Lugol's stain (49).

Venous blood samples were obtained at baseline and at the end of years 1 and 2. Haemoglobin was analysed using the Hemocue apparatus (50) and biochemical analyses of micronutrients were carried out only for Cohort I. C-reactive protein was assessed as a marker of infection and inflammation (51). Malaria parasites were detected by thick and thin blood smears (quantitative counts of the number of parasites per red and white blood cells) (49). Also, malaria *Plasmodium falciparum* antigen dipsticks were used to compare results to microscopy and found nearly 50% more cases of malaria (52). These analyses are described in detail elsewhere (53,54). A random urine sample was collected to assess iodine status, with analyses carried out at a World Health Organization (WHO) Iodine Reference laboratory at the University of Nairobi.

Growth

Measurements of head and arm circumference, height, weight, triceps and subscapular skin folds were obtained longitudinally every three months using methods described by Jelliffe and Jelliffe (55) and WHO (56). Methods are fully described by Grillenberger *et al*. (57). Indices such as arm fat area, arm muscle area and body mass index were derived from the above measurements (58,59).

Food intake

Usual daily intake was assessed by semi-quantitative 24-h recall from the mother and from the child, if present. Data at baseline from three consecutive visits, spaced 2–3 weeks apart, were averaged to give the usual 24-h intake of nutrients. Thereafter, food intake was obtained monthly. The WorldFood Minilist was used to convert the data to nutrient intakes (42). The nutrient database for Embu was based on Embu foods with 48 ingredients and dishes actually analysed for nutrients (Medallion Laboratories) and the remainder estimated from a variety of appropriate high-quality data sources (48,60).

Cognitive, behavioural and activity measures

The cognitive tests, and behavioural and activity assessments, were those extensively used in the 1984–1987 NCRSP studies in the same population (36,39). The same highly trained and experienced field staff performed the testing and observations reported here. The measures have been subjected to repeated scrutiny, and their reliability and validity have been demonstrated (36,39). The methods, which included the Verbal Meaning Test designed in East Africa, Digit Span (61) and RPM, have been fully described by Whaley *et al*. (45). The RPM is a non-verbal test of performance, abstract meaning, perception and problem-solving (fluid intelligence) (38). For all cognitive tests, raw scores were used in the analyses, as standardization is not available in Kenya and standardization based on children in the USA is not appropriate or meaningful (36,39). Cognitive assessments were carried out once every 3-month term. End-of-term examination scores were obtained from the Head Teacher's office. These examinations were zone-wide and uniform in content and grade level across the schools in the area. Total scores and scores in each school subject were obtained from the schools for each child for each term. Frequent quality control, validity and reliability measures, and training exercises were carried out.

Physical activity and behaviours

These were measured by observation techniques using time sampling to obtain estimates of child activity and social interaction during unstructured play in the schoolyard and activity and attentiveness in the classroom. Timed observations were used: 30 s for observation and 30 s for recording. A total of 30 min per child per term was required. Strict criteria to define activity and behaviours were used (39,40). Levels of high, medium and low activity were recorded using predetermined criteria. Behaviours of leadership, initiative, solitary play, sustained activity and display of negative or positive emotion were all strictly defined and recorded once per term. In the classroom, paying attention to schoolwork at hand and to the teacher, talkativeness and playing were used to evaluate on-task or off-task behaviours or paying attention in class (39). As for cognitive testing, frequent quality control, validity and reliability measures, and training exercises were carried out.

Statistical methods for the intervention study

Once schools were randomized to one of the four intervention groups (control, plain *githeri* (energy), milk or meat), data collection began with baseline measurements (times before 0) and then continued as the school feeding intervention was initiated. Children were observed from one to 18 times at different intervals, depending on the type of measurement.

The study had a nested or hierarchical design (62): schools within feeding groups and children within schools. The primary goal of data analyses was to compare rates of change across children and feeding groups. The software SAS for Windows 8e (SAS Institute, Cary, North Carolina, USA) was used with SAS PROC MIXED to compute estimates and standard errors for two types of parameter: (i) fixed effects (feeding group, baseline age, gender, school), including the mean intercepts and slopes for the four groups; and (ii) random effects (morbidity, anthropometry and food intake), including the intercepts and slopes of the individual children and school effects (63). Validity of the models was confirmed using standard statistical methods.

Results

Baseline findings

Selected baseline characteristics are shown in Table 6.2. No significant relationships were seen for any variables by feeding group. Although not significantly different among the groups, the mean SES score for the milk group was somewhat lower than for the meat group. The average household size was six, and families tended to be nuclear or extended but small. Most mothers completed six primary grade levels. The writing ability of mothers was at a mean grade level of 4.6, and for reading, 6.6. For schooling, fathers completed one grade higher than the mothers, completing a mean grade of 7, and their reading and writing literacy abilities were consistently a grade higher than those of the mothers, with a mean grade level of 8.0 for reading and mean grade level of 6.5 for writing.

Both height and weight were reported as Z scores (height-for-age, HAZ; weight-for-age, WAZ) (54). The mean age of the children at baseline was 7.4 years, range 6–14 years. Children are permitted to start Standard I classes at any age, with the poorer children tending to start as late as 14 years. Stunting (HAZ ≤ -2) was found in 19.4% of the sample as a whole, 23.0% percent of the boys and 15.5% of the girls. Severe stunting (HAZ ≤ 3) was found in 4.6% of the children; the younger the group, the lower the percentage of stunting. Underweight (WAZ ≤ -2) occurred in about 30% of boys and 30% of girls. Mild underweight ($-2 < \text{WAZ} < -1$) was seen in 42.1% of boys and 31.1% of girls.

Body composition estimates

Children were generally lean, with mean triceps and subscapular skin folds below the 5th percentile based on reference data for African-American children from the National Health and Nutrition Examination Survey (64). On average, arm fat area was in the 5th percentile and arm muscle area in the 5th–10th percentile (58). A higher percentage of older children were underweight compared with younger children.

Food intake

Foods were converted into nutrients consumed per day. Detailed information on food intake is presented elsewhere (48). Total energy intake was within the recommended range for a child weighing 20 kg (the mean baseline weight), which is the 20th percentile of weight-for-age. At the 50th percentile of weight for this age, the recommended intake would be 9211 kJ/day (2200 kcal/day) (56,65). Total protein intake was also in the normal range, but total animal-source

Table 6.2. Selected baseline characteristics of Cohort I children.

		Feeding group			
	n	Meat	Milk	Plain *githeri* (energy)	Control
Household SES[a]	494	95 ± 5	83 ± 5	87 ± 6	93 ± 1
Household SES[a]	494	95 ± 5	83 ± 5	87 ± 6	93 ± 1
Age of child (months)[a]	484	93.6 ± 2.7	88.5 ± 2.6	87.0 ± 2.7	88.1 ± 2.7
Male children (%)	494	50	53	51	53
Female children (%)	247	50	47	49	47
Anthropometrics[a]					
Height (cm)		116.5 ± 1.3	115.8 ± 1.3	115.7 ± 1.3	115.8 ± 1.3
Weight (kg)		20.1 ± 0.4	19.7 ± 0.4	19.8 ± 0.4	19.8 ± 0.4
WAZ		–1.3 ± 0.1	–1.2 ± 0.1	–1.0 ± 0.1	–1.1 ± 0.1
HAZ		–1.6 ± 0.2	–1.3 ± 0.2	–1.3 ± 0.2	–1.3 ± 0.2
WHZ		–0.4 ± 0.1	–0.4 ± 0.1	–0.2 ± 0.1	–0.3 ± 0.1
AMA		1558.4 ± 26.8	1566.7 ± 25.8	1575.1 ± 27.1	1560.03 ± 27.4
AFA		424.5 ± 21.4	435.7 ± 20.7	440.0 ± 21.8	429.3 ± 21.8
Maternal height (cm)		156.2 ± 0.6	157.0 ± 0.6	156.6 ± 0.6	156.3 ± 0.6
Paternal height (cm)		164.9 ± 1.0	167.9 ± 1.0	165.6 ± 1.1	166.9 ± 1.1
Nutrient intake					
Energy (kJ)		7376	7480	7132	7312
Energy (kcal)		1758	1781	1698	1741
Protein (g)		54.7	53.4	53.6	50.7
Vitamin B_{12} (μg)		0.37	0.39	0.73	0.54
Riboflavin (mg)		1.06	1.02	1.04	1.03
Vitamin A (μg RE)		274	240	359	333
Calcium (mg)		274	269	268	307
Available iron (mg)		1.51	1.39	1.44	1.4
Available zinc (mg)		1.13	1.02	1.09	0.99
Micronutrient status (% below cut-off)	Cut-off[b]				
Haemoglobin	<115 g/l	51.6	46.3	49.6	48.4
Plasma ferritin	<15 μg/l	2.4	10.9	1.5	10.7
Serum iron	<9.0 μmol/l	63.9	40.0	47.1	56.1
Serum zinc	<10.7 μmol/l	61.5	70.1	64.0	66.7
Serum copper	<11.0 μmol/l	0	0.8	0.7	0.8
Plasma vitamin B_{12}					
severe	<125 pmol/l	46.9	30.6	23.0	19.7
moderate	125–221 pmol/l	33.9	41.0	37.1	38.5
Plasma folate	<6.8–13.6 nmol/l	0	0.9	0.8	0.8
Plasma retinol					
severe	<0.35 μmol/l	31.3	23.9	16.7	17.5
moderate	0.35–0.70 μmol/l	67.6	65.0	66.7	75.7
RBC riboflavin	<170 μmol/l	14.9	18.4	28.8	33.7

WAZ, weight-for-age *Z* score; HAZ, height-for-age *Z* score; WHZ, weight-for-height *Z* score; AMA, arm muscle area; AFA, arm fat area; RE, retinol equivalents; RBC, red blood cell.
[a]Values are means and standard deviations.
[b]Cut-offs for deficient values are provided by Siekmann *et al.* (54).

protein and protein from meat, fish and poultry were extremely low. Fat intake was generally low, 24 g/day or 13% of energy, as were the intakes of saturated fat and cholesterol. Both fibre and phytate intakes were high, 43.8 ± 18.0 g/day and 3361 ± 1402 mg/day (mean±standard deviation), respectively (42).

Micronutrient intake

Inadequate micronutrient intakes were highly prevalent, particularly iron, zinc, vitamin B_{12}, calcium, vitamin A and, to a lesser degree, riboflavin. Given the low haem iron in the diet, the bioavailability of both iron and zinc was low (3,42). For most micronutrients, the group differences in intake were not significant. However, intakes of vitamins A and B_{12} were significantly lower in the milk and meat groups compared with the plain *githeri* (energy) and control groups. Vitamin A intake from animal-source foods was low, with total intake below recommended levels and most of the vitamin A derived from carotenoid sources. Low riboflavin intake was found in almost a quarter of the children. Inadequate intakes of vitamin B_{12} were highly prevalent.

Total iron intake was 17.7 ± 6.3 mg/day (mean±standard deviation). However, available iron and haem iron, from meat, fish or poultry, were generally very low or negligible, with estimated iron availability of only 9–10% (3,42). A similar picture was seen for zinc. Although zinc intake was 7–9 mg/day, estimated zinc absorption was only 11–12% (42). Calcium intake was also low, with daily calcium intake of 261 ± 118 mg (mean ± standard deviation; about 35% of the recommended level).

Biochemical micronutrient status

Baseline biochemical micronutrient determinations confirmed the deficiencies predicted from food intake data referenced above. The main deficiencies found were of vitamins A and B_{12}, iron, zinc and riboflavin (54). Vitamin B_{12} deficiency was present in 68.2% of the children, with 30.5% having severe deficiency and 37.7% having mild-to-moderate deficiency. The meat group had the highest prevalence of severe vitamin B_{12} deficiency at baseline compared with the other groups. Vitamin A deficiency was present in approximately 90% of the sample with severe deficiency present in 22% and mild-to-moderate deficiency found in 65–75% of all groups. No clinical signs of vitamin A deficiency were found during the baseline physical examination.

Low haemoglobin concentrations (<115 g/l) indicative of anaemia were seen in 48.9% of the sample as a whole, and severe anaemia (<70 g/l) in 9.0%. The latter children were treated with ferrous sulfate for 30 days and had a moderate improvement in anaemia. There are multiple possible aetiologies for the anaemia. Malaria is endemic in Embu, iron deficiency is likely based on its low dietary availability, and vitamin B_{12} and vitamin A deficiencies can also cause anaemia (66). Hookworm is not common, but a high percentage of children had amoebiasis, a source of intestinal blood loss (54).

Results of the intervention

Cognitive function

Results of the intervention on children's cognitive function have been explained in detail by Whaley *et al*. (45). There were significant group differences on RPM test scores ($P = 0.01$) (Fig. 6.1). The meat group showed the steepest rate of increase in RPM test scores. The milk group showed the lowest rate of increase in RPM test scores, significantly below all other groups. On arithmetic tests, both the plain *githeri* (energy) and meat groups performed significantly better over time than the milk and control groups ($P < 0.02$ to 0.03). No significant differences were seen in scores on tests of verbal meaning and digit span. As for school performance as measured by end-of-term test scores, the greatest percentage increase in zone end-of-term total test scores was observed in the meat group, with the greatest percentage increase in arithmetic subtest scores also seen in the meat group, both statistically significant increases (Fig. 6.2) (45).

Physical activity and behaviours during free play

Results of the intervention on physical activity and behaviours have been presented in detail by Sigman *et al*. (46). Over time, the highest percentage of time spent in high levels of physical activity during free play was seen in the meat group (Fig. 6.3). The meat group also showed the greatest decrease in percentage of

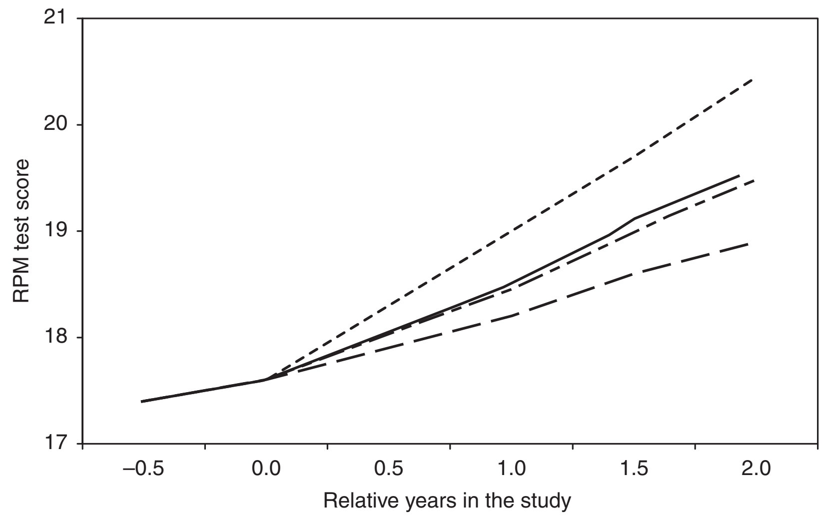

Fig. 6.1. Changes in Raven's Progressive Matrices (RPM) test scores by relative year in the study (over a 2-year period) and feeding group (—, control group; — –, plain *githeri* (energy) group; — —, milk group; – –, meat group). (Adapted from Neumann, C.G., Murphy, S.P., Gewa, C. Grillenberger, M. and Bwibo, N.O. (2007) Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. *Journal of Nutrition* 137, 1119–1123 with permission from the American Society for Nutrition.)

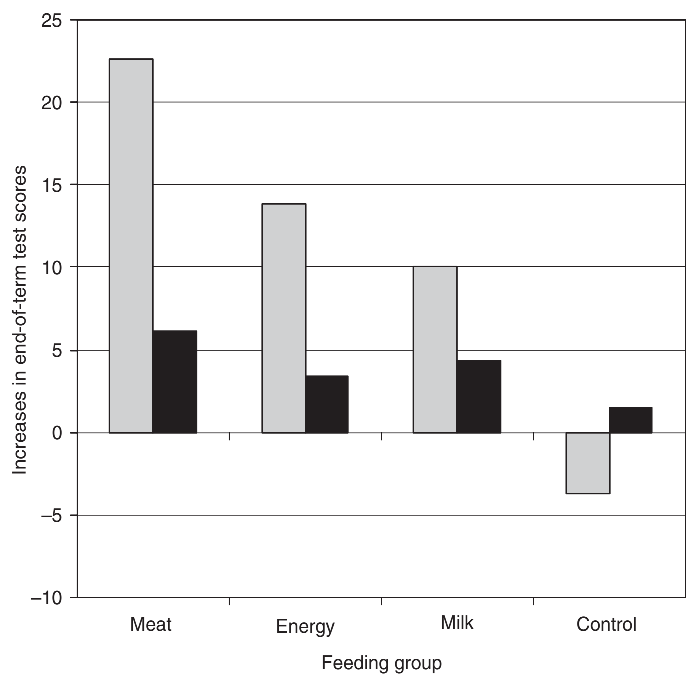

Fig. 6.2. Increases in end-of-term test scores (■, total scores; ■, arithmetic scores) by feeding group (Cohort II). (Adapted from Neumann, C.G., Murphy, S.P., Gewa, C. Grillenberger, M. and Bwibo, N.O. (2007) Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. *Journal of Nutrition* 137, 1119–1123 with permission from the American Society for Nutrition.)

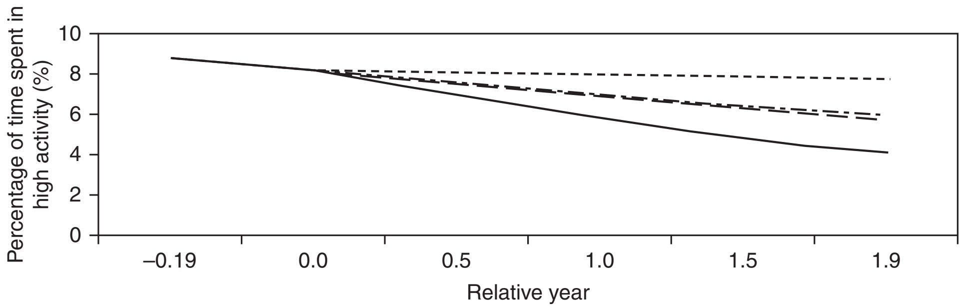

Fig. 6.3. Change in high activity over time by feeding group (—, control group; — –, plain *githeri* (energy) group; — —, milk group; – –, meat group). (Adapted from Sigman *et al*. (46), with permission from the *Food and Nutrition Bulletin*.)

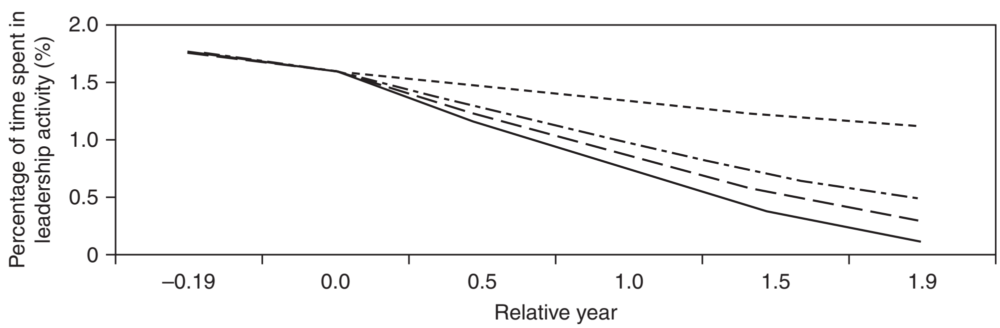

Fig. 6.4. Change in leadership activity over time by feeding group (—, control group; — –, plain *githeri* (energy) group; — —, milk group; – –, meat group). (Adapted from Sigman *et a l*. (46), with permission from the *Food and Nutrition Bulletin*.)

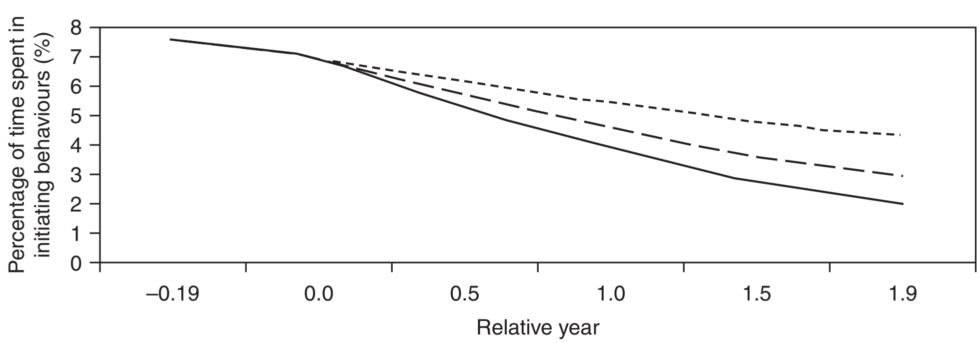

Fig. 6.5. Change in initiating behaviour over time by feeding group (—, control group; — –, plain *githeri* (energy) group; — —, milk group; – –, meat group). (Adapted from Sigman *et al*. (46), with permission from the *Food and Nutrition Bulletin*.)

time spent in low levels of physical activity. When compared with all other groups, the meat group showed the greatest increase in percentage of time in leadership activities (Fig. 6.4) and the greatest increase in percentage of time in initiative behaviour (Fig. 6.5). Children in the plain *githeri* (energy) group were also more active and displayed more initiative and leadership behaviours than those in the milk and control groups, although not nearly as much as for the meat group. The milk group performed the most poorly of the three intervention groups.

Growth

All feeding groups showed a greater rate of weight gain compared with the control group. For the milk group, only younger children (≤6 years) and stunted children (HAZ ≤ −2) showed a greater rate of gain in height than the other children in the milk group. None of the other groups showed any significant rate of gain in height. The meat group showed the steepest rate of increase of mean arm muscle area (indicative of lean body mass) (Fig. 6.6), and the milk group showed the next greatest improvement. A significant positive association was found between mean arm muscle area and percentage of time spent in high levels of physical activity in the meat group.

Discussion

This chapter describes the first randomized, controlled, feeding intervention study with meat supplementation ever carried out. It shows a causal set of positive relationships between meat intake and important functional outcomes in children: improved cognitive performance; increased high levels of physical activity; increased initiative and leadership behaviours; and increased mean arm muscle area. Milk supplementation resulted in improved linear growth in younger and already stunted children. Compared with the control group, all supplemented groups improved overall weight gain, suggesting a chronic energy deficit and inadequate energy intake for any catch-up growth.

The improved cognitive performance and increased physical activity and leadership and initiative behaviours in the meat group may be linked to the greater intake of

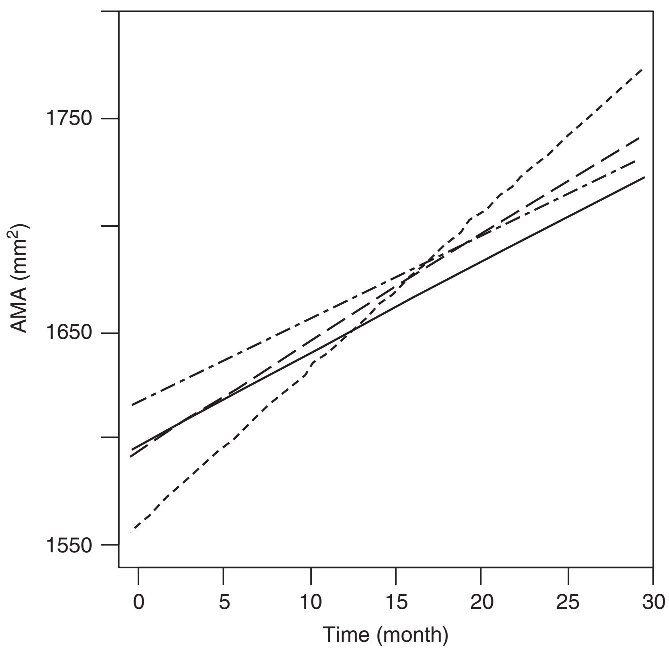

Fig. 6.6. Increases in mid-upper-arm muscle area (AMA) by time in study (Cohort I and II) and feeding group group (—, control group; — —, plain *githeri* (energy) group; — , milk group; — —, meat group). (Adapted from Neumann, C.G., Murphy, S.P., Gewa, C. Grillenberger, M. and Bwibo, N.O. (2007) Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. *Journal of Nutrition* 137, 1119–1123 with permission from the American Society for Nutrition.)

vitamin B_{12} and more available iron and zinc as a result of the presence of meat, which increases iron and zinc absorption from fibre- and phytate-rich plant staples (3). Meat, through its intrinsic micronutrient content, other constituents and high-quality protein, may facilitate specific mechanisms, such as speed of information processing, that are involved in learning tasks such as problem-solving. This is reflected in the significant increase in RPM test scores in the meat group. The milk group performed the poorest on the RPM testing. A possible explanation is that milk, with its high casein and calcium content, impedes iron absorption; and iron is intimately involved with cognitive function (45). The increase in mean arm muscle area in the meat group may be because of the intake of zinc and complete protein, which both promote protein synthesis (67–69). In summary, this chapter documents health, cognitive and functional benefits associated with animal-source food consumption. These benefits were seen with the addition of relatively modest amounts (60 g) of meat.

Recent studies have also documented the benefits of food-based approaches integrating meat. A recently completed study in Guatemalan children reported improvements in vitamin B_{12} status and development following supplementation with beef or vitamin B_{12} (70). A quasi-experimental community-based dietary intervention in Malawi involving dietary diversification with an increase in the utilization of fish reported significant improvement in lean body mass of stunted children after 12 months (22). Other studies are underway integrating animal-source food into diets to ameliorate deficiencies in both infants and children using a variety of types of meat.

Challenges for integrating animal-source foods in food-based approaches

A number of constraints impede the integration of animal-source food, especially meat, into diets, particularly in resource-poor settings. At both the household and the community level, various approaches for addressing micronutrient deficiencies and increasing access to and availability of animal-source food, particularly meat, are being used. Various traditional food processing and preparation methods such as soaking, fermentation, germination/malting, thermal processing and mechanical processing can be used to enhance the bioavailability of micronutrients from plant-based diets (71,72) by reducing the phytate.

Promotion of small-animal husbandry, particularly by women and children, primarily for household consumption and secondarily for income generation, is being promoted by a number of non-governmental organizations (NGOs) as a strategy for improving nutritional outcomes in populations with little access to animal-source food. This approach is being tried in multiple sites in Ghana though a project initiated by the Global Livestock Collaborative Research Support Program, called 'Enhancing Child Nutrition through Animal Source Food Management (ENAM)' (73). This project has documented an increased diversity of animal-source food in the diet when mothers had an income-generation activity based on animal-source food, as well as an increase in mothers' nutrition knowledge and greater diversity of animal-source foods fed to their children (74,75). Other studies have shown household livestock ownership and production to positively affect production and consumption of animal-source food, overall dietary intake, household income and nutritional status (76,77). At the household level, small animals can provide a variety of products, including meat, milk, butter, yoghurt and fat, to meet nutritional needs. After meeting those needs, animal-source food can be sold for income generation. Microcredit can help promote nutrition improvement with maternal education and income generation by providing small loans to start small businesses. Badly needed are services from extension agencies and NGOs targeted at women by women, as they do the bulk of care for small household animals (78,79). Gender issues need to be addressed with regard to intra-household distribution of animal-source food, as the most vulnerable household members – young children, women of reproductive age and

HIV-positive individuals – are often denied animal-source food.

More household and community initiatives for food preservation are needed to prevent spoilage and wastage and to ensure a steady supply of animal-source food, especially for poor households who cannot afford to purchase meat, fish and poultry in the cash economy. Creative preservation techniques for animal-source food have included blood biscuits as well as cereals fortified with dried blood, used in Latin America and in parts of Africa, resulting in improved iron status (80–83). A study is underway in Kenya of HIV-positive women and their children using a meat-containing biscuit.

A problem with rearing animals for consumption, including fish, is the need for preservation to prevent spoilage in the absence of refrigeration. Smoking and solar drying are common options to produce safe, shelf-stable products under controlled conditions. The NutriBusiness project whereby community women's groups produce weaning foods has been successful (84–87). Their groups, on a trial basis, have solar-dried rabbit and chicken, producing finger foods such as chips that can be powdered for inclusion in weaning porridge. Weaning mixes are sold for income generation, as are non-meat products. Several African countries have now adopted this approach. The NutriBusiness project provides an example of a successful enterprise by rural Kenyan women to preserve plant and meat foods. Meat products are now being added to weaning mixes as a strategy to improve meat, fish and poultry intake in children. Small-scale community development approaches address not only the problem of improving children's health, nutrition and development, but also interrelated problems of rural poverty and gender inequity.

At farm and community level, improvement of the nutrient content of soil in which forage is grown is required, and affordable fertilizer and more sustainable agricultural practices through improved extension services are badly needed. Appropriate models for small livestock development utilize zero-grazing. Aquaculture to produce small fish for human domestic consumption is gaining in popularity and needs to be better balanced with fish production for animal feed. Schools can also be used to improve nutrition status. School gardens and small-animal husbandry projects can increase children's knowledge as well as access to animal-source food. Agricultural extension services (government and NGOs) need to be extended to women and schoolchildren who perform much of the raising of small animals at a household level by women extension workers. Several NGOs such as Heifer Project International, Farm Africa and World Vision already have successful programmes to promote raising small livestock using appropriate technologies and education on animal husbandry targeting communities. In the Paravet programme in Kenya, women veterinarians train local women to take care of animals through agricultural extension (88,89). Appropriate nutrition education emphasizing the preparation and value of different foods for dietary improvement would greatly enhance these programmes (20).

While food-based solutions are more complex and interdisciplinary in nature and require long-term commitments, they are more likely to address malnutrition at its source, leading to long-term sustainable improvements. Food-based approaches, we believe, can offer more protection and sustainability than single- or multiple-micronutrient non-food supplements. The addition of modest amounts of meat, fish, poultry and other animal-source foods to the diet can greatly improve the health, micronutrient intake, overall nutrient status and function of rural populations, particularly of women and children (20,44,90,91). Putting 'meat on the table' requires a supply of small animals within the production capabilities of smallholder farmers and families. Extension workers need to provide technical support and nutrition education to women in household animal production and in the preparation, preservation and feeding of such animal-source foods, particularly meat, to children and young women.

Nutrition improvement is vital and should be an integral part of health, education and development efforts. A major constraint on the development of human capital and capacities is the loss of human potential, both physical and mental, due to poor nutrition (92). Food-based approaches in rural areas are most likely to be sustainable in improving diet quality and energy density with animal-source food in contrast to 'pill-based' approaches. Improved nutritional status is important in building human capital and is a first and fundamental step to reducing poverty and promoting social and economic development.

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7 Small-animal Revolving Funds: an Innovative Programming Model to Increase Access to and Consumption of Animal-source Foods by Rural Households in Malawi

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Abstract
Increased intake of animal-source foods is a key means to improve nutritional status in populations with high levels of nutrient deficiencies. However, there are few examples of programming models that have successfully improved both access to and consumption of animal products in resource-poor settings. This chapter presents a case study of a community-based intervention to increase household access to and consumption of animal-source foods, implemented as part of a comprehensive, 9-year nutrition and health programme in Malawi.

A community-managed revolving fund scheme was used to distribute small animals to rural households, accompanied by training on animal husbandry and intensive nutrition education to promote consumption of the animal products. This was integrated into a broader anaemia control strategy, which included iron supplementation and malaria control. Cross-sectional surveys were used to evaluate programme effectiveness, including comparison of beneficiary communities with non-programme areas.

Household rearing of all small animals increased from 43% to 65% in programme areas. Significantly more households in the programme area both raised and consumed the target animals at the final evaluation. Anaemia prevalence in pregnant women decreased from 59% to 48% in the programme area, but increased to 68% in the comparison group. In pre-school children, anaemia prevalence decreased similarly in both groups.

The revolving fund scheme successfully increased access to and consumption of small animals in programme communities. Anaemia prevalence decreased in women, but the specific contribution of the animals to this cannot be separated from the combined impact of the integrated programme.

Key words: animal-source foods, anaemia, revolving fund

Introduction

The nutritional benefits of animal-source foods are well documented, as is the lack of these foods in the diets of many populations suffering from high levels of nutritional deficiencies (1). However, the identification of effective strategies to increase access to and

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consumption of animal-source foods by vulnerable populations has proven challenging. Many projects which promote livestock-raising are oriented towards improving household income rather than nutritional status, and therefore fail to promote consumption of the animals or to measure changes in dietary patterns of beneficiaries (2). There are few published examples of interventions that have both successfully increased household access to animal-source foods and demonstrated an impact on specific nutritional deficiencies. Strengthening knowledge and experience in this area therefore remains a priority for the international nutrition community.

This chapter presents a case study from Malawi, where an intervention to increase households' raising and consumption of small animals through a revolving loan distribution scheme accompanied by intensive nutrition intervention was implemented as part of a comprehensive micronutrient and health programme. Although animal-source foods have multiple nutritional benefits, a major emphasis of the overall programme was on prevention and control of iron deficiency, and therefore anaemia prevalence was used as the outcome indicator.

Iron deficiency anaemia is the most common nutritional disorder in the world, disproportionately affecting a significant percentage of women and children in developing countries (3). Often subtle in manifestation, anaemia exacts a tremendous burden in terms of lost earnings, premature death and poor health outcomes. Lack of dietary iron is the primary causal factor in approximately half of anaemia cases worldwide (3). The iron sources with greatest bioavailability (i.e. most readily absorbed and utilized by the body) are animal products, which contain haem iron. However, typical diets in many developing countries provide very little iron or iron that is poorly absorbed by the body. Rural families in Malawi, for example, tend to consume a maize-based diet that is high in phytate, a strong inhibitor of iron absorption, and very low in haem iron and other enhancers of iron absorption. Anaemia prevalence has been assessed as 73% in children under 5 years old, with 82% of their mothers also anaemic (4). An analysis of the iron intake of pregnant women in rural Malawian communities found that 89% of dietary iron was non-haem, and that the intake of bioavailable iron was significantly associated with iron status (5). Interventions to improve dietary intake of bioavailable iron, particularly through animal-source foods, are urgently needed in such settings to combat the high levels of iron deficiency and anaemia. Such interventions have the added advantage of reaching the whole population and providing a variety of nutritional benefits, including high-quality protein and multiple micronutrients (6).

However, among the limited published reports of studies aiming to increase iron intake through animal-source foods, few have effectively paired the dietary interventions with improved nutritional status. In Vietnam, iron intake in children increased following an intervention that included home gardens, fishponds and animal husbandry, but iron status was not assessed (7). Iron status (serum ferritin) of schoolgirls in Thailand improved following a similar multidimensional food-based intervention, but concurrent interventions (iron supplementation and an improved school meal programme) prevented attribution of the biochemical results directly to household dietary changes (8). In some cases, food-based interventions have resulted in improved family income but no changes in diet quality of target beneficiaries (9). Other intervention studies have demonstrated an increase in household food security and consumption of animal-source foods by women and children, but did not measure changes in nutritional status (10,11). Thus there remains a critical need for well-designed and evaluated interventions to increase access to haem iron sources in populations where anaemia is highly prevalent.

An important lesson from these previously published reports is that effective strategies to increase intake of iron-rich animal-source foods require significant effort to integrate nutrition education with activities to increase access to appropriate animal products (12). Interventions need to be oriented towards household consumption of the animals raised, as opposed to a primary focus on income generation through livestock sales (2). Additionally, the animals must be able to reproduce frequently enough to provide a regular source of meat and must be culturally acceptable and able to thrive in the local environment. Incorporating an understanding of cultural factors affecting preferential food allocation within the household is also key in many settings, as these issues may play a role in limiting the intake of animal-source foods by children and women (13).

Food-based interventions to address anaemia must also be delivered in combination with essential primary health care measures. Although iron deficiency is the most common cause of anaemia, other factors also contribute to and exacerbate anaemia status (14). These include infectious diseases, particularly malaria and hookworm infection; other micronutrient deficiencies, such as folate, vitamin B_{12} and vitamin A; blood losses during menstruation and childbirth; and inherited conditions such as sickle cell disease. The aetiology of anaemia in Malawi includes both iron deficiency, due to the dietary limitations discussed earlier, and malaria and parasitic infections. The 2001 Malawi Micronutrient Survey found malaria prevalence to be extremely high, ranging from 17% in non-pregnant women to 60% in children aged 6–36 months (15).

Methods

World Vision, an international non-governmental organization, initiated the MICronutrient And Health (MICAH) programme in Malawi in 1996, with funding from the Canadian International Development Agency and World Vision Canada. The programme goal was to improve the nutrition and health status of women and children, specifically focusing on iron and iodine deficiencies. MICAH was implemented from 1996 to 2005 in 16 project sites throughout Malawi, covering 14 of the 26 districts in the country, primarily in rural areas.

The raising of small animals was identified as the focal intervention of MICAH's dietary diversification strategy due to the high bioavailability of key micronutrients such as iron and zinc in animal-source foods. A revolving fund scheme was developed as the implementation strategy for this intervention.

MICAH's small-animal revolving fund scheme (SARF) employed a distribution method whereby the programme provided initial animal stock to a number of individuals who were selected according to criteria determined by the community. These individuals were then required to give the first offspring from their animals to others in the community, and so on until full distribution throughout the community was achieved. Prior to receiving any animals, the beneficiaries were required to construct a shelter to house them, according to training provided by staff from the Ministry of Agriculture's Department of Veterinary Services. Where the community identified beneficiaries (such as the elderly or adults with chronic illnesses) who were unable to construct the required shelter, a committee would be formed to assist that household. The type of shelter constructed varied throughout the country according to the local environment. The animals distributed included goats (initially), rabbits, chickens and guinea fowl. The accompanying nutrition education promoted the consumption of all animal-source foods.

Significant resource investments were made from the very onset of the programme to engage the community, so that MICAH's SARF was developed as a collaboration between village health committees; Ministry of Agriculture, Irrigation and Food Security (MoA) veterinary extensionists; MICAH staff; local implementing partners; and community members. Preliminary capacity-building initiatives included a five-day training session led in partnership with MICAH staff and representatives from the MoA and the Ministry of Health (MOH). In addition to education on the other programme activities, these sessions focused on animal husbandry techniques. Trainings were developed by MICAH partners to address regional differences and were based on the expertise of the local veterinary extensionist and his/her MoA resources. In many cases a community 'expert', such as a successful farmer in that locale, was asked to assist with MICAH training to share their knowledge and lessons learned. Workshop participants, comprising four or five men and women from each village, left the training sessions to act as trainers of trainers to initiate promotion and peer education activities within their own communities. Building upon these health promotion initiatives, community members were surveyed regarding their interest in participating in the SARF. Interested households were then provided with education on animal husbandry, including the construction of the animal enclosures.

Initially the programme focused on goats, by providing an improved variety of male goats for breeding with traditional local female goats to produce offspring with better meat and milk production potential. However, a mid-term evaluation revealed that because goats are relatively large and important animals within the community setting, they were not being consumed on a regular basis by households and were not under the control of the women, who provided meals for the household. Rather, they would be used for ceremonial purposes such as a chief's wedding, a funeral or major religious events. At these events, it was usually the men who would consume the meat and women would often only receive a small portion, if any at all. It was thus concluded that although the goats were valued as an input by the communities, the intervention was not directly contributing to an increase in consumption of animal-source foods by women and children, the key target groups of the programme.

Through collaboration and discussion with the MoA, MOH and MICAH implementing partners, the promotion of rabbits was identified as a possible means of improving the quality of dietary intake within the target area, as an alternative to goats. Rabbits are small and therefore not as highly valued as the larger goats. Also, rabbits reproduce quickly, unlike the one goat kid per year, and were thus more likely to be used by women for family meals. The lower perceived value of the rabbits also enabled the women to have decision-making control over the use of the rabbits, whereas the goats were under the control of the male household head.

Since the consumption of rabbit meat was new to most project communities, significant effort was required in introducing the concept. Cooking demonstrations and taste tests involving influential members of the communities, particularly religious leaders, proved an effective means of overcoming initial hesitation regarding the rabbits. The staff also assessed each community to decide on the committee that would take up the responsibility of the rabbit revolving funds and identification of initial beneficiaries. In some cases, the initial beneficiary was the chief's household, or another influential member of the community. This was due to the fact that once these influential people adopted the new practice of rabbit-rearing, it would be deemed acceptable by the others. In other cases, especially needy families would be identified as primary beneficiaries so that the community would be able to see the difference made in the diet and lives of people with few resources. In this way, the programme adapted to the unique characteristics of each community in order to maximize the acceptance and coverage of the intervention.

The SARF was managed by local village health committees, which were responsible for overseeing and monitoring the intervention. While MICAH suggested that animal offspring benefit at least three other households, it was ultimately the responsibility of the local community to define the payback plan for their village. A sub-committee was responsible for gathering village-level statistics. The sub-committee secretary maintained a master registry of village households, SARF animals distributed and their related statistics, including births, deaths, probable cause of death, vaccination status and dates of mass vaccinations.[1] MICAH staff then used these data to address any issues that needed to be resolved; however, beneficiaries were encouraged and empowered to resolve problems at the community level. The local veterinary extensionist was also required to submit reports on small-animal husbandry activities (including MICAH SARF) to the MoA.

[1] While MICAH recommended that the community collect certain information, each SARF sub-committee established its own registry format with data collection based on local needs.

Within each village, MICAH also established a small-animal revolving drug fund. SARF training included the identification and treatment protocols for common animal illnesses that beneficiaries might encounter. Animal owners were encouraged to purchase the appropriate medicine from the revolving drug fund when an animal was ill. This revolving fund was also administered by the village health committee, which had a designated treasurer in charge of finances. Medicines were sold for a small profit to cover the cost of transportation (for restocking) and inflation. Although the initial animals introduced in the community were pre-vaccinated, it was the responsibility of the local veterinary extensionist and animal owner to follow up on immunizations for future offspring. The local veterinary extensionist also organized periodic mass immunization campaigns with vaccines provided by the government via the existing MoA system.

In addition to the small animals, MICAH Malawi promoted and supported the establishment of household and communal gardens, in close collaboration with the MoA. The emphasis was on cultivation of fruits that enhance iron absorption through vitamin C (such as citrus fruits) or that are rich in vitamin A (mango, papaya), and indigenous varieties of dark green leafy vegetables. Solar driers were introduced as a best practice in preservation of fruits and vegetables, to provide a year-round source of micronutrients. The SARF intervention was also integrated into MICAH's overall anaemia prevention and control strategy, which included the following activities: iron supplementation (weekly to women of childbearing age and children under 5 years old, daily to pregnant women); fortification of staple foods with iron, zinc, vitamin A, B vitamins and folate; malaria prevention and treatment; hookworm control; latrine construction; and capacity building and advocacy for improved anaemia programmes at all government levels.

Programme evaluation

Effectiveness of the MICAH programme in Malawi was evaluated through cross-sectional surveys, a baseline in 1996 and final evaluation in 2004. Two-stage cluster sampling was employed, using proportionality to population in the selection of clusters and households. Key indicators were assessed through semi-structured interviews with a standardized questionnaire and by collection of biochemical, clinical and anthropometric data (16). At the final evaluation in 2004, a sample of communities outside the programme areas (hereafter referred to as the non-MICAH group) was also included as a means to evaluate the MICAH programme effectiveness through comparison with similar communities which received the usual government interventions, but not the additional anaemia control package delivered by MICAH.

Mobile laboratories were set up in the participating communities to collect data on haemoglobin, malaria and parasite infection. Haemoglobin was measured onsite from finger-prick blood samples using a portable haemoglobinometer (HemoCue AB, Angelholm, Sweden). Malaria parasites were also examined onsite by thick blood smears using Field's A and B staining technique (17). A direct microscopy technique was used for stool examination to look for ova, cysts and parasites. All laboratory procedures were conducted by qualified technicians from selected health facilities in Malawi.

Data were entered and analysed using standard statistical packages (e.g. EpiInfo, SPSS). Significance testing for differences from baseline to follow-up, and between MICAH and non-MICAH groups in the final evaluation, was done by chi-square tests for categorical variables and *t* tests for continuous variables. A wealth index (18) was applied to confirm the similarity of the MICAH and non-MICAH communities.

The MICAH programme, including the evaluation design, received ethics clearance from the Ministry of Health in Malawi. At the community level, the surveys were conducted after verbal consent from traditional authorities in the participating clusters, and from the sampled household heads and respondents, on behalf of their children.

Results

The MICAH programme was implemented in 16 project sites, directly reaching 272,400 people in 45,400 households throughout Malawi. General characteristics of the target population are described in Table 7.1. There were improvements in women's literacy, household access to water and sanitation facilities, and child growth in both MICAH and non-MICAH areas over the 8-year period between the baseline and final surveys. However, the improvements in access to clean water and prevalence of childhood underweight were markedly greater in the MICAH programme areas.

The findings of the wealth ranking analysis are not presented here, but there was no material, nor statistically significant, difference in median household wealth score by MICAH versus non-MICAH village.

Ownership and utilization of small animals

The MICAH SARF intervention provided 40,000 small animals as initial inputs to communities. At the close of the programme, 15,000 offspring had been distributed through the revolving loan system. The resulting increase in small-animal ownership in MICAH households is reflected in the 2004 evaluation data (Table 7.2).

An important element of the SARF intervention was educating the target population to view their animals as a food source, not primarily as an income-generating activity. To this end, an extensive nutrition education effort accompanied the distribution of animals and training on their care and breeding. Table 7.3 presents evaluation data indicating that household consumption of animal products did increase over the programme lifetime and in 2004 was significantly greater in MICAH compared with non-MICAH households for chicken, goat and rabbit meat.

In the 2004 survey only, 24-hour recall data were collected to determine food consumption patterns among children aged 6–59 months using a 7-point scale. Approximately 25% of the children (n = 408) reported consuming meat the previous day. However, the questionnaire did not assess either the specific types of meat or the quantity consumed.

Prevalence of anaemia

The ultimate purpose of the SARF intervention, as one component of the broader integrated strategy of the MICAH programme, was to reduce anaemia in vulnerable groups through increased household access to a

Table 7.1. General characteristics of the study population.

Indicator	1996 (n)	2004 MICAH (n)	2004 non-MICAH (n)
Illiteracy among women ≥14 years old (%)	55 (1682)	27[a] (4322)	31 (2210)
Households with access to a clean water source (%)	55 (1269)	81[a,b] (1932)	73 (981)
Households with access to sanitary facilities (%)	49 (1269)	94[a,b] (1935)	90 (988)
Stunting in children aged 6–59 months (% with HAZ < –2)	56 (504)	40[a] (1387)	39 (651)
Underweight in children aged 6–59 months (% with WAZ < –2)	29 (504)	13[a,b] (1387)	23 (651)
Wasting in children aged 6–59 months (% with WHZ < –2)	8 (504)	2[a] (1387)	2 (651)

MICAH, MICronutrient And Health (programme); HAZ, height-for-age Z score; WAZ, weight-for-age Z score; WHZ, weight-for-height Z score.

[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).

[b]Statistically significant difference compared with 2004 non-MICAH group ($P < 0{\cdot}05$).

Table 7.2. Household ownership of animals.

Indicator	1996 (n = 1272)	2004 MICAH (n = 1930)	2004 non-MICAH (n = 988)
Households with any small animals (goat, chicken, rabbit, guinea fowl, duck, pigeon) (%)	43	65[a,b]	50
Households with goats (%)	32	27[a]	26
Households with chickens (%)	40	59[a,b]	47
Households with rabbits (%)	1	17[a,b]	3
Households with guinea fowl (%)	<1	8[a,b]	3
Households with ducks (%)	3	6[a]	6
Households with pigeons (%)	4	5[a]	4

MICAH, MICronutrient And Health (programme).
[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).
[b]Statistically significant difference compared with 2004 non-MICAH group ($P < 0{\cdot}05$).

Table 7.3. Household consumption of animal products.

	Households with various small animals reporting consumption as main use (%)		
Product	1996	2004 MICAH	2004 non-MICAH
Chicken eggs	28	52[a]	47
Chicken meat	33	58[a,b]	42
Goat meat	13	26[a,b]	17
Rabbit meat	0	65[b]	39
Guinea fowl meat	0	63	52

MICAH, MICronutrient And Health (programme).
[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).
[b]Statistically significant difference compared with 2004 non-MICAH group ($P < 0{\cdot}05$).

highly bioavailable source of iron and other key micronutrients. The changes in anaemia observed from baseline to final evaluation are presented in Table 7.4.

Significant reductions in anaemia prevalence were observed in MICAH areas for both pregnant women and children under 5 years old, whereas a similar improvement occurred only in children in the non-MICAH area. No baseline data were collected for non-pregnant women of childbearing age, but, in 2004, women in the MICAH area had a significantly lower prevalence of anaemia compared with those in the non-MICAH communities.

While iron deficiency is the major cause of anaemia worldwide, it is not the only relevant cause in Malawi. Table 7.5 presents the prevalence of malaria and hookworm, major contributors to anaemia, in MICAH and non-MICAH areas. However, it is not possible to determine the relative contribution of each causative factor to the high rates of anaemia with the level of data collected in the MICAH surveys.

The coverage of other essential anaemia control interventions, implemented in conjunction with the SARF, is described in Table 7.6.

The comprehensive anaemia control strategy implemented by MICAH Malawi prevents determination of the specific contribution of the SARF intervention to the observed reductions in anaemia. However, statistical analysis of data collected from women in 2000 (not presented here) and 2004 found a positive association between several key interventions and higher mean haemoglobin levels (19). For both pregnant and non-pregnant women these included absence of malaria infection, consumption of iron supplements and presence of a household latrine. The presence of small animals at the household was positively associated with haemoglobin for non-pregnant women.

On the other hand, further analysis of 2004 data from pre-school children found that neither consumption of meat in the past 24 h nor household ownership of livestock was protective for anaemia. Associations with being non-anaemic were consuming dairy products in the past 24 h (odds ratio (OR) = 0.40, 95%

Table 7.4. Prevalence of anaemia in vulnerable groups.

Target group	1996 (*n*)	2004 MICAH (*n*)	2004 non-MICAH (*n*)
Children under 5 years old (% with Hb < 11 g/dl)	86 (637)	60[a] (1337)	63 (729)
Pregnant women (% with Hb < 11 g/dl)	59 (392)	48[a,b] (203)	68 (85)
Women 15–49 years old (% with Hb<12 g/dl)	N/A	39[b] (1518)	53 (787)

MICAH, MICronutrient And Health (programme); Hb, haemoglobin; N/A, data not available.
[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).
[b]Statistically significant difference compared with 2004 non-MICAH group ($P < 0{\cdot}05$).

Table 7.5. Prevalence of malaria and hookworm.

Indicator	1996 (*n*)	2004 MICAH (*n*)	2004 non-MICAH (*n*)
Malaria in children under 5 years old (%)	33 (648)	13[a] (1284)	13 (694)
Malaria in pregnant women (%)	24 (392)	7[a] (199)	6 (82)
Hookworm in school-age children (%)	18 (690)	0[a] (1019)	0.3 (506)

MICAH, MICronutrient And Health (programme).
[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).

Table 7.6. Coverage of anaemia control interventions.

Indicator	1996 (*n*)	2004 MICAH (*n*)	2004 non-MICAH (*n*)
Daily iron supplementation to pregnant women (%)	49 (168)	51[a,b] (465)	46 (238)
Weekly iron supplementation to women aged 15–49 years (%)	N/A	72[b] (299)	8 (147)
Weekly iron supplementation to children under 5 years old (%)	N/A	68[b] (1061)	6 (577)
Households consuming fortified maize flour (%)	N/A	12[b]	2
Children under 5 years old sleeping under an insecticide-treated bednet (%)	N/A	87[b]	75
Pregnant women sleeping under an insecticide-treated bednet (%)	N/A	78[b]	60

MICAH, MICronutrient And Health (programme); N/A, data not available.
[a]Statistically significant difference compared with results for 1996 ($P < 0{\cdot}05$).
[b]Statistically significant difference compared with 2004 non-MICAH group ($P < 0{\cdot}05$).

confidence interval (CI) 0.19, 0.85); living within 4 km of a health facility (OR = 0.60, 95% CI 0.45, 0.78); and ownership of cultivated land (OR = 0.15, 95% CI 0.03, 0.71). De-worming, after adjustment for confounders, had no or negative associations with anaemia.[2]

However, there was an apparent impact of household small-animal ownership on child growth. Normal weight-for-age was positively associated with belonging to a household producing dairy products or eggs for home consumption (OR = 0.72, 95% CI 0.57, 0.92), iron supplementation (OR = 0.58, 95% CI 0.46, 0.75), preserving fruit or vegetables (OR = 0.63, 95% CI 0.43, 0.91) and access to a village health committee (OR = 0.72, 95% CI 0.52, 1.00[3]). Improved height-for-age was positively associated with consumption of two forms of protein in the previous 24 h (OR = 0.59, 95% CI

[2] Rose, G., Main, B. and Namarika, R. (2007) Health and nutrition practices associated with child growth and anemia in rural Malawi: findings from an integrated Micronutrient and Health Program. Unpublished paper.

[3] Note: rounding error, upper confidence limit <1.0, *P* = 0.049.

0.38, 0.91), proximity to health facility (OR = 0.75, 95% CI 0.60, 0.93) and weekly iron supplementation (OR = 0.79, 95% CI 0.64, 0.99).[4]

Discussion

Small-animal ownership and consumption

The SARF intervention of MICAH Malawi was successfully implemented on a large scale, and resulted in a significant increase in both small-animal husbandry and consumption of animal foods at the household level (Tables 7.2 and 7.3). However, the survey did not assess the number of animals owned by individual households, such that a household with one chicken was weighted the same in the analysis of animal ownership as a household with several animals of different species. This additional detail would have provided a stronger picture of the differences between MICAH and non-MICAH areas in terms of animal husbandry, as well as clarifying the potential extent of animal food consumption by the beneficiary households.

It is not surprising that the small animals promoted by the programme (particularly rabbits and guinea fowl) were found in a higher proportion of MICAH households compared with the non-MICAH group in 2004, which points to the specific contribution of the programme to increased animal husbandry at the household level. However, it is noteworthy that some non-MICAH households were also raising these animals, which previously were uncommon in the rural areas targeted by the programme. This likely reflects the strong integration of the MICAH SARF intervention within the MoA, such that it was adopted as a core MoA strategy and began to reach into non-MICAH areas through MoA staff and support. In addition, in 2001, the SARF methodology was incorporated into several other development programmes in Malawi. Through advocacy from the Malawi National Micronutrient Coordinator (a position within the MOH but supported by MICAH), MICAH's success with small animals was shared with the World Health Organization (WHO) and Malawi Red Cross Society, resulting in SARF expansion in non-MICAH areas. United States Peace Corps Volunteers also received training in SARF programming, allowing further expansion due to the wide coverage of the Peace Corps' operational areas in Malawi. This replication of MICAH's SARF outside the programme areas likely led to dilution of the impact of MICAH on small-animal ownership in the evaluation data, although a significant difference was still observed between programme and non-MICAH households. However the adoption of this intervention by various development initiatives is a strong indication of the high degree of acceptability of the SARF model, as well as its perceived value and effectiveness as a means to sustainably improve the dietary quality of rural households in Malawi.

During the intervention period, a major drought in Malawi took place in the 2001/02 maize-growing season. In order to cope with the severe food shortage, households were forced to sell valuable resources in order to find food. This included the small animals distributed as part of the MICAH programme, which were either sold for money to buy maize or were consumed. In normal circumstances, at least a breeding pair would be kept, but in such a time of severe food shortage, hunger and malnutrition, all resources available were used in order to survive. Although the MICAH programme did not collect nutrition data during the drought period, it is assumed that levels of malnutrition of all types, including anaemia, either did not improve or deteriorated during this crisis and that recovery and nutritional repletion afterwards would require a significant period of time, as well as inputs from external programmes such as MICAH. In response, the MICAH programme launched an intensive animal restocking programme in 2002–2003, and by the final programme survey in 2004, 72% of households in the programme area had small animals. This coverage might have been even higher without the major losses of the drought period.

[4] Note: rounding error, upper confidence unit <1.0, $P = 0.049$.

Formal qualitative analysis of the critical factors for success of the SARF intervention was not conducted. However, ongoing analysis of monitoring data and reflective discussions between staff, implementing partners and beneficiaries of the programme resulted in common agreements. The following key components of the SARF intervention are believed to have led to its success in increasing household access to and consumption of animal-source foods: (i) community management of the entire process and ongoing responsibility for the revolving fund scheme; (ii) promotion of animals over which women have primary control; (iii) strong integration and partnership with relevant government ministries; (iv) intensive nutrition education to promote consumption of the small animals; and (v) locally developed strategies to increase acceptability and adapt the care and housing of animals to the environment and available resources.

Anaemia prevalence

Anaemia prevalence decreased significantly in pregnant women in MICAH areas compared with non-MICAH, and was significantly lower in non-pregnant women in MICAH areas in 2004. In pre-school children, a similar dramatic decrease from baseline to 2004 was observed in both MICAH and non-MICAH areas (Table 7.4). It was beyond the scope of the programme evaluation to assess the prevalence of iron deficiency or the relative contribution of various causes of anaemia in the study population. Therefore, the following discussion of probable explanations for the difference in results between women and pre-school children when comparing MICAH and non-MICAH communities is based on reasonable interpretation of available data.

The positive results for anaemia in women in MICAH areas are likely a reflection of the impact of the integrated, comprehensive anaemia control strategy implemented by the programme. The small animals were a key component of this, as a means to improve dietary intake of a highly bioavailable source of iron and other key micronutrients. However, it is not possible to determine the specific contribution of the SARF intervention to the improvements in anaemia, as individual consumption data are not available, nor can the contribution of animal-source foods be separated from the role of other essential anaemia control interventions.

The MICAH programme established a community-based delivery system for weekly iron supplementation to women of childbearing age and pre-school children, resulting in high (over 65%) coverage of these target groups (Table 7.6). In contrast, less than 10% of non-pregnant women and pre-school children in non-MICAH areas reported taking regular iron supplements. In addition, MICAH initiated fortification of maize with multiple micronutrients (including iron) at the village level. This intervention was expanded to include 19 mills in six partner project sites by the end of the programme. Coverage of insecticide-treated bednets for malaria prevention was higher in MICAH areas, but malaria prevalence declined significantly from baseline to similar levels in both MICAH and non-MICAH areas by 2004 (Table 7.5). This can be attributed to national-level efforts to address the high prevalence of malaria, which MICAH also supported in its operational areas (including distribution of nearly 97,000 insecticide-treated bednets). Furthermore, hookworm prevalence in school-age children was virtually eliminated in both MICAH and non-MICAH areas by 2004 (Table 7.5), again due to efforts broader than the MICAH interventions alone.

The anaemia control interventions unique to the MICAH areas were the small-scale fortification, routine community-based iron supplementation and promotion of small-animal husbandry for household consumption of bioavailable iron. Fortification was not implemented on a wide enough scale to be the main contributor to improved anaemia levels in women, as only 12% of households were consuming the fortified maize at the final evaluation (Table 7.6). Both iron supplementation and small-animal husbandry reached high (65% or greater) coverage levels, but it is not possible to determine the exact contribution of each to the successful reductions in anaemia prevalence.

It may be that the observed reduction in anaemia among pre-school children in both MICAH and non-MICAH areas was primarily a response to improved malaria control interventions. Mid-term data collected in 2000 (not presented here) indicated that anaemia prevalence in pre-school children had been reduced but remained critically high despite MICAH's emphasis on iron interventions for this age group. This led programme staff to conclude that malaria prevention played a greater role in anaemia of young children than previously anticipated. Malaria prevention efforts were therefore greatly expanded in the remaining years of the programme, in conjunction with the national malaria campaign, and, in 2004, anaemia levels in pre-school children had further declined in both MICAH and non-MICAH areas, both of which benefited from high coverage of malaria control interventions.

It is noteworthy that, despite iron deficiency being a major cause of anaemia worldwide, neither the higher coverage of iron supplementation nor the increased availability of small animals at the household level appears to have resulted in greater improvements in anaemia among children in MICAH areas. Furthermore, analysis of the available food consumption data failed to find a protective effect on anaemia of meat consumption in the previous 24 h. However, no data were collected on portion size or frequency of meat intake. It may be that the quantities consumed were insufficient to impact anaemia prevalence. More detailed analysis of intake patterns would be helpful to strengthen the benefit of the SARF intervention for the youngest children, a group in which anaemia prevalence remains unacceptably high. At the same time, it is important to recognize the benefits of consumption of animal foods beyond the potential for a specific impact on anaemia. It has been well documented that the high-quality protein and multiple bioavailable micronutrients contained in animal-source foods have an important impact on optimal child growth and cognitive development (20). Therefore, the lack of an apparent impact on anaemia in young children does not imply that the SARF intervention was not effective for this age group. Indeed, regression analysis of the MICAH 2004 24-hour recall data indicated a positive association between household small-animal ownership and production of dairy products and eggs and weight-for-age in young children.

Limitations of the evaluation

The MICAH Malawi programme design followed the WHO/United Nations Children's Fund recommendation that an integrated approach to the management of iron deficiency anaemia is needed for maximum effectiveness (14). The SARF intervention was therefore one component of a multipronged anaemia control strategy, which also included iron supplementation to women and children; fortification of staple foods with multiple micronutrients; malaria control; and prevention and treatment of parasitic infections. This integrated approach is a strong point of the programme in terms of its ability to address the multidimensional aetiology of anaemia, but prevents the determination of the specific contribution of the food-based intervention to the observed reductions in anaemia.

In addition, the effectiveness of the SARF intervention in terms of improvements in intake of dietary iron cannot be established, due to the lack of individual-level consumption data. Dietary intake data are difficult to collect with accuracy, particularly in large household surveys. As the purpose of the MICAH surveys was to measure the overall effectiveness of the programme, not to conduct detailed research on specific interventions, it was beyond the scope of the evaluation to assess individual food intake patterns. Thus, while reported consumption of animals at the household level increased in MICAH programme areas, intra-household allocation is unknown. Therefore, no conclusions can be drawn as to the extent key target groups benefited from the increased availability of animal-source foods. It is known that, in some contexts, intra-household distribution of animal-source foods does not favour the most nutritionally vulnerable family members (13). MICAH did address such issues in the decision to promote rabbits rather than goats, once it was identified that goats were not likely to be consumed by the target beneficiaries. However, further study on individual consumption patterns and related underlying issues would strengthen the case for the SARF's potential as an anaemia control intervention, as well as providing valuable information to enhance the intervention design for future replication in similar settings.

Conclusions

The SARF intervention implemented by MICAH Malawi resulted in increased access to animal-source foods for MICAH households. In addition, household consumption of animal-source foods in all categories was higher among MICAH households compared with those in the non-MICAH areas in the 2004 evaluation. This experience provides a model for a food-based approach with strong potential for replication in other similar contexts. Critical factors leading to the success of the intervention include community management and ownership; integration with government ministries; promotion of animals over which women have primary control; and development of locally adapted methods to promote acceptability and to care for the animals.

The positive evaluation findings for reduced anaemia prevalence among women in MICAH areas are attributed to the combined effect of multiple anaemia control interventions, particularly those aimed at increasing iron intake. While it cannot be proven from the available data, it is likely that the increased access to animal-source foods contributed to the results observed. MICAH Malawi's experience demonstrates that food-based interventions can be successfully implemented at the community level, and when integrated with other essential nutrition and health interventions, contribute to improvements in nutritional status, including reductions in iron deficiency and anaemia.

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8 Aquaculture's Role in Improving Food and Nutrition Security

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Abstract
This chapter provides an overview of aquaculture and discusses the significant nutritional value of its products and its role in rural development. Nearly half of the total global food fish supply comes from aquaculture, making it not only an important source of nutrition, but also a key sector that can reduce poverty through improving livelihoods and well-being at global and community levels. Fish is the primary source of animal protein in developing countries, contributing about 20% of total animal protein supply. Aquaculture has the potential to improve the diets of even the poor segments of the world's population through increased consumption of protein, fatty acids (*n*-3), vitamins and minerals (calcium, phosphorus, iron, selenium and iodine). The main aquaculture-producing countries are in Asia. Employment in aquaculture is highest in China, where 13 million people worked in this sector in 2006. Aquaculture is growing faster than all other animal food-producing sectors with an average rate of 7.0% per annum since 1970. As growth in this sector is expected to continue, aquaculture infrastructure needs to be improved to ensure the success of this thriving industry. There is a need to strengthen aquaculture planning and policies that support the small-scale fisheries sector in developing countries as it is often overlooked by governments when designing policies and strategies for rural development. Small-scale aquaculture has to be developed as a responsible and sustainable entrepreneurial activity that is financially viable so as to assure its efficacy in poverty reduction and nutrition improvement.

Key words: aquaculture, fish, nutrition, food and nutrition security, rural livelihoods

Introduction

This chapter discusses the contribution that aquaculture makes to the diet at global and community levels, and its role in poverty reduction and food and nutrition insecurity, to provide guidance to planners on how this sub-sector can play a greater role in fighting hunger and malnutrition.

Hunger and malnutrition remain among the most devastating problems facing the world's poor. Tragically, a considerable portion of the global population is currently suffering from one or more forms of nutrient deficiency. This remains a continuing travesty of the recognized fundamental human right to adequate food, and freedom from hunger and malnutrition, particularly in a world that

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has both the resources and the knowledge to end this catastrophe (1).

The challenge is to rapidly accelerate the pace by which hunger and malnutrition are eliminated. Aquaculture has an important role to play in this effort by providing fish and other marine and freshwater products, which commonly are rich sources of protein, essential fatty acids, vitamins and minerals, and by providing incomes and employment opportunities. This can be especially important for poor artisanal fisherfolk whose livelihoods depend on small-scale fisheries activities. With support for aquaculture the worldwide availability of good-quality marine and freshwater animal products can be increased, allowing per capita supplies to keep pace with the increase in demand. To ensure that such benefits reach those who need it most, the involvement of the artisanal fisherfolk in this effort must not be neglected.

Fish can make a unique contribution to efforts to improve and diversify dietary intakes and promote nutritional well-being among most population groups. Fish have a highly desirable nutrient profile providing an excellent source of high-quality animal protein that is easily digestible and of high biological value. Fatty fish, in particular, are an extremely rich source of essential fatty acids, including *n*-3 polyunsaturated fatty acids (PUFAs) that are crucial for normal growth and mental development, especially during pregnancy and early childhood. Fish are also rich in vitamins and minerals (especially calcium, phosphorus, iron, selenium and iodine in marine products). Fish, therefore, can provide an important source of nutrients particularly for those whose diets are monotonous and lacking in other animal-source foods. Increasing the availability of fish in the diet increases palatability and leads to increased consumption of a range of foods, thereby improving overall food and nutrient intakes.

An Overview of Global Aquaculture

The following information and data are from *The State of World Fisheries and Aquaculture 2008* (2), unless otherwise stated. Aquaculture makes a significant contribution to food and nutrition security. At the global level, it helps fill the gap between the rising global demands for fishery products and the limited increases in capture fisheries production. Aquaculture is the fastest growing food-producing sector in the world. It is estimated that, by 2012, over 50% of global food fish consumption will originate from aquaculture. Over 92% of this production comes from the developing world.

Aquaculture's contribution by weight to global fish supply increased from 3.9% in 1970 to 36.0% in 2006. It now dominates all other animal food-producing sectors in terms of growth, growing at an average rate of 7.0% per annum since 1970 compared with 1.4% and 2.8% per annum for capture fisheries and terrestrial farmed meat production, respectively. In 2006, 51.7 million metric tonnes (mmt) of aquatic products, not including aquatic plants valued at US$78.8 billion, was produced globally, over half in the form of finfish. When aquatic plants are considered in the total production of aquatic products, world aquaculture production is 66.7 mmt, worth US$85.9 billion. In contrast to terrestrial farming systems, where the bulk of global production is based on a limited number of animal and plant species, the aquaculture sector comprises over 200 different species. This large number of species raised reflects the diversity of the sector, particularly the wide variety of candidate species farmed and different production systems used.

Currently, the majority of aquaculture-producing countries are in Asia: eight out of the top ten aquaculture producers in terms of quantity in 2006 were Asian countries. In 2006, the top ten producing countries in descending order were China, India, Vietnam, Thailand, Indonesia, Bangladesh, Chile, Japan, Norway and Philippines. The main species groups reared in freshwater are finfish while high-value crustaceans and finfish predominate in brackish water, as molluscs and aquatic plants do in marine waters. Of these three environments, freshwater aquaculture could be considered as the most important in terms of contributing to achieving food and nutrition security. Marine aquaculture, particularly of seaweeds and molluscs, also contributes to food and nutrition security and poverty alleviation, as most of its products are produced within small to medium-scale operations. While brackish-water shrimp culture is generally aimed at producing a high-value export commodity, coastal shrimp culture also plays an important role in rural livelihoods and food and nutrition security.

Trends in Consumption and Nutritional Importance of Aquatic Products

Globally, two-thirds of the total food fish supply is obtained from marine and inland capture fisheries; the remaining one-third being derived from aquaculture. The contribution of capture fisheries to per capita food supply stabilized at 10 to 11 kg during the period 1970–2000. Recent increases in per capita availability were obtained from aquaculture production. Globally, aquaculture's contribution to per capita food availability grew from 0.7 kg in 1970 to 7.8 kg in 2006 – at an average rate of 7.0% per annum. In China, aquaculture dominates fish food supply. Fish farming practices there have deep traditional roots and aquaculture accounted for 90% of the fish food supply in 2006, compared with a worldwide average of 24%.

More 'food fish' is consumed globally on a per capita basis than any other type of meat or animal protein (16.7 kg per capita in 2006). In terms of animal protein, food fish represented 15.3% of total supply in 2005 (when total global animal protein supply was reported as 27.1 kg per capita), followed by pork (14.7%), beef and veal (13.6%), and poultry meat (12.5%). It is interesting to note here that farmed aquatic meat production in China currently ranks second to pig meat, per capita availability of food fish increasing from 4.5 kg in 1984 to 26.1 kg in 2006 (2,3).

The main factor behind the high demand for staple food fish (in particular, inexpensive farmed freshwater fish species feeding low on the aquatic food chain) within most developing countries is their greater affordability to the poorer segments of the community (4). At present, food fish represents the primary source of animal protein (contributing about 20% of the total animal protein supply) in developing countries.

Although levels as high as 753 kJ/day (180 kcal/day) are reported from countries such as Japan and Iceland, the average per capita energy supply from fish is only 84–126 kJ/day (20–30 kcal/day). In the diets of many countries, fish contributes more than or close to 50% of total animal protein (e.g. The Gambia, Ghana, Equatorial Guinea, Indonesia, Sierra Leone, Togo, Guinea, Bangladesh, Republic of Congo, Cambodia, Sri Lanka, Philippines). The International Conference on Sustainable Contribution of Fisheries to Food Security, held in Kyoto in 1995, recognized that aquatic products contribute meaningfully to the maintenance of good nutrition (5).

As mentioned, fish are important sources for many nutrients, including protein of very high quality, retinol (vitamin A), vitamin D, vitamin E, iodine and selenium. Evidence is increasing that the consumption of fish enhances brain development and learning in children, protects vision and eye health, and offers protection from cardiovascular disease and some cancers. The fats and fatty acids in fish, particularly the long-chain *n*-3 fatty acids (*n*-3 PUFAs), are highly beneficial and difficult to obtain from other food sources. Of particular importance are eicosapentaenoic acid (20:5*n*-3, EPA) and docosahexaenoic acid (22:6*n*-3, DHA). A review of the benefits of fish consumption for mothers and infants was published by the Food and Agriculture Organization of the United Nations (FAO) in 2000 (6). Fish intake during pregnancy is positively associated with enhanced neurodevelopment during infancy including higher behavioural attention scores, better visual recognition memory, and improved language comprehension (7).

The fat content of fish varies from 1.0 g/100 g in lean white fish to 30 g/100 g in fatty fish. The *n*-3 PUFAs are lowest in white fish (0.5 g/100 g in cod), medium in crustaceans (0.7 g/100 g in mussels) and roe (1.0 g/100 g) and highest in fatty fish (>5 g/100 g in mackerel). Many factors can influence the nutrient content of fish, including stage of maturity and feed formulation.

The high-quality protein and essential fatty acids, vitamins and minerals found in fish and the effects of adding fish to traditional bland staple diets are important to stimulate appetite and increase food consumption, thereby maximizing macronutrient utilization and boosting the host immune system. This is particularly advantageous in protecting vulnerable populations including young children and the aged, and for immunocompromised persons such as those living with HIV/AIDS.

The Role of Aquaculture in Rural Development

Although aquaculture complements many other food-production systems, such as integrated agriculture–aquaculture, rice–fish farming and livestock–fish farming, aquaculture's potential for contributing to global food production is still not fully realized. The decision to establish the Sub-Committee on Aquaculture under the Committee on Fisheries (COFI) during 2001 reflects the importance that FAO Members attach to aquaculture as a tool for national development. Many recent international gatherings, including the Conference on Aquaculture in the Third Millennium (8), and the Declaration of the *World Food Summit: five years later* (9), recognize the role that aquaculture can play in national economic development, global food supply and achievement of food and nutrition security, and declared that the sector has the potential to continue to contribute even more to people's livelihoods.

The objective of rural development is to facilitate a sustainable rural economy and to secure improvements in the welfare of rural populations. The opportunities for the integration of aquaculture into rural development are characterized by diverse aquatic resources and a wide range of stakeholders with diverse livelihoods. Objectives may further include food production, income generation, and wild stock enhancement for recreation (ornamental fish or sport). The scale may be intensive commercial or subsistence management within developed and less-developed economies. At the local/national level, the integration of aquaculture into rural development may take place in growing (e.g. developing economies) or declining (e.g. remote rural regions in developed economies) populations. At all levels, this is occurring within the context of globalization and increased mobility of goods, services, capital and ideas, combined with increased transfers of aquatic species and disease transmission. Investment is generally attracted by stable and predictable political and institutional environments, transparent laws, fair competition and reliable legal systems. Where rural development fails to create the policy environment and skills to exploit global opportunities, aquaculture – like other sub-sectors – may decline.

Aquaculture provides worldwide employment to millions of people. Total employment in the aquaculture sector is highest in China where, in 2006, almost 13.06 million people worked in this sector (10). In Vietnam, the employment is estimated at over 700,000 people (11), although these figures do not yet reflect the large number of people employed in affiliated industries (fish feeds, equipment, fish processing and marketing). In the USA, where aquaculture is identified as a major growth industry for the 21st century, around 200,000 people are employed within the sector (12). In contrast, between 2002 and 2003 in the European Union (EU), approximately 65,000 people were employed in aquaculture, i.e. 15.5% of the total employment in the fishery sector (13).

Studies in various developing countries (e.g. China and Vietnam) have shown that 80–100% of the aquaculture products from rural farm households are marketed. This suggests that aquaculture can be considered as a cash-generating activity and thus an important indirect source of food and nutrition security. In many countries the average market prices of fish are lower than those of other animal products such as chicken, pork and red meat. Especially in Asia the low prices of aquaculture commodities such as carp and tilapia make fish highly accessible to even the poorest segments of the population. Poor people in land-locked countries, such as Nepal and Lao PDR, largely depend on freshwater aquaculture for their fish. In Savannakhet Province, Lao PDR, fish is the main source of animal protein food in the diet with average daily per capita consumption estimated at 55 g and reported to be present in 85% of all meals, confirming the importance of fish for the poorest communities (14).

Economic feasibility studies have shown that aquaculture is economically feasible under many different circumstances. Many types of low-cost, low-risk, simple technologies have emerged in recent years. Comparative studies between rice, rice–fish and fish–farming systems in sub-Saharan Africa demonstrated that farmers investing in aquaculture increased their household incomes considerably with only minor investments. In Europe, the USA, China and other Asian countries the increases in production and the number of people active in aquaculture over the last decade have shown that production systems ranging from extensive to highly intensive can be economically feasible.

The average annual per capita income of people employed full-time in the fisheries sector (including aquaculture) in China was about US$540 in 1999, which was more than double that of rural terrestrial farmers. In South-east Asian countries, such as Cambodia, Thailand and Indonesia, a similar situation can be found; farmers engaged in aquaculture generally generate higher household incomes than those who are not. In Vietnam, 50% of the farmers involved in aquaculture consider it as their main source of income and derive on average 75% of their household income from it. Specifically, catfish and shrimp culture have, in recent years, provided an average annual household income of over US$1000, which is significantly more than that generated by comparable agriculture practices (15).

Initial data from a study in the Mekong Delta in Vietnam suggest that aquaculture development can contribute to a decrease in migration by young women from rural areas to urban centres by offering local opportunities to earn a living. The decreased need for urban migration could prevent women from being compelled into prostitution, thus fewer women would be at risk of becoming infected with HIV/AIDS.

Unlike many other sectors of the economy worldwide, aquaculture has been resilient to the global economic crisis. Although precise figures are lacking, aquaculture's contribution to poverty alleviation, food security, employment, trade and gender opportunities has increased over the past decade. This is reflected in the growth in volume and value of production and through the expanding presence of aquaculture products in world markets, in particular as raw material to the processing sector and through the availability of aquaculture products. Issues such as ownership by the beneficiaries, people-centred approaches, growing species which feed low on the food chain, targeting all household members, use of farmer field school type methodologies, as well as technologies that are developed according to the local context with network approaches, have all contributed to this.

Utilizing Aquaculture to Improve Food and Nutrition Security

The role that fish can play in improving diets is undisputed, and this can be particularly important in regard to children's diets and child nutrition. A household food and nutrition security survey conducted in Luapula, Zambia, in 1997–1998 illustrates this point (16). In the Luapula Valley, fish is often the most important source of high-quality protein foods (other sources include milk, eggs and meat). The data show that children whose main staple food is cassava and whose diets regularly include fish, and other high-quality protein-containing foods, had a significantly lower prevalence of stunting than those whose diets did not. When programmes that improve access to fish are combined with effective nutrition education to promote the inclusion of fish in children's diets, child nutrition can be markedly improved in a very cost-effective manner.

Aquaculture can contribute to improved food and nutrition security through various channels: local food supplies can be improved through the increased availability of low-cost fish; employment opportunities and incomes can be raised; and consumption of fish can be increased directly. While increasing the quantity and variety of fish and other foods consumed by the poor will reduce undernutrition, such dietary improvements are not automatic benefits of aquaculture development. Food consumption and good nutrition are not determined solely by how much food is produced or available. Households must have physical and economic access to an adequate amount and variety of food, and household heads and caregivers must have the time, knowledge and motivation to make the best use of the household's resources to meet the food and other basic needs of all members. The key to securing the maximum nutritional benefits from aquaculture development is to ensure that the poor and undernourished gain greater access to the increased supplies of fish and that they can enhance their aquaculture-derived income.

Aquaculture comprises diverse production systems of farming plants and animals in inland and coastal areas, many of which have relevance for the poor. In the context of the rural poor, aquaculture often complements catches from traditional fisheries. The latter continue to play an important role and, in many areas, remain adequate to satisfy subsistence needs and provide a valuable source of income for farmer/fishers. In many cases, the captured species form the basis for household food and nutrition security, enabling the use of livestock or cultured fish as sources of income. Aquaculture becomes an attractive and important component of rural livelihoods in situations where increasing population pressures, environmental degradation or loss of access limit catches from wild fisheries (17).

Aquaculture in small-scale integrated farming systems can provide high-quality animal protein and other nutrients that can be especially valuable for nutritionally vulnerable groups. Aquaculture commonly provides protein at prices generally affordable to the poorer segments of the community, and it creates 'own enterprise' employment, including jobs for women and children, while providing income through sale of what can be relatively high-value products (18). Employment opportunities are also possible on larger farms, in seed supply networks, market chains and manufacture/repair supporting services. Indirect benefits include increased availability of fish in local rural and urban markets and possible increases in household income through sales of farm products, which will become available through increased local consumption of fish. Aquaculture can also benefit the landless from utilization of common resources, such as finfish cage culture, culture of molluscs and seaweeds, and fisheries enhancement in communal waterbodies (1).

An important, though often overlooked, benefit which is particularly relevant for integrated agriculture–aquaculture systems is their contribution to increased farm efficiency and sustainability. Agricultural by-products, such as manure from livestock and crop residues, can serve as fertilizer and feed inputs for small-scale and commercial aquaculture. Fish farming in rice fields not only contributes to integrated pest management (IPM), but also management of vectors of human medical importance (17). Furthermore, ponds become important as on-farm water reservoirs for irrigation and livestock in areas where there are seasonal water shortages (19). Aquaculture activities may provide supplementary income during lean seasons when food and nutrition security is low, thus smoothing the seasonal flows of income related to annual cropping. Fish can also be a form of investment of savings that can be used as collateral for securing loans or sold in times of hardship to buffer the effects of lean seasons or loss of income.

Aquaculture producers have, through various technological interventions (e.g. improved feed, better performing broodstock, good health management, genetic improvements, etc.), achieved important productivity gains and cost reductions. Over time, this has led to a decrease in prices, despite short-term intervals of significant price swings. The prices of fishery products have not increased as a result of the growing international demand. Instead, they show a decreasing trend (20). Prices of some aquaculture products in the EU and the USA have decreased considerably over the past years. While salmon and shrimp were considered high-value commodities for affluent society in the 1980s, they are now much more common fare. The increase in salmon and shrimp consumption can be considered a result of their lower prices, as well as of wider availability, diversification in products, and use of salmon and shrimp in convenience and ready-to-eat meals. The price of internationally or locally traded aquatic products dictates its contribution to food and nutrition security as it affects production. The current trend indicates that these price fluctuations are in favour of increasing local production, thus assisting rural livelihoods and food and nutrition security.

Many aquaculture activities, including marketing, are undertaken by women. This is particularly the case for small-scale operations. Aquaculture may therefore provide supplementary income to women who are the key managers of household resources that may be preferentially directed to consumption. Increasing women's income strengthens their position in society. Their empowerment encourages them to become further involved in decisions in the development process.

Research into the use of genetically modified aquaculture species is increasing, although commercial availability of genetically modified fish is still scarce and the contribution of genetically modified organisms (GMOs) to food fish production almost nil. FAO does not discourage the use of GMOs as food, provided that they pose no risk to the environment and are safe to eat. The emphasis on biotechnology and its contribution to food and nutrition security, poverty reduction and income generation is increasing. Preparedness to address this challenge in a responsible manner is required. The major biotechnology sectors involved in aquaculture are similar to those for agricultural sectors. Development of the knowledge required to optimize safe biotechnological innovation in aquaculture is of particular significance, and presents a unique set of challenges, mainly due to the diversity of species cultured and production systems used. Biotechnological interventions – such as achieving higher feed conversion rates, improving aquatic animal health through accurate molecular diagnostic tools and vaccines, and adapting species to difficult environmental circumstances (e.g. tilapia for cold or saline environments) – assist in increasing aquaculture's contribution to global food and nutrition security. Although such biotechnologies are yet to be fully utilized in aquaculture, mainly due to the small-scale nature of the global aquaculture sector, particularly in the systems producing high-value species such as salmon and shrimp, many biotechnologies are duly utilized. Many genetic improvements in aquatic species have been achieved and these are through the employment of traditional selective-breeding programmes. It may be noted that most cultured fish species can be considered much closer to their wild genetic origins than currently farmed livestock (21).

Managing Environmental Impacts of Aquaculture

Malnutrition is more prevalent in resource-poor areas, and in those with poor infrastructure and services. A challenge from an environmental point of view is to identify technologies suitable for such circumstances. The selection of those technologies must be based on a thorough understanding of why environmentally undesirable land uses are practised. Policies must induce farmers, especially poor farmers on marginal lands, to adopt improved farming methods which are ecologically sound, socially acceptable and economically beneficial.

Negative environmental impacts (such as the destruction of mangrove areas, effluent discharge, abandonment of farms) which traditionally were inextricably linked to aquaculture, and shrimp culture in particular, are no longer common. The introduction by many countries of Good Management Practices and sectoral codes of practice, often based on the FAO Code of Conduct for Responsible Fisheries (CCRF), is a clear sign of changes within the sub-sector (22). Aquaculture, as other natural resource users, is sometimes criticized for paying little attention to the impact of its activities on biodiversity and the natural resource base. Cases of escaped salmon causing sea lice to be transferred to wild stocks, and the capture of shrimp broodstock in the wild, are just some examples from the recent past. FAO has been actively working in these fields and improvements (in planning and regulation) are being made to avoid negative impacts on the environment and biodiversity (23). Such efforts towards minimizing the environmental impacts of aquaculture and ensuring its sustainable development within the framework of CCRF will enhance the sub-sector's contribution to food and nutrition security, poverty alleviation and rural development.

Community-centred Approaches to Strengthen Household Food and Nutrition Security

Experiences of the last decades have shown that initiatives to alleviate poverty and achieve food and nutrition security can seldom be sustained if planned without the involvement of the community. Community-centred approaches encourage self-reliance and self-help and, by doing so, raise self-esteem. Such approaches aim at empowering communities to make optimal use of locally available resources, and to effectively demand additional resources and better services to improve their livelihoods. Building on traditional social networks of support and mutual assistance, community-centred approaches mobilize community members in activities to meet their perceived needs and development priorities, thus making a significant contribution to sustainable development at local and national levels. Community-centred approaches help ensure that a range of stakeholders, including women and marginal groups, become part of the development process, real issues and needs are addressed, implementation and monitoring are improved, and sustainability enhanced by giving users the leading role in developing and adapting activities.

Community-centred approaches rely on participatory planning and appraisal techniques. They have been used widely to increase the adoption and dissemination of aquaculture and the guiding principles have been reviewed by FAO. Household food and nutrition security and nutrition have shown to be good entry points for coordinating and planning local development projects that feature aquaculture activities and participatory approaches have been adapted to the local setting. One such example is the experiential learning in Farmer Field Schools (FFSs) in rice farming, which opened opportunities for the integration of aquaculture to better crop management, particularly in relation to IPM. Farmers spend weekly five to six hours together, of which two hours are spent in the field observing the ecosystem. The process is facilitated by trainers, who themselves have spent a whole season in the field learning about the ecosystem and designing curricula for the FFS. Rice farmers experiment with physical modifications of the fields to accommodate fish, such as digging trenches in different shapes and sizes or small ponds at different locations. They are innovative in adapting their production systems to local market conditions – raising larger fish for sale or household consumption or smaller fish if they can sell them to grow-out operations nearby. Better utilization of resources, increased income and a healthy crop of rice and fish reinforce farmers' acceptance of IPM and rejection of pesticides. Experience shows that many groups of farmers decide to continue the process of information exchange in self-organized 'farmer clubs' long after project and programme promoted FFSs have ended.

A Framework for Increasing Contribution of Aquaculture for Food and Nutrition Security and Poverty Alleviation

The Bangkok Declaration and Strategy (8) emphasizes the need for the aquaculture sector to continue development towards its full potential, making a net contribution to global food availability, domestic food and nutrition security, economic growth, trade and improved living standards.

Integration of aquaculture into national development

In order to achieve the full potential of aquaculture, it should be pursued as an integral component of community development, contributing to sustainable livelihoods, promoting human development and enhancing social well-being of poorer sectors. Aquaculture policies and regulations should promote practical and economically viable farming and management practices that are environmentally sustainable and socially acceptable. If aquaculture is to attain its full potential, the sector may require new approaches in the coming decades. These approaches will undoubtedly vary in different regions and countries, and the challenge is to develop approaches that are realistic and achievable within each social, economic, environmental and political circumstance. In an era of globalization and trade liberalization, such approaches should not only focus on increasing production, they should also focus on producing a product that is affordable, acceptable and accessible to all sectors of society.

Stakeholder participation in decision making in aquaculture

Aquaculture development initiatives until the early 1990s aimed largely at the increase of production to satisfy the rising demand of the growing world population and compensate for local declines in capture fisheries production. Before the 1990s, aquaculture development approaches focused mainly on the transfer of technologies, research and extension, ensuring that there would be sufficient fish seeds/fingerlings through centralized, state-owned hatcheries. In the 1990s, this approach, like that in other rural sectors, changed with a growing awareness on the part of governments that market liberalization was important for the development of the sector. Since the second half of the last decade of the 20th century, it was acknowledged that aquatic resources are extremely important for the livelihoods of millions of poor people in developing countries and that the participation of the poor in decision-making processes affecting their livelihoods is essential.

Strategic planning, appropriate policies and good legal and institutional frameworks

The aquaculture development paradigm of the 1990s resulted in a number of successes and failures. The main cause of failures, in particular in Africa, was the focus on subsistence aquaculture accompanying production increases, without taking into consideration the other preconditions for development of the sector such as feed and credit availability and need to market the produce. Other reasons for failure were: mismanagement, unclear land and water rights, emphasis on technologies, disregard for the environment, and the use of inefficient and centralized government hatchery systems.

Aquaculture successes, however, are also found in many regions. In Europe and in North and South America, the boom in the culture of salmonids in the 1990s has created employment in areas with few alternative possibilities with the result of increasing standards of living of many coastal areas. Together with the boom in aquaculture, the affiliated industries (feed, drugs, equipment, processing and marketing) flourished. In Asia and Latin America, development of shrimp culture has provided employment and income to many coastal populations.

The weakness of government and civil society institutions in many developing countries reduces the capacity to support aquaculture development. Influencing institutions to provide increased and better-quality services in support of aquaculture development needs a long-term effort, internal commitment from the management, well-directed capacity-building programmes and a network approach with partner institutions, in order to become successful.

Aquaculture development can further be enhanced by applying participatory and transparent policy development processes. Aquaculture is often neglected by governments when designing policies and strategies for rural development. For instance, few Poverty Reduction Strategy Papers of The World Bank and Country Strategy Papers of the EU consider aquaculture as a means to rural development or achievement of food and nutrition security and alleviation of poverty.

Aquaculture interventions focused on poverty alleviation and food and nutrition security that have proven to be successful are characterized by, among other factors: ownership by the beneficiaries, use of participatory approaches, designed as small scale in terms of investment, demand-led with farmers first, people-centred approaches, raising species which feed low on the food chain (e.g. carp, catfish and tilapia), targeting all household members, and use of FSS type methodologies as well as technologies that are developed according to the local context with network approaches. On the other hand, aquaculture interventions that failed to contribute to the alleviation of rural poverty and achievement of food and nutrition security generally made use of inappropriate subsidies and training allowances, established large centralized hatcheries, used technology-led interventions, were short term, with management, extension and planning approaches that were top-down (24).

Small-scale aquaculture contributes to the alleviation of poverty and achievement of food and nutrition security. In addition, commercial, larger-scale aquaculture, as is practised in many developed and developing countries with species such as shrimp, salmon, tilapia, catfish, grouper and carp, can enhance the production for domestic and export markets and the generation of employment (in production, processing and marketing). Indirectly, tax revenues from commercial aquaculture enterprises and foreign exchange earnings (when exporting) allow governments to invest in sectors that add to the achievement of food and nutrition security.

New markets are emerging worldwide. As high-value species are increasingly exported (intra- or inter-regionally) and low-value products are imported (a particular trend in Asia where, for example, shrimp are exported and canned pilchards imported), there is a clear need by aquaculture farmers to improve the quality and safety of their products in order to gain a wider access to export markets. However, with the more stringent requirements of export markets, small-scale farmers are facing difficulties in producing for export. As they strive to meet export consumer requirements, they may become uncompetitive. The lack of competitiveness could drive them out of the sector. Empowering small farmers to become competitive in global trade is becoming urgent and, perhaps, a significant corporate social responsibility (25).

Education and capacity building

Raising awareness at all levels of society of the potential of aquaculture is one of the main components of any framework for aquaculture development. Education, information sharing and capacity building are other cross-cutting themes that are relevant to most aspects of aquaculture development and management, particularly for harnessing the potential for food and nutrition security and poverty alleviation. Better integration of aquaculture in rural development is important in view of the often limited government resources for education and extension. In this respect, a framework for aquaculture development should address, at farm level, issues such as resource use efficiency and the economic or livelihood incentives that influence farm household members when they decide on cropping patterns and the use of water, feeds, fertilizer, chemical treatments and other inputs. Emphasis should also be given to farmers' knowledge of the available production and pest management options, as well as on their ability to apply these.

Farmers' management strategies are not based solely on economic criteria but also include minimization of risk, cropping flexibility, traditional and cultural preferences for species and techniques, available labour and labour requirements. Extension and capacity building are crucial for informed decision making (26). Other important elements of any framework that increase the contribution of aquaculture to the achievement of food and nutrition security are related to legal, financial, investment, marketing and trade aspects. The existence of good aquaculture legislation can provide an important contribution to sustainable aquaculture development. It can minimize (or avoid) environmental impacts and can contribute to the development of an environment in which aquaculture is economically viable. Moreover, land, fisheries and aquaculture legislation can increase the access of poorer parts of the population to aquatic resources, which directly contributes to the achievement of food and nutrition security.

Access to banking services, credit and insurance allows aquaculture farmers to work more effectively, which indirectly will lead to higher production, growth in income and employment. Investment in aquaculture is often negatively affected by a weak institutional framework. Investments in aquaculture are generally made for the long term. Unstable political and administrative environments may therefore entail less investment, including direct foreign investment. Trade barriers can affect the viability of aquaculture activities to a large extent.

Public–private sector partnership and regional cooperation

Public–private partnerships in aquaculture and the establishment of aquaculture networks have been shown to contribute considerably to the sub-sector's development. Although the establishment of such partnerships and networks may be a time-consuming, costly and difficult task, they make it possible to address constraints and opportunities in a manner that otherwise would not have been allowed. Cooperation between government, non-governmental organizations and civil society further provides opportunities for raising awareness, targeting and creating dialogues between the various stakeholders on aquaculture–food and nutrition security linkages. Regional cooperation between aquaculture farmers, producers and marketing associations, research institutes and governments is essential. In this respect, a good example in South-east Asia is the Support to Regional Aquatic Resources Management (STREAM) programme of the Network of Aquaculture Centres in Asia-Pacific/FAO/UK Department for International Development and Voluntary Services Overseas. This programme has proven to be successful in bringing aquaculture to the agenda of national and regional conferences that deal with rural development, food and nutrition security and poverty issues in particular. South–South cooperation between Asian countries and those in Africa and Latin America is a useful tool to disseminate these experiences.

Recommendations

If an effective enabling environment is created, cultured fish and other aquatic products could play a significant role in achieving the Millennium Development Goals. In this respect, the following actions are recommended.

1. Improve the extension and development approaches used for rural aquaculture, including:

- A holistic, farming systems-based approach integrating aquaculture into rural livelihoods.
- A participatory, needs-based approach that takes full account of the capacity of the poor, the resources available to them and the risks they face.
- Farmer-led extension and research.
- Promotion of sustainable, appropriate technologies commensurate with the resources available.

2. Encourage and promote the production of aquaculture products as a source of nutrition for human consumption with the help of targeted nutrition education programmes.

3. Promote effective rural development through sound governance and with the participation of the rural poor for decision making at all levels. Rural aquaculture has to be developed as an entrepreneurial activity that is financially viable, even for small-scale operations. All aquaculture developments should specifically address and minimize any potential adverse impacts on the poor.

4. Give greater emphasis to advocacy (outside the sub-sector) to raise awareness on the role for aquaculture in rural development, while empowering and linking stakeholders to policy decisions.

5. Improve information on small-scale rural aquaculture, its role in rural livelihoods, and its impact on food and nutrition security and poverty alleviation programmes.

6. Establish monitoring systems with better indicators.

7. Increase institutional capacity and the allocation of resources to ensure the appropriate role of aquaculture in alleviating poverty and improving food and nutrition security.

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9 A Home Gardening Approach Developed in South Africa to Address Vitamin A Deficiency

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Abstract
Home gardening, focusing on provitamin A-rich vegetables, is a long-term strategy that can contribute to combating vitamin A and other nutritional deficiencies which are of public health significance in developing countries. The provitamin A carotenoid content of foods and their potential contribution towards meeting the vitamin A requirements of the target population are predominant considerations in the selection of crops to be planted. This chapter describes a home garden approach that integrates gardening activities with nutrition education, using community-based growth monitoring as entry point. Studies using this approach in South Africa showed a favourable effect on maternal knowledge of vitamin A nutrition, dietary intake of provitamin A-rich vegetables, caregiver-reported child morbidity and children's vitamin A status. Provitamin A-rich vegetables and fruits contributed significantly towards achieving the recommended dietary intake of vitamin A and various other micronutrients. Seasonal availability of provitamin A-rich vegetables and fruits needs to be taken into consideration to ensure year-round availability of provitamin A-rich foods.

The approach is flexible and entry points other than community-based growth monitoring can be used to promote production and consumption of provitamin A-rich vegetables and fruits. Demonstration gardens to serve as training centres, community-based nurseries for orange-fleshed sweet potato cuttings and a seed distribution system are important components of the home garden projects. Various constraints experienced with vegetable gardens and possible solutions are highlighted. Participation in gardening projects is self-selective. Non-participating households within the project areas are, however, exposed to the promotion activities, resulting in a spill-over effect to non-participating households.

Key words: food-based approach, home gardens, vitamin A, provitamin A carotenoids, vegetables and fruits, South Africa

Introduction

Vitamin A deficiency is prevalent in most developing countries. Globally 33.3% or 190 million children younger than 5 years are deficient in vitamin A, with South-east Asia and Africa having the highest prevalence of vitamin A deficiency at 49.9% and 44.4%, respectively (1).

Vitamin A is essential for maintaining immune function, eye health, vision, growth and survival in humans (2). Vitamin

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A deficiency is the leading cause of preventable blindness in the world. Children who are vitamin A-deficient have lower resistance against common childhood infections such as respiratory and diarrhoeal diseases, measles and malaria (2). Globally, vitamin A deficiency resulted in 6% of deaths (0.6 million) among children under 5 years old in 2004 (3). Improving the vitamin A status of children between 6 months and 5 years reduces the all-cause mortality by 23% in areas with high vitamin A deficiency (4).

Nutritionally vulnerable communities often consume monotonous low-energy, low-protein diets that are predominantly based on starchy staples and often include little or no animal products, limited dietary fat and few vegetables and fruits. As a result their diets are low in a number of micronutrients, including vitamin A. Dietary modification strategies that aim to increase the vitamin A intake include various approaches to increase: (i) the production, availability and access to vitamin A-rich foods; (ii) the consumption of vitamin A-rich foods; and/or (iii) the bioavailability of vitamin A in the diet (5).

Dietary sources of vitamin A consist of either preformed vitamin A (retinol) from foods of animal origin or provitamin A carotenoids (predominantly β-carotene) from foods of plant origin that are converted to retinol by the body. Preformed retinol from foods of animal origin is the most bioavailable dietary source of vitamin A, but these foods are often not within the financial reach of the poor. Foods of plant origin are more affordable and can be cultivated at household level. Local production of provitamin A-rich vegetables and fruits, including the underutilized indigenous wild-growing leafy vegetables, can provide households with direct access to foods rich in provitamin A carotenoids. Therefore, home gardening is a fundamental strategy to address vitamin A deficiency in resource-poor communities by increasing the availability of, access to and ultimately consumption of foods that are rich sources of vitamin A. Integration of small-animal husbandry (such as fish, poultry, small livestock, milking cows or goats) with home gardening increases dietary variety and availability of foods rich in preformed retinol (6).

Home gardening can be part of a sustainable long-term strategy that complements household food security, nutrition education, supplementation and food fortification interventions. It is recognized that the various interventions to address vitamin A deficiency should be used in combination because they each serve a particular target group and none of them has 100% coverage (6). It is further recognized that home gardening projects that aim to produce particularly provitamin A-rich foods for household consumption will not eliminate vitamin A deficiency, but can help to reduce the risk of vitamin A deficiency by increased consumption of home-grown provitamin A-rich vegetables (6).

Berti *et al.* (7) argued that home gardening is inherently an effective intervention which most people, given access to land and other agricultural inputs, can adopt. However, to ensure that gardening activities translate into improved dietary quality, home gardening projects need to include a strong nutrition education and behaviour change component (5). Dietary modification through successful promotion of behaviours that provide adequate dietary intake, together with ensuring availability of supply, is likely to be both sustainable and affordable (8).

Furthermore, it is believed that home gardens are preventive, cost-effective, sustainable, culturally acceptable and have the potential for income generation (9,10). Gardening projects empower households to take ultimate responsibility for the quality of their diet by growing their own nutrient-rich foods and making informed consumption choices. It has further been argued that the benefits of gardening projects are tangible and rewarding for the community (11). Home gardening projects can reach a majority of rural and many urban/peri-urban households and all their members, not just a particular age group, as is the case, for example, in high-dose vitamin A supplementation programmes. Generally, communities that have no or limited access to supplementation and food fortification programmes benefit the most from home gardens.

Home Garden Projects to Address Vitamin A Deficiency in South Africa

The national prevalence of vitamin A deficiency among 1- to 9-year-old South African children was 64% in 2005 (12). Compared with a national survey conducted in 1994 (13), the vitamin A status of South African children appears to have deteriorated despite the national vitamin A supplementation programme which targets 6- to 59-month-old children and postpartum mothers within 6–8 weeks of delivery. National vitamin A supplementation coverage rates were found to be 72.8% for children aged 6–11 months and 13.9% for children aged 12–59 months (14).

Children in South Africa generally consume a diet that is low in animal foods, vegetables and fruits, resulting in approximately half of the children consuming less than 50% of the required amount of vitamin A (15). The consumption of vegetables and fruits is generally low in the rest of the South African population as well. Analysis of household availability of different foods showed that 196 g of vegetables and fruits were available per person per day at the household level (16). This amount is about half of the World Health Organization's recommended daily intake of more than 400 g of vegetables and fruits per person to protect against cardiovascular disease and certain cancers (17). Rural and urban South African women in KwaZulu-Natal and Western Cape Provinces considered affordability, and to a lesser extent availability, as major constraints for the consumption of vegetables and fruits (18).

Home gardens can provide households with direct access to provitamin A-rich vegetables that are not readily available or within their financial reach. In theory, a well-planned home garden of size approximately 15 m × 10 m can supply a sufficient amount of provitamin A-rich vegetables to fulfil the vitamin A requirements among other micronutrients of a household of six throughout the year (19).

This chapter gives an overview of home garden projects that were done in South Africa by the Medical Research Council (MRC) and Agricultural Research Council (ARC). The aim of these projects was to address vitamin A deficiency through increased production and consumption of vegetables and fruits all year round, particularly those rich in provitamin A carotenoids. Integral to these projects is the emphasis on nutrition and agriculture linkages.

The first project was initiated in 1998 and formed the foundation for the second project. The study population for the first project was composed of residents of Ndunakazi, a rural village in the Valley of a Thousand Hills in KwaZulu-Natal Province. Almost 50% of the children in the area were previously shown to be vitamin A deficient (20). The population density of this village was low and approximately 200–300 households with, on average, eight persons per household were scattered over a mountainous area of approximately 11 km long and 1 km wide. The gardening activities were integrated with community-based growth monitoring and linked to nutrition education. The project had high input from the research team and was closely monitored. Project evaluation showed a positive impact on maternal knowledge regarding vitamin A nutrition, dietary vitamin A intake and the vitamin A status of children aged 2–5 years (21). The research team gradually withdrew while putting mechanisms in place to enable continuation of the gardening activities. Aspects that were given consideration included seasonal availability of vegetables and fruits (determined during 2003–2005) (22) and a sustainable seed system. Unpublished results from a survey done in 2007 suggested that the gardening activities were sustained after withdrawal of the research team. The latter survey showed that a substantial number of households obtained provitamin A-rich vegetables and fruits from either a home garden or a community/group garden; and that the vitamin A intake was higher than at baseline.

In the second project from 2002 to 2005, a similar approach was used but with less input from the research team, and with the focus on community mobilization and technology transfer. The study population resided in seven rural villages, approximately 200–700 households per village, in Lusikisiki, situated in the Pondoland Coastal Plateau in the Eastern Cape Province.

Crops cultivated in the home gardens

The aim of the aforementioned two projects was to improve the vitamin A intake of nutritionally at-risk populations. The β-carotene content of the crop and its potential contribution towards the vitamin A requirements of the target population were predominant considerations in the selection of crops to be planted. Crops inherently rich in provitamin A carotenoids (particularly β-carotene) include dark-green leafy vegetables (e.g. spinach and wild-growing leaves), carrot, orange-fleshed sweet potato, butternut squash, pumpkin, mango and papaya.

Although the bio-efficacy of provitamin A carotenoids in plant foods is less than previously thought (23), it has been shown that plant provitamin A carotenoids from green/yellow vegetables can sustain vitamin A status, as demonstrated in Chinese children (24). Consumption of cooked green leafy vegetables (25–27), sweet potato (26,28,29) and carrots (27) was shown to improve vitamin A status, providing evidence supporting the use of provitamin A-rich plant foods in food-based strategies to address vitamin A deficiency.

Orange-fleshed sweet potato varieties offer one of the highest sources of naturally occurring β-carotene, but are currently not widely grown in Africa (30). A randomized controlled trial done in South Africa showed that orange-fleshed sweet potato was accepted well by primary-school children and improved their vitamin A status when given as part of the school meal (29). Between 70% and 92% of the β-carotene in orange-fleshed sweet potato is retained during cooking (31).

Of the orange-fleshed varieties available, some were found naturally, while others have been developed through conventional breeding (32). Sweet potato varieties have also been developed through improved biotechnology (33,34). Sweet potato is adaptable to a broad range of agro-ecological conditions and is suitable for low-input agriculture. It is, in many ways, an ideal crop for gardening projects, as it grows on low-nitrogen soils, is more drought-tolerant than conventional vegetable crops, crowds out weeds and suffers from relatively few pests (35).

The colour of the sweet potato is directly related to the β-carotene content, and colour intensity (cream, yellow, yellow-orange, dark orange) may therefore be used as an indicator of provitamin A value (36). Vegetable garden projects in South Africa use varieties with an orange to dark-orange colour and are supported by a breeding programme for orange-fleshed sweet potato at the ARC – Roodeplaat Vegetable and Ornamental Plant Institute. Orange-fleshed varieties had been used as early as the 1980s in the ARC programme but were mainly aimed at the frozen-food industry, and were characterized by low dry-matter content, poor storability, and tended to have long curved shapes (37). In 1996, the renewal of orange-fleshed sweet potato breeding began by examining breeding lines used in the 1980s, selecting some with higher dry-matter content and acceptable shape; and, in addition, orange-fleshed cultivars originating from the USA were obtained from the germplasm collection of the International Potato Center. Vegetable garden projects in South Africa originally used some of the US varieties (particularly Resisto, W-119 and Excel). After several years of crossing, evaluation and selection, three orange-fleshed varieties (Khano, Serolane and Impilo) were released from the ARC programme between 2006 and 2008 (38,39). The breeding programme is developing sweet potato cultivars with high β-carotene content, good yield, good taste, drought tolerance and tolerance to major diseases, and is linked with the HarvestPlus Sweet Potato Biofortification Program (40,41).

Orange-fleshed sweet potato is a new crop in South Africa. Nevertheless, in a paired preference test, 85% of respondents preferred the taste of orange-fleshed sweet potato to the usual white-fleshed sweet potato, and 53% had a definite liking for the colour (42).

The use of orange-fleshed sweet potato to combat vitamin A deficiency is an international trend. Orange-fleshed sweet potato is used to combat vitamin A deficiency in sub-Saharan African countries, e.g. in Western Kenya, Mozambique and Uganda (43–45), as well as South and West Asia (46).

Ndunakazi project

The Ndunakazi home garden project was initiated in 1998, with the aim of improving the vitamin A status of children through production and consumption of provitamin A-rich vegetables and fruits.

Community-based growth monitoring activities were used as a platform for the promotion and implementation of the home garden project. The community-based growth monitoring project was established in 1995 because of the lack of health facilities within the area (47). The growth monitoring project had an estimated coverage of 90% and an average monthly attendance ratio of 71% for children aged 5 years and younger (48). The community-based growth monitoring activities, therefore, provided a suitable platform for the promotion and implementation of the home garden project as a large number of mothers had access to the nutrition education and agricultural training activities that were given during the growth monitoring sessions.

Growth monitoring sessions were hosted at households which were identified taking into consideration the geographical location, accessibility, number of pre-school children in the vicinity of the household, availability of space and willingness of the mother within the household to participate. The households made their homes available on a voluntary basis, once a month, to serve as meeting points. Activities during the monthly sessions included: (i) growth monitoring of children aged 5 years and younger; (ii) basic nutrition education (including aspects of breastfeeding, complementary feeding, hygiene and sanitation); and (iii) counselling of mothers or referral to the clinic when growth faltering occurred in children. The growth monitoring activities were carried out by nutrition monitors (local people, but not specifically from within the village, trained for the project), who were employed by the MRC.

A home garden project was integrated with the growth monitoring activities during the last quarter of 1998. Demonstration gardens, which served as training centres for gardening activities, were established at each growth monitoring site. During the monthly growth monitoring sessions, household production and daily consumption of provitamin A-rich vegetables and fruits were promoted through: (i) education on vitamin A nutrition (simple, inexpensive education material that was attractive and acceptable to both the mothers and the nutrition monitors was used to guide the nutrition monitors through the lessons); (ii) cooking of locally produced provitamin A-rich vegetables; and (iii) demonstrations of the planting process in a demonstration garden. Many of the mothers were not familiar with the provitamin A-rich vegetables, so cooked vegetables on growth monitoring days were used to: (i) introduce the mothers and children to these vegetables; (ii) teach the mothers various ways of preparation; and (iii) give the mothers the opportunity to observe their children eat and enjoy it. The latter served as motivation for the mothers to plant these vegetables at household level and to prepare them at home.

The nutrition education component of the garden project focused on, among other things, optimal food preparation methods to maximize the bioavailability of provitamin A carotenoids. Based on evidence that between 3 g (28) and 5 g (49) of fat per meal is required to enhance carotenoid absorption, the mothers were encouraged to add the minimum amount of fat to the meal containing provitamin A-rich foods.

Destroying the food matrix in which the carotenoids are incorporated may help to improve the bioavailability of carotenoids. During food preparation, mechanical processing of vegetables through, for example, cutting, chopping or grinding disrupts the sub-cellular membranes in which the carotenoids are bound (50). The mothers were therefore encouraged to grate carrots, for example. To retain the nutrients (particularly heat-labile and water-soluble micronutrients) during cooking, the mothers were encouraged to use little water and not to overcook the vegetables. The mothers were further encouraged to eat yellow fruits (e.g. mangoes, papayas and yellow peaches) when fully mature.

On the day of growth monitoring, gardening activities were promoted and demonstrated by a nutrition monitor to all mothers attending the growth monitoring session. Crops that were planted in the demonstration gardens were orange-fleshed sweet potato, carrot, spinach (Swiss chard) and butternut squash. KwaZulu-Natal has a tropical climate and a papaya tree was therefore planted in each demonstration garden. Pumpkin and *imifino* (a collection of various dark-green leaves that is eaten as a vegetable; the leaves either grow wild or come from vegetables such as pumpkins, beetroots and sweet potatoes) were already produced locally, but the quantity grown and eaten was low (51). Consumption of pumpkin and *imifino* was promoted, but these vegetables were not planted in the demonstration gardens.

Mothers were encouraged to plant provitamin A-rich vegetables and papaya trees at the household level in addition to any existing crops. A crop rotation system was recommended for soil improvement and pest control. Staggered planting, which is small, regular plantings at intervals during the planting season, was promoted to lengthen the period of availability of individual provitamin A-rich vegetables.

Impact of the home garden project on maternal nutritional knowledge, vitamin A intake and vitamin A status

The effect of the garden project on maternal knowledge, dietary intake and vitamin A status of 2- to 5-year-old children was evaluated through two cross-sectional surveys – one at baseline (February–March 1999) and a follow-up survey 20 months later (November 2000). A neighbouring village that had similar community-based growth monitoring activities but no home garden project served as control village.

A significant improvement in maternal knowledge on vitamin A nutrition was observed. Within 20 months, most of the mothers in Ndunakazi could: (i) name at least three food sources of vitamin A (Ndunakazi 71% versus control village 18%); (ii) relate the colours yellow/orange and dark green with vitamin A-rich vegetables (Ndunakazi 82% versus control village 15%); and (iii) name at least one symptom related to vitamin A deficiency (Ndunakazi 74% versus control village 27%) (21).

Before implementation of the garden project, the children consumed a cereal-based diet, with staple foods being a stiff porridge made with maize meal, bread and rice. Legumes, mostly beans, formed an integral part of the diet. The intake of vitamin A-rich foods was low, resulting in a median vitamin A intake of 35% of the required amount (52). The home gardening project added variety to the diet and did not replace a major component of fruits and vegetables previously consumed (mostly cabbage, banana and orange). The intake of yellow/orange-fleshed and dark-green leafy vegetables increased, and as a result, the intake of vitamin A increased, with at least 85% of the vitamin A intake being from provitamin A-rich fruits and vegetables (53).

The prevalence of vitamin A deficiency (serum retinol <20 μg/dl) decreased from 58% at baseline to 34% in the Ndunakazi village. Ndunakazi children from households with project gardens had a significantly higher mean serum retinol concentration than (i) the Ndunakazi children without a project garden at household level and (ii) children from the control village (21). During the two weeks prior to the follow-up survey, children in Ndunakazi suffered less from diarrhoea than children in the control village (10% versus 22%) (54).

A qualitative assessment using focus group discussions showed that the community gained a sense of empowerment through a better understanding of *what* makes their children healthy (through the nutrition education), *how* to check this (through the growth monitoring) and skills to produce food to *achieve* this (through the training in gardening activities). The community was positive towards the home gardens, realizing the health benefits and relating the project with poverty alleviation (55). The mothers' understanding of the underlying factors of poor growth and health of their children, which was obtained through monthly growth monitoring and nutrition education, contributed towards the success of the home garden project.

Seasonal dietary intake of provitamin A-rich vegetables

The dietary surveys that were done in February and March 1999 and November 2000 showed seasonal variations in the consumption of yellow and dark-green leafy vegetables (56). Climatic conditions and seasonal patterns affect the cultivation of provitamin A-rich vegetables and this can potentially affect dietary vitamin A intake. Additional data were, therefore, collected on the seasonal availability of these vegetables and the impact thereof on dietary vitamin A intake (22). The proportion of 2- to 5-year-old children who consumed provitamin A-rich vegetables and fruits at least once weekly was determined from February to December in 2003, and during February, May, August and November in 2004 and 2005. Although the absolute values differed, results of these surveys showed that butternut squash, pumpkin and orange-fleshed sweet potato were consumed mostly during the first quarter/half of the year, while spinach and carrot were consumed mostly during the second half of the year. The proportion of children who consumed orange-fleshed sweet potato was low, suggesting that a more intensive promotion campaign was needed to sustain local production and frequent consumption of this newly introduced crop.

Foods reported during a quantified dietary survey in 2005 showed that consumption of spinach and *imifino* complemented each other, with *imifino* being consumed mostly during the first and last quarter of the year and spinach (mostly Swiss chard) during the third quarter (57). This highlights the importance of promoting the consumption of both conventional (spinach) and traditional (*imifino*) leafy vegetables to ensure year-round consumption of dark-green leafy vegetables.

Quantified dietary intake for 2- to 5-year-old children during February, May, August and November of 2005 showed that the prevalence of inadequate dietary vitamin A intake was approximately 20% or less, with the lowest prevalence (6%) reported for the November survey. The provitamin A-rich vegetables and fruits contributed between 49% and 74% of total vitamin A intake (22). This suggests that provitamin A-rich vegetables and fruits can sustain an adequate vitamin A intake throughout the year for the majority of the population. Promoting and cultivating a variety of provitamin A-rich vegetables and fruits will extend the period of and ensure year-round availability, provide variety and spread the risk for crop failure. The period of availability of certain vegetables can be lengthened by manipulating agricultural practices. Du Plooy *et al*. (58) showed, for example, that the availability of orange-fleshed sweet potato can be extended to at least nine months of the year in areas with moderate winter climate by using various planting and harvesting dates, plant spacing and soil storage.

Availability of provitamin A-rich vegetables and fruits

The 2003 survey showed that unavailability was the main reason for not consuming specific vegetables during the off-season. This survey showed that the majority of households did not have access to butternut squash for the period April to December, pumpkin and orange-fleshed sweet potato during the second half of the year, and carrots and spinach during the first half of the year (22).

To ascertain to what extent the households had access to provitamin A-rich vegetables and fruits through the local shops, the availability of vegetables and fruits in the five most accessible shops in the village and surrounding areas was recorded during 2004. Potato, cabbage, onions and tomato were available most of the time in all five shops. The provitamin A-rich vegetables pumpkin, butternut squash and carrot were not available in the shops. In terms of fruits, apples and bananas were available for most of the time, while the availability of oranges fluctuated. For provitamin A-rich fruits, mangoes were never available, some yellow peaches were available during February to April, and some papayas were available during December (22). In areas where provitamin A-rich vegetables and fruits are not available in local shops, the community will not have easy access to these foods unless they produce them locally.

Contribution of provitamin A-rich vegetables and fruits towards dietary intake of nutrients other than vitamin A

Two surveys in the project area showed that home gardens focusing on provitamin A-rich vegetables and fruits can improve the overall nutritional quality of the diet, and address multiple nutrient deficiencies simultaneously. In the first survey, which was done in February–March 2000 (one year after implementation of the project), dietary intake was determined for 2- to 5-year-old children from households with and without a project garden. Children from households with a project garden had significantly higher dietary intakes for riboflavin, vitamin B_6 and vitamin C, and a tendency towards a higher calcium intake; provitamin A-rich vegetables and fruits contributed more than 50% of total intake for calcium and iron, and between 25% and 50% of total intake for magnesium, riboflavin and vitamin C (53).

Similar findings were observed through a repeated cross-sectional dietary survey that was done for 2- to 5-year-old children in February, May, August and November of 2005, which showed that provitamin A-rich vegetables and fruits contributed towards total dietary intake of especially calcium and iron, and to a lesser extent of magnesium, riboflavin and vitamin C (22). This is a significant additional benefit of the home gardening project, more so as these nutrients were all shown to be deficient in the diets of 1- to 9-year-old South African children as determined in the National Food Consumption Survey of 1999 (15).

Community-based nursery for orange-fleshed sweet potato and distribution of seeds

To ensure that the households have access to orange-fleshed sweet potato planting material, a community-based sweet potato nursery in a netted structure, 10 m × 5 m, was established at one of the households in 2003. The nursery contains approximately 200 plants in planting bags from which cuttings are obtained. The plants are replaced with virus-tested stock plants every two to three years to keep supply cuttings of good quality. The number of cuttings that were distributed from the nursery was 1377 in 2004, 2430 in 2005, 3220 in 2006, 7970 in 2007, 3955 in 2008 and 5750 cuttings in 2009. Considering that there are approximately 200–300 households in this village, these numbers are quite significant. The nursery supplies cuttings not only to households in the village, but also to households and schools in nearby villages.

A distribution system for seeds for butternut squash, carrot and spinach is linked to the community-based orange-fleshed sweet potato nursery. Seeds are bought in bulk, repacked and distributed at a price significantly lower than in the shops in the village or nearby towns, where small packages are sold at expensive prices.

Sustainability of the project

The research team gradually withdrew after the impact evaluation that was done in November 2000 (21). The growth monitoring project, which served as a platform to promote the gardening activities, was terminated through a gradual withdrawal process in 2006. Since the implementation of the community-based growth monitoring project in 1995, the roads and transport system improved considerably. As a result, the community now had relatively easy access to the nearest clinic, and households were encouraged to take their children to the clinic for regular growth monitoring, as this would also give them regular access to health programmes such as the vitamin A supplementation programme.

From March to May 2007, a questionnaire was completed for 100 randomly selected households that were recruited through grade 4 to grade 7 scholars of the local school (unpublished data). The caregivers of the scholars were interviewed using a structured questionnaire to determine sources of vegetables and fruits, household food consumption, knowledge of nutritional benefits of provitamin A-rich vegetables and fruits, and gardening practices at household level. Dietary intake was quantified for the scholars and caregivers using a 2-day repeated 24-hour dietary recall. The SAS software package version 9.1 (SAS Institute Inc., Cary, North Carolina) was used to convert food intake to macro- and micronutrients, using the SAFoods food composition database.

The average age of the caregivers who were interviewed was 38 ± 10 years (mean ± standard deviation), and 48% had some secondary school education (grades 8 to 12).

Eighty per cent of the households collected *imifino* from the wild. Approximately one-third of the households obtained provitamin A-rich vegetables from a community or group garden. This could be a reflection of two group gardens planting mostly provitamin A-rich vegetables that were established in the area (one in 2004 and the other in 2005). More than 40% of the households planted provitamin A-rich vegetables in their own gardens. Figure 9.1 shows the percentage of households who obtained provitamin A-rich vegetables from either a home or a community/group garden. Although the main function of the vegetable gardens was to produce food for home consumption, 40% of those households with vegetable gardens (20% of the total study population) sold some of their produce.

Crops faced a variety of physical, economic and structural challenges. Animals destroying the crops were seen as the major physical threat, and this problem can be attributed to the lack of fencing affecting nearly two-thirds of households growing vegetables. Other major problems experienced by more than half of the households growing vegetables were plant diseases, insects, lack of money to buy supplies and shortage of water for irrigation. Lack of seeds and access to orange-fleshed sweet potato cuttings was a problem for less than 10% of the households growing vegetables.

The respondents were knowledgeable on the nutritional benefits of provitamin A-rich vegetables and fruits. Ninety-six per cent of the respondents thought that yellow/orange vegetables are good for their children. Main reasons given for this were because it is healthy (42%), contains vitamin A (13%) and promotes child growth (10%). A variety of other reasons were listed (each by <10% of the caregivers). When asked to name one symptom related to not eating yellow/orange vegetables, four symptoms were each named by at least 10% of the respondents: eye problems (26%), diarrhoea (22%), sores (15%) and poor child growth (13%).

Ninety-one per cent of the respondents were familiar with the term vitamin A: 62% knew that vitamin A is a nutrient in food; 78% associated the colours yellow and orange with provitamin A-rich vegetables; 68% named three foods that are rich sources of vitamin A; and 89% could name one symptom related to vitamin A deficiency.

The quantified dietary data showed that the median (interquartile range; 25th–75th percentile) vitamin A intake for the caregivers was 662 (444–886) retinol equivalents

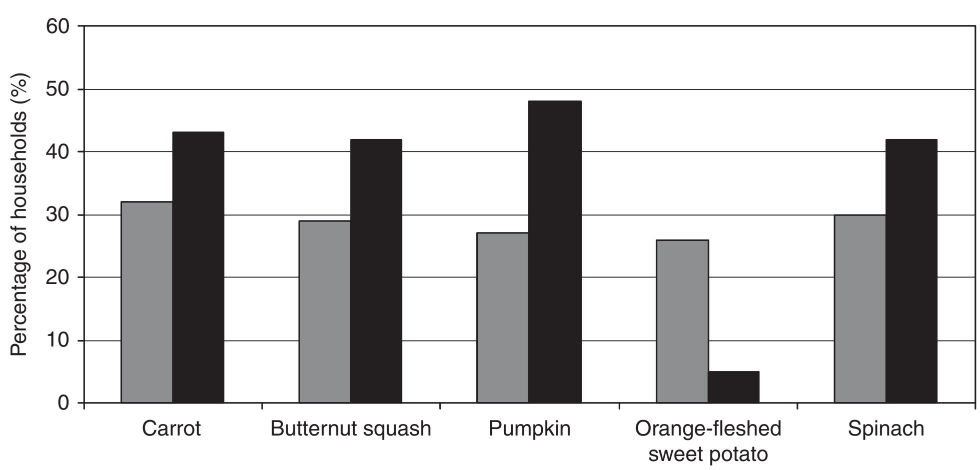

Fig. 9.1. Percentage of households in Ndunakazi obtaining provitamin A-rich vegetables from either a community/group garden (■) or a home garden (■) in 2007.

(RE) and for the scholars 561 (406–797) RE. This is substantially higher than the vitamin A intake reported for children and caregivers in the area before implementation of the home garden project; a median vitamin A intake of 150 (56–579) RE for 2- to 5-year-old children and 177 (97–644) RE for caregivers was reported (52).

In summary, the results of the 2007 survey showed that the caregivers were knowledgeable on the nutritional benefits of provitamin A-rich vegetables and fruits; a substantial number of households obtained provitamin A-rich vegetables and fruits from either a home or community/group garden; and vitamin A intake was higher than at baseline. These results suggest that that the gardening activities in the area were sustained after withdrawal of the research team.

Lusikisiki project

The Ndunakazi project had high input from the research team and was closely monitored. The question, though, was whether this approach could be implemented on a wider scale and with less input from the research team. The Lusikisiki project was implemented in 2002, with the aim of promoting local production and frequent consumption of provitamin A-rich vegetables and fruits. The focus of the project was on technology transfer, mobilization of the local community and involvement of the local governmental Departments of Health and Agriculture. This enabled reduced input from the research team. Agricultural extension officers served as agricultural advisors for the project and acted as links between the researchers and community members involved in the project.

Two community members per village were identified and trained as project health volunteers. Implementation was based on the 'training of trainers' principle and, during the second year of the project, each group of volunteers trained two more groups in each village. The project health volunteers were responsible for cultivating and promoting provitamin A-rich vegetables with the support of the agricultural extension officers, providing nutrition education, and for growth monitoring for 1- to 5-year-old children with the support of the Department of Health.

The project built on existing structures and activities, namely: (i) decision making and problem solving were linked with existing monthly farmer forum meetings; (ii) growth monitoring was added mostly to crèche activities; and (iii) the demonstration plots were established mostly in existing gardens. Since the existing gardens were already fenced, there were no additional costs to fence the demonstration gardens.

At four of the seven sites, growth monitoring was added to crèche activities. Crèches are convenient sites, as access to children attending the crèche is readily available. However, using a crèche as the site for growth monitoring has its limitations. The caregivers of the children were often not present during the growth monitoring sessions, making it difficult for the project health volunteer to give feedback to the caregiver on the child's growth (which is an integral part of growth monitoring). Also, caregivers who did not attend the growth monitoring sessions held at a crèche could not benefit from the nutrition education and promotion given during the growth monitoring sessions.

The monthly growth monitoring sessions and annual/biannual farmers' days were used to: (i) create awareness on the importance of vitamin A and health; and (ii) promote project activities in the area (e.g. distributing pamphlets on vitamin A-rich vegetables, making cooked and processed products of orange-fleshed sweet potato available for tasting).

In each of the seven villages, orange-fleshed sweet potato field nurseries were established in order to ensure a continuous supply of cuttings. Selection criteria for sites for demonstration plots and community-based field nurseries included fencing, water available for irrigation and willingness to engage in the process. Training in gardening activities was done at both the demonstration plots and the field nurseries.

Homesteads at the demonstration gardens and nursery sites were used to demonstrate the preparation and processing of orange-fleshed sweet potato, with emphasis on sweet potato bread, soup, chutney, juice, sweet potato leaves as green vegetables and a sweet potato curry dish. This introduced a variety of preparation methods, which could potentially lead to a more frequent use of the orange-fleshed sweet potato. Using a variety of products also could create a greater demand for the orange-fleshed sweet potato, which could potentially enhance the sustainability of local production. Bottled products such as chutney are a way to lengthen the period of availability of orange-fleshed sweet potato for consumption. When using orange-fleshed sweet potato in baking bread, part of the wheat flour is substituted with boiled orange-fleshed sweet potato. It is, however, important that the dark-orange varieties are used to ensure that the baked bread provides adequate amounts of vitamin A (59). Processed products using orange-fleshed sweet potato should also be economically viable (59). With the high prevalence of overweight and obesity in South Africa (56% of adult females are either overweight or obese) (60), it is important that prepared dishes and processed products are low in fat, sugar and salt.

In 2005, three years after initiation of the project, participating and non-participating households were compared in terms of child morbidity, nutritional knowledge, dietary intake and gardening practices. Table 9.1 shows that the project activities had a favourable effect on the caregivers' knowledge of vitamin A nutrition, morbidity of 1- to 5-year-old children as reported by the caregivers, consumption of provitamin A-rich vegetables and growing of provitamin A-rich vegetables (61). These observations suggest that the project contributed significantly towards nutritional outcomes. However, a significant limitation of the project was the lack of quantitative baseline data. Thus, the study cannot provide conclusive evidence that the observed differences between participating and non-participating households were because of the project per se.

Community-based growth monitoring as platform to promote provitamin A-rich vegetables and fruits

In the two projects described above community-based growth monitoring activities,

Table 9.1. Summary of results comparing project households with control households in the Lusikisiki food-based project three years after implementation. (Adapted from Laurie and Faber (61).)

Caregiver's knowledge of vitamin A nutrition	Morbidity for 1- to 5-year-old children	Vegetable consumption for 1- to 5-year-old children	Obtained provitamin A-rich vegetables from own garden
Thought yellow vegetables/fruits are good for children: 73% versus 45%	Vomiting: 6% versus 13%	Butternut squash: 32% versus 22%	Butternut squash: 38% versus 24%
Familiar with the term 'vitamin A': 89% versus 63%	Experienced fever: 30% versus 42%	Carrot: 31% versus 31%	Carrot: 28% versus 18%
Knew that vitamin A is a nutrient in food: 83% versus 53%	Sores on the skin: 6% versus 19%	Pumpkin: 67% versus 67%	Pumpkin: 70% versus 61%
Named three foods rich in vitamin A: 56% versus 27%	Continuous runny nose: 20% versus 33%	Orange-fleshed sweet potato: 24% versus 15%	Orange-fleshed sweet potato: 24% versus 10%
	Diarrhoea: 2% versus 7%	Spinach: 73% versus 63%	Spinach: 41% versus 28%
	Poor appetite: 7% versus 14%		

Results are given for the project versus control households.

which extended and complemented the growth monitoring activities of the Department of Health, provided the platform to promote the production and consumption of provitamin A-rich vegetables and fruits. For sustainability, methods of integrating gardening activities with existing community-based growth monitoring activities, particularly those activities falling under the Department of Health, should be investigated. For instance, in the Eastern Cape Province, the local Department of Health implemented community-based growth monitoring in 2005 and, by 2008, there were 148 growth monitoring sites in the province. Growth monitoring is done by community health workers who are attached to a clinic, and each growth monitoring site has a vegetable garden at the clinic (62).

In the Lusikisiki project, where the growth monitoring was done by project health volunteers who were not remunerated, various concerns regarding the sustainability of the growth monitoring activities were highlighted. These concerns included a lack of a continuous and adequate supply of provitamin A-rich vegetables to cook for the children attending the growth monitoring sessions; a lack of financial resources needed to maintain food preparation activities during the growth monitoring sessions (e.g. cooking oil, sugar, paraffin, firewood); broken scales and flat batteries and lack of resources to fix/replace them; and poor interpretation of the growth curve by the project health volunteers (61). Funding from local government departments or external agencies is needed to sustain the activities at the community-based growth monitoring sites and for the provision of sustainable stipends for the project health volunteers. Besides the need for adequate funds to sustain community-based growth monitoring, the growth monitoring process (weighing procedure, plotting the weight and appropriate counselling) and using appropriate weighing scales were identified by the Department of Health in the Eastern Cape Province as areas within community-based growth monitoring that need to be strengthened (62).

The Ndunakazi and Lusikisiki projects showed that community-based growth monitoring is a suitable platform for promoting the production and consumption of provitamin A-rich vegetables and fruits, but there are constraints as described above. To strengthen the food-based approach described in this chapter, it is important that first the constraints of community-based growth monitoring be addressed, and second that the feasibility of other platforms to promote provitamin A-rich vegetables and fruits be investigated.

As part of their technology transfer and capacity development activities, the ARC explored various other entry points to be used as a platform to promote the production and consumption of provitamin A-rich vegetables and fruits. They collaborated with other role players and used existing infrastructure to implement the food-based approach. Entry points that were explored included school gardens, clinic gardens, crèche gardens, community gardens and institutional programmes such as sustainable land-use programmes or agricultural assistance programmes (63).

School gardens were used as the entry point in one of the provinces as part of 'Sustainable Food Production in Schools', which is a sub-programme of the National School Feeding Programme of the Department of Education. Teachers from 200 schools received training in the food-based approach and demonstration plots were established in existing school gardens. The community was introduced to the cultivation of provitamin A-rich vegetables, particularly the orange-fleshed sweet potato, during large-scale open days. In some cases, the orange-fleshed sweet potato was introduced in clinic gardens that were used as a platform for training as well as the distribution of cuttings of orange-fleshed sweet potato to people visiting the clinics.

The 'Mdantsane for Vitamin A Program' is an example of a local project that integrated the promotion of provitamin A-rich vegetables, particularly the orange-fleshed sweet potato, with the vitamin A supplementation programme. Evaluation of the integrated project showed an increase in the number of children who received vitamin A supplementation, as well as an increase in the cultivation and consumption of orange-fleshed sweet potato (64).

Spill-over effect

Participation in gardening projects is voluntary and self-selecting, and not all households will opt to grow their own vegetables. Non-gardening households can, however, potentially benefit from community-based gardening projects because of the increased awareness that is created by the visibility of the demonstration and home gardens, as well as the nutrition education and promotion that is done during, for example, growth monitoring sessions or farmers' days.

An evaluation one year after implementation of the Ndunakazi project showed an increased vitamin A intake for both participating and non-participating households (53). Although some mothers opted not to have a project garden, many of them realized the nutritional benefits of these vegetables and negotiated with other community members to obtain some of these vegetables. The non-participating households also showed an increased consumption of *imifino* and pumpkin, two vegetables that were promoted but not planted in the project gardens because they were already grown locally. The increased vitamin A intake in non-participating households was, however, not sufficient to improve the vitamin A status of the children (21).

A spill-over effect was also observed in the Lusikisiki project. Approximately half of the non-participating caregivers received nutritional information from the project health volunteers, who were local people from within the villages. Nutritional information was provided not only during the monthly growth monitoring sessions, but also at local events such as annual farmers' days (61).

Problems experienced with the vegetable gardens and possible ways to solve them

Problems experienced with vegetable gardens and possible ways to handle them are shown in Figs 9.2 and 9.3. Figure 9.2 contains data for food-based projects done at Ndunakazi (as determined during the 2007 survey), Lusikisiki (61) and Giyani (unpublished data). Giyani is situated in a dry subtropical region in Mopani District in Limpopo Province, and data were collected in five rural villages from 153 households growing vegetables in either a home or communal garden.

Shortage of water was a problem for at least 50% of the vegetable gardens in all three of the projects. Water is a critical element of productivity as South Africa is classified as a water-stressed country (65). Households often do not have easy access to water for irrigation. In Lusikisiki, for example, nearly two-thirds of the households with vegetable gardens depended on water from the river for irrigation (61). The time and labour needed to collect irrigation water from the river places an additional burden on the gardening activities. Gardening projects should, therefore, include aspects of water-saving and water-harvesting techniques (66,67).

A lack of fencing, resulting in animals destroying the vegetables, was also a major problem (although to a lesser extent in Giyani). Proper fencing is expensive and most households in resource-poor rural communities do not have the financial means to fence their vegetable gardens. The formation of small garden groups (approximately ten persons per group) could potentially help to alleviate the problem with fencing. In Ndunakazi, for example, two groups were formed on their own initiative and they were assisted by the research organization to obtain sponsorship for fencing of the two gardens. Natural fencing is another strategy that can be used to prevent animals destroying the vegetables. It has been recommended that food-based approaches to address vitamin A deficiency include not only local production of provitamin A-rich plant foods, but also local production of animal foods that are rich in vitamin A such as poultry, small livestock, milking cows or goats (6). The practicality in terms of the animals destroying the vegetable gardens should be taken into consideration when implementing food-based projects.

Including aspects of integrated pest management can address some of the problems experienced with plant diseases and insects. Compost-making and buying agricultural supplies in bulk and then redistributing within the community can help to overcome

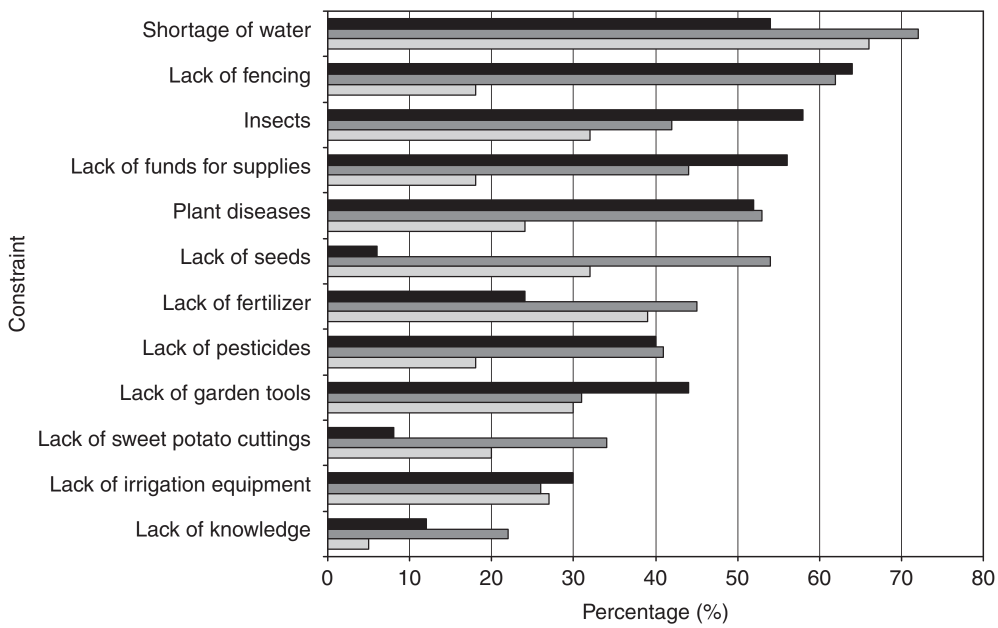

Fig. 9.2. Constraints experienced in home garden projects at Ndunakazi (■), Lusikisiki (■) and Giyani (■) in South Africa.

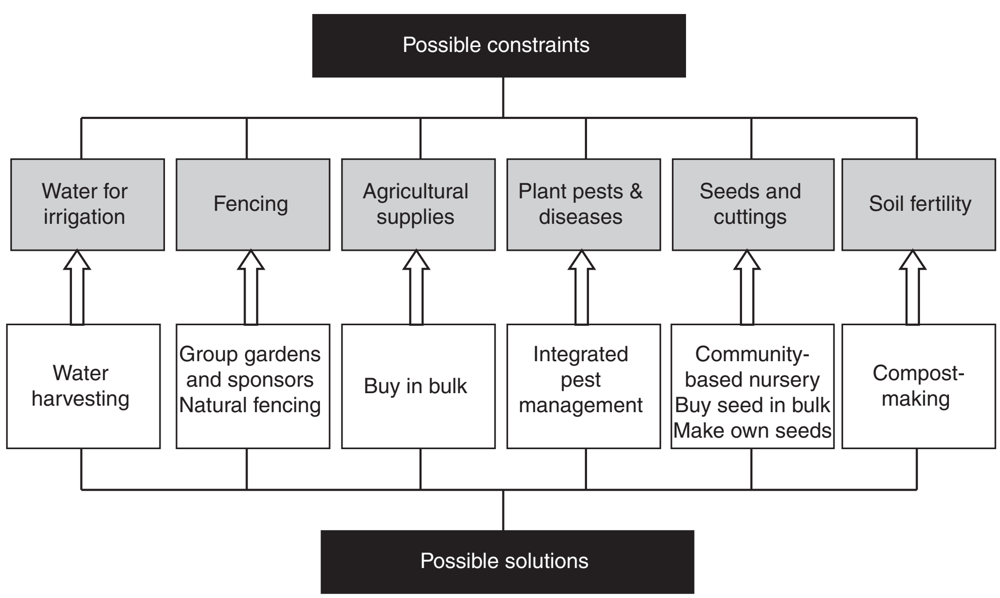

Fig. 9.3. Possible solutions for handling constraints in home garden projects.

the lack of funds to buy agricultural supplies. It is further important to address soil fertility to ensure that households growing their own vegetables obtain reasonable yields. A situation assessment in Lusikisiki showed low soil fertility (61), which often is a constraint in rural crop production (68).

In 2007, lack of seeds and access to orange-fleshed sweet potato cuttings were not seen as a major problem (<10% of the households with a home garden) in Ndunakazi, which probably could be ascribed to the community-based nursery and seed distribution system that was put into place in 2003. Easy access to a regular supply of quality seed, seedlings and e.g. virus-free, orange-fleshed sweet potato cuttings at an affordable price is critical for the success and long-term sustainability of gardening activities. A study in South Africa showed that most of the capital cost of home gardening is spent on buying seeds (69). Strategies to ensure an affordable supply of seeds include using crops that can be vegetatively propagated (e.g. sweet potato), buying seeds in bulk which are then repacked and sold at the community level, and own seed production (e.g. butternut squash and papaya).

Conclusions

Integral to the approach described in this chapter is the integration of nutrition and agriculture. Nutritionists from the MRC and agriculturists from the ARC have been working together since 1998 to develop a food-based approach contributing towards the elimination of vitamin A deficiency. This is in line with the view that food-based interventions should have a well-designed agricultural component as well as a well-designed nutritional component, and that these two components should be mutually reinforcing (70).

The critical components of the approach are illustrated in Fig. 9.4. The approach is flexible and allows for different entry points to be used as platforms for the education and promotion activities. The food-based approach as described by Faber *et al*. (19) acknowledges the underlying causes of childhood malnutrition (71) and topics other than vitamin A nutrition are covered in the nutrition education component, such as breastfeeding, immunization, vitamin A supplementation, hygiene and sanitation (19).

Increasing the access to micronutrient-rich foods through, for example, home production is one of the ways in which agriculture can contribute to improved nutrition (72). The main aim of the gardening activities in the projects described in this chapter was to produce adequate amounts of provitamin A-rich foods for household consumption. Income generation was a secondary aim, and only in cases where there was a surplus of vegetables.

Potential criticism towards an approach focusing on provitamin A-rich crops is that people need a range of nutrients, not only vitamin A. Production of provitamin A crops was shown to improve the intake not only of vitamin A, but also of some other micronutrients (53). The provitamin A-rich vegetables and fruits were shown to contribute significantly towards dietary intake of nutrients such as calcium, iron, magnesium, riboflavin and vitamin C (22), nutrients which were all found to be deficient in the diet of South African children (15). Because production of provitamin A-rich crops was promoted in addition to existing crops already being planted, the variety of vegetables consumed increased. In Ndunakazi, for example, vegetables consumed prior to the project were mainly tomatoes, cabbage, pumpkin and *imifino*. The gardening project added butternut squash, carrot, spinach and orange-fleshed sweet potato. Increasing the intake of vegetables and fruits in general will not only improve micronutrient status, but could also reduce many non-communicable diseases (73). An additional benefit of specifically provitamin A-rich foods is that food carotenoids are credited with other beneficial effects on health, independent of their vitamin A activity, such as the reduction of the risk of degenerative diseases like certain types of cancer, cardiovascular disease, cataract and macular degeneration (74).

Integrating the food-based approach with existing health, agricultural and development programmes will enhance sustainability and cost-effectiveness and will provide scope for national implementation.

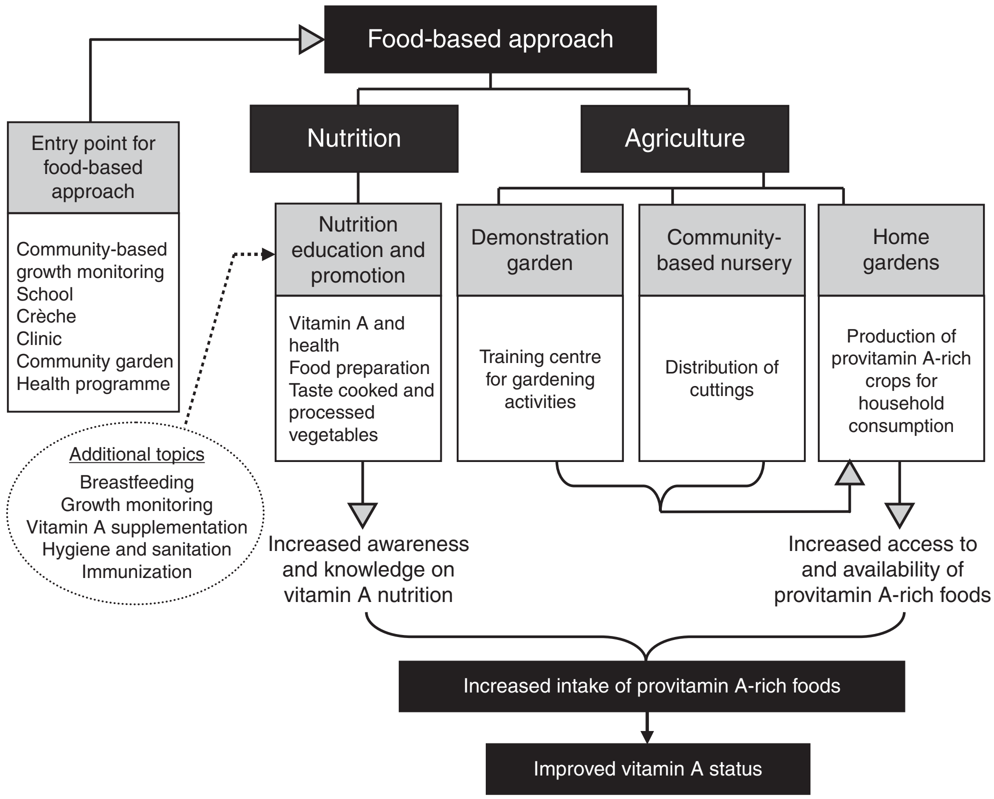

Fig. 9.4. Overview of the food-based approach to address vitamin A deficiency developed in South Africa.

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10 AVRDC – The World Vegetable Center's* Approach to Alleviate Malnutrition

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Abstract
AVRDC conducts research and development activities to increase access to and improve consumption of diverse and nutrient-rich vegetables, particularly in areas where malnutrition is prevalent. AVRDC aims to improve human nutrition through increasing vegetable productivity, availability and consumption; improving the nutrient content and phytochemical density of vegetables; enhancing the bioavailability of nutrients from vegetables; and improving the health and economic status of the poor in developing countries. Activities to increase vegetable productivity, availability and consumption include the genetic improvement of vegetables (biotic and abiotic resistance and tolerance), development of production systems to increase year-round availability of vegetables, good crop management practices to improve yield and reduce chemical inputs, development of postharvest technologies to reduce losses, and the promotion of vegetable consumption through information technology, school and home gardening, nutrition education and designing nutrition seed kits for home gardens. Activities to improve the nutrient content and phytochemical density of vegetables include collection and evaluation of vegetable genetic resources, identification and promotion of underutilized indigenous vegetables high in nutrients and bioactive compounds, and selection and/or breeding to increase content of nutrients and bioactive compounds. To enhance the bioavailability of nutrients, optimum food preparation methods and recipes are developed and promoted. Finally, the impact of vegetable consumption on health and economic development, as well as the health benefits of consuming vegetables high in bioactive compounds, is discussed.

Key words: vegetables, indigenous vegetables, micronutrients, bioavailability, breeding, germplasm, school and home gardens, nutrition seed kits, phytochemicals

Introduction

Hunger is the most severe result of poverty, causing undernourishment from low energy intake and nutritional deficiencies. Approximately one billion people suffering from hunger live in the developing world (1). While the main reason for undernourishment among the poor is the lack of capacity to obtain adequate, nutritious food, malnourishment can also exist in poor populations with adequate (in terms of quantity but not quality)

* AVRDC – The World Vegetable Center was formerly known as the Asian Vegetable Research and Development Center (AVRDC). Since 2007, AVRDC expanded its regional mandate worldwide to become AVRDC – The World Vegetable Center, abbreviated as AVRDC throughout the chapter.

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food supply. Where there is a sufficient quantity of food, but not always sufficient quality, the diet can be deficient in one or more micronutrients. The number of people with micronutrient deficiencies is estimated to exceed two billion.

Vegetables in the diet are essential to combat malnutrition in the developing world. Vegetables are rich in essential micronutrients such as vitamins and minerals, carotenes, folates and thiamin, as well as dietary fibre. Although vegetable production is increasing globally, it is still far too low in many developing countries. In 2003, when global vegetable production was 135 kg per capita, production in the least developed countries was only 73 kg per capita. Not only is per capita production of vegetables unevenly distributed, but per capita consumption is also uneven. Total vegetable production is highest in the People's Republic of China (313 kg per capita) while, in contrast, production in developing countries of Asia is only 80 kg per capita (2). This uneven production and consumption highlights the urgent need to increase both vegetable production and the availability of affordable vegetables for consumption in the developing world. Furthermore, it is essential for nutrition that these vegetables have high nutrient bioavailability. By increasing vegetable production, consumption and nutrient bioavailability, vulnerable populations will be better nourished and therefore more able to tackle the many other issues associated with poverty.

The mission of AVRDC is 'to alleviate poverty and malnutrition in the developing world through the increased production and consumption of nutritious and health-promoting vegetables'. The Center's activities are grouped under five research and development themes. Theme 1 addresses germplasm conservation, evaluation and gene discovery; Theme 2 comprises genetic enhancement and varietal development of vegetables; Theme 3 consists of seed and safe vegetable production systems; Theme 4 covers postharvest management and market opportunities; and Theme 5 includes nutrition security, diet diversification and human health. This chapter presents the approaches and activities undertaken at AVRDC to improve human nutrition through research and development activities on the production and consumption of safe vegetables.

Increasing Vegetable Productivity, Availability and Consumption

AVRDC's major research and development activities focus on the needs of the poor in developing countries, increasing vegetable productivity and availability while also promoting increased consumption.

Adapting improved varieties to tropical environments

Vegetable production in the tropics is highly seasonal and severely constrained by low yields and poor quality due to high temperatures, excessive or insufficient moisture, pests and diseases and poor postharvest handling. The development of tropically adapted, high-yielding vegetable varieties is critical and will result in increased productivity. The first step taken in the late 1970s by AVRDC was to adapt vegetables to tropical conditions by developing heat-tolerant lines of tomato (*Solanum lycopersicum*), Chinese cabbage (*Brassica rapa* var. *pekinensis*) and sweet pepper (*Capsicum annuum*) through genetic improvement (3). Increased tolerance to heat enables vegetable production during hot summer seasons, thus ensuring a good harvest even during 'vegetable-lean' months and particularly in areas closer to markets which are often in hot, humid lowlands.

AVRDC is well known for the heat-tolerant vegetable lines it has developed. By 1978, heat-tolerant tomato lines that set abundant fruits at maximum/minimum temperatures of 30°C/22°C had been identified (4). AVRDC's improved lines are now routinely tested at temperatures normally unfavourable to fruit set, i.e. maximum/minimum temperatures of 33.6°C/25.4°C, mean relative humidity of 79% and total rainfall of 96 mm. In this adverse tomato production environment, inbred lines that yield exceptionally well have been identified (5), thus increasing the range of environments where tomatoes can be grown. Tomatoes, when consumed in large quantities, can provide significant amounts of provitamin A, vitamin C as well as lycopene. The most recently identified heat-tolerant vegetable lines are four heat-tolerant and early-maturing broccoli (*Brassica oleracea*) lines. The highest yielding is BR117SF1203, which yields above 10 t/ha in the hot, wet summer season in Taiwan (6). Broccoli is of particular interest because of its flavour, the possible potential it provides for protecting against cancer and its other nutritional qualities. Sweet pepper, which is high in provitamin A and vitamins C and E, could contribute significantly to improved nutrition. However, sweet pepper production in the tropics and subtropics is limited because of the narrow seasonal production windows primarily due to the lack of heat-tolerant cultivars. To develop a 'tropical' sweet pepper, AVRDC uses chilli pepper as a source of genes for heat tolerance and disease resistance (3). At least 35 heat-tolerant Chinese cabbage lines have been developed. Most of these lines have been distributed to partners in national agricultural research systems (NARS) where they have been either tested directly or incorporated into national vegetable breeding programmes.

Tropical environments are also subject to heavy disease burden and insect pest pressures. The next step taken by the AVRDC was therefore to combine heat tolerance with multiple resistance to pests and diseases. AVRDC's current tomato lines combine heat tolerance and resistance to bacterial wilt (*Ralstonia solanacearum*) and geminiviruses. The combination of resistance to both these diseases has enabled farmers in southern India to double their tomato yields from 19 t/ha to 37 t/ha in on-farm trials (7). Geminivirus resistance also allows farmers to reduce pesticide applications for the control of whiteflies (*Bemisia tabaci*), the insect vector that transmits geminiviruses. Additionally, geminivirus resistance permits tomato production to be extended into periods when the vectors and virus are prevalent. Most of AVRDC's new tomato lines are also resistant to late blight (*Phytophthora infestans*), root-knot nematode (*Meloidogyne incognita*) and *Tomato mosaic virus* (TMV), in addition to heat tolerance and resistance to bacterial wilt and geminiviruses.

Increased stable yields of chilli pepper (*C. annuum*) have been achieved through increased resistance to anthracnose (*Colletotrichum* spp.), bacterial wilt (*R. solanacearum*), Phytophthora blight (*P. infestans*) and a complex of viruses including *Cucumber mosaic virus* (CMV), *Chilli veinal mottle virus* (ChiVMV), and tobamoviruses (3).

Introgression from wild or related species has been used extensively to incorporate resistance to pests and diseases in tomato and chilli pepper, aided by molecular marker-assisted selection. The short growth duration or early maturing lines developed by AVRDC has also facilitated the integration of these crops into various cropping systems. AVRDC's improved mungbean (*Vigna radiata*) lines combine high yields and early maturity with resistance to both *Mungbean yellow mosaic virus* (MYMV) and powdery mildew (*Erysiphe polygoni*). With these traits, mungbean easily fits into the wheat-based cropping systems in South Asia and in cereal fallows in the Indo-Gangetic Plains (6). About two million hectares in South and South-east Asia are planted annually with AVRDC's mungbean lines, or varieties derived from its improved mungbean germplasm (3).

After an initial focus on adaptation to tropical environments and ensuring high and consistent yields, AVRDC's focus shifted to include improvement of nutrition quality and postharvest characteristics. As malnutrition remains a key concern, AVRDC includes evaluation for nutritional factors as a core part of its crop improvement activities. For example, while new tomato lines are routinely evaluated for β-carotene and vitamin C, the additional focus on postharvest characteristics has meant that the new improved lines also have firm fruits, longer shelf-life and better postharvest handling characteristics.

The success of the vegetable breeding programmes at AVRDC is largely due to the wide array of genetic material in its genebank which is available for use by vegetable breeders worldwide. The genebank currently holds more than 55,000 accessions of vegetable germplasm which are sources of many of the traits used in the vegetable breeding programmes not only of AVRDC, but also those of NARS and the private sector.

In addition to tomato, sweet and chilli pepper, crucifers and legumes, AVRDC also has cucurbit and bulb allium improvement programmes. Improved lines and selections are freely available, accompanied by the appropriate Material Transfer Agreement, to public and private institutions. AVRDC has a strong tradition of working with NARS and has contributed to the release of 325 varieties in 53 countries. The Center also collaborates with the private seed sector, particularly in Asia and increasingly in sub-Saharan Africa.

Production systems and good crop management practices to increase year-round vegetable availability, with increased yields but reduced use of chemical inputs

Through the development of tropically adapted lines of tomato, chilli and sweet pepper, and Chinese cabbage, AVRDC has substantially widened the production window for vegetables in the tropics and semi-tropics. Where genetic improvement is not the only answer, vegetable production issues are addressed through other means, such as better crop management practices or integrated pest management.

The yield of vegetables grown under the hot, wet conditions of the lowland tropics can be increased through better crop management practices. AVRDC develops and adapts technologies to meet the challenges of vegetable production under harsh conditions such as the lack of irrigation water, drought, flooding, pest and disease pressures, poor soil quality, etc. These crop management strategies include grafting (to increase tolerance to flooding and associated diseases), improved fertilizer application methods (to ensure the appropriate amounts of nutrients are available, appropriately placed and at the right time), practices such as mulching and the use of shelters and raised beds (to conserve soil moisture, prevent soil degradation especially during heavy rains and flooding, and to enhance soil fertility), and the use of efficient and appropriate irrigation systems that deliver water directly to plant roots (thus avoiding wastage and also reducing the prevalence of some diseases associated with flood irrigation).

AVRDC has developed grafting techniques that can mitigate the effect of excessive soil moisture and other soil stress conditions, as well as confer resistance to bacterial wilt. For example, extension of tomato production in the hot, wet summers in the lowland tropics has been facilitated by the use of rain shelters and the use of grafted tomatoes (tomato scions are grafted on to flood and/or bacterial-wilt-resistant tomato or aubergine (*Solanum melongena*) rootstocks).

The benefits of mulching on tomato have been demonstrated in Taiwan (8) using rice straw to protect the soil. This reduces both weed growth and conserves soil moisture. In India, Pandita and Singh (9) demonstrated the significant improvement due to mulching with polythene sheets on the growth of several vegetables such as okra, aubergine and a range of cucurbits. The benefits of mulching are therefore clearly demonstrated, but the most appropriate mulching material must be determined to suit specific needs and environments.

Vegetables, especially tomato, often incur substantial yield losses due to heavy rain during the hot, wet seasons. Plastic rain shelters prevent impact damage due to heavy rain on seedlings and particularly on flowers and young fruit. They also reduce waterlogging. This protection results in higher marketable yields (10). The improved drainage due to the use of raised beds can also minimize the effect of flooding on tomato yields (8).

The yield and quality of vegetable produce depend also on the efficiency of the water management around the plants. Inadequate, or too much water, results in plants succumbing easily to pathogen infection and nutritional disorders. With a micro-drip irrigation system, such as that developed by International Development Enterprises (IDE), water losses due to runoff or unnecessary deep infiltration are minimized. This cheap and simple irrigation system has been tested extensively and AVRDC now works closely with IDE and promotes this irrigation technology. Experiments have shown that the water-use efficiency of chilli pepper and other vegetables was significantly higher in drip irrigation compared with furrow irrigation (11).

Postharvest technologies to reduce produce losses

Vegetables are usually highly perishable and require careful handling. Additionally, their production is highly seasonal, often leading to over-supply, a consequent collapse of prices and then a scarcity of vegetables. Providing storage and processing technology options are measures that can expand the vegetable market, increase year-round availability and reduce excessive price fluctuations.

AVRDC conducts research on vegetable postharvest technologies to help small-scale producers overcome the constraints caused by the limited shelf-life of most vegetables, to better understand approaches and obstacles to enhanced market opportunities, and to contribute to policy-enabling environments.

An analysis of the quantity and value of losses along the vegetable supply chain in Vietnam, Cambodia and Laos PDR identified the major reasons for these losses among the major vegetable crops in the region. This knowledge made it possible for preventive measures to be instituted to help reduce postharvest losses. For selected vegetables, about 17% of harvested crop was lost due to postharvest problems, with farmers, among all actors in the supply chain, bearing the brunt of those losses. The middlemen and retailers were found to have more power over market prices (12) and less risk than the farmers, who generally had less information or knowledge and therefore lower capacity to deal with the postharvest issues.

The degree of perishability and susceptibility to postharvest stresses differ, depending on the prevailing environmental conditions. Although postharvest losses varied between the three countries, and between the different kinds of crops and the seasons under which the crops were grown, on average, it appeared that the vegetable industry in the three countries shares similar levels of postharvest losses. In all the countries, most of the supply-chain players complained that they incur huge losses with vegetables which are harvested at the mature-green stage, like tomatoes, due to shrinkage once the fruits have ripened, unlike chilli pepper which is harvested at fully ripe stage, or yard-long beans and cucumber which are harvested at the young stage and which incur fewer postharvest losses.

The loss of potential revenues associated with postharvest losses in vegetable crops is expected to impact the whole supply chain negatively, with the farmers prone to be exposed to the highest risk. In 2005, the total combined worth of vegetable production of the three countries amounted to US$2612 million. If postharvest losses and/or wastage are at the 17% level described above, this translates to about US$461 million loss of potential income. Losses are expected to increase when qualitative and nutritional reductions are factored into the estimation.

A number of causes of postharvest losses have been identified that could be resolved by both technological and non-technological interventions. For example, previous works on timing and methods of harvesting are still applicable to overcome current problems, while other technologies can be adapted to resolve specific problems. Some technologies depend on specific factors, such as type of crop, environmental conditions, etc., to be effective. The effectiveness of a technology in the country where it is intended to be used must be validated before it is recommended.

In Cambodia, Laos PDR and Vietnam, the farmers were aware of most of the existing postharvest problems and their solutions, and were able to exercise necessary precautions to avoid or minimize postharvest losses. For example, harvesting damage no longer seemed to be a major cause of postharvest losses. Disease problems were identified to be a significant cause of postharvest loss, but the farmers were unclear on which measures to apply to minimize the losses. This highlights the urgent need to give priority to research on disease control measures. Disease control measures that combine an integrated disease management approach with host plant resistance or tolerance (particularly against dormant infections such as anthracnose in tomato and chilli pepper) may be the answer to the problem.

Promoting vegetable consumption through school and home gardening and nutrition education

AVRDC promotes school gardens, home gardens and nutrition education as part of its activities to promote the production and consumption of indigenous vegetables, and has been particularly successful in Bangladesh, seven South-east Asian countries and sub-Saharan Africa.

Home gardens

The main purpose of the home garden as a vegetable production system is to enhance the availability and consumption of micronutrients, as well as to increase incomes and food security in areas where there is an insufficient or unreliable supply of food. The home garden system was adopted by approximately 10,000 resource-poor households in Africa in 2001–2005 and the feedback on these home gardening interventions indicates that home gardeners in sub-Saharan Africa can harvest 170–250 kg of nutritious vegetables annually from an average-sized home garden, providing an excellent alternative for food and nutrition security and income generation (13). Several short training programmes in home garden vegetable production, cropping patterns, utilization and the use of Healthy Diet Gardening Kits have been conducted in Kenya, Malawi, Mozambique, Rwanda, southern Sudan, Tanzania, Uganda and Zambia.

School gardens

Indigenous vegetables can play a major role in the diversification of diets, leading to a more balanced source of micronutrients. However, despite the recognized importance of indigenous vegetables in supplementing nutritional needs, they are underutilized. In a school garden project that promoted indigenous vegetables in the province of Laguna, the Philippines, children and their families were monitored to assess changes in knowledge, consumption and health between 2004 and 2006 as a result of participating in the school garden project. All selected children in three sites (two intervention schools and one control school) participated in surveys on knowledge on indigenous vegetables and their blood haemoglobin values were measured. Their household representative was interviewed for a 24-hour food recall. Schoolchildren who participated in the school garden project had a greater knowledge of indigenous vegetables and there was an increase in their overall vegetable consumption. The children in the intervention sites had higher blood haemoglobin levels after participating in the school garden project than children who did not. Households in the intervention sites were found to consume significantly greater quantities of vegetables compared with households in the control site. While there was no identifiable effect on the consumption of the indigenous vegetables that were promoted in the school gardens, there was a significant and positive effect on the overall vegetable consumption of households living in the intervention sites (14).

While the impact on parent knowledge was less, positive significant changes associated with participation of children in the school garden project were still found. For overall vegetable consumption, a significantly positive difference was found between control and intervention groups. Seasonal influences may have overlaid the impact of the project intervention, as may have the overall economic situation of households in the study area.

Training of women

In Tanzania, over 1000 women farmers were trained on vegetable production and utilization. Regular courses, held at least monthly, on good agricultural practices for vegetable crops, marketing and different recipes for cooking the vegetables were conducted at the Center's Regional Center for Africa (13).

Data from training of women in Cambodia, Lao PDR, the Philippines and Indonesia demonstrate the important role that women have in vegetable production. In Cambodia, 94% of women members of households grew the vegetables for family consumption. The participants could name 42 types of indigenous vegetables that they normally eat. The most commonly consumed indigenous vegetables are ivy gourd (*Coccinia grandis*), kangkong (*Ipomoea aquatica*), squash (*Cucurbita moschata*), amaranth (*Amaranthus* spp.), aubergine (*Solanum* spp.) and Malabar spinach (*Basella alba*). Jute (*Corchorus* spp.), which was known to Cambodia's neighbouring countries, was not familiar to the Cambodian women participants (15), confirming the understanding that the consumption of indigenous vegetables is often influenced by the cultural background as well as geographical location.

During training, the women participants learned better food preparation methods to enhance the availability of nutrients. In Lao PDR, women were taught how to prepare vegetables to increase the availability and absorption of vitamin A. Dr Bounthom Phengdy of the National Nutrition Program under the Ministry of Public Health claims that 59% of the mortality of Lao children under 5 years old is associated with malnutrition. Additionally, 30% of Lao women of childbearing age and 46% of children under 5 years of age suffer from anaemia. About 46% of the Lao population in general is deficient in vitamin A. Lao women usually cook leafy indigenous vegetables by boiling in water, but this does not maximize the availability of vitamin A as leafy vegetables should be cooked with oil to ensure that the vitamin A is readily available when consumed in the form of cooked vegetables.

Assessment of the in-country training for women showed that the participants gained new knowledge about indigenous vegetables and their dietary importance and potential. The participants learned the importance of the different indigenous vegetables not only as a source of food, but as a source of vitamins and essential minerals. The participants appreciated the need for proper treatment of vegetables during cooking in order to preserve the vitamins and minerals and to ensure their availability in the cooked foods (15). The women learned about home gardening and growing indigenous vegetables in their home gardens, as well as how to preserve seeds for future planting.

Training on development of recipes using nutrient-rich mungbean to enhance protein, iron bioavailability and to diversify cereal-based diets was conducted for the women farmer groups in Rajasthan, Bihar and Punjab. Nutritional studies in southern India showed that providing schoolchildren with an inexpensive mungbean/vegetable dish for lunch significantly improved the levels of iron in their blood (16). The effect of supplementation on haemoglobin levels, serum iron, serum ferritin and serum total iron-binding capacity were all significant. The effect on the change in haemoglobin level was highest for children who received a daily supplementation with β-carotene-enhanced mungbean preparation. For this group, the haemoglobin level after intervention was 0.8 g/dl higher than for the control group, indicating an average increase of about 10% in this group (Table 10.1).

Food scientists from Indian universities and AVRDC have developed recipes to enhance the bioavailability of iron using affordable vegetables; these high-iron mungbean recipes have been published and widely distributed in the region (17,18).

Development of indigenous vegetable and nutrition seed kits

Since a lack of seeds has been identified as one of the main reasons for the underutilization of indigenous vegetables, AVRDC's promotional activities include the development and distribution of Indigenous Vegetable Seed Kits in South-east Asia and Healthy Diet Gardening Kits in sub-Saharan Africa.

AVRDC has developed the Healthy Diet Gardening Kit for home gardens to promote micronutrient-rich indigenous vegetable crops such as *Amaranth* spp., African aubergine, nightshade, Ethiopian kale, jute mallow, spider plant, vegetable cowpea, okra, pumpkin, moringa and high-β-carotene and cherry tomatoes as well as other protein-rich crops like vegetable soybean and mungbean. The seed kits, each containing seeds of 14 nutrient-rich vegetable crops, have been

Table 10.1. Effects of supplementation on biochemical indicators. (Adapted from Vijayalakshmi *et al.* (16).)

	Hb (g/l)		Serum iron (μg/l)		Serum ferritin (μg/l)		TIBC (μg/dl)	
	Coeff.	*t* value	Coeff.	*t* value	Coeff.	*t* value	Coeff.	*t* value
Constant	0.37	1.49	23.91	0.37	–1.23	–0.39	136.43	0.83
Initial Hb level (g/dl)	–0.01	–1.77	0.17	0.28	0.06	1.94	–0.84	–0.55
Initial BMI	0.00	0.04	–2.24	–0.59	–0.07	–0.37	–11.89	–1.25
Member of TR (yes = 1)	0.34	15.59	19.29	7.01	0.62	4.67	–31.38	–4.51
Member of IR1 (yes = 1)	0.77	33.07	24.84	7.83	2.02	13.26	–56.44	–7.05
Member of IR2 (yes = 1)	0.79	35.92	27.22	6.81	2.06	10.72	–68.62	–6.80
Sex (girls = 1)	–0.07	–4.32	–5.86	–2.74	–0.28	–2.75	–1.17	–0.22
Age	–0.02	–1.03	–0.41	–0.09	0.10	0.45	–1.66	–0.14
R^2	0.91		0.87		0.94		0.85	
F value	305.12		23.75		52.81		18.98	
n	225		23		23		23	

Hb, haemoglobin; TIBC, total iron-binding capacity; TR, received a traditional preparation of mungbeans with low iron bioavailability; IR1, received a preparation of mungbeans and cabbage or tomato for a high iron bioavailability based on ascorbic acid; IR2, received a preparation of mungbeans and carrot for a high iron bioavailability based on β-carotene.

distributed to about 10,000 poor households in Kenya, Malawi, Mozambique, Rwanda, southern Sudan, Tanzania, Uganda and Zambia since 2001. The feedback indicates that many African farmers have adopted the Healthy Diet Gardening Kit system which has helped them to produce vegetables for home consumption, thus providing the households with many essential micronutrients (13).

Under the Seed Village Program and through demonstrations, about 500 summer mungbean seed kits (for one acre each) have been distributed to farmers in Punjab, Rajasthan and Bihar since 2005. This is an important step to improve the bioavailability of iron and protein in these areas of India. To ensure further improvements in food and nutrition security in South Asia and Africa, Healthy Diet Gardening Kits must continue to be promoted and popularized to contribute significantly to ameliorating micronutrient malnutrition.

AVRDC's seed kits are useful and popular after natural disasters. After any natural disaster, vegetables usually become unavailable to the survivors both as a result of destruction of the crops in the field and due to poor infrastructure after the disaster which prevents transportation and marketing of any vegetables that are available. Emergency food relief attempts are often focused on providing basic staple foods to prevent hunger. The tsunami of 26 December 2004 was one of the deadliest natural disasters of recent times in South and South-east Asia. AVRDC responded to the tsunami by distributing 50,000 vegetable seed kits to the survivors in Sri Lanka and Indonesia. This response was based on AVRDC's positive responses to distributing kangkong and other vegetable seeds to families affected by severe floods in Bangladesh in 1998 (19). The kits distributed to the tsunami victims included vegetable varieties which quickly produced both nutritious and marketable vegetables (e.g. water convolvulus, peppers and pak-choi), fertilizers and hoe heads. The effort was expected to increase the availability of vegetables in a very short period to provide the much-needed addition of micronutrients to the basic staples provided by emergency food relief. Many recipients of the vegetable seed kits were able to generate income by selling the surplus produce.

The Center's indigenous vegetable activities have also attracted disaster relief interest in the Philippines, where indigenous vegetable seed kits were provided to 50 families of displaced gold panners in Pangasinan Province and families affected by landslides in Quezon Province.

Improving Nutrient and Phytochemical Density

Collection and evaluation of vegetable genetic resources including indigenous vegetables

AVRDC has long recognized the potential of indigenous vegetables, as well as the diversification of the agricultural environment to contribute to the alleviation of poverty and for improving nutrition. Indigenous vegetables are part of the AVRDC's list of priority germplasm for collection, evaluation and utilization. Over 55,000 accessions of seed, leafy and fruit vegetable germplasm have been assembled, of which about 12,000 accessions belong to more than 200 species of indigenous vegetables originating from Africa and the South and South-east Asian countries. The collection is housed in the genebank at AVRDC Headquarters and also in its Regional Center for Africa. It is being characterized and evaluated for the potential of the accessions to improve nutrition and contribute to farm productivity. In the case of exotic vegetables, promising accessions are evaluated for incorporation of traits through the respective breeding activities. Indigenous vegetables and promising lines are evaluated further for agronomic and nutritional qualities and pest and disease resistance.

Identification and promotion of underutilized indigenous vegetables high in nutrients and bioactive compounds

The large collection of vegetable germplasm in AVRDC's genebank provides an opportunity to identify nutrient-rich germplasm. Initially, some of the indigenous vegetable species were evaluated for antioxidant activity, oxalate (anti-nutritional factor), vitamins A, C and E, and the minerals calcium and iron (20). Chinese cedar (*Toona sinensis*) was identified as a highly nutritious vegetable with a high (18.6 mg/100 g) β-carotene content, and high levels of iron (8.65 mg/100 g) and vitamin E (29.3 mg/100 g). The β-carotene content of Chinese mahogany was twice that found in jute (9.46 mg/100 g) and Jew's mallow (*Corchorus olitorius*; 19.6 mg /100 g). Jute was also shown to be a good source of vitamin C (500 mg/100 g fresh weight), as were Jew's mallow (480–610 mg/100 g fresh weight) and baobab tree (*Adansonia digitata*; 350 mg/100 g fresh weight). Different species of vegetables indigenous to Asia show a wide range of antioxidant activity. There was more than a 1000-fold difference in antioxidant values among 125 edible plant species. Species high in antioxidant activity include Chinese cedar, Damocles tree (*Oroxylum indicum*), rue (*Ruta graveolens*), cassod tree (*Cassia seamea*), sickle senna (*Cassia tora*) and sweet potato (*Ipomoea batatas*) leaf. Different accessions within the species also show a wide range of antioxidant activity, thus confirming the need to select and promote species, and lines within the species, that have higher nutritional values including high antioxidant activity for improving diets.

In Tanzania, indigenous vegetables form a substantial proportion of the diets of most of the low- to middle-income group because indigenous vegetables are inexpensive and easily accessible. However, many indigenous vegetables are still gathered from the wild and only a few have been domesticated or described. Micronutrient dietary deficiencies that lead to nutritional disorders are still common in Tanzania. It is therefore important to identify indigenous vegetables and food preparations that have great potential with regard to such micronutrients. A study was undertaken to investigate the micronutrient content of commonly consumed indigenous vegetables in several localities in Tanzania. This was to identify those that are rich in micronutrients known to be commonly deficient in the diets of many local people. These deficient micronutrients included minerals (iron and zinc) and β-carotene (a common precursor of vitamin A). Commonly utilized indigenous vegetables from three rural districts of Kongwa, Muheza and Arumeru in Tanzania were analysed for iron, zinc and β-carotene content. African spider plant (*Cleome gynandra*), bitter lettuce (*Lactuca virosa*) and amaranth have a high iron content (of up to 49.95 mg per 100 g edible portion), while pumpkin (*C. moschata*) leaves, puncture vine (*Tribulus terrestris*), cassava (*Manihot esculenta*) leaves, amaranth and cape myrtle (*Myrsine africana*) have a high zinc content (up to 1.63 mg per 100 g edible portion). The highest content of β-carotene was found in African spider flower, puncture vine and cassava leaves (up to 16.13 mg per 100 g edible portion). However, while the analysed samples contained high levels of the nutrients, there were large variations within the species. These variations may be caused by genetic or environmental factors or by genotype and environment interactions, and there is need for careful and detailed analyses and selection of appropriate lines for promotion as sources of micronutrients.

Breeding to increase content of nutrients and bioactive compounds

Nutrient contents of vegetables vary greatly. Tomato, pepper, onion (*Allium* spp.), cabbage (*Brassica* spp.) and cucumber (*Cucumis sativus*) are the more commonly consumed vegetables in the world; even modest improvements in their micronutrient densities would benefit human health. Vegetable breeding can increase the nutrient content and concentration of bioactive compounds in vegetables, thus developing lines which will be of greater benefit for alleviating micronutrient malnutrition (20).

High-β-carotene tomato

Tomato can be an important source of provitamin A if consumed in sufficient quantities. An increase in the β-carotene content of the tomato fruit by genetic enhancement could contribute significantly to better nutrition. Using a single gene called *Beta* that originated from wild tomato, AVRDC has developed high-β-carotene cherry and fresh market tomato lines. The β-carotene content of the orange-fruited high-β-carotene tomatoes ranges from 3.81 to 6.55 mg/100 g fresh weight compared with 0.60–0.90 mg/100 g for the common, red-fruited tomato. Heat tolerance and multiple disease resistance have been bred into the high-β-carotene lines for tropical adaptation, and this high-β-carotene tomato is being actively promoted for home and school gardens.

High-antioxidant solanaceous crops

Tomato and pepper are both important sources of antioxidants, including carotenoids, vitamin C and phenolics. AVRDC has designed breeding strategies to increase the concentrations of antioxidants in these crops. The highest levels of lycopene, vitamin C and phenolics, as well as the greatest solids content, were found in the small-fruited wild relative of tomato, *Solanum pimpinellifolium* (21). Interspecific crosses are being made with *S. pimpinellifolium* to introgress alleles that improve lycopene and vitamin C content in cultivated tomato. Antioxidant activity in tomato is highly correlated with the total phenolics content and AVRDC's breeding programme is investigating strategies to increase the total phenolics content of the fruit. Within the pepper species, significant genetic variation has been identified for capsanthin, zeaxanthin, lutein, β-cryptoxanthin, β-carotene, ascorbic acid, total phenolics and α-tocopherol. The highest levels of provitamin A carotenoids were found in the brown-fruited lines. Among the red-fruited peppers, several entries of the Ancho types from Mexico ranked among the highest for all carotenoids, vitamin C, α-tocopherol and total phenolics (21). Genetic studies are in progress at the Center to understand the inheritance of specific pepper antioxidants and facilitate the development of high-antioxidant solanaceous crops. Within the 150 edible plants from 127 species evaluated for antioxidant activities, it is clear that the distribution of antioxidant activity is highly skewed. Based on data from AVRDC, most of the species containing high levels of antioxidants are Asian perennial and locally utilized vegetables, which are also rich in total phenolic compounds, suggesting great potential to increase antioxidant consumption by including Asian native or underutilized vegetables in the diet (22). Several plant species including Chinese cedar, moringa (*Moringa oleifera*), sweet potato and amaranth were among the most promising species for promotion to ameliorate micronutrient malnutrition due to their ease of production, high antioxidant levels, high micronutrient and phytochemical contents, marketing attributes, processing properties and palatability.

Enhancing the Bioavailability of Nutrients

Absorption of plant-based non-haem iron, although variable (2–15%), is lower than that of haem iron from meat (~25%) and such absorption is more subject to factors like those affecting interactions with enhancers and inhibitors. Populations in developing countries with limited resources consume more plant-based food than the usually more expensive animal-source foods. Although total iron intake from vegetables and other plant-based sources may meet dietary recommendations, iron deficiency may still be prevalent due to the low bioavailability of plant-based iron. Vegetables in which the level of iron bioavailability is relatively high include tomato and pepper, and efforts are continuing to further improve the bioavailability of iron in plant-based diets.

Better food preparation can enhance iron bioavailability in iron-deficient populations. AVRDC groups vegetables into three categories which reflect the iron bioavailability before and after cooking (23): (i) those which have a low iron bioavailability when raw, but higher after cooking, such as cruciferous vegetables and amaranth; (ii) those with low iron bioavailability both before and after cooking, such as mungbean and kangkong; and (iii) those with high iron bioavailability before and after cooking, such as tomato, pepper and ginger. However, the prolonged storage of cooked vegetables reduces the bioavailability of iron.

Cooking can double or even increase tenfold the iron bioavailability of some vegetables. The bioavailability-enhancing effect of cooking can be achieved with different heating processes including boiling, stir-frying and hot-air drying. The iron bioavailability-enhancing effect of cooking is independent of the vegetable vitamin C content. In the case of cabbage, the cooking effect is due to the reduction of iron–polyphenol interactions which commonly occur during plant cell destruction. The nature of the enhancing factors in these vegetables is similar to the effect of ethylenediaminetetraacetic acid (EDTA) which stabilizes iron when it is released from cells.

The effect of cooking in enhancing iron bioavailability can be extended to vegetables with low iron bioavailability and to legumes, by adding vegetables with high iron bioavailability, such as tomato and moringa, during cooking (24). High-iron mungbean recipes were designed accordingly for South and North India (17,18). Dishes were selected and modified based on the availability and prices of ingredients in local markets. In a one-year trial with schoolchildren (16), in collaboration with the Avinashilingam Institute for Home Science and Higher Education for Women in southern India, mungbean supplementation improved health parameters (clinical signs, body weight index, haemoglobin level and productivity). Haemoglobin levels increased by 0.8 g/dl for children eating recipes designed for higher iron bioavailability while those eating traditional mungbean recipes still had an increase of 0.3 g/dl in haemoglobin levels. Promoting dishes and recipes with a higher iron bioavailability based on mungbean appears to be a viable strategy to enhance body iron stores in regions where diets are predominantly vegetarian and the inclusion of animal products into diets is not feasible. Opportunities to promote the modification of existing preparation practices, i.e. through nutrition education and local media, can be used to reach a large number of households. However, while there was an improvement in haemoglobin levels through these recipes, and it is clear that a food-based approach with a cost-effective plant-based diet can improve iron deficiency, complementary dietary strategies including the consumption of animal-source foods are needed to resolve severe anaemia. Complementary approaches required are iron supplementation for people with severe anaemia, home fortification for population groups at high risk of anaemia (pregnant women, children aged 6–23 months), and food-based approaches including fortification of staples and condiments for the prevention of anaemia at population level.

The productivity of households engaged in agricultural labour in India, measured by wages and income, is affected by insufficient iron intake. Wages would on average be 5.0–17.3% higher if households achieved recommended iron intake levels (25). Enhancing micronutrient intake can contribute significantly to the overall economic growth and development of any region – as clearly illustrated in India.

Assessment of Health and Economic Benefits

Evaluation of agricultural research often neglects consumption and nutrition aspects, yet agricultural research can address micronutrient malnutrition by improving both the quantity and quality of food intake. AVRDC has reviewed the conceptual linkages between agriculture and nutrition to estimate the strength of the relationship between iron intake and productivity outcomes, and to estimate the nutritional benefit of improved mungbean varieties in terms of net present value.

AVRDC has developed a methodology for assessing the nutritional impact of mungbean, and summarized for evidence impact on the steps from mungbean research to consumption (26). A food consumption study among female piece-rate workers in Pakistan to analyse the impact of iron consumption on productivity, measured in wages, showed that anaemia among women was widespread. Approximately two-thirds of women suffered from mild or severe anaemia (Hb <12 g/dl). The elasticity of bioavailable iron on productivity measured in wages was 0.056, and the marginal effect was 9.17 Pakistani rupees per additional milligram of bioavailable iron consumed. In this study, iron intake was measured as intake of bioavailable iron, based on the method proposed by Bhargarva *et al*. (27). This is estimated based on total iron intake and haem iron is assumed to constitute 40% of iron from meat, fish and poultry. An enhancing factor is then calculated based on the intake of ascorbic acid and corrected for phytate intake. Using the model results, the estimated impact of mungbean research on nutrition, in terms of productivity effects, was found to be substantial, ranging from US$7.6 to 10.1 million cumulative present value (in 1995 US$ at 5% discount rate).

Agriculture plays an important role in the reduction of malnutrition. Agricultural research has greatly contributed to the reduction of hunger and starvation by providing millions of hungry people with access to low-cost starchy staple foods. As the challenge shifts to the reduction of micronutrient deficiencies, more efforts must be directed toward crops high in micronutrients, such as pulses and vegetables.

The 'nutrition transition' which occurs with development has reached developing countries and is contributing to a fast change in food habits. Indigenous or traditional vegetables are declining in importance in the diet, particularly in wealthier, urban areas. Weinberger and Swai (28) showed that the share of indigenous vegetable consumption to total vegetable consumption is much higher among poor households (approximately one-third) than among the wealthiest households (approximately one-fifth). The variety in consumption of indigenous vegetables decreases as households become wealthier, while, at the same time, the variety in consumption of exotic vegetables increases. By valuing collected indigenous vegetables produced in local gardens at market prices, Weinberger and Swai (28) found that, in the poorest group of households in the surveyed areas in Tanzania, approximately 8% of all food value consumed comprises indigenous vegetables, the average share for all households being only 4.8%.

Poor households, in particular, rely on the consumption of indigenous vegetables to help provide their daily requirements of micronutrients, especially vitamin A and iron. In poor households, approximately a quarter of all vitamin A requirements and 11% of iron requirements are provided by indigenous vegetables. Thus, while indigenous vegetables are not a panacea for the complete elimination of micronutrient deficiencies, they do have an important role to play in raising levels of micronutrient consumption in low-income societies.

Not only are indigenous vegetables an important subsistence crop for poor consumers, they can also provide good opportunities for commercialization if properly exploited. A study from Tanzania found that approximately 40% of all produce consumed by wealthy households is acquired through the market (28). For instance, traditional African aubergine has now acquired commercial status in Arusha and is sold in supermarkets and also transported to markets as far away as Dar-es-Salaam. Indigenous vegetables can usually be harvested over a longer period of time than exotic types. Under good management, African aubergine and amaranth selections can be harvested year-round and can be useful to compensate for price fluctuations. Input requirements for indigenous vegetables are also comparatively low relative to the production of exotic vegetables; for example, pesticides are rarely used in the production of indigenous vegetables but they are necessary to produce exotic vegetables. In order to tap the potential of indigenous vegetables for the benefit of small-scale, resource-poor farmers, it is essential that future research specifically incorporates the needs of these farmers (28,29). This particularly relates to the selection of improved lines with traits that are important for small-scale farmers. Indigenous vegetables enjoy the advantage of being produced with relatively low levels of inputs and thus with low capital risk; it is unlikely that farmers will change this production pattern in the short term. Thus, selecting indigenous vegetable lines that require an intensive input regime will generally be less attractive to farmers. More emphasis is needed on seed production, to make high-quality seed of indigenous vegetables available to small-scale, resource-poor farmers. Private seed companies usually have little interest in indigenous vegetables because domestic markets for such vegetables are perceived to be small. However, in partnership with both the public and private sectors, AVRDC is tackling this major constraint for the wider production of high-quality seed of indigenous vegetables, particularly in sub-Saharan Africa.

Clearly, traditional or indigenous vegetables are very important in resource-poor communities; thus preserving biodiversity and indigenous knowledge on production and consumption, while improving lines and cultivation practices, will contribute to the well-being of poor farmers by enabling them to participate in markets as well as contributing to the health of their households through increased consumption and thereby alleviating micronutrient malnutrition.

Conclusions

AVRDC develops vegetable lines and other technologies that lead to increases in vegetable production and consumption in developing countries. Vegetables are the most affordable source of micronutrients and health-promoting phytochemicals. Changing consumption practices is only one of several components of a food-based approach to combat micronutrient malnutrition; this can be advanced using nutritional education and mass communication technologies. Other components of such a strategy include a focus on improved production technologies for vegetables, as diversity in vegetable consumption increases when production of vegetables increases (30–32). Billions of people are still undernourished and could benefit from increased vegetable production and consumption. Greater attention and emphasis should be given to horticulture as an engine of economic growth and as a means to better diets and nutrition to bring greater and lasting benefits to the poor.

Terminology

- *Allele*: one member of a pair or series of different forms of a gene.

- *Furrow irrigation*: irrigation method in which water travels through the field by means of small channels between each group of rows.
- *Germplasm*: genetic resources for an organism. For plants, the germplasm may be stored as a seed collection in a genebank or, for trees, in a nursery.
- *Grafting*: a method of asexual plant propagation where the tissues of one plant are encouraged to fuse with those of another.
- *Indigenous vegetables*: vegetable crop species that are native to a particular environment, or introduced historically to a region from other geographical areas, and are regarded as underutilized crops.
- *Introgression*: the movement of a gene from one species into the gene pool of another by backcrossing an interspecific hybrid with one of its parents.
- *Micro-drip irrigation*: a water-saving irrigation technology which enables slow and regular application of water directly to the roots of the plants through a network of economically designed plastic pipes and low-discharge emitters.
- *Molecular marker-assisted selection*: a breeding process whereby a DNA/RNA variation-based marker is used for indirect selection of a genetic determinant or determinants of a trait of interest.
- *Mulching*: putting a protective cover over the soil, primarily to modify the effects of the local climate by conserving soil moisture and moderating soil temperature.

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11 Introducing Vegetables into the India Mid-day Meal (MDM) Programme: the Potential for Dietary Change

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Abstract

Adequate nutrition is crucial during childhood and a diet rich in micronutrients is vital for good physical growth and mental development and prevention of infectious diseases. Fruits and vegetables are a vital part of a balanced diet and a good source of vitamins and minerals, including vitamin A. Schools are increasingly recognized as important settings for promoting healthy nutrition and eating practices in children.

This chapter reviews recent research from Africa and Asia on the effectiveness of food-based interventions to combat vitamin A deficiency. A few recent studies suggest that schools in developing countries can effectively channel nutrition support to a critical target group of children, using dietary solutions to improve vitamin A status. An outstanding question remains how such potentially life-giving dietary changes can most effectively be promoted and maintained on a larger scale.

To respond to this question, this chapter also reviews current literature on school-based fruit and vegetable initiatives in developed and developing countries. Using country-based data, it then outlines the process and results of a pilot intervention carried out in urban Indian schools in the Municipal Corporation of Delhi to promote increased vegetable consumption through the Mid-day Meal (MDM) programme and create awareness among teachers and children on the health benefits of vegetables. Despite limitations in the intervention design, many lessons can be learnt from this pilot intervention. It shows that the introduction of vegetables into MDM is feasible and sustainable, provided that adequate funds are allocated. If used effectively, the MDM can become a major tool for improving vegetable consumption among school-aged children in urban and rural India.

Key words: India, schoolchildren, Mid-day Meal, vegetables, vitamin A, nutrition education

Introduction

Adequate nutrition is crucial during childhood and a diet rich in micronutrients is vital for good physical growth and mental development and prevention of infectious diseases. There is some evidence to suggest that a good-quality diet, with plenty of vegetables and fruits, during childhood and adolescence may also protect against chronic diseases such as heart disease and some cancers in later life (1,2). The need to increase vegetable and fruit consumption by children is currently receiving much attention owing to their known

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beneficial effects on health (3). Schools are one favoured location for these interventions.

This chapter first reviews the current literature on school-based fruit and vegetable initiatives and then outlines the process and results of a pilot intervention carried out in a small number of urban Indian schools in the Municipal Corporation of Delhi (MCD) to promote increased vegetable consumption through the Mid-day Meal (MDM) programme and to create awareness among teachers and children on the health benefits of vegetables.

The Role of Vegetables and Fruit in Nutrition and Health

It is well accepted that vegetables and fruit are a vital part of a balanced diet. They are good sources of a range of vitamins, minerals, phytochemicals and dietary fibre and they play an important role in preventing and controlling micronutrient deficiencies, including deficiencies in vitamins A, B (folate), C and E. Vegetables and fruit, owing to their high natural vitamin C content, can help alleviate iron deficiency by boosting the absorption of non-haem iron from plant-source foods (4). Yellow/orange fruits and vegetables (e.g. carrot, pumpkin, papaya and ripe mango) and dark-green leafy vegetables, including indigenous vegetables, are rich in provitamin A carotenoids, which the human body can convert into the active form of vitamin A provided there is adequate fat in the diet. While it is understood now that the bioavailability of provitamin A carotenoids in plant foods is significantly lower than indicated several decades ago (i.e. it requires not six but 12 molecules of β-carotene in the diet to make one molecule of vitamin A) (5), evidence from around the world shows that provitamin A-rich vegetables and fruit can make a valuable contribution to vitamin A intakes and improve the vitamin A status of children in communities where animal-source foods and/or fortified foods are infrequently consumed or beyond the reach of poor people. Recent worldwide hikes in food prices are putting animal-source foods even further beyond the means of economically disadvantaged households (6). It is also likely that the diet consumed early in life, in particular high consumption of fruits and vegetables, can influence the risk of stroke and coronary heart disease in later life and reduce the prevalence of obesity, high cholesterol and high blood pressure as well as the risk of cancer (1,2). Thus, the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) recommend a minimum of 400 g of fruits and vegetables per day (7), while the World Cancer Research Fund says that this amount should be raised to 600 g (8).

Average intakes of fruit and vegetables throughout the world are however still much below the recommended population intake goal, while in developing countries the situation is critical. A recent study using data from the WHO 2002–2003 World Health Survey (200,000 people from 52 developing countries) (9) indicates that 78% of respondents from mainly low- and middle-income countries consumed less than the recommended daily minimum (400 g) – too few to maintain health and prevent disease – with the poorest populations showing the lowest consumption.

Effectiveness of Food-based Approaches in Addressing Vitamin A Deficiency

In view of the critical role of vitamin A in protecting health, the effectiveness of food-based approaches in improving vitamin A status is of particular interest. Recent research from South Africa and Mozambique demonstrates that horticultural interventions such as home and community gardens, backed up by nutrition education, can successfully increase the dietary intake of vitamin A-rich plant foods and result in a significant reduction in the prevalence of vitamin A deficiency in preschool children (10,11). Research from South Africa and the Philippines indicates that the provision of β-carotene-rich plant foods can increase the vitamin A status of school-aged children. A randomized controlled trial implemented in South Africa showed that orange-fleshed sweet potato was accepted well by primary-school children and improved their vitamin A status when given as part of the school meal (12). In the Philippines, the consumption of carotene-rich yellow and green leafy vegetables improved the vitamin A status of school-aged children, with only a small amount of dietary fat (i.e. 2.4 g/meal × 3 meals/day; total of 21 g/day[1]) needed for optimal utilization of plant provitamin A carotenoids (13). The community-based studies underline the importance of diversifying food availability and improving access through horticultural interventions in contexts in which food insecurity is a major constraint to increased consumption. The results from the South African and Philippines studies confirm that schools in developing countries can effectively channel nutrition support to a critical target group of children. An outstanding question is therefore how such potentially life-giving dietary changes can most effectively be promoted and maintained.

Schools as Entry Points for Dietary Diversification and Behaviour Change

Schools are increasingly recognized as important settings for promoting healthy eating practices in children (14–17). The first reason is the urgent need to improve the quality of school-aged children's diets. Undernutrition and micronutrient deficiencies continue to impede child growth and development when children reach school, reduce children's capacity and motivation to learn, and lead them to drop out of school early (18,19). Children are current and future consumers and need dietary guidance to create lifelong healthy eating habits. A second reason is the high potential for effective intervention in real-life settings. Nutrition education, the promotion of healthy diets in school, abundant (often free) fruits and vegetables in school meals, parental involvement and practical food and nutrition-related activities in the school environment, such as food gardening or food preparation, can demonstrably increase young people's knowledge and improve their dietary habits and nutrition status; in particular, they can encourage them to eat more fruit and vegetables (11,12,20–22).

Multi-component approaches are particularly effective (3,23). For example, reviews of school fruit and vegetable schemes in developed countries (3,23) suggest that fruit and vegetable promotion schemes are likely to result in significantly increased intakes among children if programmes are associated with a mix of components including: promotion in the canteen and around school through school meal modification; practical learning by preparation skills and tasting (as opposed to traditional lectures); special training of teachers and peer leaders; active participation of school food personnel; involvement of parents at school and at home; and a sufficiently long period of implementation and follow-up (at least 12 months) (3). The influence of hands-on food gardening, together with nutrition education, on consumption of fruits and vegetables is particularly interesting in that the research findings support intuition rather than logic. Growing food and preparing it oneself does not necessarily increase its nutritional value and there is no logical reason why this should make children like and value it more; the persuasive factors appear to be deeper: psychological investment, familiarity and ownership (21).

A third point is sustainability (20). As eating habits are learned early and childhood diet is a significant determinant of consumption patterns in adulthood, school-based interventions, reinforced by nutrition education, can also create long-term dietary behaviour change by increasing opportunities for children to access fruit and vegetables and making them aware of the significance of fruit and vegetable intake at an early age, provided that programme implementation is continued for several years (3,22).

[1] Self-selected snacks contributed additional dietary fat which were not eaten during meals, so that the total fat intake for the study group with low fat intake was 21 g/day, providing 12% of total dietary energy intake. The study concluded that it is possible to improve the total-body vitamin A pool size and restore low liver vitamin A concentrations to normal concentrations by eating sufficient amounts of carotene-rich yellow and green leafy vegetables and minimal amounts of dietary fat.

The FAO Curriculum Concept and Learning Approach

There are compelling reasons for developing effective strategies to reach school-aged children through their daily diet. The concept of nutrition education adopted by FAO reflects these considerations. It is embodied in the publication *Nutrition Education in Primary Schools: A Planning Guide for Curriculum Development* (17), which extends to nutrition education the WHO concept of the health-promoting school (24). This assumes that health and diet are above all a way of life, centred on the child and learnt in all the contexts of a child's life. To be effective, nutrition education should be part of a 'whole school' approach that involves not only the classroom, but also the whole school environment as well as the family and community (25). An action-oriented, rather than an exclusively knowledge-based, food and nutrition curriculum can be linked to the school environment, which can offer ample scope for making healthy dietary choices through the provision of healthy school meals and tuck shops offering a variety of food choices; clean water and sanitation; and for learning practical skills, such as growing, harvesting, processing and preparing micronutrient-rich food. Families and communities can provide help in preparing and serving school lunches and running school gardens, and (together with the school) can be regarded as part of the learning community. Fresh vegetables and fruits are also procured from local agricultural producers and food suppliers, thus offering opportunities for local farmers and suppliers to benefit from increased incomes by creating effective demand.

Interventions aimed at enhancing schoolchildren's dietary status take many forms and operate at many levels. In respect of fruit and vegetable consumption, for example, different programmes have variously aimed at, monitored and evaluated the following objectives or outcomes:

1. Vegetables and fruit are abundant, varied and available at school through the year.
2. School meals are balanced and incorporate a range of micronutrient-rich vegetables and fruit in appropriate quantities.
3. Children, families, teachers and school food service providers understand the nutritional value of vegetables and fruit and their role in the diet.
4. Children, families, teachers and school food service providers value and express more preferences for vegetables and fruit (preferences go beyond knowledge and understanding).
5. Vegetables and fruit are regularly consumed at school in appropriate quantities and variety as part of diet (practices are not the same as values and preferences).
6. School vegetables and fruit snacks are available and are increasingly chosen by children.
7. Home diet improves, incorporating more vegetables and fresh fruit.
8. Children's micronutrient status improves measurably during the programme.
9. New dietary habits at school, home and in snacking are maintained.
10. Improved micronutrient status is maintained.

From a research point of view, actions 1 to 5 are stages on the path to outcomes 6 to 10. Nevertheless, they cannot be neglected: they present challenges which must be tackled in order to prepare the ground for substantive research which will demonstrate the potential feasibility of such initiatives to policy and decision makers for expansion and broad-scale implementation.

Nutrition in India

Currently there is little research from developing countries that assesses the feasibility and effectiveness of real-world school-based vegetable and fruit promotion. Thus it is all the more valuable to have a study of the MDM programme from India, where vegetable consumption among all segments of the population is very low.

During the last two decades there has been rapid economic growth in India; however, this has not resulted in a commensurate decline in undernutrition or of micronutrient deficiencies. Despite steady economic growth of an average of 6% in the past 15 years, the percentage of children under 3 years of age who are underweight fell by only 6 percentage points between 1993 and 2006, from 52% to 46% (26). Micronutrient deficiencies, particularly of iron, folate and vitamin A, continue to be widespread among rural and poor urban populations. Lack of dietary diversity is partly due to poor access to vegetables and fruits and other micronutrient-rich foods at affordable cost throughout the year, and partly to lack of knowledge and awareness about the nutritional value of horticultural crops, as well as repeated infections, and is a major factor in the high prevalence of micronutrient deficiencies (27). Concurrently there appears to be a slow but progressive increase in overweight and obesity, possibly resulting from a steep reduction in energy expenditure due to increasing mechanization of transport, occupational and household work and some increase in the consumption of energy-dense foods (27). As these foods are often low in vitamins and minerals, even overnourished persons may suffer from anaemia and micronutrient deficiencies.

Indian diets

Indian diets are predominantly cereal-based with rice and/or wheat as the main staple food(s), complemented by pulses, vegetables, some milk and other dairy products. Production of milk and other dairy products has risen significantly in the last two decades (27,28) and per capita annual milk availability doubled between 1980 and 2005. Despite this increase in overall availability, intakes of milk and dairy consumption have remained low among the poor, especially in rural areas (29). Consumption of meat and meat products that are rich in iron, zinc and vitamin A (mainly liver) has also remained very low: at an estimated 5.2 kg per capita in 2005, it constitutes one of the lowest average per capita consumption levels worldwide compared with 59.5 kg per capita in China. The reasons for this are partially cultural as well as economic and therefore consumption of animal-source foods is likely to grow only slowly.

India is ranked as one of the world's biggest producers of horticultural produce, growing nearly 11% of the world's vegetables and 15% of all fruit (29). Despite steadily growing availability nationally (Table 11.1), actual consumption of vegetables and fruit, the main sources of vitamin A in populations that depend largely on plant-based diets, is very low among both adults and children (30,31) (see Tables 11.2 and 11.3).

There is evidence that the entire family's diet, including pre-school children's, schoolchildren's and women's diets, are low in vegetables and fruit in both rural and urban populations (30–32). Data from the National Consumer Expenditure surveys carried out by the National Sample Survey Organization further confirm that consumption expenditure on vegetables and fruits is low, with the exception of urban areas and among affluent consumers, where fruit consumption expenditure is higher (33).

In addition to economic factors and physical access to vegetables and fruit through markets, poor awareness about what constitutes a healthy diet is an important factor determining dietary patterns (34), suggesting that the Indian population is not aware of the health benefits of eating adequate amounts of vegetables and fruit.

To address micronutrient deficiencies, the Indian Government has adopted a multipronged strategy, which includes dietary diversification through improved access to vegetables and fruits at affordable prices, micronutrient supplementation for vulnerable groups like pregnant women and pre-school children, and food fortification such as the addition of iron and iodine to common salt. In addition, dietary diversification is to be accompanied by effective nutrition information and education to promote improved dietary practices and nutritional intakes, especially for young children (35).

Table 11.1. Per capita availability (g/day) of fruits and vegetables. (Data from FAOSTAT – Food Balance Sheets: 1990–2003 (28).)

	1990	2000	2003
Fruits	76	95	101
Vegetables	145	178	186

Table 11.2. Average intake of foodstuffs (g/day per consumption unit). (Data from India Nutrition Profile (INP), 1998 (31).)

	Area	Cereals	Pulses & legumes	GLV	Roots & tubers	Other veg.	Fruits	Condiments & spices	Flesh foods	Milk & milk products	Fats & oils	Sugar
RDA		460	40	40	50	60				150	20	30
Delhi	C	366.0	66.6	17.5	125.0	63.9	49.3	12.6	16.7	169	24.1	25.9
	R	484.3	86.6	6.1	163.2	7.3	55.3	11.2	0.9	115	43.9	17.6
	U	361.4	65.9	18.0	123.5	66.1	49.0	12.6	17.3	171	23.3	26.2
INP	R	488	33	32	108	70	15			143	14	
	U	420	55	23	120	75	37			126	14	2

GLV, green leafy vegetables; RDA, Recommended Daily Allowance; C = combined; R = rural; U = urban.

Table 11.3. Dietary intakes (g/day) by age and sex. (Data from India Nutrition Profile (INP), 1998 (31).)

Age group/ sex	Cereals	Pulses	GLV	Roots & tubers	Other veg.	Fruits	Condiments & spices	Flesh foods	Milk & milk products	Fats & oils	Sugar
1–3 years											
Boys	182.9	14.5	17.2	41.4	29.0	10.1	4.5	20.6	97.4	6.5	12.7
Girls	185.2	14.5	19.0	40.0	29.3	10.6	4.3	24.1	92.5	6.2	12.0
RDA	120	30	50	50	50	100			500	20	25
4–6 years											
Boys	265.2	20.2	21.9	62.3	40.7	13.8	6.2	20.5	93.8	9.2	13.2
Girls	269.7	20.1	24.3	59.7	40.0	11.8	6.4	23.0	85.9	8.5	13.6
RDA	210	45	50	100	50	100			500	25	30
7–9 years											
Boys	327.9	23.9	22.6	72.4	50.6	12.9	7.3	22.4	92.9	10.0	14.7
Girls	321.4	24.2	28.2	69.3	49.7	11.8	7.1	23.0	90.5	9.8	14.1
RDA	270	60	100	100	100	100			500	25	30
10–12 years											
Boys	384.9	28.8	28.8	84.3	57.1	15.6	8.8	20.9	96.7	11.0	15.9
RDA	330	60	100	100	100	100			500	25	35
Girls	373.8	26.7	27.3	80.3	53.8	15.4	8.9	22.2	94.2	11.0	15.4
RDA	270	60	100	100	100	100			500	25	30
13–15 years											
Boys	453.2	32.6	33.4	93.6	67.0	16.4	10.1	27.0	108	13.0	17.4
RDA	420	60	100	100	100	100			500	25	35
Girls	437.6	32	38	88.2	60.8	15.5	9.5	33.9	100	14.0	16.5
RDA	300	60	100	100	100	100			500	25	30
16–17 years											
Boys	530.1	38.0	45.4	98.0	78.9	19.1	11.2	46.9	113	14.0	18.3
RDA	420	60	100	100	100	100			500	25	35
Girls	484.7	34.8	43.0	84.2	66.3	19.2	12.4	49.1	125	14.0	19.6
RDA	300	60	100	100	100	100			500	25	30
≥18 years											
Boys	543.2	40.9	41.0	112	81.4	20.1	12.7	36.4	119	17.0	19.0
RDA	420	60	100	100	100	100			500	25	35
Girls	467.9	37.3	36.6	101	72.2	18.8	11.7	33.5	113	26.0	18.4
RDA	270	60	100	100	100	100			500	25	30

GLV, green leafy vegetables; RDA, Recommended Daily Allowance.

The Mid-day Meal Programme

Schoolchildren are seen as a priority target group for government programmes aiming at improved nutrition. As early as 1974, Dr Gopalan emphasized that 'the school could be a valuable second front in our attempts to bring about nutrition and health upliftment of our population' (36). Concerned about the continued high proportion of 'out of school' children in the country, in 1995 the Government launched the programme of 'Nutrition Support to Primary Education', popularly referred to as the MDM. The programme aimed to increase enrolment, improve school attendance and retention, inculcate good food habits in children, promote social integration and improve children's nutritional status. The success of this scheme is illustrated not only by the tremendous increase in school participation and completion rates in most of the Indian states (37), but also by recent evidence from rural Madhya Pradesh which suggests that the mid-day meal, which provides 100 g of rice/wheat, 20 g of pulses and 50 g of vegetables, has a substantial effect on reducing hunger in school by helping to close the gap between actual intakes of energy, protein and iron of school-aged children and recommended daily allowances (RDA) by 30%, 100% and 10%, respectively (38).

Initially, the Government provided 3 kg of wheat or rice, to be distributed free of charge to children in government primary schools from grades 1 to 5 (pupils aged 6–14 years) who achieved over 80% attendance in the previous month (39). In 2001, the MDM became a legal entitlement with the Supreme Court ruling that all primary-school children in India in grades 1 to 5 have the right to receive a cooked mid-day meal containing 1255 kJ (300 kcal) of energy and 12 g of protein per day for 200 days, in all government, local body and government-aided primary schools (40). This landmark directive converted the MDM into a legal entitlement, the violation of which can be taken up in a court of law. The Supreme Court also directed that States and Union Territories (UT) ensure adequate community participation and suggested that community-based organizations, people's representatives, non-governmental organizations and parents be involved in monitoring and supervision to promote accountability and ensure that needy children can derive optimal benefit from the programme. The direction and further follow-up by the Supreme Court have been a major instrument in universalizing the scheme although wide variations continue to exist in the regularity, quantity, content and quality of the meal supplied (35,37).

The right kind of food

While appreciating the directives from the Supreme Court, which have made it possible for over 120 million children to benefit from the MDM, nutritionists have been concerned that the right to food has not been translated into the 'right to the right kind of food'; that is, a balanced, healthy meal throughout the school year. Given high levels of micronutrient malnutrition among children and low intake of vegetables among low-income populations in India, the Department of Primary Education revised the MDM guidelines to include, in addition to 100 g of cereal and 20 g of pulses, 50 g of non-tuber vegetables per child per day starting in the academic year 2006/07 (37). Central Government sanctioned additional funds to the states to cover the cost of vegetables.

Logistical problems

Despite additional funding, many states have been slow in implementing the new guidelines owing to logistical problems and the unforeseen rise in food prices which has eroded states' purchasing capacity. For example, food service providers in urban MCD had concerns that the cost of vegetables could fluctuate seasonally, thus jeopardizing the continuity of adequate supplies. Fresh vegetables are perishable and have to be purchased daily or every second day to ensure a continuing supply of fresh produce. Some challenges suggest the importance of shared nutritional knowledge, understanding and attitudes. Some state governments have decided to provide eggs or dairy products twice a week as eggs and milk are considered more nutritious (41). There was also concern that children do not like eating yellow and green vegetables and may therefore reject the food. These are in part issues related to nutrition education, suggesting that the educational potential of MDM must not be neglected.

Major implementation questions in the introduction of vegetables in MDM were: (i) Can the supply side be made to work? (ii) Will children accept vegetables in meals? (iii) Will they eat them? (iv) Will all concerned (i.e. food suppliers, school meal service providers, teachers, parents and children) learn to value vegetables and perceive their importance?

The pilot intervention

The pilot intervention was carried out in three government primary schools in MCD to test the feasibility and effectiveness of promoting vegetables in primary schools, using the MDM as an entry point. The intervention study was undertaken by the Nutrition Foundation of India (NFI), New Delhi, with funds from Solution Exchange, an electronic forum for the food and nutrition security community in India, supported by FAO.

The objective of the intervention was twofold: (i) to accelerate the process of introduction of vegetables into MDM by interacting with the MDM programme officers, the vegetable suppliers and food service providers; and (ii) to orient primary-school teachers on how to use MDM as a focal point for nutrition education to children on the importance of a balanced meal with vegetables and on how low- and middle-income families can include vegetables into their daily meals at affordable cost. The Education Department of MCD permitted NFI to carry out the pilot intervention through collaboration with local food service providers. The pilot intervention was carried out in Central Zone of New Delhi from 2006 to 2007 for 6 months.

Introduction of vegetables in the mid-day meal

The first step was to identify a large-scale vegetable supplier. Mother Dairy, a cooperative vegetable supplier, was willing to supply seasonal vegetables and green leafy vegetables at the cost of Rs. 10/kg throughout the year to identified food service providers as part of their corporate social responsibility. Since the quantity of vegetables supplied was large (about 250 kg/day) the cooperative was willing to ensure regular daily delivery of good-quality mixed vegetables (onions, tomatoes, potatoes, greens and seasonal vegetables) to the food service provider's kitchen. They underwrote the small subsidy when the cost of the vegetables soared and undertook periodic monitoring of the quality of vegetables supplied. ISKCON Food Relief Foundation, one of the not-for-profit private food suppliers providing MDM to 50,000 schoolchildren per day in MDC, agreed to introduce vegetables in the MDM without any additional funds for the duration of the pilot project (42).

Recipe testing

The next step was to demonstrate how to introduce vegetables into the recipes. The food service providers were providing six traditional rice or wheat and pulse or lentil-based recipes cyclically in MDM. Each of these was modified to include 50 g of seasonal vegetables such as spinach, carrots, yellow pumpkin, cauliflower or cabbage. Earlier NFI studies had shown that children disliked green leafy vegetables and yellow pumpkin and removed pieces of these from their food. To prevent this, these were cooked, mashed and blended into the gravy. Children and teachers from the three test schools enjoyed eating these dishes and did not find any difference in taste. Children liked eating tomatoes, potatoes, cauliflower, cabbage and peas; these were introduced as large well-defined pieces in colourful rice dishes.

By using different recipes with both visible and invisible vegetables, it was possible to provide 50 g of vegetables in MDM per child every day. After initial testing, which showed that children accepted the recipes, production of vegetable dishes was scaled up to all 50,000 schoolchildren covered by ISKCON in MCD schools. Sensory evaluation showed that these dishes were tasty and children accepted and relished the MDM with vegetables. ISKCON continued supplying vegetable dishes throughout the project period, indicating that the introduction of low-cost nutritious vegetables in MDM is feasible and sustainable provided that adequate funds are available.

Nutrition education

Three schools were purposively selected for the implementation of nutrition education activities, using MDM as a focal point, involving 36 teachers and 249 children in grade 4. The schools were located in well-constructed buildings with good toilets and safe drinking water to ensure that health and hygiene messages were supported by a health-promoting school environment which would encourage children to practise appropriate behavioural modifications. The children in these schools are not from the poorest of the poor and they are provided with school uniforms, books and school bags free of cost every year. In some schools children sat on the floor but the floor was swept clean. The schools also had good classrooms with audio-visual facilities to enable more compelling health and nutrition education. Teachers were graduates with educational training. The teachers were given a one-hour orientation on nutrition education with 20 minutes on how to communicate nutrition messages effectively, using MDM as a focal point. They were given information on how to prepare a balanced meal and to ensure health, hygiene and food safety, the affordability of a balanced diet and the different types of foods to eat regularly to prevent and combat nutritional deficiencies.

Development and implementation of learning materials for nutrition education

As the first step to providing nutrition education to children, appropriate nutrition and health education materials were developed and tested for children aged 5 to 11 years. Major nutrition education messages included: (i) what a balanced meal is (or 'the nature of a balanced meal') and its health and nutritional benefits; (ii) main nutritional problems among children, including undernutrition, anaemia, iodine-deficiency disorders and vitamin A deficiency; (iii) food items which prevent nutritional deficiencies; (iv) importance of a variety of vegetables in the diet and how to incorporate them in meals; and (v) nutritional and health benefits of good eating habits in children. Complementary health and hygiene messages emphasized the importance of washing hands, bringing a clean plate or lunch box from home for taking the MDM; eating without spilling food; and never throwing away leftover food in the school premises.

In order to make these classes interesting and entertaining, a variety of attractive depictions of fruits and vegetables were developed and used to initiate discussions on the importance of vegetables (Fig. 11.1). The educational material included some wall charts but was mainly play-based, including puppet shows, snakes-and-ladders games and jigsaw puzzles. Children were given intensive nutrition education for the period of 1 week. The children enjoyed learning nutrition and health messages through attractive visual materials. A pre- and post-intervention knowledge test was administered before classes were begun and within a week of completing the 6 days of nutrition education.

Impact of orientation training on teacher's nutrition knowledge: results after 1 week

All teachers completed a questionnaire with 20 questions before and after the orientation training relating to topics reviewed during the training. All questions carried equal marks. A paired *t* test was used to assess improvements in knowledge.

Even prior to the orientation training the knowledge levels in teachers were quite high. There was significant improvement in terms of both mean scores and the range of scores when

Fig. 11.1. Fruit and vegetable motorcycle.

tested 1 week after the training. The correlation between the pre- and post-intervention scores was low and not significant, perhaps because the initial knowledge levels were high (Fig. 11.2). These data suggest that the teachers had the necessary knowledge to undertake nutrition education of schoolchildren even before the orientation training.

Impact of nutrition education on schoolchildren's knowledge

Two hundred and forty-nine children studying in class 4 were given nutrition education using MDM as the focal point for 35 min per day for 6 days; of these, 149 children were taught by the researcher while the teachers watched and 100 children were taught by the teachers who had received orientation training while the researcher watched. In addition the researcher had informal interactions with children during the mid-day meal. A pre- and post-intervention knowledge test consisting of ten questions on food sources of nutrients, functions of nutrients, balanced diet and hygiene was administered before classes were begun and within 1 week after completion of the 6-day nutrition education. All questions carried equal marks. Improvement in knowledge was tested using a paired *t* test.

Pre-intervention test scores were low, indicating that the knowledge level in these children was low. As the teachers' knowledge level was quite good, this implies that perhaps adequate focused attention was not being given to nutrition education. Comparison of the pre- and post-intervention test scores showed that there was improvement in knowledge soon after nutrition education was given to children. Children's increase in knowledge was greater when the researcher taught children but there was also substantial gain in knowledge when teachers taught. There was a good correlation between pre- and post-intervention knowledge scores in children (Figs 11.3 and 11.4). These data

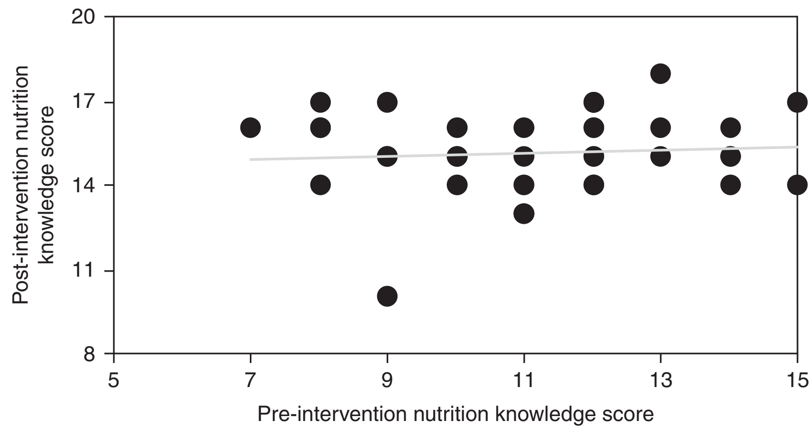

Fig. 11.2. Correlation between pre- and post-intervention nutrition knowledge scores of teachers (correlation = 0.0743, not significant).

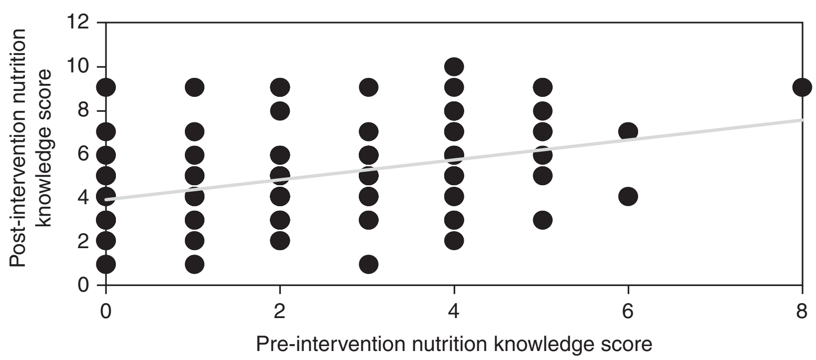

Fig. 11.3. Correlation between pre- and post-intervention nutrition knowledge scores of children taught by researcher (correlation = 0.4267, $P < 0.05$).

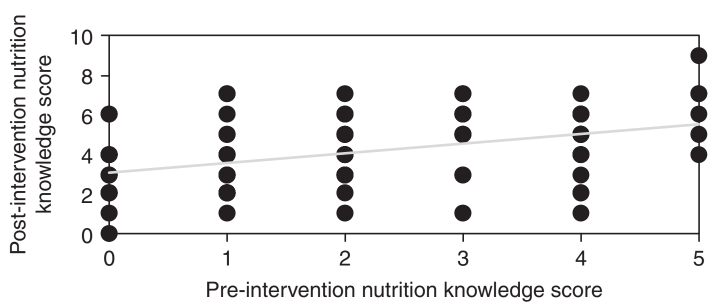

Fig. 11.4. Correlation between pre- and post-intervention nutrition knowledge scores of children taught by teachers (correlation = 0.3642, $P < 0.05$).

suggest that if adequate time is allocated and efforts are made to undertake focused nutrition education, classroom teaching can have a key role in improving children's nutrition knowledge. However, how long these messages are retained is an important question, as is the effect that this knowledge has on action and behaviour.

Results after 6–12 months

Data on follow-up of the teachers and children after 6 months showed that teachers had lost some of the knowledge they had acquired soon after the orientation training. For the children, repeat testing showed that although their scores were higher than before they had the nutrition education, their scores had declined over time. This decline in knowledge may be due to the fact that teachers did not have the time to reiterate the nutrition education messages even once during the intervening period, as they were not part of the curriculum. Also, children did not have any lessons or material in their textbooks in one place which they could read or show to their parents at home. It is therefore hardly surprising that they had forgotten many things they were taught during the intensive 1-week nutrition education.

Parents' response

In this project active contacts with parents were limited and not specifically planned as part of the study. Available evidence indicates that to a large extent the parents (especially mothers) viewed MDM as a useful programme, which gave them a respite from preparing lunch early in the morning for their children. They were satisfied with the hot cooked meals being provided because children enjoyed eating them. There was insufficient interaction with them to assess whether their children talked about the introduction of vegetables in MDM and their nutritional benefits and whether they were sensitized regarding the introduction of vegetables in home food.

Limitations of the intervention study

The intervention had several limitations. Although vegetables in MDM were provided for 6 months during the 2006/07 school year, intensive nutrition education was provided for 1 week only, which is too short to enable sustained knowledge gains. The intervention was non-randomized and thus the scope of study was limited to the specific reference population. There was no control group to determine differences in knowledge between children who received and did not receive nutrition education. Moreover, the intervention was not set up to show a link between a short-term increase in knowledge and a change in eating behaviour or preferences resulting from the nutrition education. The second objective implied that some spin-off on family food practices was anticipated, but this outcome was not assessed. Also there was no assessment to determine whether the vegetable-enriched MDM resulted in an overall net increase in children's dietary intakes of vegetables by using pre/post assessment methodologies such as 24-hour children's food diaries or food-frequency questionnaires through interviews with children and parents, which could subsequently be used, based on food composition data, to calculate the nutrients obtained from a typical school meal. Despite these limitations, the intervention study contributes valuable logistical experience, explores some essential intervention components needed to lay the ground for further research and highlights some of the strategies required.

Discussion

Implications for future interventions and research design

To address these limitations, what is needed in future studies of this kind? Reviews of effectiveness trials suggest that nutrition education, for both teachers and students, requires a great deal more time: six lessons are wholly inadequate to embed knowledge or change attitudes and practices (3,23). Nutrition education initiatives should be carried out over at least 12 months (3). The learning community should be broadened with the aim of raising awareness of healthy eating in the school community at large and creating more interaction with the home, since research suggests that involvement of the wider community enhances impact (43). Such outcomes should be assessed as rigorously as knowledge gain. For the children's nutrition education, learning must be recycled and built on over time. Coherent and focused lesson sequences in course books, grouped around nutrition topics, would help teachers to undertake nutrition and health education systematically, enable students to revise and make it possible to carry nutrition messages out of school. Finally, knowledge transmission should not be the sole educational aim for teachers, students, families or the community. Lesson objectives should be oriented towards changes in practice and discourse at home and in the community. This could involve some reassessment of classroom methodology and teacher education, and closer practical links between MDM and lessons.

The study was a useful beginning and it is appropriate to look beyond it. Policy makers need to become aware of the importance of such interventions, and be persuaded to consider integrating nutrition into the school curriculum and the teacher education curriculum, supporting this with nutrition-friendly school policies. The approach to food supply adopted by the study is also a good pattern for further initiatives, suggesting potential long-term benefits to the economy. Increasing the availability and intakes of vegetables and fruit among a new generation of consumers will generate demand for fresh local produce and stimulate agricultural markets (44,45). Creating an enabling policy environment for small-scale producers may be particularly important in a rapidly changing economic environment like India, where there are risks of cooperative suppliers and small farmers being pushed out of the market by large retail companies that can offer better conditions to farmers who produce at scale.

In terms of research design, pre- and post-intervention assessment should be part of the project plan, and assessment should not be limited to knowledge gain. There is a need to identify what constitutes meaningful change in knowledge, attitudes and practices and the effectiveness of specific components of interventions (23). Measuring dietary intakes among children is acknowledged to be a challenge (22), even greater in countries where research expertise is limited and lack of financial resources poses major constraints. Knai *et al*. (3) convincingly argue that countries need support in the design, conduct and evaluation of robust interventions and research. This is therefore an appropriate and timely opportunity to appeal to the international research community to develop reliable, valid and inexpensive assessment tools to measure knowledge, behaviour modifications and changes in the quality of children's diet. Finally, barriers to effectiveness must be assessed and taken into consideration to maximize the success of future interventions.

Conclusions

The intervention study shows that the introduction of vegetables into MDM is feasible and sustainable, provided that adequate funds are allocated and there is thoughtful planning. If used effectively, the MDM can become a major tool for improving vegetable consumption among school-aged children in urban and rural India.

Despite the limitations in the intervention design, many lessons can be learnt from the pilot intervention. Children accept and appreciate vegetable-based dishes. However, prior testing for acceptability and palatability is a key factor. The pilot study clearly brings out the need to take account of affective factors (e.g. dislike of green vegetables) in MDM planning. Cost was kept down by linking the food service provider and a large cooperative vegetable supplier. The Delhi supply chain, using large centralized kitchens, may be appropriate for urban areas; alternative solutions are needed for rural areas. Local self-help efforts in different parts of India show that school farms and low-cost community greenhouses can supply vegetables to schools for incorporation into mid-day meals (46, unpublished results[2]).

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Children's nutrition knowledge can be improved by teaching and maintained if adequate time is allocated and materials are sufficiently focused. It remains to ensure that the transition from knowledge to behaviour is given the same amount of educational attention as pure knowledge, and that the MDM is fully exploited educationally as an object lesson for the children, the school and the community. It is to be hoped that as the MDM programme develops, it will provide the opportunity for many more coordinated experiments and research projects, which will build on each other.

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12 Developing Micronutrient-rich Snacks for Pre-conception and Antenatal Health: the Mumbai Maternal Nutrition Project (MMNP)

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Abstract

Observational and trial data suggest that poor maternal micronutrient status as a result of poor dietary quality before and during pregnancy impairs fetal growth and development. This chapter describes the development of palatable food supplements produced from locally available vegetarian foods that improve the quality of the diet of young Indian women living in Mumbai slums.

A vehicle in the form of a cooked snack food that could be distributed daily was developed to provide the women with supplementary green leafy vegetables (GLVs), fruit and milk. The target nutrient content of the snack was defined based on intake data from the study population and the UK Estimated Average Requirement (EAR). The snack was analysed to measure these target nutrient levels and palatability was assessed.

Several approaches were used to deliver the amount of GLVs, fruit and milk that were considered sufficient to have an impact on the women's nutritional status. A vehicle was developed that contained these micronutrient-rich foods and was palatable and acceptable to the women. Some of the target micronutrient levels were achieved using combinations of fresh GLVs, dried fruits and milk powder. Mean micronutrient levels of the final product (per serving) were: β-carotene 123 retinol equivalents; folate 68 μg; riboflavin 0.14 mg; iron 4.9 mg; calcium 195 mg; vitamin B_{12} 0.24 μg. These values are between 12% and 43% of the UK EAR. To date, target vitamin C levels have not been achieved.

It is possible to develop palatable, culturally acceptable and safe micronutrient-rich food supplements using a low-tech approach and locally available fresh and dehydrated ingredients.

Key words: micronutrient, food supplement, green leafy vegetables, fruit, milk, India

Introduction

Suboptimal maternal micronutrient status during the periconceptional period, and during pregnancy itself, adversely affects fetal growth and the development of all body tissues, impairing the subsequent health of the baby, child and adult (1). Birth weight is a crude measure of fetal development, but nevertheless it has been shown to be associated

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with long-term health outcomes including cardiovascular disease and diabetes (2). According to data from the third Indian National Family Health Survey (NFHS3) (3), in 2005 almost 22% of neonates in India weighed less than 2.5 kg. A more recent estimate published in 2009 by the United Nations Children's Fund (UNICEF) is 28% (4). It has been documented that babies born small are more likely to be stunted in childhood (5–7), which in females is a risk factor for low birth weight in the next generation and for both males and females is associated with lower adult income (8). Estimates of the prevalence of stunting in India range from 38% for children under 5 years of age (UNICEF) (4) to 45% for children under 3 years (NFHS3) (3). Stunting, wasting and underweight for age at 3 years are all more prevalent among children of lower socio-economic status (3).

The Mumbai Maternal Nutrition Project (MMNP) is a randomized controlled trial investigating the effect of providing women with a micronutrient-rich food for consumption before and throughout pregnancy on infant outcomes, including size and weight at birth, infant mortality, childhood growth, cognitive development and cardiovascular risk. The trial participants are married women of childbearing age who are intending to become pregnant and are living in a slum community in the city of Mumbai, India. The trial was launched in January 2006 and is due to run until 2011. It was approved by the research ethics committee of the Nair Hospital, Mumbai, and is on the International Standard Randomized Controlled Trial Register (ISRCTN 62811278).

The MMNP was inspired by the Pune Maternal Nutrition Study (PMNS) which was carried out between 1994 and 1996. The PMNS was an observational study in a rural Indian population in which women were interviewed about their dietary habits twice during pregnancy using a food-frequency questionnaire (FFQ) developed specifically for the population. The women were then followed up at pregnancy and detailed anthropometry of the baby was carried out within 72 h of birth. The results showed that mothers (*n* 633) with higher self-reported intakes at 28 weeks' gestation of green leafy vegetables (GLVs), fruits and milk delivered fewer low-birth-weight babies (9).

The MMNP was subsequently designed to investigate whether this relationship was causal, i.e. whether consumption of these foods by the mother before and during pregnancy positively affected the development of the fetus. The intervention is based on locally available foods, rather than synthetic nutrients. This approach requires that the women consume the foods on a regular basis prior to and during pregnancy. It is intended that the intervention is an addition or supplement to the women's daily intake rather than a replacement for any of the foods she would habitually eat. It was therefore decided that the supplement would take the form of a snack food similar to those available locally from street-side stalls and be made available to women at a time of day when they would not usually be eating a meal. Once enrolled in the study, the women are asked to visit a distribution centre within walking distance of where they live six days per week in order to receive the supplement. The woman's attendance at the centre and consumption of the supplement are recorded by health workers on each visit. Pregnancies are identified by recording the women's last menstrual period date. Women who become pregnant are asked to continue to eat the supplement until delivery.

The trial has an intervention and a control arm. The control supplement contains vegetable ingredients of relatively low micronutrient content that were not associated with birth outcomes in the PMNS. Blinding is not possible in this study but in order to mask the true nature of the intervention the women are randomized to one of four groups. On a given day, four different snacks are sent to the field, two varieties of intervention and two varieties of control.

This chapter describes the stages of development of the intervention supplement and the degree to which the following requirements have been achieved:

1. Produced from locally available foods.
2. Acceptable to vegetarians.
3. Contains target levels of several 'marker' micronutrients.

4. Possible to prepare daily in large quantities by local staff in a 'low-tech' kitchen.
5. Palatable enough to be eaten daily over a period of months.
6. Microbiologically safe (not containing salmonella, *Escherichia coli*, coliforms or unacceptable levels of mould).
7. Nutritionally safe (not exceeding UK safe upper limits for any nutrient) (10).

The project started with a two-year pilot study (2004–2005) in the Shetanchowki area of Mumbai, based in the Streehitakarini Health Centre. The main trial started in 2006 in Bandra, based at the Centre for the Study of Social Change, and as of April 2010 has recruited approximately 5000 women.

Methods

It was decided that the supplement would take the form of a snack food similar to those available locally from street-side stalls and be made available to women at a time of day when they would not usually be eating a meal. Nutrient content, acceptability, safety, cost and availability of ingredients, manpower and cooking facilities have been considered when developing the snacks. There have been four chronological stages of snack development: pilot study; main trial 1; main trial 2; and main trial 3.

Target nutrient content

The starting point for setting the target nutrient content of the snacks was information from the PMNS which collected data on women's habitual food intake using a 111-item FFQ (9). We estimated average intakes of 'marker' nutrients: β-carotene, riboflavin, folate and vitamin C. The amount of nutrient that would increase daily intakes of the 'marker' nutrients above the 75th centile of intakes of the women in the PMNS was then calculated (Table 12.1). Because it was anticipated that MMNP participants would be more likely to attend on alternate days (i.e. three days per week) rather than six days per week, the target nutrient content was set at double the amount that would move intake to the 75th centile of the PMNS. This amount was found to be approximately equal to one-third of the UK Estimated Average Requirement (EAR) for riboflavin and folate (11).

At each stage of the trial, samples of the snacks were tested for nutrient content. Homogenized and frozen snacks were flown to the UK on dry ice and analysed at a commercial laboratory (Eclipse Scientific Group, Cambridge). Reversed-phased high-performance liquid chromatography was used to test for riboflavin, β-carotene and vitamin C; vitamin B_{12} content was analysed using surface plasmon resonance inhibition assay; folic acid was analysed by bioassay

Table 12.1. Amount of nutrients consumed by women in the PMNS and the target nutrient content of the MMNP supplement.

	β-Carotene (RE)	Riboflavin (mg)	Folate (μg)	Vitamin C (mg)
Women's median daily intake during pilot study	600[a]	0.65	126	21
75th centile of intake in PMNS	654[a]	0.82	164	23
Target nutrient content of snack	108[a]	0.34	76	4
UK EAR (11)	500[a]	1.2	250	25
Safe Upper Limit (where applicable) (10)	1166[b]	–	–	–

PMNS, Pune Maternal Nutrition Study; MMNP, Mumbai Maternal Nutrition Project; RE, retinol equivalents; EAR, Estimated Average Requirement.
[a]Figures relate to all sources of retinol.
[b]Figures relate to β-carotene only.

(*Lactobacillus rhamnosus*); and all minerals were analysed by inductively coupled plasma-atomic emission spectrometry.

Formulation

We initially considered supplying the food in the form of a milk drink, a piece of raw fruit and an ordinary cooked GLV preparation. However, this was not feasible in the context of the trial, for a number of reasons. First, the daily purchase of all these fresh ingredients was too costly in terms of staff time. Second, it was not possible to deliver these foods in a palatable state, or to maintain microbiological safety, during their distribution throughout the large slum area. Third, it would have been difficult to record the women's intake, in a simple way, with the foods in this form. Finally, it was clearly impossible to make the intervention and control supplements appear similar using this approach. We therefore decided to combine the three ingredients and to make them into cooked snacks, similar to street snacks, like samosas, widely available in Mumbai.

During the pilot study phase, it was not possible to purchase and prepare sufficient quantities of fresh ingredients for the snacks due to manpower constraints. Initial formulations therefore contained dehydrated, powdered GLVs, fruit and milk. A Mumbai-based commercial company supplied vegetable and fruit powders prepared using a novel technique of room-temperature drying. These powders have superior smell and flavour compared with heat-dried powders and nutrient retention is maximized. The use of powders allowed the inclusion of greater quantities of the GLV, fruit and milk in the limited volume available. They were combined with other 'binding' or 'covering' ingredients such as chickpea flour or semolina and seasoned with local spices to give a product which resembled a food like a samosa or patty.

Product development

The recipes for the snacks were initially developed by the project nutritionists, experimenting on a small scale at home in their kitchens. Preparation of the snacks was then scaled up with the installation of a large project kitchen, staffed by 19 men and women and equipped with a range of basic kitchen facilities (including a large gas stove, oven, chilled storeroom and stainless steel preparation surfaces). Development of new recipes (to avoid monotony for the women) and the introduction of more palatable formulations have been an ongoing process throughout the pilot study and the main trial.

Choice of specific green leafy vegetable

The choice of GLV to be added to the supplements was initially based on the availability of the dehydrated powders and the opinions of project staff as to acceptability. In early 2007, the dehydrated powders of ten different GLVs (radish leaf, red amaranth, fenugreek, green amaranth, coriander, colocasia, drumstick leaf, onion stalk, shepu, spinach and curry leaf) were analysed by a UKAS accredited laboratory (Eclipse Scientific Group) for micronutrient content. The powders were also analysed for polyphenol (Global Analytical Services, Heidelberg, Germany) and oxalate content (Lincoln University, Canterbury, New Zealand) (12). Polyphenols and oxalates are considered 'anti-nutrients' because they inhibit absorption of minerals, specifically iron and calcium, respectively (13,14). The dehydrated powders were crudely ranked according to nutrient and 'anti-nutrient' content; those with the lowest overall score being the most nutritious and containing the least anti-nutrient.

Stages of development

As the study progressed a series of major changes was made to the snacks (Table 12.2). These were mainly to improve the nutrient quality and palatability, the latter having an impact on participant compliance. First, the amount of GLV powder added to the snacks was reduced; this was to make the snack more palatable (large amounts of dried GLV made

Table 12.2. Ingredients, mean nutrient composition and mean percentage contribution to nutrient requirements of the supplements at each stage of the trial.

	Pilot study	Main trial 1	Main trial 2	Main trial 3
	Dry GLV, fruit powder	Reduced GLV powder	GLV powder + fresh GLV	Fresh GLV
	Jan 2003 to Jun 2005	Jan 2006 to Oct 2006	Oct 2006 to Jun 2007	Jun 2007 to present
Ingredient				
Dry GLV powder (g)	10	7.5	3.8	0
Milk powder (g)	8	16	12	12
Fruit powder (g)	4	4	4	0
Fresh GLV (g)	0	0	29	30
Dried fruit (g)	0	0	0	4
Micronutrient content per supplement				
β-Carotene (RE)	282	114	200	123
Riboflavin (mg)	0.58	0.20	0.21	0.14
Folate (μg)	135	26.0	50.8	67.5
Vitamin C (mg)	1.6	<1	0.5	1.5
Vitamin B_{12} (μg)	0.61	0.64	0.58	0.24
Calcium (mg)	298	210	275	195
Iron (mg)	5.46	6.85	5.90	4.90
Macronutrient content per supplement				
Energy (kJ)	795	741	703	611
Energy (kcal)[a]	190	177	168	146
Protein (g)[a]	7.0	7.3	6.9	6.4
% of target (% of EAR[b])				
β-Carotene	261 (56)	105 (23)	185 (40)	114 (25)
Riboflavin	170 (48)	59 (17)	62 (18)	41 (12)
Folate	177 (54)	34 (10)	67 (20)	89 (27)
Vitamin C	40 (6)	<1 (<1)	13 (2)	38 (6)
Vitamin B_{12}	(48)[c]	(51)[c]	(46)[c]	(6)[c]
Calcium	(48)[c]	(34)[c]	(44)[c]	(31)[c]
Iron	(48)[c]	(60)[c]	(52)[c]	(43)[c]
Compliance (% of participants consuming whole rather than half supplement)	Not measured	64	72	89

GLV, green leafy vegetable.
[a]Macronutrient content calculated using Indian Food Tables (16).
[b]UK Estimated Average Requirement during pregnancy (11).
[c]No target was set for these nutrients.

it taste bitter) (Table 12.2, main trial 1). Next, 50% of the GLV powder was substituted with fresh GLVs (Table 12.2, main trial 2). There were, however, other reasons for some of the changes; a problem with rat infestation on the premises of the commercial dehydrated powder suppliers forced a complete change to the use of fresh rather than dried GLVs and dried fruit rather than dried fruit powder. The final and current formulation being used in the trial is shown in Table 12.2 (main trial 3).

Assessment of the acceptability and safety of snacks

New snack recipes were tested for palatability by project staff and small panels of local women before being distributed to the field. In addition to this anecdotal approach, acceptability was assessed more objectively using data recorded daily by health workers on the consumption of the snacks. The proportions of women attending the distribution centre and consuming the whole snack (recorded as '1'), at least half but not the whole snack (recorded as '0.5') or less than half (recorded as '0') were calculated and used to assess the acceptability of each recipe (Table 12.2, compliance). Microbiological testing for the presence of coliforms in snacks was performed during the pilot study at a Mumbai food safety laboratory. All snacks are prepared and cooked fresh every day and leftovers discarded.

Cost

The costs of the ingredients, staff wages, cooking fuel and packaging were used to calculate the unit cost of the snacks. This was compared with the cost of the UNICEF multiple micronutrient tablet (15).

Food intake

We assessed the baseline food intake of the women using a 213-item FFQ which was administered by trained interviewers to women at enrolment. The reference period was the most recent week. The questionnaire covered the vast majority of foods that the women were likely to eat and provided detailed information on the amount of fruit, vegetables and milk products consumed. The increase in intake of these foods as a result of consumption of the snack was then calculated with reference to the baseline median intake.

Results

Nutrient content/acceptability

Table 12.2 shows the average nutrient content of the snacks broken down by trial stage. The first version of the snack (Table 12.2, pilot study) was rich in micronutrients with the exception of vitamin C. However, the dry GLV powder made the snacks dense and difficult to eat, and some women ceased to comply with daily consumption. Reducing the GLV powder and increasing the milk powder content (Table 12.2, main trial 1) improved compliance but led to an unacceptable drop in certain nutrients, particularly folate. The best overall combination of palatability, compliance, nutrient content and appearance has been achieved by complete substitution of the GLV powder with fresh GLVs (Table 12.2, main trial 3). The target of raising the daily intake to that of the 75th centile of the PMNS women is met for the majority of the 'marker' nutrients. A significant proportion of the UK EAR is also met for several nutrients. None of the snacks has achieved target vitamin C levels and vitamin B_{12} levels were low.

Choice of green leafy vegetable

The results of the GLV analysis are shown in Table 12.3. The GLVs with the lowest overall score were the most favourable. If the results are interpreted including all of the nutrients in Table 12.3, curry leaves and spinach have the lowest content of bioavailable nutrients and radish leaves and red amaranth have the highest.

Since the results of these analyses were available in mid-2007, the choice of GLV added to the supplements has been based on these results where availability and cost have allowed. The acceptability according to the project team has also been taken into account. For example, despite having a favourable nutrient profile, fenugreek was removed from the snacks as the women did not like the bitter taste of this GLV.

Safety

All microbiological tests for coliforms were negative in the pilot study. These were not repeated during the main trial. None of the snacks exceeded the safe upper limit for β-carotene content.

Table 12.3. Nutrient and anti-nutrient composition of GLV dehydrated powders and ranking according to nutrient content.

GLV	Nutrient content per 100 g									Nutrient score[a]	Anti-nutrient content		Anti-nutrient score[b]	Overall score	Overall rank[c]
	Ca (g)	Fe (mg)	Mg (g)	Zn (mg)	Vitamin B_{12} (µg)	Vitamin B_2 (mg)	RE (µg)	Vitamin C (mg)	Folate (µg)		Soluble oxalate (% of total oxalate)	Polyphenol (mg/kg)			
Radish leaf	2.61	57.40	0.90	5.92	2.40	1.52	7250	51.1	800	38	0.00	10.90	2	40	1
Red amaranth	2.79	212.00	1.66	4.60	1.40	0.80	6200	35.6	1300	38	43.90	16.50	10	48	2
Fenugreek	1.33	129.00	0.34	2.50	1.10	2.02	3820	186.0	770	56	0.00	15.50	3	59	3
Green amaranth	2.71	97.00	2.16	4.00	0.93	0.33	7900	10.6	890	51	46.50	15.90	10	61	4
Coriander	1.10	108.00	0.39	4.40	2.90	1.09	6100	58.0	730	60	0.00	25.90	5	65	5
Colocasia	2.12	46.50	0.52	3.10	<0.2	1.55	8320	15.9	680	58	25.20	10.30	7	65	6
Drumstick	3.02	58.90	0.64	1.90	1.10	1.29	2480	167.0	540	63	0.00	17.80	4	67	7
Onion stalk	1.68	95.30	0.40	1.70	3.70	0.79	3180	51.0	550	69	0.00	9.04	1	70	8
Shepu	1.63	102.00	0.49	3.10	1.20	0.34	2920	105.0	770	64	0.00	26.20	6	70	9
Spinach	1.07	87.00	1.17	5.10	1.00	1.43	5280	13.3	440	70	94.60	8.51	9	79	10
Curry leaves	2.80	43.10	0.60	2.90	1.60	0.30	1460	45.5	150	78	0.00	41.00	7	85	11

GLV, green leafy vegetable; RE, retinol equivalents.

[a]Nutrient score = sum of the ranks for each nutrient. Lower score represents GLV with a greater nutrient content.

[b]Anti-nutrient score = sum of the ranks for each anti-nutrient. Lower score represents a GLV with a lower anti-nutrient content.

[c]Overall rank: 1 is most favourable nutrient and anti-nutrient profile.

Cost

The average unit production cost of snacks made using dehydrated leaves (main trial 1) was 13 Indian rupees (approximately US$0.33). This cost was reduced to 5 rupees (US$0.13) for the snacks made with fresh GLVs. These prices are comparable to the cost of similar 'street' snack foods that women consume in this part of India. The unit cost is higher than that of the UNICEF multiple micronutrient tablet, which is approximately US$0.02 per daily dose (15).

Food intake

The baseline frequency of intake of GLVs and fruit in this population was found to be very low: median (interquartile range, IQR) of 1.1 (0.57–1.29) and 0.3 (0.15–0.6) servings/day, respectively. Milk was frequently consumed, the median (IQR) frequency being 2.1 (2–3), but in approximately 80% of cases the serving was that added to tea and therefore a relatively small quantity (approximately 30 ml/serving).

In this population, one serving (and one FFQ portion size) is approximately 30 g. Consumption of the snack increased median intake of fruit and GLV by approximately 34 g/day (or 113%). Cow's milk is approximately 88% moisture (16), so 12 g of milk powder is equivalent to approximately 100 ml of milk. The median frequency of milk intake was two portions of 30 ml/day. Consumption of the snack therefore increases daily median milk intake by approximately 167%.

Discussion

We have demonstrated that it is possible in the context of an urban community in India to develop palatable micronutrient-rich snacks that young pre-pregnant and pregnant women will eat on a daily basis. This has been achieved using a variety of locally available foods and employing local staff. The potential advantages of a food-based supplement made using low-tech methods from local ingredients over synthetic nutrients, such as implemented in the MMNP, are important and should be emphasized. It is likely that such an approach will be more acceptable and sustainable in the long term as a means of improving health and nutrient status. It also provides social enterprise opportunities within the community (including for agriculturalists and kitchen staff), thus benefiting local people financially.

While the nutrient content of such foods is unlikely to exceed that of pharmaceutical interventions, it was possible to achieve target micronutrient levels for some of the nutrients using locally available 'food' ingredients without the addition of any synthetic micronutrients. A synthetic micronutrient preparation requires selection of particular nutrients, and it is not always known which nutrients should be included. It is likely that there are nutrients (e.g. essential fatty acids) and phytochemicals (bioactive non-nutrient plant compounds, e.g. flavonoids) in such foods that are important in disease prevention (17,18) and are not present in pharmaceutical interventions. No data are available on the bioavailability of the nutrients present in the snacks or changes to the health or nutrient status of the women. It will be important to examine the longer-term effects of daily supplementation on the micronutrient status of people in this community. The baseline GLV and fruit intake of the women was found to be very low and while the snacks may not be providing the full recommended daily intake of fruit and vegetables, the increase as a result of consuming the snacks is substantial. The aim of the supplementation programme is to positively shift the distribution of nutrient intake to ensure that all women are achieving a nutrient intake that is associated with better health outcomes for their children. The aim is not to change the distribution of intake such that all women are receiving the reference nutrient intake (equivalent to two standard deviations above the average requirement). We believe that this public health approach is likely to be more acceptable to the women and more sustainable for their community.

The unit cost of the snack in the MMNP was substantially more expensive than that of a micronutrient tablet. However, as pointed out by Gopalan (19), in countries such as India where micronutrient deficiencies exist as a result of a poor dietary quality, increasing the consumption of micronutrient-rich foods in a manner which is sustainable to the community is likely to be more effective than giving out tablets that are manufactured in high-income countries. The commercial viability or marketability of the snack has not been tested at this stage. The average cost of a similar type of street food snack in this community would, however, be at least as much or slightly more than the cost of producing our snack, so we are confident of the viability of scaling up the project if the trial shows that there is a positive effect on birth outcomes.

In our experience, this method of supplement development takes a substantial amount of time. The length of time is dependent on a number of factors. Each recipe requires experimentation in the kitchen by project staff with a prescribed set of ingredients. The next stage is for taste panels to approve the snack. They must then be analysed for nutrient content. For the current study, it was not possible to find a suitable laboratory in India for nutrient analysis to be carried out. This necessitated transportation of samples to the UK, adding to the development time. Finally the 'acceptability' of the snacks to the women participating in the study had to be assessed to ensure that they would consume them on a regular basis.

Perishability of the snacks is a potential problem that could limit the adoption of this approach on a large scale. The snacks in the trial are cooked and eaten on the same day. Another is lack of availability of some of the 'active' ingredients at certain times of the year (e.g. during the monsoon months, fewer GLVs are available, and those that can be obtained tend to be the less nutritious ones). We believe that the problems of poor availability or contamination should not be insurmountable, and have plans to re-introduce some dried leaf into the intervention supplements. Dried GLV and fruit powders offer one method of long-term storage of micronutrient-rich foods that could be viable at community level in India. Future plans include the development of a supplement with a longer shelf-life. This will enable the kitchen staff to plan for holidays, festivals and times when ingredients are in short supply.

To date, we do not know the effects of supplementation on any of the outcomes in the trial, which include maternal nutrient status, birth weight and infant body composition. It is expected that the trial will be completed in 2011, and that data will be available from 1600 pregnancies.

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13 Approaches and Lessons Learned for Promoting Dietary Improvement in Pohnpei, Micronesia

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Abstract

The island state of Pohnpei, Micronesia, has experienced much change in diet and lifestyle since the 1970s. Serious problems of micronutrient deficiencies and non-communicable disease such as diabetes, heart disease and cancer have emerged, following the neglect of traditional local foods and the shift to rice and imported processed foods. An awareness campaign on the benefits of local food, especially carotenoid-rich bananas for nutrition, is the subject of this chapter. A community, inter-agency, participatory programme was implemented focused on raising awareness on island food production and consumption. Messages were shared on horticulture, cooking, food processing and conservation through mass media, posters, print materials, photography, national postal stamps, workshops, displays, youth clubs, farmers' fairs, competitions, e-mail and slogans: 'Go Yellow' and 'Let's Go Local'. Research was undertaken in food analysis, genebank collections and community case studies as part of a global health project.

As yellow-fleshed carotenoid-rich foods (banana, taro, pandanus and breadfruit varieties) were identified and promoted, banana and taro consumption increased as did the number of the varieties consumed. Carotenoid-rich banana varieties not previously marketed such as *Karat*, *Utin Iap* and *Daiwang* became popular. Foods ready for consumption using local banana and taro varieties appeared in the markets where these had not been sold previously. The awareness campaign stimulated great interest in Pohnpei and throughout the region with invitations to present at international meetings and 'Go Local' workshops outside Pohnpei. It was proclaimed as an awareness success and consideration should be given to applying this approach to other Pacific Islands.

Key words: local food, provitamin A carotenoid, food composition, inter-agency, participatory, community

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Introduction

The Federated States of Micronesia (FSM), comprising the four states of Pohnpei, Chuuk, Yap and Kosrae (1), is located just north of the equator and has a population of about 107,000. Its 607 islands are spread over a million square miles of the western Pacific Ocean (2). Pacific nations share many of the same traditional staple foods: starchy fruits (breadfruit, banana) and root crops (taro, cassava and yam), which are commonly termed 'local food', and are eaten with coconut, fish and some fruits and vegetables in the traditional diet (3–5). Large amounts of local foods may be eaten, from 1 kg up to 3 or 4 kg daily (6).[1]

In addition to sharing similar foods, Pacific Islanders share many strongly held beliefs and values: the 'Pacific Way,' a community spirit born of similarity of life and living values where the extended family and communalism are fundamental (3,4,7). It is essential to understand such beliefs and values before planning a food-based approach for behavioural change and dietary improvement.

This chapter focuses on work on Pohnpei Island (population about 34,500), seat of the national government (8,9). Pohnpei State has one main island, which is a high volcanic island, and five outlying low atolls. Pohnpei was successively colonized by Spain, Germany and Japan during the period from 1885 to 1945, when these islands became a part of the United Nations Trust Territory of the Pacific Islands under United States' administration. In 1986, FSM became independent but continued a close relationship with the USA through a Compact of Free Association, which has provided immense sums of money to the country and greatly affected local food use and production (9,10). Although the Compact is to continue to the year 2023 (9,10), the economic outlook for FSM is described as 'fragile' (9,10) and 29.5% of Pohnpeians live under the basic needs' poverty line (10).

Pohnpei Island, with its verdant tropical foliage, warm temperatures and year-round heavy rainfall (about 250–500 cm annually in populated areas), is rich in agricultural resources. The primary economic activity on Pohnpei, as throughout FSM, is subsistence farming and fishing (9).

Micronutrient deficiency and other health and nutrition issues

Previously vitamin A deficiency (VAD) appeared to be non-existent in FSM and Pohnpei (11,12) as a public health problem. Evident cases of night blindness and VAD were identified in Chuuk in the late 1980s (13,14) on the basis of conjunctival impression cytology and serum retinol. In a randomized population-based survey in Pohnpei in 1994, 51% of the pre-school children (24–47 months of age) had VAD, as defined by serum retinol <20 g/dl, and 33% of Pohnpei children were anaemic, defined as haemoglobin <11.5 g/dl (15,16).

Micronutrient deficiencies, as well as serious problems of non-communicable diseases (diabetes, heart disease, and cancer), appear to be the result of massive dietary and lifestyle changes which gathered momentum in the 1970s (11,17,18). Lifestyle changes in Pohnpei refer to the increasing shift from activities related to traditional methods of food crop production, food gathering and fishing, walking and canoe paddling, and manual household activities related to traditional food preparation and other activities such as clothes washing, towards the adoption of modern lifestyles such as salaried office work, shopping for foods and use of motorized vehicles and mechanized household equipment, such as washing machines. Whereas immediately after World War II there was almost a complete absence of obesity and diabetes in Pohnpei (12), approximately one-third of Pohnpei adult women are now overweight in every age group (19,20) and 32.8% of Pohnpei adults now have diabetes (21).

In 2007, a report based on World Health Organization (WHO) data showed that of 194

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[1] A kilogram of local food can easily be proportioned throughout the day, two cups (each about 250 g) at midday and two cups in the evening.

nations, FSM was listed second in the world for problems of overweight and obesity. Based on body mass index (BMI)[2] greater than 25 kg/m^2, about 91% of the nation was overweight, closely following Nauru, another Micronesian nation. Of the ten nations listed as being the most overweight, eight were from the Pacific Islands region (22).

The overweight problem in the Pacific may partly be due to a genetic predisposition towards overweight[3] as well as a cultural preference towards being heavy (23). Data indicate that, in recent years, there has been a clear increase in weight among Pohnpeians (21). However, there are difficulties in using BMI as a health risk indicator, as BMI does not distinguish between weight associated with muscle and weight associated with fat (18,24). Nevertheless, problems of non-communicable diseases (e.g. diabetes, cancer and heart disease) have clearly increased (25).

The traditional food system

Pohnpei has a striking diversity of plants and food crops, including over 130 breadfruit, 170 yam and 50 banana varieties (26–29). In addition, there are over 40 giant swamp taro[4] and 20 pandanus fruit[5] varieties, numerous varieties of cassava, sweet potato, coconut and many fruits and vegetables. Pohnpei has a wealth of seafood, with over a thousand kinds of edible fish (30). Despite the shift towards imported foods, a dietary study in 2004 showed that many people still largely depend on these locally grown food crops and seafood (31).

There is much concern about the loss of traditional knowledge due to many factors, including changing lifestyles and changing values (27,32). The shift in the diet is part of the change in lifestyle. Imported processed foods are convenient, easily available, affordable, and are well liked for their taste and the prestige associated with consuming purchased foods. Other reasons for the shift to imported foods include changes in family structure and shift to the cash economy (11). The US food aid and school lunch programmes initiated in the 1960s and 1970s, including US Department of Agriculture (USDA) surplus commodities, have been criticized as a major reason for the rapid changes in the diet (11,19,33–36). Some food-related programmes have been criticized for spreading US-oriented and culturally inappropriate messages, often promoting US-type foods and food guides, undermining efforts to promote local foods (35).

Programmes were carried out to attempt to counter the shift towards imported foods, including the regional Family Food Production and Nutrition (FFPN) Programme[6] (37) and efforts associated with the World Food Day, supported by the Food and Agricultural Organization of the United Nations (FAO) and the United Nations Children's Fund (UNICEF), but the effect of these programmes was small in comparison with other forces affecting Pohnpei.

In 1998, a programme for providing vitamin A supplements to Pohnpei children from 1 to 12 years of age was initiated by the FSM Government with assistance from UNICEF Pacific (38). Animal-based foods advised elsewhere for their rich vitamin A content, such as milk, egg and liver (39–41), are not common foods of the traditional diet and not easy

[2] BMI is an indicator calculated as weight in kilograms divided by the square of height in metres.

[3] This may also be expressed as a metabolic efficiency for saving caloric energy (Thrifty Gene Theory), referring to the concept that a 'thrifty' metabolism developed among hunter-gatherers facing periods of famine and which enabled them to survive by a greater ability to store excess fat.

[4] Giant swamp taro (*Cyrtosperma merkusii*) is distinctive from common taro (*Colocasia esculenta*) and other taro types in that it is a large plant, growing to over 6 m high, with huge arrow-shaped leaves pointing upwards; the corm, which is the edible part of the plant, often weighs 1–5 kg, and larger ones more than 25 kg.

[5] Pandanus (*Pandanus tectorius*) is a fruit that is particularly important on atoll countries in the Pacific. The individual pieces making up this multiple fruit may be sucked and chewed for the sweet pulp, or the fruit may be cooked and the pulp extracted for making a number of traditional recipes.

[6] The FFPN programme was started in FSM in 1988, focusing on promotion of local food, gardening and breastfeeding.

or cheap to obtain. Yellow- and orange-fleshed fruits such as ripe mango and papaya, and vegetables including carrots and green leafy vegetables, contain provitamin A carotenoids – β-carotene being the most important – which are converted in the body to vitamin A (41). However, a literature review and key informants clearly revealed that green leafy vegetables are not well liked and were not commonly eaten in the past in Pohnpei (11,35,37). Mango and papaya were introduced to the island after 1826 (29,42) and still are not major foods, and carrots do not grow in the hot Pohnpei climate. Thus, these foods could not have been among those that protected people against VAD in the past.

The foods on which Pohnpeians rely most are banana, breadfruit and giant swamp taro (3,11,28,31). Data available in 1998 provided no indication that there may be varietal differences in carotenoid content among these foods or that some varieties may be carotenoid-rich (43–46). None of the local Pohnpei varieties had been analysed for carotenoids and few had been analysed for any nutrient. Through key informant interviews, *Karat*, an Fe'i banana with deep yellow-orange flesh, was described as the traditional infant food of Pohnpei (Fig. 13.1).

Karat was rare and not commonly available in 1997, despite reports that it was once a commonly consumed banana.[7] A sample of ripe *Karat* was obtained and arrangements made for sending off-island to a laboratory for carotenoid analysis. The results showed that ripe *Karat* is a very good source of β-carotene (47). A sample of an unidentified Yap giant swamp taro variety was also

[7] *Karat* is more difficult to grow than other banana varieties and is somewhat sensitive to sunlight, growing better in shady rainy areas rather than in open sunny areas. Also young suckers are vulnerable to roaming pigs. For these reasons, along with lack of awareness about the health benefits from consuming *Karat*, farmers started turning to the cultivation of newly introduced banana varieties that were easier to grow.

Fig. 13.1. *Karat* is a traditional banana variety of Pohnpei, known as an infant food. It has a striking deep yellow/orange flesh. This photograph presents a postal stamp series focused on *Karat* banana, produced in 2005 as a collaborative project by the Federated States of Micronesia Philatelic Bureau and Island Food Community of Pohnpei. (Photograph by Lois Englberger.)

analysed for carotenoid content and found to be carotenoid-rich. These findings led to research interest in Pohnpei about the nutritional potential of local foods, which led to the study of *Karat* and systematic study of other Pohnpei foods and varieties (48).

Thus, the purposes of the project described in this chapter were to: (i) assess the composition of local foods and varieties, with a focus on carotenoid content; and (ii) promote the production, availability and consumption of local foods and varieties that are rich in carotenoids, using a range of methods (education/communication, horticulture, appropriate technology, conservation, food processing), thereby improving health and well-being to alleviate micronutrient deficiency and other nutrition-related diseases.

Methods

The project period lasted 10 years, from December 1997 to December 2007. The inter-agency project team included members of specific research teams as well as other individuals who assisted in the project implementation, including from agriculture, education and health agencies, non-governmental organizations (NGOs), the business sector and communities. The lead and second author of this chapter were involved throughout the project.

An ethnographic multiple-methodology approach, including literature review, key informant interviews, informal focus group discussions, photography and participant observation, was used to document the traditional food system (49–51).

In order to achieve behavioural change and increase production and consumption of local foods, educational and communicative methods (including mass media as well as inter-personal methods) were used. These methods focused on inter-agency community-based collaboration and advocacy work, participatory activities and social marketing approaches found successful elsewhere (52). The formation of an NGO, the Island Food Community of Pohnpei (IFCP), to assist with coordination of activities for this project was a major step.

Food collection and analysis

Previous papers describe the work in collecting and preparing the samples of food for analysis, sample transport and the analytical methods (53–60).

As carotenoids are characterized by yellow and orange flesh colouration, efforts were made to identify those foods and varieties with yellow or orange flesh. Ethnographic studies were used to learn about local foods, which varieties of the staple foods have yellow flesh, and which are more acceptable for production and consumption that might make them suitable for promotion.

As some varieties were rare and difficult to obtain and variety lists incomplete, with inadequate flesh colour descriptions, much time was spent constructing lists of varieties and describing the varieties prior to collecting and preparing the samples. A systematic approach was followed for photographing the foods, in order to present the flesh colour and other characteristics. The DSM Yolk Color fan,[8] with its 15 segments of increasing yellow and orange colouration, was used to provide a standard assessment of flesh colour (61).

As there are no analytical laboratories in Pohnpei or FSM, samples were collected, prepared, frozen and stored in home freezers, and transported to the laboratories. This presented great challenges due to the need for keeping the samples frozen throughout the transport process of indirect flights, long transit periods and quarantine requirements. State-of-the-art analytical methods, including high-performance liquid chromatography for carotenoids, were used for the analyses.[9]

[8] These fans were provided by Sight and Life, a humanitarian initiative of DSM Nutritional Products, based in Switzerland. The fans were developed for assessing the colour of egg yolk, but also were found useful for assessing banana flesh coloration.

[9] The analyses were conducted at laboratories in Suva, Fiji; Basel, Switzerland; Honolulu, Hawaii, USA; San Francisco, California, USA; Madison, Wisconsin, USA; and Adelaide, Australia.

Dietary and health assessments

Although no population-based dietary survey was conducted in Pohnpei in this period, several dietary assessments were conducted, providing information on dietary intake. Three assessments were carried out using modified versions of a 7-day food-frequency questionnaire, which had previously been developed for FSM (31,62,63). One of these was carried out in municipalities throughout Pohnpei and two focused on one community as part of its involvement as a case study in a global health project (see following section). In addition, a quantitative assessment of the diet in the case study community was carried out in 2005, and repeated in 2007 for evaluating the impact of the campaign for consuming local foods. These assessments were structured to provide information on the reliance on imported versus local foods.

IFCP carried out health assessments in the case study community, both at the beginning of the project and at its end. A WHO-supported STEPS[10] survey conducted in 2002 provided a wealth of information on levels of overweight and chronic diseases.

Results

Identifying and promoting local sources rich in micronutrients

The assessment of local foods with potential for alleviating VAD began in 1997. Many Pohnpei banana varieties were analysed and in 1998 the banana variety *Karat* was found to be a rich source of provitamin A carotenoids. A campaign promoting *Karat* was carried out in 1999 involving workshops, radio and newspaper releases, and the distribution of planting materials (64,65). This generated much interest, as indicated by interviews and market changes (66). Although *Karat* had not been previously sold, it started appearing in the markets in early 2000, about a year after the campaign started, reflecting the amount of time needed for a banana plant to bear fruit. In 2006, the volume of *Karat* marketed was almost 500 kg in a two-month period (66).

Establishment of the Island Food Community of Pohnpei

Concern about the trend towards imported foods and increasing health problems led to the formation of an inter-agency NGO, the IFCP, to address the nutrition dilemma (67,68). Participants at a foundation meeting held on 16 October 2003, World Food Day, indicated strong support for the formation of this NGO. World Food Day is celebrated each year on 16 October, the day on which the FAO was founded in 1945. It is an event carefully followed in FSM, as well as many countries throughout the Pacific Islands. The meeting was established to focus on local food research and promotion, and to serve as a unifying body among the various organizations working in these areas (i.e. on activities and initiatives to promote micronutrient-rich local foods).

The IFCP vision is to live on a productive, environmentally sound island where a diversity of local island food is produced and consumed, providing food security, sustainable development, economic benefits, self-reliance, improved health, cultural preservation and human dignity. The nine Board Members of IFCP were selected to represent a wide range of backgrounds, including health, nutrition, agriculture, education, cultural/historic preservation, local business, gender balance and community representation. Membership is open to all who would like to help promote island foods and there is an active e-mail discussion group.

Strategic planning

A strategic planning session was held by IFCP members in April 2004 to plan how the production and consumption of local foods might best be increased (69). A SWOT (strengths, weaknesses, opportunities and threats) analysis

[10] STEPS is a WHO research process tool for non-communicable disease risk factor surveillance.

showed some of the difficulties that are faced in promoting local foods: imported foods are convenient and well liked; few resources are available for project implementation; there are negative attitudes about growing foods and agriculture; many people have a lack of awareness about the values of local foods and lack of understanding about the relationship between diet and health. On the other hand, Pohnpei has tasty local foods, compelling research findings of their rich nutrient content, great agricultural resources, committed people who would like to promote local food, and the beginnings of community interest.

One participant commented: 'There is a big difference these days in our promotion of local food, and that is because it is based on information of analyses of our own foods'. This participant pointed out that these data are essential in promoting local food and that information based on actual Pohnpei varieties is more convincing than general information from food composition tables or information from other parts of the Pacific.

In order to best promote local foods, research includes different areas: food analysis, dietary/health assessments, and documentation of Pohnpei's food varieties and primary characteristics. Follow-up planning sessions in 2006 and 2007 advised a continuation of the focus on these four activity areas (70). This strategic planning process provided an important framework to the overall local food promotion and research work in Pohnpei.

Micronutrient content of Micronesian local foods

Of Pohnpei foods alone, 21 banana, 24 giant swamp taro, seven breadfruit and 11 pandanus varieties were assessed for carotenoids[11] (Table 13.1).

[11] This included β-carotene, α-carotene and β-cryptoxanthin (provitamin A carotenoids) and lutein, zeaxanthin and lycopene, which are carotenoids that add to total carotenoid and antioxidant activity.

In addition, six banana, 21 giant swamp taro, seven breadfruit and 22 pandanus varieties from other Micronesian states and countries (including the Marshall Islands, Kiribati and Palau) were analysed for carotenoid content. These assessments have provided further understanding of the nutritional value of Micronesian foods (53–60,71–73). The analyses included different varieties, different methods of preparation (raw versus boiled, baked, steamed or dried) and maturity (half-ripe versus fully ripe). Sixty-four banana, 83 giant swamp taro, 28 breadfruit and 51 pandanus samples were analysed for carotenoid content. From the analysis, many varieties were identified as carotenoid-rich, including 15 Pohnpei banana varieties, one breadfruit variety (the seeded variety *Mei Kole*) (55,58) and most of the giant swamp taro and pandanus varieties.

Karat, and to a lesser extent *Utin Iap*, an Fe'i banana with upright bunches, cause the urine to turn bright yellow after they are consumed. Riboflavin (vitamin B_2) is rapidly excreted in the urine and is known to have this effect. Thus, *Karat* and other bananas were assessed for riboflavin content. *Karat* was found to contain rich concentrations of riboflavin. *Utin Iap* had medium levels and other Pohnpei bananas contained concentrations similar to those in common bananas[12] (57).

Pohnpei foods, focusing mainly on banana and giant swamp taro, were analysed for eight essential vitamins (vitamin A, riboflavin, thiamin, niacin, vitamin B_6, folate, vitamin C[13] and α-tocopherol) and 16 essential minerals, including zinc, iron and calcium. In total, 21 vitamin analyses and 137 mineral analyses were conducted. In the case of vitamin A, which is found in animal products only, the analyses were of three types of

[12] Common banana refers to *Cavendish*, which is the variety most widely marketed throughout the world.

[13] Vitamin C is very labile and there is great difficulty in getting samples from Micronesian to the distant laboratories without destruction of the vitamin C content of the samples. Thus, meaningful work on assessing Pohnpei foods for vitamin C content could not be done.

Table 13.1. Summary of Pohnpei foods analysed from 1997 to 2007 by substance analysed.

Foods/cultivars analysed[a,b]	Maturity, processing	Substance analysed[c,d]	Reference
Banana			
Akadahn	ripe, raw, steamed	A, D, F	54, 55
Akadahn Weitahta	ripe, raw	B, G, H	57
Daiwang	ripe, raw, boiled	A, D, F, K	54, 55
Dukerehda	ripe, boiled	A, B, C, D, E, F	57
Iemwahn	ripe, boiled	A, D, F	57
Inahsio	ripe, raw	A, D, F, J	53, 54
Ihpali	ripe, boiled	A, D, F	54, 55
Karat	ripe, raw, steamed	A, C, D, F, G, H, I, J, K	47, 53, 54, 55, 57
Karat en Iap	ripe, boiled	A, B, C, D, E, F	57
Kudud/Utin Rais	ripe, boiled	A, F	57
Kundina	ripe, boiled	A, C, D, E, F	57
Mangat	ripe, raw	A, J	53
Mangat en Seipahn	ripe, boiled	A, D, F	57
Peleu	ripe, boiled	A, C, D, E, F	57
Preisihl	ripe, boiled	A	57
Utin Kerenis	ripe, raw	A	55
Utin Ruk	ripe, raw, boiled	A, D, F, J	53, 54, 55
Utin Iap	ripe, raw, baked	A, D, F, G, H	54, 55, 57
Utin Menihle	ripe, raw, boiled	B, G, H	57
Utiak	ripe, boiled	A, D, F	57
Utimwas	ripe, boiled	A, D, F	57
Utin Pihsi	ripe, boiled	A, D, F	57
Breadfruit			
Mei Kole	ripe, raw, boiled, with/ without skin	A, D, F	54, 55
Meiniwe	ripe, boiled	A, D, F	54
Meisaip	ripe, raw	A, D, F	54, 55
Meitoal	mature and ripe, raw and boiled	A, D, F	54, 55
Mei Kalik	ripe, boiled	A, D, F	54, 55
Mei Uhpw	ripe, boiled	A, D, F	54, 55
Mahr product	fermented (*mahr*) dough, raw	A	55
Paku kura product	sun-dried baked paste	A, C, D, F	58
Giant swamp taro			
Anetchimo	raw and boiled	A, D, F	54, 59
Fanal	raw and boiled	A, D, F, K	54, 55
Jikohki	boiled	A, C, D, E, F	59
Lahsekir	boiled	A, C, D, F, K, L	59
Mwahngin Eir	boiled	A, C, D, F	59
Mwahng Kisilap	boiled	A, C, D, F	59
Mwahng Medel	raw and boiled	A, D, F, K	54, 55
Mwahngin Meir	boiled	A, C, D, F, K, L	59
Mwahngin Palau	boiled	A, C, D, F, K, L	59
Mwahng Pwiliet	boiled	A, C, D, F, K, L	59
Mwahng Tekatek Weitahta	boiled	A, C, D, F, K, L	59
Mwahngin Wel	boiled	A, C, D, F, K, L	59
Mwashei	raw and boiled	A, D, F, K	54, 55
Nihn Jaimon	boiled	A, C, D, E, F	59
Nihn Jehm	boiled	A, C, D, E, F	59

Continued

Table 13.1. Continued.

Foods/cultivars analysed[a,b]	Maturity, processing	Substance analysed[c,d]	Reference
Nihn Peres	boiled	A, C, D, E, F	59
Pahmot	boiled	A, C, D, F	59
Ponon	raw and boiled	A, D, F	54
Simihden	raw and boiled	A, D, F, K	54
Six-moon	raw and boiled	A, D, F	54
Six-moon red	boiled	A, C, D, E, F	59
Six-moon white	boiled	A, C, D, E, F	59
Wahrau	boiled	A, C, D, E, F	59
Wiklale	boiled	A, C, D, E, F	59
Pandanus			
Unspecified cultivar	ripe, raw	A, D, F, J	53, 54
Juaipwehpw	ripe, raw	A, C, D, E, F	71
Luarmwe	ripe, raw	A, C, D, E, F	71
Binu-Dolongahai	ripe, raw	A, C, D, E, F	71
Nehnkedak	ripe, raw	A, C, D, E, F	71
Kipar en Majal	ripe, raw	A, C, D, E, F	71
Mwajak	ripe, raw	A, C, D, E, F	71
Jorum	ripe, raw	A, C, D, E, F	71
Mehkilkil	ripe, raw	A, C, D, E, F	71
Doapwoadin	ripe, raw	A, C, D, E, F	71
Binu-Dalinga	ripe, raw	A, C, D, E, F	71
Enkehlen	ripe, raw	A, C, D, E, F	71
Fruits			
False durian	partially ripe, boiled	A, D, F	54, 55
Noni fruit	partially ripe, raw	A, J	53
Garlic pear	ripe, raw	A, C, D, E, F	71
Greens			
Chaya	raw	A, J	53
Bird's nest fern – *tehnlik*	boiled	A, D, F	54
Pele	raw	A, J	53
Seafood			
Fish liver, yellow-fin tuna	boiled	M, N	48
Fish liver, skipjack tuna	boiled	M, N	48
Fish liver, parrot fish	boiled	M, N	48
Fish egg, skipjack tuna	boiled	M	48
Fish heart, skipjack tuna	boiled	M	48

[a]Names of the local cultivars are presented. Scientific names are: banana = *Musa* spp.; breadfruit = *Artocarpus altilis*, *Artocarpus mariannensis*; giant swamp taro = *Cyrtosperma merkusii*; pandanus = *Pandanus tectorius*; noni = *Morinda citrifolia*; false durian = *Pangium edule*; garlic pear = *Crataeva speciosa*; chaya = *Cnidoscolus chayamansa*; pele = *Hibiscus manihot*; bird's nest fern = *Asplenium nidus*; yellow-fin tuna = *Thunus albacores*; skipjack tuna = *Katsuwonus pelamis*; parrot fish = *Scarus nuchipunctatus*.

[b]Some cultivars are known in other parts of the Federated States of Micronesia by further names: *Utin Menihle* = *Usr Kulasr*, *Inahsio* = *Usr Apat Poel*, *Utin Ruk* = *Usr Apat Fusus*. Some giant swamp taro cultivars (*Anetchimo*, *Fanal*, *Mwashei*, *Ponon*) were brought recently from Chuuk to Pohnpei and retained their Chuukese names.

[c]Substance analysed: A = β- and α-carotene; B = β-carotene; C = β-cryptoxanthin; D = lutein, zeaxanthin; E= lycopene; F = water; G = riboflavin; H = folate; I = thiamin, niacin, pyridoxines, ascorbic acid, α-tocopherol; J = kilojoules, protein, fat, carbohydrate, fibre, calcium, phosphorus, iron, sodium, potassium, magnesium, manganese, zinc, copper, ascorbic acid, β- and α-carotene; K = iron, zinc, calcium, magnesium, phosphorus, manganese, copper, sodium, potassium; L = aluminium, boron, cadmium, cobalt, molybdenum, nickel, sulfur; M = retinol; N = mercury.

[d]β- and α-Carotene, β- and α-cryptoxanthin are provitamin A carotenoids, whereas lutein, zeaxanthin and lycopene are carotenoids with no vitamin A activity. Common names for the vitamins are: retinol = vitamin A, thiamin = vitamin B_1, riboflavin = vitamin B_2, pyridoxines = vitamin B_6, ascorbic acid = vitamin C, α-tocopherol = vitamin E.

fish liver and one type of fish egg and fish heart, for which there was no previous information available. Liver from all three fish species were rich sources of vitamin A, but showed great differences in concentrations. The giant swamp taro varieties were rich in essential minerals, in particular iron, calcium and zinc.

The 'Yellow Varieties Message'

A basic concept relayed throughout IFCP's awareness programme has been the 'Yellow Varieties Message' or 'Go Yellow'. Photographs show light-fleshed varieties pictured alongside deep yellow-fleshed varieties, along with their β-carotene content and health benefits listed. This visual way of communicating scientific food composition data is a simple but effective way of showing that the deep yellow- or orange-fleshed banana varieties have greater levels of carotenoids and health benefits. Community people showed interest in these initial photographs, as shown by observation, key informant interviews and other qualitative assessment methods. People spent time at the post office and local markets studying the posters displayed there and groups started asking for training on the posters.

Posters, booklets, T-shirts and banners were developed to present the 'Go Yellow' message, focusing first on bananas (74,75), but later covering giant swamp taro, breadfruit and pandanus (76,77). Posters pointed out that, although white (or light)-fleshed varieties contain less carotenoids than yellow- or orange-fleshed ones, all these local foods still contain some carotenoids (43).

This message caught the attention of many people, as shown by the results of structured questionnaires evaluating the posters (62,63). When this message is shared, the group usually shows a noticeable 'waking up' and many start making comments, as they realize the value of their own foods which have been so greatly neglected. When the opportunity permits, information is shared about other rich micronutrient content and health benefits of fresh local food, such as vitamin C and fibre.

Behavioural change relating to banana marketing

Another IFCP activity focused on raising the low status of certain banana varieties. This includes *Daiwang*, which has been known as the banana for 'feeding the pigs'. This attitude was said to have developed because Pohnpei farmers look down on crops that are easy to grow, and this banana is considered as the easiest of any to grow, hardly requiring weeding or other care. Not a single market in Pohnpei was selling *Daiwang* in 2003. Yet *Daiwang* is sweet and tasty and is often considered as the best variety for making the traditional Pohnpei baked recipe, *pihlolo* (77). *Daiwang* is rich in β-carotene and is one of the varieties highlighted in the Pohnpei Bananas poster and other IFCP promotional materials. As Pohnpeians learned about the health benefits of *Daiwang*, attitudes started changing. The Governor of Pohnpei at this time gave full support to promoting this variety and posed for a photograph as he ate the banana. This was included in an article for the local newspaper (78).

A banana market study in 2006 showed that over an eight-week period, *Daiwang* was sold by four out of 14 markets (79). Approximately 170 kg of *Daiwang* banana were purchased, compared with none marketed previously. This indicates a great shift in attitudes about this variety. There was an even greater change in market behaviour relating to *Karat*. In 1999, *Karat* was not sold in the market, whereas in the 2006 banana market study, eight of 14 markets sold *Karat*. The markets reported that they had purchased a total of 450 kg of *Karat* for marketing and that they could not always meet the demand for this banana, which is valued as an infant food. *Utin Iap*, another traditional banana variety with an even higher carotenoid content than *Karat*, is also now regularly marketed.

Carotenoid-rich foods for alleviating chronic disease

Studies have indicated that consumption of carotenoid-rich foods may help to prevent cancer, diabetes and heart disease (80–83). A Pacific Island study has shown that eating local foods can help to maintain and even lose weight (84). Public health officers in Pohnpei reported that people are concerned about these chronic diseases, asking about what to eat to avoid contracting them, due to the urgency of the 'obesity epidemic' in Pohnpei and FSM (85). They do not ask about what to eat to avoid micronutrient deficiency. Thus, the promotion of carotenoid-rich food for its potential health benefits for alleviating chronic disease was integrated into the 'Yellow Varieties Message' along with the health benefits of carotenoid-rich foods for alleviating VAD and other micronutrient deficiency disorders. This approach has the potential of attracting more attention to the local food campaign than focusing only on the prevention of micronutrient deficiency.

'CHEEF' benefits of local food

Those promoting local food were encouraged to remind the public of the many benefits of local foods in addition to health, and to use an acronym 'CHEEF' for helping to remember these benefits: 'C' for Culture, 'H' for Health, 'E' for Economics and savings, 'E' for Environment and 'F' for Food security.

Food security and ensuring local food availability are critical for survival on islands in the event of global economy and ship transport disturbances. Local foods are fresh, with greater assurance that nutrients have not been lost, and local island food has been shown to be health-promoting, rich in micronutrients and fibre. Savings can be made by consuming food crops that are already available, such as breadfruit, and income could be earned by selling home-grown food crops and small-scale processed local food. Imported food involves transport, either by sea or air, which adds emissions to the environment and contributes to global warming, a serious risk for small islands. Conservation and use of local food preserves traditional customs and culture and helps ensure that traditional knowledge is not lost.

Therefore, by teaching about 'CHEEF', the 'Go Yellow (Varieties) Message' was broadened to more effectively present the wide-ranging values of local food. People often related to one of these other benefits, in particular culture, more than to health. The use of the 'CHEEF' acronym has been taken up, translated into the local language and used by community, government and even youth leaders, evidence that this way of describing the benefits of local food is effective.

A further expansion of the 'Yellow Varieties Message' has been about 'happiness' and the mood-enhancing properties of the banana. Early in the programme, it was noticed that many people, particularly youths, are not interested in talking about health. On the other hand, 'happiness' appears to be of universal interest. The question 'Do you want to be happy?' was asked in order to catch attention, and then information shared (including handouts) on the rich tryptophan content in banana and how this is converted in the body to the mood-enhancing substance of serotonin, which gives a happy feeling (86,87). A competition was held to spread the message, capturing the interest of many Pohnpeians. Key informants reported that they were eating more bananas because of this message and also that they were telling their friends about it and passing on the message, due to their interest in it. In addition to booklets and posters, the 'Yellow Varieties Message' was communicated through a range of other materials: newsletters, calendars, pens, T-shirts, postcards and car bumper stickers (88–92), as well as PowerPoint presentations conducted in communities.

Farmers' fairs and an agriculture approach for promoting health and biodiversity

A unique way of bringing the 'Yellow Varieties Message' to farmers in Pohnpei has been through the Farmers' Fair/World Food Day event in Kolonia, Pohnpei, the first held in 2004 with the theme 'Grow and Eat Yellow Varieties for Health and Wealth' (93) (Fig. 13.2). From 500 to 1000 people attended

Fig. 13.2. The Pohnpei Farmers' Fair is an event celebrated as part of the annual World Food Day celebration. (Photograph by Luciano Mathias.)

each year, with over 100 crops exhibited. Seventeen varieties of bananas were exhibited each year.

This event is based on collaboration between Pohnpei Agriculture of the Office of Economic Affairs, College of Micronesia–FSM Cooperative Extension Services (CES), IFCP and other agencies, along with the participation of farmers and communities. Greater monetary prizes were awarded for yellow- and orange-fleshed bananas, in comparison to other varieties, in order to focus on their important health benefits. Healthy cooking competitions and essay and art competitions in schools contributed much interest to this event. Since 2004, the Farmers' Fair/World Food Day celebrations (94–96) and municipal fairs have been annual events. In addition to the health awareness focus, another aim has been to promote rare varieties and island biodiversity. During the fairs some of the rarest Pohnpei bananas were exhibited.

The proclamation of *Karat* as the State Banana of Pohnpei has been a powerful method for increasing awareness of the value of this banana (97). Copies of this proclamation were framed and widely distributed throughout Pohnpei for hanging in offices and public places, and mention of *Karat* as the State Banana was included in press releases and local food promotion activities. As shown in the 2006 banana market study, there were almost 500 kg of *Karat* sold in an eight-week period, whereas *Karat* was not sold at all in the markets in 1999, showing the impact of this campaign (79).

The 'Let's Go Local' message

A slogan that has caught wide attention and interest in Pohnpei, and throughout the Pacific, and seems to have a uniting effect, is 'Let's Go Local' (98,99). This term was first coined in Pohnpei in the 1980s, catching widespread attention. In 2006, IFCP members suggested using the term on a colourful billboard to promote local food. Two signs were placed in Kolonia, the main town of Pohnpei (Fig. 13.3) and a third was placed in Mand community, as part of the project on Traditional Food for Health (see later section on this). The design included a symbolic drawing of a father teaching his son to plant local food, with a mother, as supporting figure, along with eye-catching drawings of

Fig. 13.3. The 'Go Local' billboard presented a colourful design with local foods and aimed at increasing production and consumption of local foods. (Photograph by Lois Englberger, billboard design by Wehns Billen.)

selected local foods, including pandanus, *Karat*, breadfruit and others.

The 'Let's Go Local' slogan was incorporated in the theme song written for the 'Going Yellow' video (see next section), and was broadcast on local radio, becoming popular among youth. The 'Let's Go Local' slogan was also placed on IFCP's promotional T-shirt.

In August 2006, a group of 15 high school students formed the 'Let's Go Local Club' as a result of the interest developed through a class taught by IFCP staff on local foods and health. The students decided to carry out community services by distributing the Pohnpei Bananas posters and teaching about the value of local foods. Later, the students recruited others, reaching around 30 core members, including students from two high schools. Activities included performances at World Food Day 2006, at a US Embassy Pot Luck Dinner for promoting local food, and at the 2007 Pohnpei Cultural Day events. In 2007, the members taught a programme to elementary school students at two schools in Kolonia, again sharing the 'Yellow Varieties Message' and values of local foods (100). This is a new programme and there are few data to demonstrate that high school students are now eating more local food. However, students are voicing their interest in local foods and have asked for fresh ripe bananas and other local foods to be provided in the school lunch.

Catching attention through film

Karat and the 'Yellow Varieties Message' and 'Let's Go Local' slogans have become known throughout Pohnpei and the Pacific through the video entitled 'Going Yellow' (101) (Fig. 13.4).

This locally produced 18-minute video was filmed by Micronesian Seminar[14] along

[14] Micronesian Seminar (www.micsem.org) is a research and development organization based in Pohnpei, but serves the entire Micronesian region.

Fig. 13.4. 'Going Yellow' was another campaign slogan referring to the yellow-fleshed varieties of local food and their health benefits. The Island Food Community of Pohnpei's local food DVD was given this name and referred to how the family in the DVD drama shifted to eating yellow-fleshed foods. (Photograph from Micronesian Seminar.)

with collaboration with IFCP on the script with financial support from Sight and Life. The story opens with the dramatic television news story on the problem of VAD in Micronesia, leading to a humorous drama, involving a family used to eating rice, ramen, turkey tail[15] and other imported foods, and how a visit from a stranger named Bubba helps the family to see how valuable and important their local foods are. The actors and actresses include Pohnpei youth, such as a young woman who plays the role of a beauty queen, proclaiming *Karat* and taro as her beauty secrets. The film was shown on local television, up to five times daily when it was first completed in October 2005. Due to its popularity, it has continued to be shown on television up to the time of writing this chapter. The film is also available at local video shops, where it can be rented out for US$1 (102). One Pohnpei video shop owner, who made ten copies of the video, said in December 2007: 'Young and old people like it. We still are renting it out up to this time'. Although there are no data to show that this film directly caused an increase in local food consumption, key informants maintain that the film was a contributing factor to the growing interest in the Pohnpei local food promotion programme and greater availability of prepared foods ready for consumption. For example, one business and community leader said, 'I can see an impact from your programme'. He started sending e-mail comments to the IFCP Go Local Email network and invited IFCP to give the guest speaker presentation at one of their large community celebrations.

The 'yellow varieties' and 'go local' theme was further strengthened by a short film of four 'Let's Go Local Club' members, as they explain the Pohnpei Bananas posters, yellow-fleshed and carotenoid-rich bananas, and the 'CHEEF' benefits of local foods. The actors wear their 'Let's Go Local' theme T-shirts and encourage people to 'go local' for the importance of honouring their forefathers

[15] Turkey tail, an imported food, is literally the tail of turkey. It is a popular food in Pohnpei and considered delicious.

and ensuring the future of the generations to come. The 5-minute film was shown over 50 times on the local television programme and many people saw it. The high school students were greatly encouraged by the public showing.

Regional and international organizations have come to Pohnpei to film documentaries on Pohnpei's local food promotion. In December 2006, the film production unit of the Secretariat of the Pacific Community (SPC), Pacific Way, based in Suva, Fiji, filmed IFCP activities (103) and included these in their Australian government-supported Pacific-wide documentary focusing on plant genetic resources and health. The title of their film, 'Let's Go Local: Looking after Plant Diversity and our Health' shows how popular Pohnpei's 'Let's Go Local' slogan has become. This film attracted great interest as it was distributed at the first Pacific Food Summit, held on 21–23 April 2010 at Port Vila, Vanuatu.

Sight and Life filmed a documentary in Pohnpei in 2006 to present how they have assisted in the Pohnpei work on alleviating micronutrient deficiency. They highlighted the fact that Pohnpei faces the 'double burden of malnutrition', problems of micronutrient deficiency along with chronic disease (104). The College of Micronesia–FSM produced films of the Farmers' Fairs/World Food Day events and other short IFCP-coordinated events, which have been broadcast on local television, generating interest in local foods.

Getting the message out!

Since 2003, over 115 IFCP articles have appeared in the local newspaper, usually accompanied by photographs and recipes (105). To widen distribution, articles are copied and provided free to local Pohnpei businesses and other agencies.

An e-mail exchange for sharing island food information started in early 2006 for IFCP members (106). Membership spread to local food promoters throughout FSM, Kiribati, Marshall Islands, Palau, other parts of the Pacific and beyond, and by 2007 included over 500 members. Many people contribute items and much interest is expressed. Participants have explained that they use the information as classroom material, share it with colleagues or broadcast it on local radio, indicating that the messages are used multiple times. IFCP news items were shared on other e-mail list servers, including the Plant Genetic Resources (PGR) News (about 500 members) and the Pacific Regional Medical Distribution List (over 190 members).

Another way that IFCP communicates its messages is via local government radio. Since August 2006, 80 items (in English) were sent to the V6AH radio announcer, who translated them into Pohnpeian and then broadcast three times daily in Pohnpeian and English (107). Sometimes the messages were repeated and transmitted over a period of two or three days. The announcer is enthusiastic: 'My listeners like this information on local foods and now ask for more'.

The IFCP website (www.islandfood.org), established in June 2005, provides further information on a range of topics, including scientific papers and the newspaper articles from the *Kaselehlie Press* Health and Nutrition column. The increasing number of 'hits' indicates that interest is growing. We know that staff of the Governor's Office and students from the College of Micronesia–FSM have started to use this source of information, and the site provides information to those in faraway places (108).

Micronesian bananas featured on national postal stamps

One of the most innovative promotions of Pohnpei local foods is through collaboration with the FSM Philatelic Bureau and the development of two national postal stamp series highlighting Micronesian bananas (Figs 13.1 and 13.5). The first focused on *Karat* banana and was a Commemorative Series coming out for World Food Day 2005 (109), including different stamps in four denominations (Fig. 13.1). The First Day of Issue Ceremony for this stamp series was celebrated with great pomp and

Fig. 13.5. A series of Federated States of Micronesia postal stamps was produced, which promoted yellow-fleshed banana varieties. (Photograph by Lois Englberger.)

signing of programmes (which are stamp collector items). A second series in 2007 (Fig. 13.5), with denominations ranging from 22 cents to $4.60, focused on eight micronutrient-rich Micronesian bananas that grow in Pohnpei (110).

Displays, presentations, workshops and other types of promotion of local food

Displays of local foods were a powerful tool for promoting local food. Plates of rare micronutrient-rich bananas were displayed and shared at conferences, workshops and public events. During an Asian Tsunami relief fundraising event conducted by the Red Cross, several plates of *Karat* were auctioned for over US$30 per plate, simultaneously prompting lots of laughs and raising awareness (111). IFCP provided fresh drinking coconuts and local bananas at community 'fun walks/runs' in order to counter the trend to offer soft drinks and sweet cookies at these events. The FSM National Olympic Committee (NOC) facilitates most of these runs, and now regularly provides the opportunity for IFCP to talk to participants about the health and other benefits of local foods. The FSM NOC now actively promotes water and healthy drinks and snacks at all events, even mentioning this change in one of their newspaper articles. IFCP has a policy of providing only local foods at their workshops and meetings (no rice, sweets or soft drinks) and encourages other organizations to do the same.

Many displays and presentations relating to the rich micronutrient content of local foods, as well as occasional cooking lessons, were implemented during other local events such as Pohnpei Cultural Day, International Women's Day, Earth Day and Dental Day (104–106,112,113). Involvement in a programme supported by the United Nations Development Project to assess national agrobiodiversity capacity provided another opportunity to highlight FSM micronutrient-rich foods (114).

A 'Banana Bingo' game developed by IFCP (115) became popular among children from elementary up to high school levels. The game includes cards presenting photographs of different Pohnpei banana varieties (showing bunches) and is played by calling out the Pohnpei banana variety names and marking the cards until a winner is found. A variation of the game is to ask the winner to correctly name the flesh colour of the banana varieties marked, providing even greater potential for teaching the 'Yellow Varieties Message'.

Involvement in overseas conferences offered the opportunity to present findings of the research on micronutrient-rich foods of Micronesia, to make arrangements for further analyses of Micronesian foods, and to show the Micronesian community about the international interest in their foods and local food promotion work (47,58,116–119). Invitations to present at six international meetings and 24 'Go Local' workshops beyond Pohnpei were honoured in 2007–2008 alone. The events are not linked with direct data showing a change in dietary intake, but they are linked with a demonstrated increase of interest in local foods. Qualitative data showed an increase in discussions on local food linked to these activities, and some community people even started requesting that newspaper articles be written on certain local food topics of interest. Such discussion of local foods is a critical part of the process leading towards greater local food intake.

Traditional Food for Health Project in a global health study

In January 2005, representing the Oceania region, the IFCP joined (as the twelfth case study) in a global health project, conducted in collaboration with the Centre of Indigenous Peoples' Nutrition and Environment (CINE), based at McGill University in Canada (62). The project was composed of two phases. Phase 1 documented the traditional food system of a selected rural community with a population of about 500 for a 4-month period. Baseline information on diet, health and other information relevant to local food production, marketing and consumption, including an agroforestry study (120,121), was included. Phase 2 was a two-year intervention in that same community to promote those local foods selected in the first phase of the project and employing the approach selected as most likely to being successful.

With assistance from the Pohnpei Department of Health, Mand Community in the municipality of Madolenihmw was selected as the target community and a Research Agreement was signed between CINE, IFCP and Mand Community. Interviewers, fluent in the local language and familiar with local customs, were trained on research methods and procedures, including data confidentiality. The team, working side by side with IFCP, included community members and representatives of three Pohnpei State Departments (Health, Education, Land and Natural Resources), Pohnpei Agriculture of the Office of Economic Affairs, the College of Micronesia–FSM CES and Peace Corps Micronesia.

This community project was a truly rewarding experience. Many people of Mand were sceptical at first, indicating that they did not want to be 'guinea pigs' in a research project, but after they learned about the aims of the project, i.e. to learn about the foods that they have and how to use them for better health and living, they gave full support. Workshops and ongoing follow-ups were carried out, focusing on health awareness, recipe development, energy-efficient charcoal ovens (which provide convenience, cost-saving and environmental benefits) and training on container gardening.

An evaluation in 2007 at the close of the project showed that significant impact had been achieved (63). Results showed an increase in the frequency of consumption of banana and taro and an increase in the number of banana varieties consumed. Local foods were more frequently served and consumed at community events, and overall awareness and behaviour towards local food changed positively. Data on Pohnpei food nutrient content and photographs were organized and put online at the CINE website (122). Further evaluation data are under preparation.

Conservation of rare varieties

A genebank (field collection) of rare varieties of Pohnpei food crops was started in

2003 at the Pohnlangas Pilot Farm as a collaborative project of Pohnpei Agriculture and IFCP (123). As assessed in November 2007, this collection included 32 banana, 13 breadfruit, 14 pandanus and 69 giant swamp taro accessions. The purpose of the genebank project is for collection, awareness, research, planting material propagation and evaluation of these rare varieties, many of which are micronutrient-rich.

Another important IFCP effort in conserving bananas was to contract a banana taxonomy and agronomy consultant to provide international classifications of the Pohnpei varieties and other advice on banana development (124). The work of this consultant is closely linked to improving dietary patterns. The information gained has increased understanding of Pohnpei bananas, their pest and disease status. This, in turn, has expanded the potential to increase the production and the variety of marketable, longer shelf-life, banana products.

An ongoing effort is the Youth to Youth Project, a collaboration with the Conservation Society of Pohnpei, which provides educational sessions to grade 6 schoolchildren, raising awareness about the importance of conserving Pohnpei's unique banana varieties, many of which are rare (125) (Fig. 13.6). IFCP became involved in this activity in 2003, and since first joining has carried out these lessons in five elementary schools. In addition to learning about the 'Yellow Varieties Message' and other characteristics of the different varieties, practical lessons are given, involving the students in planting bananas and preparing interesting new banana recipes.

Development of small-scale food processing

In the past, large amounts of breadfruit were preserved by pit fermentation. Drying foods, such as breadfruit and fish, was a common practice, particularly on the atoll islands. However, along with the shift to imported foods, there has been a neglect of traditional food processing and few modern food preservation methods have been adapted to traditional foods.

Fig. 13.6. Schoolchildren learn about Pohnpei bananas through use of the 'Pohnpei Banana: Carotenoid-rich Varieties' poster. (Photograph by Lois Englberger.)

There appears to be great potential in producing micronutrient-rich, value-added products from local Pohnpei crops and making better use of the local food resources. Workshops involving overseas consultants were held from 2004 to 2007, raising awareness about local food products that can be prepared by using simple methods of food processing, including dried bananas, banana and fruit nectars, and banana and taro flour (126–129). Additional training on making these products and further development of food processing capacities in Pohnpei are planned in collaboration with the College of Micronesia–FSM CES. This effort will increase production of these products and an overall increase in local food use. Three different designs of solar dryers and one design of a charcoal dryer (for night-time or rainy period use) were developed and built. Plans are in place for further assessment and development of these dryers.

Overseas students' collaboration and local internships

A great boost to island food initiatives in Pohnpei has been provided through research collaboration with students from prestigious overseas universities, including Emory University, University of Hawaii and McGill University. Since 2004, five students have collaborated with IFCP in carrying out research projects as a part of their graduate or undergraduate degree programmes (31,63,78,121). Their topics included assessments of Pohnpei nutritional practices and beliefs, agroforestry relating to changing dietary patterns, banana marketing, small-scale processing of local foods and evaluation of the Mand community project as a part of a global health study. These projects have provided valuable data, such as the volume of banana marketed and documentation of the types and volume of processed local foods. These data can play a significant role in the programme for promoting local foods, as well as establishing networks for further potential collaboration in research and programme development. For example, the work on documenting the local food products marketed locally provides the first such data collected and gives baseline figures for further evaluation of the impact of the local food campaign.

In addition, Pohnpei students at high school and college levels have served as interns with IFCP, providing a boost for island food initiatives. From 2006 to 2007, six students have worked with IFCP through collaboration with the Pohnpei State Department of Education and the College of Micronesia–FSM internship programmes. They have assisted in research projects, organizing and distributing island food promotion materials and helping in awareness events, such as the island food display at the FSM President's Inauguration Ceremony in August 2007. These students report that, as a result of their internships, they and many of their family members are consuming local foods as a larger proportion of their meals.

International interest in Pohnpei's micronutrient-rich foods

International interest has provided a further boost in the local food revival in Pohnpei. The findings of rich micronutrient content of *Karat* and other Pohnpei bananas were presented at the First International Congress on Banana in 2004 held in Penang, Malaysia (130). Articles by Bioversity International (previously International Plant Genetic Resources Institute) (131) and *New Scientist* (132) led to press releases in newspapers and magazines throughout the world. Catchy titles and striking photographs of *Karat* and its flesh colour were presented, along with information on *Karat*'s rich β-carotene content and potential health benefits (133–137).

Karat was highlighted as one of the 'shining stars in the traditional food galaxy' (138) and was included in an FAO-supported global poster of indigenous foods offering particular nutritional potential (139), as well as in the newly produced Pacific Indigenous Food Poster, where not only *Karat*, but also many other yellow- and orange-fleshed banana varieties are highlighted, along with other major Pacific Island foods (140).

The Eden Project, in Cornwall, England, featured *Karat* and other Pohnpei bananas as part of their permanent banana exhibit, along with fruit from only one other banana-producing country, Uganda. The Eden Project (www.edenproject.com) is described as a 'green theme park' with living biomes, confirmed by the *2004 Guinness Book of Records* as the biggest conservatory in the world, and has up to 8000 visitors daily. Its *Friends* magazine featured a prominent article on *Karat* bananas and *Karat* stamps (141). A voice recording of a Pohnpeian telling about the importance of bananas to Pohnpeians is part of the exhibit (142). Pohnpeians were truly moved about their involvement in this project (143).

Karat and a Pohnpeian man eating *Karat* were featured in the travelling exhibition 'No End to the Banana', produced by Bioversity International's banana group (87). The exhibition has been shown at the Central Library of Leuven in Belgium, the Royal Botanic Garden of Edinburgh in Scotland, the Eden Project in England and the National Botanic Gardens in Ireland. At the time of writing this chapter the exhibition was touring the USA, where it has been displayed in the lobby of the World Bank and the USDA National Library in Washington, DC and a number of other locations (87).

The *Pohnpei Bananas: Carotenoid-rich Varieties* booklet has gained wide interest. Copies are sold in Pohnpei by local businesses and are provided free-of-charge for group teaching. The booklet is now available at many libraries worldwide.

An FAO press release highlighted the importance of the nutrient-rich Micronesian giant swamp taro varieties findings (144). Other international publications presented articles on the unique Micronesian foods (145–148) and breastfeeding promotion work in Pohnpei (149).

Discussion: Impact, Challenges and Lessons Learned

Pohnpei faces serious difficulties and challenges in maintaining its rich heritage of a diversity of crops and food varieties, both within Pohnpei and overseas. Many of the present generation have become used to eating imported foods and have developed new habits and tastes. Schools generally have small stores either on the school grounds or nearby, selling primarily imported snack foods and soft drinks, or such foods as instant noodles (which are eaten raw), fried doughnuts and biscuits. Parents and relatives often have permissive attitudes relating to eating habits, and allow children to eat too many sweets and fizzy drinks between meals. Most restaurants in Kolonia serve only rice or other imported starch foods and do not offer local staple food as an option.

Local food is expensive, with prices as high as US$1.25 per pound (450 g) for yam. Families who do not have land in Pohnpei generally feel they cannot afford to buy local food, as the corresponding cost of rice is much lower.[16] Relatively few resources are allocated to the promotion of Pohnpei agriculture and local foods, despite agreement that health and nutrition are critical issues. There is a challenge in identifying the many varieties of staple crops, in particular giant swamp taro. There are challenges to collecting samples for analysis from remote areas and then transporting samples to distant laboratories. Further challenges exist in developing expertise in small-scale processing and expanding such processing of local foods to increase their availability.

There are other obstacles to the promotion of local foods in Pohnpei. Overall education levels are low and there is a poor understanding of the relationship between diet and health. Another problem is that many overseas people and advisors have a poor understanding of the Pohnpei staple foods, often considering them 'just starch'.

The Pacific Island Food Composition Tables, which are the basis of food composition data for the region, were revised in 2004 (150), but unfortunately the findings on the rich micronutrient content of Micronesian banana, giant

[16] A 50-pound bag of Calrose rice costs US$17.95 (US$0.34 per pound (450 g) with no inedible parts). This is therefore cheaper than yam, breadfruit and banana at US$1.25, US$0.50 and US$0.30–0.50 per pound, which includes inedible parts.

swamp taro, breadfruit and pandanus varieties were not mentioned. The popular South Pacific Foods Leaflets (151) were revised in 2006 (152) to include the updated information about micronutrient content of these foods, but still these leaflets have not been made widely available or translated into the local vernacular.

Despite the challenges, IFCP members are encouraged as they hear about more people noting the values of local food, some leaders even declaring how they stopped eating rice (153). Pohnpei's involvement in the CINE-led global project to promote traditional foods for health has provided great hope, as Pohnpeians learn that the problem of neglected local foods is a worldwide problem. New ideas have been shared about how to promote local food more effectively and how to gain strength from colleagues sharing the same concerns and interests (154,155).

Social marketing has been described as the application of marketing principles to the design and management of social programmes. It is a systematic approach to solving problems, in this case public health nutrition problems related to the adoption of health-promoting behaviours (156). Social marketing has been essential in implementing this project, following examples elsewhere that use multi-sectoral, participatory and community approaches (52,157).

Lessons learned include the following:

- *Assess nutritional content of food varieties*. There are great differences in the nutrient content of different varieties. It is important to promote those that give the greatest health benefits, along with agronomic potential, good taste and acceptability. Careful documentation is important for assessing varieties for all these factors.
- *Begin with foods that are already culturally important*. Past experience has shown that it is very difficult to promote foods that are less well liked or unimportant, such as green leaves. The target audience is more likely to make behaviour changes related to foods that are well known and liked.
- *Provide a scientific basis for promoting local foods*. Pohnpeians were greatly impressed by scientific information gathered on their own local food. The case study evaluation showed that data from nutrient analyses on Pohnpei foods and varieties provided a more compelling argument than information on foods from other places. The scientific evidence also confirms the wisdom of the forefathers in Pohnpei regarding the use of the traditional food varieties.
- *Promote yellow-fleshed carotenoid-rich foods for multiple health benefits*. Many people are less familiar with micronutrient deficiency disorders than they are with cancer, heart disease and diabetes. The same carotenoid-rich foods can be promoted for both alleviating micronutrient deficiency disorders and helping to prevent chronic diseases such as cancer, heart disease and diabetes. Key informant interview data showed that using colour as a way of communicating concepts of food composition is an effective way to share health messages and has been essential to the success of this campaign.
- *Include all age levels and groups*. The leaders, including traditional, governmental and church, business sector, and women and youth are important groups to target. Adults often have very fixed food habits but youth are still forming their habits.
- *Share information utilizing a mix of media and other methods*. Mass media including radio, television and video/DVD should all be used to reach a wider audience. Face-to-face communications are needed, through workshops, schools and informal gatherings. Print materials, in particular posters, newspaper articles, newsletters and brochures, can put out important messages. The evaluation of the case study indicated that the billboard and posters were among the materials most widely known about, although further evaluation is needed for assessing the understanding of these materials.
- *Go inter-agency!* Acknowledge and engage partners and participants. Many agencies working together can achieve more and resources can be more effectively used. Acknowledging partners and participants develops good working

relationships, creating interest for further inter-agency events.

- *Work with communities to help them understand their diets and health problems*. Working at the community level helps to develop programmes that are relevant to the local needs. Communities also need to understand their diets and health problems. The evaluation of the case study in Mand showed that awareness and exposure to the intervention were high and that interest in increasing local food consumption and improving lifestyles changed positively.
- *Create and promote friendly competitive events*. Experience in Pohnpei and in other Pacific Islands has shown that competitions (i.e. food crops or recipes) are popular and are an excellent way to create local food interest.
- *Use colour, use humour and make it fun!* Colourful illustrated posters and handouts create more interest than black and white materials. Use humour, such as that in the youth dramas and skits.
- *Keep the messages short, interesting and correct, and keep them coming!* People are busy. Frequent, short, interesting messages are more likely to have a positive impact than occasional long messages.
- *Write up your work and share it widely*. Scientific findings published in peer-reviewed journals command respect and create interest internationally, as well as providing greater credibility for funding opportunities. Short items written up for radio or e-mail news can share messages widely.
- *Meet the needs expressed by communities, such as requests for planting materials of rare varieties and other crops and training on small-scale processing of local food products*. Families need planting materials of rare varieties if they are to grow more of these. Making local foods more convenient and available is important, in order to face the changing lifestyles. On-farm and institutionalized collections and small-scale food processing development are examples of the work to address these needs.
- *Share locally about the international interest in Micronesian foods*. Showing that people in far-away places and prestigious organizations highly value Pohnpei foods creates much local interest.
- *Practise what you preach!* At home and work (and at workshops), grow and eat local! Despite the convenience, availability and low cost of imported foods, it is important to make the effort to use local foods in the home and work environment (as in workshops and meetings). Key informant interview data showed that the use of local foods at public events is a strong statement in itself.

A final lesson learned is that there are three important steps in the social marketing food-based approach: (i) the various social marketing techniques create awareness; (ii) awareness creates demand for local foods; and (iii) increased demand increases local food production and use.

The IFCP used an approach to understand market factors for improving traditional food use for alleviating micronutrient deficiencies and problems of chronic disease. The banana market study showed that *Karat* and *Daiwang* banana are now regularly sold at local markets, whereas they were not sold at all prior to the campaign. Interviews were conducted with market purveyors to understand the quantities of prepared local foods packaged and marketed for consumption in 2007. While these foods were not commonly sold previously, during the month of July 2007, a total of 3554 kg of prepared local foods were recorded as marketed and, of these, banana products comprised about half the weight (158). The local foods also included cooked breadfruit, taro, yam and cassava products.

The Pohnpei case study carried out in Mand community showed that there was a significant increase in the frequency of banana and taro consumption and the number of banana varieties consumed, as well as an increased awareness and interest in local food. Many workshops in Pohnpei now choose to 'go local', serving coconut juice in place of coffee or soft drinks and local food and fish in place of imported rice and meat. Many restaurants serve local food, whereas they did not previously, and reports indicate that the 'Go Local' campaign contributed to this. Several Pohnpei leaders, including a former Lieutenant-Governor, shifted to local food and made public statements about this. However, it is noted that other factors (exercise, stress levels, environment and other lifestyle practices) also affect the disease burden, and it takes time to see an actual impact on the disease burden.

It is slow but it is happening! One of IFCP's slogans, 'Let's Go Local' was enthusiastically endorsed by participants from the SPC member countries at the 2007 regional Pacific Agriculture Plant Genetic Resources meeting. It also appears to be a theme that is being taken up globally. For example, in 2007 *TIME Magazine* had on its cover page a message including 'Eat local' (159) and Slow Food is becoming a topic of discussion.

Consideration should be given to extending the IFCP approach to other Pacific Island countries and possibly elsewhere where conditions are similar. So, remember 'go yellow!' and 'let's go local!'

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14 A Food Systems Approach to Increase Dietary Zinc Intake in Bangladesh based on an Analysis of Diet, Rice Production and Processing*

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Abstract

The potential to increase the zinc content of rice in communities has been under-exploited. An understanding of the zinc content of rice in communities may be used to plan programmes by identifying and plugging the 'nutrient leaks' in the food system from soil to plate. This chapter describes a study that aimed to measure the zinc content of rice at different stages from production to consumption in communities and determine the potential for intervention based on the magnitude of differences observed. A second objective was to demonstrate the potential impact of these interventions on zinc intake of children.

The study took the form of a cross-sectional observational study of the usual practice of growing, processing and cooking rice, with measurements of the zinc content of rice using inductively coupled plasma–atomic emission spectroscopy. Dietary assessments were undertaken on children in rice-producing communities in four districts of Bangladesh.

Comparison of the four villages suggested the potential for improvement of 11% if the soil zinc is increased from below to above the critical level (0.8 ppm DTPA-available), of 15% with adjustments to milling, of 16% with changes in cooking and up to 38% with a change in locally available rice varieties. If all these changes were implemented, the zinc content of low-zinc rice would potentially double and children's total dietary zinc would increase by 64%.

Local information on the variability in the zinc content of rice may be used to improve zinc nutrition. This would be most effective as part of an integrated, community-based nutrition strategy that addresses constraints and opportunities to improve multiple nutrient malnutrition.

Key words: *Oryza sativa*, zinc, soil, food processing, diet surveys, food-based approach, food system, Bangladesh

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Introduction

Possible approaches to improving zinc nutrition have been summarized (1,2). These emphasize supplementation, fortification, dietary diversification, agricultural strategies to increase total zinc and/or absorbable zinc content in staple foods, and household food processing methods to increase absorbable zinc. Improving the zinc content of rice may be achieved through selection of particular varieties (3,4), by applying zinc fertilizer (5–9), by other types of agricultural interventions (10–13) or by changes in processing (14,15).

While such approaches offer great potential for change in nutrient intake, in general the constraints of communities cannot be overcome and their desires met in 'mass treatment' programmes that aim to reach the whole population, for example through the introduction of a new variety of rice. The variability in the nutrient content of rice at the village level is not usually considered in the analysis of the problem or in the formulation of solutions. The approach described in this chapter is based on village-, household- and field-level variability in the nutrient content of the staple food that reflects achievable magnitudes of change that may be implemented in and by communities.

The approach is designed to optimize the nutrient content of rice by 'plugging the nutrient leaks' in the food system at the local level. This needs a detailed analysis of foods from soil to plate. After assessing the potential for improvement at each step, the next stage is to work with the communities, farmers, mill owners and other stakeholders to introduce changes that would 'plug the leaks' of nutrients in the system. The strategy is therefore designed to build on the variability that is found among and between communities by incorporating technology and best practice where possible and practical. The results presented in this chapter are for the analysis of zinc in rice in Bangladesh and are the first analytical stage for such a programme. The next stage would be to build improvements with the community.

The objectives were therefore to measure the zinc content of rice at different stages from production to consumption and determine the potential for intervention based on the magnitude of differences observed. In particular, the following possible changes have been examined:

1. Increasing soil zinc content (the portion that is available for plant growth).
2. Reducing the amount of zinc lost in milling.
3. Reducing the amount of zinc lost in cooking.
4. Choosing rice varieties that have high zinc content (after milling).

Another objective was to demonstrate the potential impact of these interventions by including a dietary survey in the study design. Simulations of the impact of the above changes on overall dietary zinc could then be undertaken. The actual dietary zinc intake in the different villages could then also be compared using household-level rice composition data.

Methods

The study was a cross-sectional observational study of the usual practice of growing, processing and cooking rice, with dietary assessments carried out on children in the rice-producing communities (16). Figure 14.1

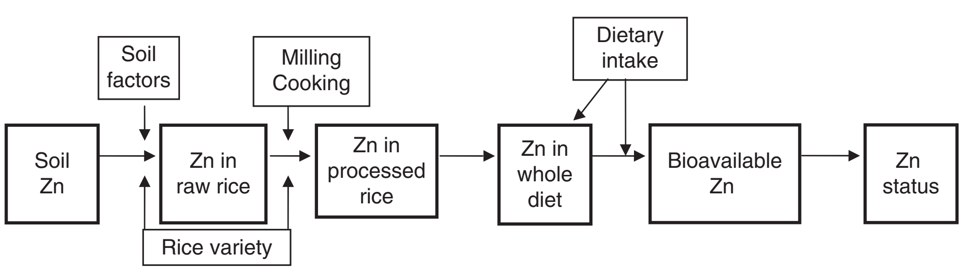

Fig. 14.1. Schematic depiction of the passage of zinc from soil to humans.

shows a schematic plan for the research. Four villages in different districts were selected for the study to obtain a range of soil types from the 14 villages that formed part of the National Nutrition Survey of Bangladesh, organized through the University of Dhaka (17). A random sample of 40 households was chosen from the census list in each village. Each household had at least one child aged 2 to 10 years and agreed to participate in the study. Ethical approval was obtained from the Cornell University Committee on Human Subjects and from the University of Dhaka. Fieldwork was carried out in May and October–November 2000 before the start of Ramadan, the Muslim month of fasting.

Agricultural production and zinc content of unpolished (paddy) rice

Soil and rice samples were collected from the *boro* (irrigated) and *aman* (monsoon) seasons from four survey villages and surrounding areas. During the harvest, farmers were interviewed in their fields and identified the variety of rice. Rice was harvested from a 1 m^2 plot from each field, then mixed, dried, winnowed and weighed. A sample of approximately 50 g was retained for chemical analysis. Soil inside the 1 m^2 harvest area was sampled using a soil auger to a depth of 15 cm. Ten samples were taken, mixed, then air-dried and a sample saved for analysis. The soil samples were analysed for available zinc content and pH. The rice zinc content could then be determined for samples grown in 'high-zinc soil' or 'low-zinc soil' based on critical levels of 0.8 ppm diethylenetriaminepentaacetic acid (DTPA)-available soil zinc for rice production (18).

Changes in zinc after milling

To measure the impact of milling on the zinc content of rice, 50 g samples were collected before and after milling from the study households and local mills in matched pairs of the same variety of rice and the same household. Unmilled rice was de-husked prior to analysis. Each time the rice was mixed well before taking the sample. The analysis is restricted to samples from two villages where there was a local mill and hence sufficient samples for analysis.

Changes in zinc after cooking

Samples of polished rice before and after cooking matched by household and variety were collected from the sample households during the first visit in May. The samples collected at this time were predominantly from the previous *aman* harvest. For this analysis the aim was for 20 samples from the survey households in each village. Some samples were spoiled and could not be analysed; therefore the final sample size was 73 from four villages. The person responsible for cooking in each household was asked about the source of water, whether any water remained after cooking rice and, if so, what was done with the water.

Varietal differences in zinc content of polished rice

A sample of polished rice was collected from each household at the time of the dietary survey and the rice compositional analysis used to individualize zinc intake from rice for each household. The respondent was asked to identify the variety of each sample of rice. Using these samples it was possible to evaluate village-level differences in the zinc content of rice varieties.

Dietary intake of zinc related to the zinc content of rice

In each household, the person responsible for cooking meals was interviewed during our second visit in October–November 2000. The 24-hour recall questionnaire format was provided by the International Food Policy Research Institute and previously field-tested. Trained enumerators conducted the interviews in Bangla. The respondent recalled all the raw ingredients of each dish (including rice) that were used to prepare the meals the previous day and the proportion of each cooked dish allocated to each household member. Adjustments were made for changes in weight of foods from cooking (19). Household measures were used for the recall, and then converted to gram equivalents. The dietary intake was then calculated for each household member in the household at the time of the survey.

A nutrient composition database for foods other than rice was supplied by the International Centre for Diarrhoeal Disease Research, Bangladesh, and included zinc and energy content for Bangladeshi foods (20). The daily zinc intake was calculated using the individual rice zinc composition data from each household and zinc intake from all other foods using food composition tables. The energy intake was calculated using the food composition tables. Daily intakes of food items for each family member (including the 2- to 10-year-old child) were calculated using the ingredients of each dish and household distribution. The zinc density of the diet was calculated using the energy intake and expressed as mg Zn/1000 kJ.

The Estimated Average Requirement (EAR) for zinc as suggested by the International Zinc Nutrition Consultative Group was used to assess the adequacy of the diet (1). This recommendation represents a mean requirement, or the dietary intake level at which 50% of individuals would meet their physiological requirement. The level for unrefined, cereal-based diets was used based on a phytate-to-zinc molar ratio of 27.7 (2 mg Zn/day for 1–3 years; 4 mg Zn/day for 4–8 years; 7 mg Zn/day for 9–13 years). The individual dietary intakes of the children were compared against the EAR within each age group.

Laboratory analysis

Analyses for soil and rice were carried out in the Soil and Crop Sciences Department at Cornell University, Ithaca, New York, USA.

Rice samples

Total mineral content (including zinc) was determined using an open acid digest. The method of open digestion of samples follows that described by Havlin and Soltanpour (21). To obtain a representative sample for analysis, approximately 25 g of each grain sample was dried and ground in a Wiley mill fitted with a stainless steel screen. The Wiley mill has been shown not to contaminate oat grain with zinc (22). A subsample of 0.5 g of the ground grain was digested with 1 ml of concentrated trace-element-grade nitric acid, 69–70% concentration, at 100°C and an extra 1 ml of nitric acid was added three times approximately every 2 h and taken to dryness. The heat was increased to 115°C and nitric acid added another two times. One millilitre of 30% hydrogen peroxide was then added. The solution was transferred to clean plastic containers and 25 ml of 5% nitric acid added. In each batch of 100 samples, a blank and a National Bureau of Standards (NBS) rice standard were included. Duplicates were run for every 20 samples. The digested rice solution was analysed using inductively coupled plasma–atomic emission spectroscopy (ICP-AES) (Spectro Ciros CCD instrument; details). The zinc content of grain was expressed as mg/100 g dry weight, a unit that is used in food composition tables. The coefficient of variation was 4.0%. Recovery of the minerals from the standards was 101.2 ± 1.1%. The samples were also analysed for phosphorus content as an indicator of phytate (16).

Soil samples

The pH of the soil samples was determined in water using a pH meter (Accumet model 620; Fisher, details) standardized to pH 7 and pH 4. Soil available zinc was determined using DTPA extraction at pH 7.3. Twenty millilitres of DTPA were added to 10 g of air-dried soil at pH 7.3. The mixture was shaken at 120 cycles/min and 8 cm/stroke for 2 h exactly. The extract was filtered through a no. 42 Whitman's filter into clean (acid-washed) plastic containers. To preserve the samples, three drops of concentrated nitric acid were added to each plastic bottle and samples were stored in the refrigerator until analysed. ICP-AES was used to determine the zinc content of the extract. The results were adjusted for moisture content, which was calculated by drying a sample of soil for 2 days at 105°C and subtracting this from the moist weight. Duplicate samples were run to assess the coefficient of variation, which was found to be 11.1% for zinc. Recovery was 99.8% using NBS standard. This extraction method is commonly used for zinc, but will not necessarily reflect the field soil conditions because zinc availability changes under flooded conditions. For this reason the samples collected during the monsoon (*aman*) season will not be as representative of soil available zinc as the samples collected when the soil was drier, during the collection of *boro* samples.

Statistical analysis

Data are presented as mean ± standard deviation. Data were analysed using SPSS version 10.0 (SPSS Inc., Chicago, Illinois, USA) for the majority of analyses. SAS version 6.12 (SAS Institute Inc., Cary, North Carolina, USA) was also used for calculation of daily nutrient intakes. Student's *t* test was used for the differences in the means. General linear models were used for analysis of association of multiple predictors and an outcome variable.

Results

Table 14.1 provides a summary of the rice samples collected for each stage of the research, the number of varieties collected and the matching system for samples. The sample size of children from four villages for the dietary assessment is also given.

Agricultural production and zinc content of unpolished (paddy) rice

The unpolished rice grown in the *aman* season had higher zinc content (2.08 ± 0.33 mg/100 g) than rice grown in the *boro* season

Table 14.1. Summary of research steps and samples collected. (Adapted from Mayer *et al.* (16).)

Research step	Samples	Location	Season grown[a]	Month collected (2000)	Number of samples	Number of rice varieties
1. Agricultural production and Zn content of unpolished rice	Unpolished rice and soil samples matched by variety and sample plot	4 survey villages plus 26 extra villages	*boro*	May	67 rice 67 soil	14
			aman	Nov	72 rice 72 soil	25
2. Changes in Zn after milling	Unpolished rice and polished rice matched by variety and household	2 survey villages with mills	*aman*	Nov	33 rice	13
3. Changes in Zn after cooking	Polished rice and cooked rice matched by variety and household	4 survey villages	*aman* (stored)	May	73 rice	15
4. Village differences in Zn content of rice	Polished rice, one sample per household in each village	4 survey villages	*aman* (stored)	May	89 rice	16
			boro (stored)	Nov	152 rice	24
5. Dietary intake of Zn related to zinc content of rice	24-hour recall of dietary intake of children aged 2–10 years	4 survey villages	–	Nov	156 households, 277 children	–

[a]The *boro* is the winter season for rice and rice is grown under irrigation. The *aman* is a monsoon season for rice (mostly rainfed). The other rice season is *aus* which is an early monsoon season.

(1.86 ± 0.34) ($P < 0.001$). Yield was 441 ± 149 g/m^2 on average in the *boro* season and 220 ± 107 g/m^2 in the *aman* season. The grain zinc was subject to the typical 'dilution effect' of increasing yield; the samples from plots with higher yield had lower grain zinc across both seasons ($r = -0.29$, $P < 0.001$). The dilution effect, and possibly genetic differences among varieties, most likely contributed to the difference in grain zinc between the two seasons.

The relationship between rice zinc and soil zinc, yield and pH has been described previously (16). Briefly, the zinc content increased with soil zinc, but on a logarithmic scale in the *boro* season, thus requiring relatively large increases in soil zinc to improve grain zinc. More acidic soils had higher grain zinc in the *boro* season. A tenfold increase in soil zinc would be needed for an increase of 0.23 mg/100 g in grain zinc, i.e.

$$\text{Grain zinc (mg/100 g)} = 3.68\text{–}0.31\ (\text{pH}) + 0.23\ (\log_{10} \text{soil zinc}).$$

In the *aman* season, rice zinc was related to neither soil pH ($P = 0.114$) nor soil available zinc ($P = 0.665$).

By way of illustration, comparing rice grown in soil greater or less than the critical zinc level (0.8 ppm) revealed significant improvements in grain zinc in the *boro* season but not in the *aman* season (Table 14.2). A difference of 11% for unpolished rice zinc on average could be expected in the *boro* season if the rice was grown in soil with more than the critical level of soil available zinc. This difference represents an increase in soil zinc from 0.36 ppm to 2.80 ppm. However, this difference would decrease after milling (see below). The varieties grown were different in the two seasons and different regions. Thus it was not possible to fully separate the effects of genetics and environment in the analysis. The assumption is, therefore, that the higher zinc in the rice from higher-zinc soils was caused by the soil or other environmental factors associated with soil zinc and not confounded by other factors, such as the choice of variety.

Changes in zinc after milling

More zinc was lost after milling in Batabaria (39%) compared with Simulia (24%; $P < 0.001$) (Table 14.3). We could hypothesize that 15% more zinc could be retained on average if the milling vigour was adjusted to the vigour of the mill in Simulia. There are two assumptions related to this. The first is that the differences in milling were related to vigour of milling and not to differences in rice varieties being milled; in future trials it is recommended that this assumption be tested. The second assumption is that the bioavailability is not decreased by the retention of phytate in the outer layers of the grain, which would make any gains in total zinc unhelpful for improving zinc nutrition. If outer layers of the grain are retained there is a trade-off between retention of zinc and reduced bioavailability caused by phytate. This issue is discussed further below.

Table 14.2. Zinc content of unpolished rice from samples grown in soil above and below the critical level of zinc for rice production (0.8 ppm of available soil zinc).

	Unpolished rice (mg Zn/100 g)							
	Soil less than 0.8 ppm[a]			Soil more than 0.8 ppm[b]				
Season	*n*	Mean	SD	*n*	Mean	SD	Difference (%)	*P* value for difference
boro	26	1.74	0.30	40	1.93	0.34	+10.9	<0.05
aman	45	2.09	0.38	26	2.07	0.23	–1.0	NS

SD, standard deviation; NS, not significant.
[a]Geometric mean of soil zinc=0.36 ppm.
[b]Geometric mean of soil zinc=2.80 ppm.

Table 14.3. Zinc content of samples of parboiled unpolished rice and polished rice matched by household and variety collected in two villages during November 2000 before and after milling. (Adapted from Mayer *et al*. (16).)

		Parboiled paddy (mg Zn/100 g)		Milled rice (mg Zn/100 g)		Zn change after milling (%)	
Village	*n*	Mean	SD	Mean	SD	Mean[a]	SD
Batabaria	13	1.86	0.24	1.13	0.21	–38.7*	10.8
Simulia	20	1.96	0.23	1.50	0.26	–23.5†	9.7

SD, standard deviation.
[a]Mean values within a column with unlike symbols were significantly different ($P < 0.05$).

Changes in zinc after cooking

In Batabaria and Dhola, where pond water was used for cooking and the excess discarded, on average 16% of zinc was lost in cooking. In Simulia and Padumhar there was little change in the zinc content and tube-well water was used for cooking and not discarded. Comparison between villages that use pond water and tube-well water showed significant differences in the percentage change in zinc and from cooking ($P < 0.01$) (Table 14.4).

From these samples, we hypothesize that if cooking water was not discarded there would be minimal loss of zinc from cooking. Approximately 16% could be retained if the water was not discarded. The assumptions are that the tube-well water was not itself a source of zinc; we did not test this. The other assumption is that the zinc discarded with cooking water was as bioavailable as that remaining in the cooked rice, which is likely because the discarded zinc is in a soluble form, as shown by cooking trials (23).

Zinc content of different varieties after milling

Polished rice samples collected from households in May (stored *aman*) on average contained 1.26 ± 0.28 mg Zn/100 g and in November (stored *boro*), 1.32 ± 0.38 mg Zn/100 g with no significant difference between the two seasons. Different varieties were generally available from different villages (Table 14.5). The village differences in rice zinc content are shown in Table 14.6. Both rice variety ($P < 0.001$) and village ($P = 0.003$) were significant predictors of rice zinc, implying that both genetic and environmental differences were important influences on

Table 14.4. Zinc content of raw polished rice and cooked rice matched by household and variety collected in four villages in May 2000 before and after cooking. (Adapted from Mayer *et al*. (16).)

			Milled rice (mg Zn/100 g)		Cooked rice (mg Zn/100 g)		Zn change after cooking (%)	
Village	Source of water	*n*	Mean	SD	Mean	SD	Mean	SD
Batabaria	Pond	21	1.12	0.27	0.94	0.34	–16.5	19.4
Dhola	Pond	16	1.31	0.26	1.10	0.25	–15.0	18.1
Simulia	Tube well	19	1.44	0.21	1.36	0.26	–4.0	20.6
Padumhar	Tube well	17	1.15	0.16	1.12	0.25	–0.4	26.3

SD, standard deviation.

Table 14.5. Zinc content of polished rice samples collected in four study villages in two seasons. (Adapted from Mayer *et al.* (16).)

Rice variety[a]	Polished rice (mg Zn/100 g)			Village[b]
	n	Mean	SD	
Collected May (stored *aman*)				
Pari	11	1.58	0.14	S
BR14 (Gazi)	10	1.34	0.20	S
Mota mota	14	1.33	0.27	D
BR 26 (Sraboni)	5	1.28	0.24	B, S
BR2 (mala)	10	1.17	0.17	P
Moisare	14	1.09	0.36	B
Unknown	5	1.02	0.27	B, D
Total	89	1.26	0.28	
Collected in Nov (stored *boro*)				
Boro Aus	22	1.99	0.28	D
Pari	9	1.46	0.18	S
Pajam	10	1.43	0.22	S, P
BR2 (mala)	13	1.34	0.28	B, D, P
BR 26 (Sraboni)	6	1.27	0.03	B, S
Shorna	14	1.17	0.30	P
BR14 (Gazi)	6	1.16	0.11	D, S
BR 16 (Shalibalam)	8	1.15	0.11	B
Unknown	26	1.12	0.19	B, S, P
Moisare	7	1.02	0.22	B
Maalshira	10	0.96	0.18	P
Total	152	1.32	0.38	

SD, standard deviation.
[a]Only those varieties with four or more samples are listed here, although all samples are included in the totals. The samples with a 'BR' designation were those released by the Bangladesh Rice Research Institute and given consecutive numbers. Those without a 'BR' designation were local varieties. The 'BR' varieties collected were developed for the *boro* season to be grown with irrigation in the dry season.
[b]B = Batabaria, Comilla district; D = Dhola, Barisal district; P = Padumhar, Dinajpur district; S = Simulia, Naogaon district.

the zinc content of rice. For comparison of varieties, we have therefore restricted the analysis to samples collected from the same village to reflect the changes that communities could make easily. The zinc content of the highest-zinc variety and the lowest-zinc variety of samples collected in October (mostly stored *boro* rice) in each village is shown in Table 14.7. In two villages with the highest average zinc content there were significant differences between the zinc content of highest and lowest varieties (38% in Dhola and 27% in Simulia; $P < 0.05$). In May the samples collected from each village tended to be the same variety, making this comparison impossible.

The assumption is that the difference between high- and low-zinc rice varieties is due to the variety itself and not to the growing conditions. If, for example, particular varieties tend to be grown in better or worse soils this assumption would be violated. Also if the differences were caused by the dilution effect they would not be helpful for interventions.

Dietary intake of zinc related to zinc content of rice

The sample of children for dietary analysis from the four survey villages included 194

Table 14.6. Zinc content of polished rice in four study villages in two seasons. (Adapted from Mayer *et al*. (16).)

		Polished rice (mg Zn/100 g)		
Season	Village	*n*	Mean[a]	SD
Stored *aman*[b]	Batabaria	28	1.14*	0.32
	Dhola	18	1.29*	0.27
	Simulia	25	1.45†	0.20
	Padumhar	18	1.14*	0.16
Total		89	1.26	0.28
Stored *boro*[c]	Batabaria	40	1.10*	0.19
	Dhola[d]	34	1.78†	0.41
	Simulia	39	1.35‡	0.20
	Padumhar	39	1.12*	0.26
Total		152	1.32	0.38

SD, standard deviation.
[a]For each season, mean values within a column with unlike symbols were significantly different ($P < 0.05$).
[b]Stored samples collected in May.
[c]Stored samples collected in November. These samples were used for the dietary analysis.
[d]These samples would also include some stored *aus* rice (early monsoon season).

Table 14.7. Highest- and lowest-zinc varieties of rice for each village for samples collected in November.

		mg Zn/100 g		
Village	Rice variety[a]	*n*	Mean[b]	SD
Batabaria	BR 16 (Shalibalam)	8	1.15*	0.11
	Moisare	7	1.02*	0.22
Dhola	*Boro* Aus	22	1.99*	0.28
	BR2 (mala)	7	1.44†	0.23
Simulia	Pajam	9	1.47*	0.19
	BR14 (Gazi)	6	1.16†	0.11
Padumhar	BR2 (mala)	5	1.20*	0.33
	Maalshira	10	0.96*	0.18

SD, standard deviation.
These comparisons were not possible for the rice samples collected in May as generally only one variety was available with sufficient samples in each village.
[a]Varieties with at least four samples of each variety in each village only were included.
[b]For each village, mean values within a column with unlike symbols were significantly different ($P < 0.05$).

children aged 5–10 years. They ate, on average, 378 g rice/day. The 83 children aged 2–4 years consumed less rice, on average 258 g/day. The average contribution of rice to total intake of zinc was 66%. The high reliance on rice and the differences in the zinc content of rice affected the zinc density of the overall diet in the different villages. The zinc density was highest in Dhola where the rice had the highest zinc content. The consumption of other foods with higher zinc density than rice was not sufficient to overcome the effect of rice zinc content on the zinc density of the overall diet in any of the villages. For example, the high meat and fish intake in Batabaria was not sufficient to improve the zinc density of the diet in this village, where low-zinc rice was consumed (Table 14.8).

Most children (86.3%) were meeting the average daily requirement for zinc by comparison to the EAR within each age group. The percentage of children meeting the EAR for zinc in each village was different ($P = 0.10$), with 79.5%, 90.8%, 84.6% and 92.2% for Batabaria, Dhola, Simulia and Padumhar, respectively. These differences relate not only to the zinc density of the diet but also the total amount of food consumed. In Padumhar, the energy intake was higher than the other villages and this compensated for the low zinc density of the diet; thus, approximately as many children were meeting their zinc requirements in Padumhar as in Dhola where the food intake was low but the zinc density higher (Table 14.8). The zinc requirements may be higher than those suggested by this analysis since children were undernourished and many were suffering from intestinal infections. In malnourished children, daily zinc requirements could be as high as 2–4 mg/kg body weight (1); using this cut-off most children would be zinc-deficient in these villages**.**

What is the potential to improve the zinc content of rice through the following actions?

The figures given below are approximate and serve to illustrate the method. They should be considered with all the assumptions described above.

1. *Increasing soil zinc content (the portion that is available for plant growth)*. Increasing the soil available zinc to above the critical level of 0.8 ppm could increase unpolished rice zinc by 11% in the *boro* season. A portion of this additional zinc would be lost following milling, thus reducing the increment to between 6.5% and 8.5%. The soil zinc improvement to achieve this increase, however, is high, considering the log relationship described above.
2. *Reducing the amount of zinc lost in milling*. An increase of 15% in grain zinc could be possible with a change in milling. The change suggested is the difference between the losses of zinc at two different mills in two villages.
3. *Reducing the amount of zinc lost in cooking*. An increase of 16% in grain zinc could be possible if the cooking water was not discarded.
4. *Choosing rice varieties that have high zinc content (after milling)*. In Dhola it would be possible to increase zinc intake from rice by 38% and in Simulia by 27% if the lowest-zinc variety was switched to the highest-zinc variety. In Padumhar and Batabaria there were no high-zinc varieties available.

Table 14.8. Total energy and zinc intakes in the diets of children aged 2–10 years and zinc density of the diet. (Adapted from Mayer *et al*. (16).)

				Percentage Zn from:					
Village		Energy intake (kJ/day)	Zn intake (mg/day)	Rice	Meat and fish	Fruit and vegetables	Legumes	Other sources	Zn density (mg/1000 kJ)
Batabaria	Mean	6058	6.17	57.5	20.5	13.5	2.4	4.9	1.00
(*n* = 83)	SD	1972	2.45	15.0	13.8	9.2	5.6	7.9	0.24
Dhola	Mean	5543	7.53	71.8	9.8	6.3	7.6	4.6	1.35
(*n* = 65)	SD	1633	2.86	14.6	10.2	7.5	10.0	7.4	0.24
Simulia	Mean	6759	7.08	73.2	10.3	9.8	1.1	5.7	1.05
(*n* = 65)	SD	2392	2.70	11.5	8.9	6.5	4.3	8.6	0.20
Padumhar	Mean	7096	7.36	62.9	11.9	14.6	4.1	5.0	0.99
(*n* = 64)	SD	2321	4.31	16.6	17.0	9.6	7.1	6.3	0.35
Total	Mean	6342	6.98	65.8	13.6	11.2	3.7	5.0	1.09
(*n* = 277)	SD	2163	3.15	15.9	13.6	8.9	7.4	7.6	0.30

SD, standard deviation.
Individual household rice zinc composition data from our analysis of household samples were used for each child and standard food table composition data for all other foods.

An example, using these data

If we had a rice sample with 1.00 mg Zn/100 g that was grown in poor soil, was a low-zinc variety and lost the maximum in milling and cooking, we could increase the zinc content to 1.07 mg/100 g by soil improvements and then to 1.23 mg/100 g by retaining more after milling. If we also retained more after cooking this would increase to 1.43 mg/100 g, then to 1.97 mg/100 g by improving the rice variety. In this example, we have shown a 97% overall improvement in grain zinc. With 66% of dietary zinc supplied by rice, the total dietary zinc intake would increase by 64% with no other improvements to the overall diet.

Discussion

The assumptions that we have made in the analysis would be best tested through further studies using interventions. Observational analysis can offer some pointers to potentially valuable interventions, but are not conclusive alone. By the nature of the study it was not possible to provide controlled environments for all of the assessments. For example, contamination from soil or tools during processing may have happened, but there is no reason to believe this would have systematically affected the results. The recovery of zinc from standards was consistently good in the different batches of rice sample analysis, so contamination in the laboratory is unlikely to bias the results. Genetic and environmental influences on rice zinc could not be separated at the different stages of the research. The strength of the research is its closeness to the reality of the situation in the field and communities.

There is wide variability in the zinc content of rice from one village to the next. It is important to understand the causes of this variability and harness the elements of that variability that could be exploited to increase zinc intake. In this example, the milling, cooking and choice of variety seem good candidates. Making changes to the soil zinc are also possible but the low initial zinc in the soils we sampled would need relatively large increases. We have shown that we could double the zinc content of a low-zinc rice sample by changes to the soil zinc, milling, cooking and the choice of variety.

The village-level differences in the zinc content of rice also have implications for dietary assessments that make use of published food composition tables; for some villages the zinc intake will be underestimated and in others overestimated if the standard zinc data were used for rice. For example, using 1.3 mg/100 g for unpolished rice from the standard food tables (20) would create an overestimation of 0.20 mg/100 g (18%) in Batabaria and an underestimation of 0.58 mg/100 g (33%) in Dhola on average for the rice collected in November. It would be difficult to produce very detailed food composition tables to allow for all the variability, but this variability needs to be considered in the interpretation of dietary data. It is especially important when zinc intakes are below or close to sufficiency levels.

Improvements to plant-available soil zinc would need to be large to increase the zinc in grain substantially, based on these data. Other studies have shown that it is possible to increase the zinc content of grain using zinc fertilizers; for example, grain zinc increased by 63% (7), 42% (23) and 44% (8) with the application of zinc fertilizers. There are also other ways to increase grain zinc. For example, vesicular arbuscular mycorrhiza, a fungus that facilitates uptake of zinc by roots, increased rice grain zinc by 32% (12). Organically grown rice was 10% higher in grain zinc than conventionally grown rice (11). These and other strategies that could increase the amount or bioavailability of zinc have been previously reviewed (25). The relationship between grain zinc and pH is of limited practical application because acidic soils are associated with agronomic disadvantages. The 'dilution effect' observed is important as it represents a challenge for farmers who wish to increase yield and grain zinc concurrently. In the future, a useful addition to a wide range of agronomic trials would be analysis of grain and soil zinc that would help to determine what practices improve the zinc content of grain.

The rice varieties that can grow in any location are limited by the soil, other environmental conditions and the availability of seeds, fertilizers and other inputs. Nevertheless, we have shown that locally grown varieties can offer a range of zinc contents. For example, in Dhola, the highest-zinc variety, *boro* Aus, had a zinc content of 1.99 mg/100 g compared with the lowest of 1.44 mg/100 g in that village and season (Table 14.7). Plant breeding efforts have recently emphasized increasing grain zinc and iron, so the options to improve zinc intake through selection of these improved varieties are also possible. For example, Stein *et al*. (26) give an example of the potential to improve zinc content of rice through biofortification from 1.3 mg/100 g to 2.4 mg/100 g (pessimistic) and 3.5 mg/100 g (optimistic). These increases are 85% and 169% respectively and are higher than the differences we have observed between high- and low-zinc varieties that are available in any one village. For these improved varieties to be adopted, however, they would need to be available and acceptable to the farmers and communities. For the zinc content to reach its genetic potential, there would need to be adequate zinc available in the soil.

Similar studies of different milling and cooking practices at the community level have not been reported (to our knowledge). Community resistance to minimally milled rice (brown rice) is widespread. We have shown that there is potential for change, however, illustrated by the differences observed between the two villages where we collected samples. It is likely that rice from less vigorous milling would be acceptable to all communities, although this would have to be verified through discussions. The extra zinc that remains with less vigorous milling is likely to be less bioavailable than zinc from more vigorous milling because more phytate is also retained. The total bioavailable zinc is likely to be greater from less vigorous milling, however, because the greater amount of zinc should compensate for the loss in bioavailability (14). The phytate is concentrated in the outer layers of the grain and tends to be removed more rapidly than zinc (27). An optimum time of milling needs to be established that balances more removal of phytate and less removal of zinc. This information could be used to make recommendations to communities. The reasons for the milling preferences and for retaining or discarding the cooking water need to be explored with the communities, before recommendations are made to reduce milling time or retain cooking water. We have not reported on the parboiling process here because it was a universal practice in the survey villages and hence there was no variability to report.

From the dietary intake data collected, the overall zinc intake of the diet was highly affected by the variability in the zinc content of rice that we observed in the four villages. We have shown that the zinc content of rice affects the zinc density of the diet considerably. There was also a positive correlation between the zinc content of rice and the zinc measured in children's hair samples (16). This is further evidence that the zinc nutritional status of children is likely to improve with improvements in zinc intake from rice and goes some way to show that the additional zinc provided by rice is well absorbed. If villagers could optimize their zinc intake using these types of improvements, the children's risk of zinc deficiency should decrease in villages that currently have low-zinc rice. These assumptions need to be tested by further research.

This method of assessing the food system for one nutrient in one crop serves to illustrate the suggested approach. The assumptions mentioned above need to be tested. For example, the genetic and environmental determinants of variability in the zinc content of rice need to be isolated by controlled experiments. The different mills could be compared with one batch of rice or, alternatively, different varieties could be compared using the same mill. The effect on the phytate content, and hence bioavailability, of any changes in milling practice should be considered. The reasons behind the practices employed in the villages also need to be investigated and the opinions, priorities and constraints of the villagers and other stakeholders included in the next stages of the work.

This analysis of the staple crop could be developed into an integrated systematic analysis of the food system of not just zinc and not just the staple crop. For different crops and nutrients these stages could be modified depending on the likely points at which programmes could be introduced in the food system. Ideally, programmes would be planned to optimize the nutrient content of several foods with several nutrients simultaneously to create synergistic benefits. This approach could be combined well with other nutrition programmes, such as vegetable gardens, nutrition education, micro-enterprises and support for child care. The initial work could be carried out through partnership of a local non-government organization, a community group and a multidisciplinary group of scientists. The advantage of this approach is that it is based on usual practice and community involvement at each stage from assessment to implementation and evaluation. The choice of programmes would be adaptable to local conditions and preferences. This method of working with communities has been implemented successfully, for example in Malawi (28).

A local analysis of the food system related to the particular staple food would be a useful addition to the biofortification strategies that offer so much potential to improve micronutrient nutrition. The application of external inputs and knowledge with community involvement and fine-tuning to the communities' priorities and circumstances offer the best chance of success. In this way, both existing good practice and new innovations for the communities could be incorporated into programmes. Our research and the literature reviewed in this chapter show that there are food-based approaches that could significantly raise zinc intakes.

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15 Combating Iron Deficiency: Food-based Approaches

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Abstract
Iron deficiency is the most widespread dietary deficiency in the world affecting close to two billion people or one-third of the world's population. Its most visible impact is iron-deficiency anaemia (IDA) which contributes significantly to high levels of maternal and neonatal deaths in poor, vulnerable populations, while the 'hidden' impact of iron deficiency extends to all areas of individual growth and development. Anaemia is most prevalent in pregnant women and pre-school children. The insidious nature of IDA has made it a difficult challenge for the international community to address effectively as its scale and impact are often overlooked.

This chapter presents the requirements for iron and related micronutrients and describes the prevalence and geographic and socio-economic distribution of anaemia. The public health consequences of anaemia on both the individual and on society are outlined and the determining or contributing factors that can lead to or hinder their alleviation are discussed.

The chapter concludes that increasing the availability and consumption of a nutritionally adequate diet is the only sustainable and long-term solution, not just for overcoming IDA, but for overcoming other micronutrient deficiencies as well. Policies and intervention programmes that effectively alleviate micronutrient deficiencies are described, including increasing overall food intake, increasing consumption of micronutrient-rich foods, modifying intake of dietary inhibitors and enhancers, using improved processing, preservation and preparation techniques, consumer education for behaviour change, improving food quality and safety and public health, and food fortification and supplementation. The Food and Agriculture Organization of the United Nations is committed to placing food-based strategies for preventing micronutrient deficiencies high on the development policy agenda and urges all parties to speed up their wider implementation if the Millennium Development Goals are to be achieved on time.

Key words: iron deficiency, iron-deficiency anaemia, bioavailability, micronutrients, food-based strategies, dietary diversification, nutrition education, food and nutrition security, food fortification

Introduction

Iron deficiency is a serious and widespread public health problem. The scale and magnitude of the problem, combined with the functional impact such deficiencies have on the quality of life, both physiologically and socio-economically, require the urgent adoption of known and effective measures. However, the focus of development practitioners on their own narrow area of interest or expertise, be it health, care or food, has prevented the

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realization of a truly comprehensive approach being taken to tackle this critical problem. This chapter is an effort to correct this imbalance, to place food-based approaches back into the centre of the debate and to encourage their adoption on a broader scale as a matter of priority.

Micronutrient deficiencies exist in both developing as well as developed countries and may be considered as 'hidden hunger'. In developing countries they exist in the context of food insecurity, where meeting overall energy needs and dietary diversity continues to remain the major challenge. Consequently, efforts to reduce micronutrient malnutrition need to be placed in the context that hunger has reached unprecedentedly high levels: in 2009 an estimated 1.02 billion people were hungry (1), an increase of 105 million people from the last estimate in 2007 of 923 million people by the Food and Agriculture Organization of the United Nations (FAO) (2). Worldwide, 20 million children under 5 years of age suffer from severe malnutrition and around one million children die due to malnutrition each year (3). In 2004, the overall disease burden attributed to IDA was 591,000 perinatal deaths and over 19 million disability-adjusted life years (DALYs) from perinatal causes, while IDA resulted in 115,000 maternal deaths and over 3 million DALYs from maternal causes (4). In children under 5 years old, the loss of healthy life due to IDA accounted for 0.2% of deaths and 0.5% of DALYs (5).

The underlying causes of such high levels of malnutrition, including the high levels of micronutrient deficiencies, are poverty, socio-political inequities, and insufficient agricultural development that lead to food and nutrition insecurity at national and household levels. To address these causes, FAO is placing emphasis on actions that promote an increase in the supply, access to and consumption of an adequate quantity, quality and variety of foods for all population groups. By promoting and supporting sustainable food-based programmes and strategies to improve nutrition, FAO is seeking to resolve micronutrient deficiency problems of developing countries through increasing the consumption of an adequate and varied diet in combination with the use of supplements and fortification strategies rather than through the use of supplements and fortification strategies alone. Despite these interventions, IDA remains the most widespread public health problem, not because of a lack of innovation and research into new interventions but due to a failure to effectively implement the aforementioned established interventions. A paradigm shift is occurring among nutrition leaders as they are starting to question the traditional research focus of discovering new interventions and instead shifting towards how best to deliver existing interventions as more practical means to curbing malnutrition, especially in low-income countries (6). This renewed focus on utilizing established interventions that are culturally appropriate, cost-effective and sustainable is needed to control and prevent IDA. FAO's food-based focus is in keeping with the right to food, a concept whose achievement means that all people should be able to gain access to a varied diet consisting of a variety of foods that provide all the energy and macro- and micronutrients sufficient to achieve a healthy and productive life.

Definitions and Terminology

Iron has several vital functions in the body. It serves as a carrier of oxygen to the tissues from the lungs by red blood cell haemoglobin, as an electron carrier within cells, and as an integrated part of important enzyme systems in various tissues. Iron is reversibly stored within the liver as ferritin and haemosiderin and is transported between different compartments in the body by the protein transferrin. Haemoglobin (Hb), mean cell volume (MCV), transferrin saturation (TSAT), serum ferritin (SF), transferrin receptor (TfR), total iron-binding capacity (TIBC) and erythrocyte protoporphyrin (EP) are measurements commonly used when investigating iron status. However, the sensitivity and specificity of these indicators is unclear and a combination of these indicators is sometimes used.

Iron deficiency may be defined as an absence of iron stores combined with signs of iron-deficient erythropoiesis (the making of red blood cells), implying there is an insufficient supply of iron to various tissues. This occurs at a serum ferritin level <15 μg/l (ng/ml). Under these conditions, insufficient amounts of iron are delivered to transferrin, the circulating transport protein for iron, resulting in a reduction in transferrin saturation. Formation of haemoglobin is reduced resulting in a reduction in mean corpuscular haemoglobin. The concentration of transferrin in plasma increases in an effort to compensate. Iron deficiency may be classified according to serum ferritin concentration, with depleted iron stores at SF <24 ng/ml, mild iron deficiency at SF = 18–24 ng/ml and severe iron deficiency at SF <12 ng/ml.

Nutritional anaemia is a condition in which the haemoglobin content of blood is lower than normal as a result of a deficiency of one or more essential nutrients. Because anaemia is the most common indicator used to screen for iron deficiency, the terms ‘anaemia’, ‘iron deficiency’ and ‘iron-deficiency anaemia’ are sometimes incorrectly used interchangeably. However, there are cases where a person may not be anaemic but is mildly or moderately iron-deficient and consequently may be functionally impaired.

Iron-deficiency anaemia (IDA) is the most common nutritional cause of anaemia and occurs when there is an inadequate amount of red blood cells caused by lack of iron. IDA is a rather imprecise concept and has no immediate physiological meaning. The World Health Organization (WHO) defines children under 5 years of age and pregnant women living at sea level as anaemic if their haemoglobin concentration is <11 g/dl, non-pregnant women as anaemic if Hb<12 g/dl and men as anaemic if Hb<13 g/dl. Mild-moderate anaemia is defined as Hb = 7–10.9 g/dl and severe anaemia as Hb<7 g/dl. The main benefit of using cut-offs is to allow comparisons to be made between population groups. IDA is usually symptomatic at haemoglobin levels of about 8 g/dl or lower.

Recommended Nutrient Intake (RNI) is the daily intake of a nutrient which meets the requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population group based on the nutrient’s Estimated Average Requirement (EAR) plus two standard deviations. A *requirement* is an intake level which will meet specified criteria of adequacy, preventing risk of deficit or excess.

Vitamins and *minerals* are referred to as *micronutrients* because the body needs them in very small quantities for growth, development and maintenance. Vitamins are organic compounds that the human body cannot produce or cannot synthesize in sufficient amounts and must be obtained from diet or else symptoms of deficiencies occur. Minerals are inorganic substances – elements that originate in the earth from soil or water – that can only be obtained from the diet, either directly from consuming plants that have integrated these minerals from the soil or water into their tissues or indirectly from consuming animals that have consumed plant materials (7).

A *food-based strategy* has the goal of improving nutrition through increasing the availability and consumption of a nutritionally adequate micronutrient-rich diet from a variety of available foods.

Food-based dietary guidelines (FBDGs) recognize that people eat foods, not nutrients, and focus on giving simple practical advice on the appropriate combination of foods that can meet nutrient requirements rather than on how each specific nutrient is provided in adequate amounts.

Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Requirements

Iron is required to replace basal losses, losses due to menstruation, losses due to disease and infection, as well as for growth. Losses from the skin and the interior surfaces of the body are estimated at 14 μg/kg body weight per day, with a non-menstruating 55-kg woman losing about 0.8 mg Fe/day and a 70-kg man about 1 mg Fe/day. Menstrual losses range from 0.48 to 1.90 mg Fe/day. Requirements to allow for growth up to 18 years of age range from 0.23 to 0.60 mg Fe/day depending on age and sex. By adding up these estimates we may calculate that total absolute iron requirements at the 50th percentile ranges from 0.46 to 1.68 mg/day and iron requirements at the 95th percentile ranges from 0.63 to 3.27 mg/day.

Requirements for iron vary depending on age, physiological status, growth rate, degree of physical maturity, body composition and activity level. Increased requirements are also noted in patients with malaria, congenital haemoglobinopathies and other causes of haemolysis. Iron requirements in relation to energy intake are highest during the last trimester of pregnancy, during the weaning period and in adolescents. It is possible to meet these requirements if the diet is diverse with a consistently high content of meat and foods rich in ascorbic acid. However, it is very difficult, if not impossible, to meet these requirements and thereby prevent iron deficiency with poor monotonous diets and in some environments and specific cases, e.g. premature infants. In such cases, the need for supplements and fortification is clear but such programmes should not put off efforts to improve the quality of diets.

Iron is present in foods in two forms, as haem iron, which is derived from flesh foods (meat, poultry and fish), and as non-haem iron, which is the inorganic form present in plant foods such as cereals, pulses, legumes, grains, nuts and vegetables. Haem iron is well absorbed with the average absorption of haem iron from meat-containing meals being about 25%, ranging from about 40% during iron deficiency to about 10% when iron stores are replete. Non-haem iron has a lower rate of absorption (2–10%), depending on the balance between iron absorption inhibitors and iron absorption enhancers present in the diet. Consequently the amount of iron absorbed depends not only on the iron content of the meal, but also – and to a marked degree – on the composition of the meal (i.e. the balance of the factors enhancing and inhibiting the absorption of iron).

Reducing substances (i.e. substances that keep iron in the ferrous form) need to be present for iron to be absorbed. These enhancing factors include ascorbic and citric acids found in certain fruit juices, fruits, potatoes and certain vegetables; cysteine-containing peptides found in meat, chicken, fish and other seafood; and ethanol and fermentation products like vegetables, soy sauce, etc., which enhance the absorption of both haem and non-haem iron. Other foods contain factors (or ligands; phytates, polyphenols, calcium and phosphate) that strongly bind ferrous ions and inhibit absorption. These inhibiting factors are found in bran products, bread made from high extraction flour, breakfast cereals, oats, rice (especially unpolished rice), pasta products, cocoa, nuts, soybeans and peas (phytates); tea, coffee, cocoa, certain spices, certain vegetables and most red wines (iron-binding phenolic compounds, polyphenols); dairy products, e.g. milk and cheese (calcium); and soy proteins (phosphate). In infant foods containing soy proteins, the inhibiting effect can be overcome by the addition of sufficient amounts of ascorbic acid. Consumption of betel leaves, common in areas of Asia, also has a marked negative effect on iron absorption. However, the addition of certain vegetables or fruits containing ascorbic acid can double or triple iron absorption, thereby counteracting much of the effects of these inhibitors depending on the other properties of the meal. As the effect is so marked, this may be considered as one of vitamin C's physiological roles. Each meal should preferably contain at least 25 mg of ascorbic acid and possibly more if the meal contains many inhibitors of iron absorption.

Bioavailability of iron from meals with a similar content of iron, energy, protein, fat, etc., can vary more than tenfold. Just the addition of certain spices (e.g. oregano) or a cup of tea may reduce the bioavailability by one-half or more. Therefore, to translate physiological iron requirements into recommendations for dietary iron intakes, the bioavailability of iron, i.e. its absorption for utilization by the body, of different diets need to be calculated. A study on the bioavailability of different Indian diets found that 1.7–1.8% of iron was absorbed from millet-based diets, 3.5–4.0% from wheat-based diets and 8.3–10.3% from rice-based diets. Other studies from South-east Asia show absorption rates can rise significantly from less than 5% to more than 15% if animal products and vitamin C are amply provided. RNIs for iron at four levels of dietary iron bioavailability (5, 10, 12 and 15%) are given in Table 15.1. In non-pathological states,

Table 15.1. Recommended Nutrient Intake (RNI) for iron[a] from meals with differing bioavailability. (Data from *Human Vitamin and Mineral Requirements, Report of a FAO/WHO Expert Consultation*, 2002 (8).)

	RNI (mg/day)			
	15% bioavailability	12% bioavailability	10% bioavailability	5% bioavailability
Infants and children				
0–6 months	[b]	[b]	[b]	[b]
1–7 months	[6][c]	[8][c]	[9][c]	[19][c]
1–3 years	4	5	6	12
4–6 years	4	5	6	13
7–9 years	6	7	9	18
Males				
10–18 years	10 (10–14 years) 12 (15–18 years)	12 (10–14 years) 16 (15–18 years)	15 (10–14 years) 19 (15–18 years)	29 (10–14 years) 38 (15–18 years)
19+ years	9	11	14	27
Females				
10–18 years	9 (10–14 years)[d] 22 (10–14 years) 21 (15–18 years)	12 (10–14 years)[d] 28 (10–14 years) 26 (15–18 years)	14 (10–14 years)[d] 33 (10–14 years) 31 (15–18 years)	28 (10–14 years)[d] 65 (10–14 years) 62 (15–18 years)
19–50 years, premenopausal	20	24	29	59
51+ years, menopausal	8	9	11	23
Pregnancy: 1st trimester	[e]	[e]	[e]	[e]
Pregnancy: 2nd trimester	[e]	[e]	[e]	[e]
Pregnancy: 3rd trimester	[e]	[e]	[e]	[e]
Lactation: 0–3 months	10	12	15	30
Lactation: 4–6 months	10	12	15	30
Lactation: 7–12 months	10	12	15	30

[a]Iron absorption can be significantly enhanced when each meal contains a minimum of 25 mg of vitamin C, assuming three meals per day. This is especially true if there are iron absorption inhibitors in the diet such as phytate or tannins.
[b]Neonatal iron stores are sufficient to meet the iron requirement for the first six months in full-term infants. Premature infants and low-birth-weight infants require additional iron.
[c]Bioavailability of dietary iron during this period varies greatly.
[d]Non-menstruating adolescents.
[e]It is recommended that iron supplements be given to all pregnant women because of the difficulties in correctly evaluating iron status in pregnancy. In the non-anaemic pregnant woman, daily supplements of 100 mg of iron (e.g. ferrous sulfate) given during the second half of pregnancy are adequate. In anaemic women, higher doses are usually required.

the RNI for men ranges from 9 mg in diets with high bioavailability to 27 mg in diets where bioavailability is only 5%. For menopausal women the range is similar although slightly lower due to variation in body size, but in premenopausal women aged between 19 and 50 years the recommended intakes are 20 mg and 59 mg, respectively (8).

In summary, the amount of dietary iron absorbed is mainly determined by the amount of body stores of iron (absorption rates increase when body stores are depleted and decrease as iron stores are replenished) and by the properties of the meal as determined by its content of haem and non-haem iron, the food preparation practices (cooking time and temperature) and the presence of enhancing dietary factors (such as meat peptides and vitamin C) and inhibiting dietary factors (such as phytates and calcium), all of which affect bioavailability.

Prevalence and Consequences of Iron-deficiency Anaemia

Iron deficiency and IDA are worldwide public health problems. Some two billion people – over 30% of the world's population – are anaemic, mainly due to iron deficiency, which is frequently exacerbated by infectious diseases, particularly in resource-poor areas of low-income countries (9). Malaria, hookworm, schistosomiasis, HIV/AIDS and other infections such as tuberculosis are particularly important factors contributing to the high prevalence of anaemia in some areas. Low plasma levels of iron, folate, zinc and vitamins B_{12} and A have also been shown to be associated with anaemia.

The latest estimates from WHO on the prevalence of anaemia by age group and region show that the highest prevalence is found in infants, children, adolescents and women of childbearing age, especially pregnant women (children of pre-school age: 47.4% or 293 million; non-pregnant women: 30.2% or 468 million; pregnant women: 41.8% or 56 million) (10). Among children, the determinants of anaemia are age (the younger the child, the higher the risk, with the weaning period in infants being especially critical because of the very high iron requirements in relation to energy requirements), sex (males are at higher risk), weight and height (stunted and underweight children are at greater risk) and plasma retinol levels (higher levels lower the risk of IDA). Among pregnant women, the determinants are age, gravidity and stage of gestation with women below 20 years of age, women with multiple pregnancy history and those in their second and third trimester more prone to deficiency. Among lactating women, the determinants are period of lactation and vitamin A status.

Africa has the highest prevalence rates of anaemia in pre-school children (74.6%), non-pregnant women (61.4%) and pregnant women (65.8%). Asia has the highest number of anaemia cases: about half of the world's anaemic women live in the Indian subcontinent, the majority of whom develop anaemia during pregnancy. In India, the National Family Health Survey (1998–1999) (11) showed anaemia prevalence of 82% in expectant mothers, 74% in children under 3 years of age, 52% in married woman aged 15–49 years, and more than 50% in adolescents. The Indian Council of Medical Research (12) reported that 62% of expectant mothers suffered from anaemia, of whom 9% had severe anaemia defined as Hb < 8 g/dl.

In many developing countries, anaemia rates in children are high (above 50%) and the severity of anaemia is marked. In many cases, this is due to low availability of dietary iron as 90% of the total dietary supply in many of these countries comes from plants which contain non-haem iron that is poorly absorbed. It has been suggested that improving the bioavailability of iron present in plant-based diets could potentially reduce IDA (13). Prevalence among vegetarians and in those reliant on cereal or tuber foods is significantly higher than in omnivore populations. Further disaggregation shows agro-ecological and country and urban/rural differences, the variation in iron status in different populations being mainly related to variation in the composition of their diet.

Iron deficiency and iron deficiency anaemia have a significant impact on human welfare, both at the level of the individual and for the economic development of a country. At the individual level, iron deficiency has several negative effects on important functions of the body. Deficiency can slow growth, hinder physical and mental development, and reduce the ability of the body to maintain itself. It is associated with impaired immune response, lowered resistance to infection and increased morbidity and mortality rates, adverse pregnancy outcome and reduced school performance. Growth faltering is associated with IDA and body mass index is positively correlated with haemoglobin concentration.

Iron nutrition is of great importance for the adequate development of the brain and iron deficiency has serious consequences for cognitive, psychomotor, physical and mental development of children. There is a relationship between even mild iron deficiency and brain development, and there are functional defects affecting learning and behaviour that cannot be reversed by giving iron later on. Infants with IDA may have reduced interaction with the physical and social world and become 'functionally isolated' which impedes their cognitive development. Studies have found indicators of iron status associated with a number of cognitive abilities in young schoolchildren, and with information processing and level of cognitive development in adult women. Several structures in the brain have high iron content with iron continuing to accumulate throughout the 20- to 30-year period of brain growth. Earlier studies that identified a possible relationship between iron deficiency and brain function and between iron deficiency and attention, memory and learning in infants and small children (14) have been substantiated by more recent studies that have added to this growing body of evidence. Systematic reviews by Grantham-McGregor and Ani (15) and Stoltzfus *et al*. (4) provided evidence to support a causal relationship between IDA during early childhood and cognitive deficits later on. Administration of iron to non-anaemic but iron-deficient adolescent girls improved verbal learning and memory (16). These cognitive effects are strong argument for the more active and effective combating of iron deficiency especially in women through adolescence and into early adulthood prior to and during pregnancy, and for infants and children.

Iron deficiency negatively influences the body's normal immunological defence mechanisms against infection. The cell-mediated immunologic response of T-lymphocytes is impaired as a result of a reduction in the formation of these cells. This, in turn, is due to reduced DNA synthesis that is dependent on the function of the radionuclide reductase which requires iron for its function. Iron deficiency also impairs the phagocytosis and killing of bacteria by neutrophil leucocytes, with probable involvement of the iron/sulfur-containing enzyme NADPH oxidase and cytochrome B, a haem enzyme. Administration of iron reverses these changes within 4 to 7 days. Anaemia increases the dangers of lead poisoning, particularly among young children.

IDA during pregnancy increases maternal haemorrhages and maternal morbidity and mortality rates. Women with low haematocrit of <37% have twice the risk of premature childbirth as women with haematocrit between 41% and 44% (17,18).

Iron deficiency reduces the physical capacity to do work, which seems to be less related to the degree of anaemia than to the impaired oxidative metabolism in the muscles due to the lack of iron-containing rate-limiting enzymes for oxidative metabolism. This reduced ability to do work can be reversed with iron administration. Studies of adolescent girls show that iron deficiency without anaemia is associated with reduced physical endurance and changes in mood and ability to concentrate. A study showed there was reduction in maximum oxygen consumption in iron-deficient non-anaemic women unrelated to the decreased oxygen transport capacity of the blood (19).

Since the highest prevalence is found in infants, children, adolescents and women of childbearing age, the burden falls not just on the individual but on society as a whole and its future as well. The debilitating consequences include loss of human capital and reduced work capacity and, therefore, of productivity in adults. In economic terms, IDA's impact can be significant. Horton and Ross used a sample of ten developing countries (Bangladesh, India, Pakistan, Mali, Tanzania, Egypt, Oman, Bolivia, Honduras and Nicaragua) to estimate the economic impact of IDA. They determined that the median value of per capita physical productivity losses is approximately US$2.32 or 0.57% of present Gross Domestic Product (GDP); after factoring in cognitive losses, the value of the median loss soars to US$16.78 per capita or 4.05% of present GDP. The cost of iron deficiency is high; for instance, in South Asia (Bangladesh, India and Pakistan) alone, the absolute value of physical productivity losses amount annually to US$4.2 billion (20).

Causal Factors

Worldwide, the most common cause of iron deficiency is nutritional iron deficiency. Does this imply that the normal diet cannot cover physiological iron requirements? For many years, nutritionists have assumed that all nutrients can be obtained from a diet containing a variety of foods drawn from a variety of sources. It has been thought that if people had access to a sufficient quantity and variety of foods, they would meet their nutritional needs. This still may be true, but despite increases in the availability of a wide variety of foods in almost every country in the world, the continued existence of micronutrient deficiencies including IDA throws this general assumption into question. Why has improved food supplies not necessarily resulted in adequate vitamin and mineral intakes?

To answer this question, we need to look at the factors that determine IDA. Low incomes and poverty result in low overall food intakes and poor monotonous diets low in micronutrient content. These may be compounded by a lack of understanding of the value of a varied diet and the importance of foods rich in micronutrients, as well as by dietary inhibitors and enhancers that interfere with the absorption of iron. Illness and infections – such as malaria, tuberculosis, HIV/AIDS and helminthic infections, e.g. hookworm (*Nector americanus*) and whipworm (*Trichuris trichiuria*) – are also contributing factors (21).

Poor dietary intake, in terms of both total quantity of food and micronutrient-rich food, is often the major cause of micronutrient malnutrition. Virtually all traditional dietary patterns can satisfy the nutritional needs of population groups so long as the capacity to produce and purchase food is not limited, for example, by socio-economic conditions or cultural practices that restrict the choice of foods. The erosion of these practices due to changing lifestyles and modernization can lead to unhealthy food choices and the protection and promotion of those diets that can provide the nutrients we require need our continued support.

The most affected population groups in need of improved nutrition generally include vulnerable resource-poor subsistence farmers and landless labourers, whose main food supplies come directly from the land and who often have restricted access to fortified foods due to low purchasing power and undeveloped distribution channels. Physiologically vulnerable groups including those with special nutritional needs or dietary problems – premature infants, young children, women of childbearing age, pregnant and lactating women, and famine-affected populations – may lack access to a diet that is sufficient in quantity or quality to provide adequate levels of iron. Special attention is needed to meet the food and nutrition needs of these vulnerable groups.

Iron requirements can be difficult to meet, and replenishment remains challenging for those severely deficient. Low bioavailability of iron in cereal- and tuber-based diets is one of the main causes of IDA in low-income countries as such diets contain high amounts of polyphenols (tannins) and phytate that inhibit iron absorption. Several practical actions and interventions that can reduce these effects are presented below.

A number of potential dietary sources need to be urgently promoted including many leafy vegetables and legumes that contain important quantities of iron, eaten in combination with animal products that are high in bioavailable iron and in iron absorption enhancers. For instance, the iron content of spinach can be three to nine times greater than that of meat (spinach: 5.4 mg Fe/418 kJ (100 kcal); steak: 1.6 mg Fe/418 kJ (100 kcal); lean chicken: 0.6 mg Fe/418 kJ (100 kcal)) (22). However, the bioavailability of iron in leafy vegetables is generally low despite its high nutrient density, whereas meat, which contains important enhancers such as vitamin C, can help improve absorption of iron.

The addition of small quantities of particular foods to a cereal- or tuber-based diet increases the overall nutrient density. The addition of legumes can slightly improve the iron content of cereal- and tuber-based diets. However, the bioavailability of this non-haem iron source is low. Therefore it is not possible to meet the recommended levels of iron from staple-based diets unless some meat, poultry or fish is included. In Kenya a study showed that meat intake in children under 3 years old was positively related to haemoglobin, suggesting that low meat intakes are an important cause of anaemia in this age group (23). The addition of 50 g of meat, poultry or fish increases total iron content as well as the amount of bioavailable iron significantly.

Variations in iron bioavailability (mg/ 418 kJ (100 kcal)) with meal composition for four basic staple diets based on white rice, corn tortilla, refined couscous and potato are presented in Table 15.2.

Under ideal conditions of food access and availability, food diversity should satisfy the micronutrient and energy needs of the general population. Unfortunately, for many people in the world, access to a variety of micronutrient-rich foods is not possible. As demonstrated in the analysis of typical staple-based diets in Table 15.2, micronutrient-rich foods including a small amount of flesh foods and a variety of plant foods (vegetables and fruits) are needed daily. This may not be realistic at present for many communities living under conditions of poverty. Food fortification and food supplementation are important alternatives that complement food-based approaches to satisfy the nutritional needs of people in developing and developed countries.

Poor monotonous diets deficient in one micronutrient are also likely to be deficient in other micronutrients, as well as low in other important foods such as fat and protein which further reduces absorption of what nutrients have been ingested, and in energy. Population groups consuming such diets are known to have multiple micronutrient deficiencies.

At the same time, increasing the consumption of a greater variety of plant foods, and especially fruits and vegetables, will provide most of the missing vitamins and minerals. In addition, a number of plant-based nutrients or phytochemicals will be consumed, and there is emerging evidence of the health benefits from food phytochemicals. This double benefit of consuming a variety of foods could play a major role in offsetting what is called the 'double burden of malnutrition'.

Intervention Strategies

Intervention programmes to overcome and prevent micronutrient deficiencies are generally considered under four main strategies:

- Dietary enhancement and diversification.
- Food fortification including biofortification.
- Vitamin and mineral supplementation.
- Global public health and disease control measures.

A comprehensive intervention programme combining elements from these strategies is considered the most effective way to prevent deficiencies. To determine the most appropriate mix, a situation analysis should first be conducted on the magnitude, prevalence and distribution of deficiencies, food consumption levels including the intake of micronutrients, and food habits and attitudes of vulnerable groups, including socio-economic data to identify major constraints and opportunities.

The most successful approach to increasing consumption of micronutrient-rich foods is likely to be a combined strategy that addresses both increased production (supply) and increased consumption (demand) of food. The special needs of particular groups, such as children and women of childbearing age, require particular attention. Food-based intervention programmes, dietary enhancement and diversification and food fortification including biofortification, play a critical role in alleviating micronutrient malnutrition. Food-based strategies focus on improving the availability, access to and consumption of vitamin- and mineral-rich foods. Benefits of such food-based strategies include not only improved intakes of specific nutrients but also improved overall diets and health status.

Government policies and regulations can influence the availability and price of micronutrient-rich foods. Vitamin and mineral deficiencies can be reduced with relatively small investments in agriculture, education and public health. National agricultural planning strategies, such as crop diversification to promote micronutrient-rich crops, agroforestry and the promotion of traditional and wild foods, can have an impact on the availability

Table 15.2. Variation of iron bioavailability with meal composition for basic diets based on white rice, corn tortilla, refined couscous and potato. (Data from *Human Vitamin and Mineral Requirements, Report of a FAO/WHO Expert Consultation*, 2002 (8).)

	Rice 598 g Veg oil 25 g	Rice 590 g Veg oil 25 g Carrots 21 g	Rice 570 g Veg oil 25 g Carrots 21 g Oranges 60 g	Rice 483 g Veg oil 25 g Carrots 21 g Oranges 60 g Lentils 95 g	Rice 477 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g	Rice 468 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g	Rice 428 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Lentils 45 g Spinach raw 50 g
Fe (mg/418 kJ (100 kcal))	1.2	1.3	1.3	4.3	2.8	4.1	5.6
	Tortilla 368 g Veg oil 20 g	Tortilla 363 g Veg oil 20 g Carrots 21 g	Tortilla 351 g Veg oil 20 g Carrots 21 g Oranges 60 g	Tortilla 314 g Veg oil 20 g Carrots 21 g Oranges 60 g Lentils 71 g	Tortilla 297 g Veg oil 20 g Carrots 21 g Oranges 60 g Beef 55 g	Tortilla 292 g Veg oil 20 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g	Tortilla 266 g Veg oil 20 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g Black beans 45 g
Fe (mg/418 kJ (100 kcal))	5.2	5.2	5.1	6.9	6.0	7.3	7.9
	Couscous 697 g Veg oil 25 g	Couscous 690 g Veg oil 25 g Carrots 21 g	Couscous 665 g Veg oil 25 g Carrots 21 g Oranges 60 g	Couscous 590 g Veg oil 25 g Carrots 21 g Oranges 60 g Lentils 70 g	Couscous 555 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g	Couscous 546 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g	Couscous 493 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g Black beans 45 g
Fe (mg/418 kJ (100 kcal))	2.6	2.8	2.7	4.7	3.9	5.3	6.0
	Potato 907 g Veg oil 25 g	Potato 895 g Veg oil 25 g Carrots 21 g	Potato 865 g Veg oil 25 g Carrots 21 g Oranges 60 g	Potato 770 g Veg oil 25 g Carrots 21 g Oranges 60 g Lentils 70 g	Potato 723 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g	Potato 719 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Spinach raw 50 g	Potato 649 g Veg oil 25 g Carrots 21 g Oranges 60 g Beef 55 g Lentils 45 g Spinach raw 50 g
Fe (mg/418 kJ (100 kcal))	0.8	2.9	2.9	4.9	4.1	5.4	6.7

of micronutrient-rich foods. Regulations that prohibit urban gardening or which reduce the availability or sale of fresh foods by street vendors can reduce the availability of micronutrient-rich foods. Examining the profitability of producing, processing and marketing such foods and reviewing the impact of policies on micronutrient status are important steps in planning food-based strategies.

Policies, intervention programmes and activities at international, national and community level are required to effectively alleviate micronutrient deficiencies. These include efforts to increase the overall quantity of foods consumed by those most vulnerable to deficiencies and, at the same time, diversify their diets. The focus should be on: micronutrient-rich sources of food including animal products, vitamin C, fruit and vegetables; better management and control of dietary inhibitors (e.g. phytates) and enhancers (e.g. vitamin C); processing, preservation and preparation practices that retain micronutrient availability including, for example, the use of iron cooking pots and improved drying techniques to reduce losses as well as counter seasonal variation in availability; nutrition education; food quality and safety issues with implications for public health and disease control measures to reduce nutrient losses by the body; maximizing the potential of fruits and vegetables as high-value commodities for income generation; fortification, including biofortification; and supplementation.

Food-based strategies to promote dietary diversification

Increase overall food intakes

Micronutrient deficiencies are closely associated with poverty, food insecurity and undernutrition and are common in those groups whose overall food intakes are not sufficient to meet nutritional requirements. Seldom is only one nutrient deficient. If a deficiency for one micronutrient exists, it is likely that multiple deficiencies are also present. For those with inadequate food intakes, increasing overall food consumption provides several essential micronutrients, thereby simultaneously addressing a combination of deficiency problems. In addition, physiological interactions between vitamins and minerals enhance the body's ability to absorb and utilize essential micronutrients. Consequently, intervention programmes need, as a first priority, to ensure that overall food supplies are adequate through increasing the production, availability, access to and consumption of an adequate and nutritious diet, especially by those who are hungry and food-insecure and most vulnerable to deficiencies. By doing so, food-based strategies address the root causes of micronutrient malnutrition and assist communities and households to adequately feed and nourish themselves in both the near and long term. Stimulating the small-scale agricultural sector can produce overall long-term economic benefits for those groups dependent on agriculture for their livelihoods and for the economy as a whole, thereby encouraging sustainable development.

Increase consumption of micronutrient-rich foods

Most traditional diets and food habits provide a range of nutrients that are able to meet the nutritional requirements of most groups. However, those physiologically challenged, such as the sick, young children, and pregnant and lactating women, may require larger amounts of micronutrient-rich foods to meet their increased needs. For those affected by relatively abrupt changes in lifestyles, for example due to civil disruption, migration, urbanization and modernization, traditional food practices may not be easy to maintain, resulting in unbalanced and inadequate diets. Where iron deficiency is widely prevalent, often the usual diet does not provide enough bioavailable iron. Under such circumstances, promoting the increased consumption of micronutrient-rich foods is the key to good health and nutrition. The promotion of dietary improvement/diversification with a focus on improving the intake of bioavailable iron through greater consumption of animal products, fruits and vegetables, especially vitamin C-rich foods, is the only intervention that can lead to self-sustained success in improving iron status. Neither supplementation nor fortification can be as effective on their own as they could be if part of an integrated and comprehensive strategy. Promoting consumption of micronutrient-rich foods fosters better overall health for all members of society, provides sustainable improvements by encouraging market solutions and long-term behaviour changes among high-risk groups, and is often linked to income-earning activities.

Efforts to address both increased production (supply) and increased consumption (demand) of food need to be undertaken simultaneously. At the district and national levels, *implementation of large-scale commercial livestock and vegetable and fruit production* can provide micronutrient-rich foods at reasonable prices. The objective is to provide micronutrient-rich foods at reasonable prices through effective and competitive markets and distribution channels which can lower consumer prices without reducing producer prices. This will serve predominantly the urban and non-food-producing rural areas. Commercial oilseed production and red palm oil, for example, can increase the availability of low-cost dietary fat that is crucial for the absorption of fat-soluble vitamins (A, D, E and K) and other micronutrients, including iron.

At the community level, small-scale *community or home fruit and vegetable gardens* can play a significant role in increasing the production of micronutrient-rich foods. *Production of fish, poultry and small animals* (such as guinea pigs, rabbits and goats) is also important, as all are excellent sources of highly bioavailable essential micronutrients such as vitamin A, iron and zinc. The production of animal foods at the local level permits communities to access foods which otherwise are not available because of their high costs. These types of project also need support from local governments or non-governmental organizations (NGOs) to overcome cost constraints of programme implementation, including the training of producers. Horticultural programmes and agricultural extension workers can encourage the production of animals, milk and dairy products, legumes, green leafy vegetables and fruits. These projects should lead to increased production and consumption of micronutrient-rich foods at the household level.

A micronutrient and health programme in Malawi used revolving funds targeted to women to increase household access to animal food sources through a small-animal (poultry, rabbits, guinea fowl and goats) husbandry programme. Over 10,000 households participated in the World Vision programme which included an education component on the nutritional benefits of animal food consumption. Over a 4-year period, anaemia rates in pregnant women fell from 59% to 42% and in children under 5 years old from 84% to 66% (24). It is clear that if production gains are to be reflected in increased intakes, community participation, the involvement of women and consumer education are essential elements. In Indonesia, among adolescent girls given iron-rich foods six times weekly for 6 months, Helen Keller International found anaemia was significantly reduced and concluded that food naturally rich in iron increases haemoglobin concentrations in anaemic Indonesian adolescents (25).

Improving the micronutrient content of soils and plants and *improved agricultural practices* can improve the composition of plant foods and enhance yields. Current agricultural practices can improve the micronutrient content of foods through correcting soil quality and pH and increasing soil mineral content depleted by erosion and poor soil conservation. Long-term food-based solutions to micronutrient deficiencies will require improvement of agricultural practices, seed quality and plant breeding. *Plant breeding* through conventional selection processes or by genetic modification (biofortification) can increase the micronutrient content of staple and other crops and may play a significant role in combating IDA.

The success of such projects requires a good knowledge and understanding of local conditions as well as the involvement of women and the community in general. These are key elements for supporting, achieving and sustaining beneficial nutritional change at the household level. Educational efforts need to be directed towards securing appropriate within-family food distribution considering the needs of the most vulnerable members of the family, especially infants and young children. Separate FBDGs for vulnerable groups, such as pregnant and lactating women, children and the elderly, should be developed.

Efficacy issues. It is argued that, in order to generate greater interest as well as resources for implementing food-based approaches, the contribution that such interventions can make compared with other interventions, such as supplementation and fortification, need to be better quantified and more information generated to demonstrate their efficacy. However, evaluations of the efficacy of food-based approaches are lacking in literature, partly because of the complexity of the interventions, the wide variety of components contained in food, the large number of inputs, outcomes and confounding factors, the range of intermediary components, and the short- and long-term impacts that present difficulties for study design. While evaluation of the nutritional impact and cost benefit of food-based approaches in combating micronutrient deficiencies is a research priority, there are compelling reasons for supporting the wider implementation of a food-based approach.

Management and control of inhibitors and enhancers

Improved food preparation and cooking methods and the modification of consumption practices to increase dietary enhancers and eliminate inhibitors of absorption can safeguard the amounts of micronutrients that are available and maximize their uptake by the body. Practical interventions to reduce dietary inhibitors and increase iron absorption facilitators include:

- Ensuring dietary intakes of oils and fats, vitamin A and ascorbic acid are adequate for enhancing absorption of micronutrients.
- Fermentation and germination for the enzymatic hydrolysis of phytates in cereals and legumes.
- Promoting non-enzymatic methods of reducing phytic acid content.
- Encouraging home processing techniques like malting.
- Avoiding drinking tea or coffee within two hours of eating meals.
- Reducing the use of tamarind as a souring agent and instead using tomato or lime juice in order to facilitate non-haem iron absorption.
- Adopting food to food fortification practices whereby selecting foods in combinations so that dietary inhibitors (e.g. phytates) and enhancers (e.g. vitamin C) are better managed and controlled.

The bioavailability of non-haem iron rises to a level similar to that of meat products when consumed with a significant source (25 mg) of vitamin C in the same meal. In Nigeria, the incorporation of baobab fruit pulp drink in the diet of children aged 6–8 years for a 3-month period significantly increased Hb from 10.85 to 12.92 g/dl and decreased the number with SF < 12 μg/l from 65% to 23%. The study concluded that the high vitamin C content of baobab, which provided 60 mg of ascorbate daily, promoted the absorption of iron (26).

Reducing phytates and tannins by oxidation with polyphenol oxidases, enzymes found in many fruits and vegetables, increases the bioavailability of iron. Incubation of cereals with fruit extracts such as banana can be done at the household level to increase the bioavailability of iron and may be encouraged as part of a food-based strategy to prevent IDA. Fermentation for a couple of days (sourdough fermentation) almost completely degrades the phytate of wheat bran and increases the bioavailability of iron in bread made from whole-wheat flour. Calcium inhibits iron absorption and so the practical solution for overcoming the negative effects of calcium on iron absorption is to increase iron intake, increase its bioavailability, or avoid the intake of foods rich in calcium and foods rich in iron at the same meal.

Processing, preservation and preparation

Fruits and vegetables are perishable products and the reduction of postharvest losses and prevention of wastage through improved processing and handling and by adopting simple methods of storage may considerably increase availability throughout the year. By improving methods of processing and preservation of surplus foods produced during the peak season, further losses may be reduced leading to greater year-round availability of these foods, improving nutritive value, acceptability and shelf-life, and thereby improving consumption. Local food preservation and processing facilities should therefore be strongly promoted. At the household level, the promotion of effective cooking methods and practical ways of preserving foods (solar drying of seasonal micronutrient-rich foods such as papaya, grapes, mangoes, peaches, tomatoes and apricots) may significantly increase access to bioavailable micronutrient-rich foods. At the commercial level, grading, packing, transport, and marketing practices reduce losses, stimulate economic growth and generate income.

Food preparation and dietary practices need also to be improved in efforts to combat iron deficiency. For example, it is important that vegetables rich in vitamin C, folate and other water-soluble or heat-labile vitamins be minimally cooked in small amounts of water. For iron bioavailability, it is essential to reduce the intake of inhibitors of iron absorption and to increase the intake of enhancers of absorption in a given meal. It is recommended to increase the intake of germinated seeds, fermented cereals, heat-processed cereals, meats and fruits and vegetables rich in vitamin C and to discourage the consumption of tea, coffee, chocolate or herbal teas at mealtimes. This advice for meal preparation is particularly important for people who consume diets with a high proportion of cereals and tubers and who therefore are most at risk of micronutrient deficiencies.

Cast iron pots and cookware can also be a source of significant quantities of dietary iron. Encouraging the use of cooking in iron pots has been shown to improve iron status. In Ethiopia, Malawi and Brazil, the use of cast iron cooking pots has been observed to increase the amount of iron in the diet and thereby reduce IDA (27).

Consumer education

Communication techniques can be used to help bring about changes in eating practices at the household level. As incomes rise, people often reduce breastfeeding, stop gathering wild foods and eat fewer green leafy vegetables. Nutritionally beneficial traditional practices are under threat of erosion from factors related to urbanization and modernization and need to be protected and supported by education campaigns and communication strategies that aim to preserve such positive traditional practices. This is especially the case for those foods which may be available but are not consumed in sufficient quantities to prevent deficiencies or perhaps not at all by some vulnerable groups. Mothers and others who directly influence food production, food purchasing, food preparation and child feeding behaviour may be specifically targeted by such programmes.

Intervention programmes should always be accompanied by a public nutrition education and promotion programme to encourage improved food consumption. Advice for a healthy diet should provide both a quantitative and a qualitative description of the diet for it to be understood by individuals, and information on both size and number of servings per day should be provided. Quantitative aspects include the estimation of the amount of nutrients in foods and their bioavailability in the form they are actually consumed. Qualitative aspects relate to the biological utilization of nutrients in the food as consumed and the potential for modifying the balance between food enhancers and inhibitors.

A healthy diet can be attained in more than one way because of the wide variety of foods which can be combined. The development of FBDGs by FAO and WHO (28,29) recognizes this and, noting that there are economic constraints which limit food supply at household level, focuses on the combination of foods that can meet nutrient requirements. FBDGs are based on the fact that people eat foods, not nutrients. The approach is first to define the significant diet-related public health problems in a community and to evaluate the adequacy of the diet by comparing the information available on dietary intake with RNIs. FBDGs can then be prepared that indicate what aspects of the diet could be modified to improve nutrition. Such FBDGs would need to take into account the dietary patterns, ecological, socio-economic and cultural factors, and biological and physical environment in which the targeted population lives.

Nutritional status can be improved significantly by educating households on food preparation practices which minimize the consumption of inhibitors of iron absorption; for example, the fermentation of phytate-containing grains before the baking of breads to enhance iron absorption. The consumption of ascorbic acid preferably through foods rich in vitamin C along with foods rich in iron enhances absorption. The tannins contained in tea and coffee, when taken with meals, strongly inhibit iron absorption and education programmes need to highlight this.

At the household level, appropriate food distribution within the family must be considered to ensure that children and women receive adequate food with high micronutrient density. Household food distribution must be considered when establishing general dietary guidelines and addressing the needs of vulnerable groups in the community. In addition, education detailing the appropriate storage and processing of foods to prevent micronutrient losses at the household level is important.

Assessing nutritional quality – food quality and safety issues

Improving the quality and safety of food has obvious benefits for health and for business. The importance of improving public health as an intervention strategy to reduce nutrient losses by the body is clear and safe, and good-quality food makes an important contribution to that. Information campaigns may raise awareness of the health problems that can arise from improper food storage and handling practices. On the business side, fruit and vegetables are valuable commodities with high potential for income generation. Processed and marketed foods need to be quality-assured to compete in the marketplace and this aspect often needs further support in the area of laws and regulations and on food quality control to ensure required standards are enforced.

Food fortification

Food fortification means the addition of nutrients at levels higher than those found in the original food. Increasing the micronutrient content of staple and other crops through biofortification has been referred to above. Biofortification enhances the nutritive value of foods using modern tools of biotechnology. Food fortification has a role in meeting iron, folate, iodine and zinc needs and is recommended when dietary iron is insufficient or the dietary iron is of poor bioavailability, which is the reality for most people in the developing world and for vulnerable population groups in the developed world. Food fortification is effective at reducing the burden of IDA in susceptible populations. Children consuming iron-biofortified foods are estimated to have between 3 and 4 g/l higher haemoglobin concentration and 28% lower risk of anaemia (odds ratio 0.72) compared with children who do not (30).

Because staple foods around the world provide predominantly non-haem iron sources of low bioavailability, the traditionally eaten staple foods represent an excellent vehicle for iron fortification. Examples of foods which have been fortified are wheat flour, corn (maize) flour, rice, salt, sugar, sweet biscuits, curry powder, fish sauce and soy sauce. For example, fortification of flour with iron can have substantial benefits at the national level, with gains in national IQ of up to 5%, increase in GDP of 2%, and 60,000 deaths of pregnant women prevented annually (31). However, even with foods fortified with iron, the consumption of iron absorption enhancers should always be promoted to get the best out of the food consumed.

Fortified foods as part of food aid protect the nutritional status of vulnerable groups and victims of emergencies, but under normal circumstances fortified foods may not be widely available to the poorest and more isolated populations. Community-based approaches to fortification, for example using rural hammer mills, may be a useful way of reaching these rural populations. In Malawi, for example, maize is being fortified with iron as well as B-vitamins, folate, zinc and vitamin A. However, dietary diversification programmes are of critical importance and should always be promoted.

Fortification of food with iron and other micronutrients is considered a valid technology and strategy for adoption as part of a food-based approach when and where existing food supplies and limited access fail to provide adequate levels of the respective nutrients in the diet, and where the fortified food is highly likely to be accessible to the target population. In such cases, fortification of food is seen as a valuable adjunct programme to ongoing nutrition improvement programmes. In FAO's view, fortification is not an alternative to the overall goal of improving nutrition through the consumption of a nutritionally adequate diet made up from a variety of available foods.

Supplementation

Supplementation refers to periodic administration of pharmacological preparations of nutrients as capsules or tablets or by injection. Supplementation is necessary as a short-term emergency measure to reverse clinical signs or for prevention in at-risk groups. Nutritional supplementation should be restricted to vulnerable groups which cannot meet their nutrient needs through food (women of child-bearing age, infants and young children, elderly people, low socio-economic groups, displaced people, refugees and populations experiencing other emergency situations). Iron supplementation is used to control and prevent IDA in pregnant women and appears to be essential during the second half of pregnancy. Often iron supplementation is administered in combination with folate. Iron and folate supplementation was shown to be significantly effective at reducing the risk of IDA in pregnant women. Pregnant women taking iron and folate supplements were estimated to have 12 g/l higher haemoglobin concentration and 23% lower risk of anaemia (risk ratio 0.77) compared with pregnant women who did not take the supplements (30). However, there is some concern about possible negative effects of iron supplementation which may be toxic at high doses. It can cause diarrhoea and other abdominal symptoms, and for newborns and in highly malaria-endemic areas it may increase the morbidity of infectious disease and reduce linear growth in iron-replete infants. Some studies suggest that iron negatively affects zinc status and that zinc and iron interact when administered together in therapeutic doses, and thus should be supplemented independently to avoid this interaction. However, evidence is mixed.

Ongoing Activities and Next Steps

There has effectively been no progress in combating iron deficiency in the developing world. Current and future activities need to address this lack of progress. Achieving food and nutrition security for all is at the heart of FAO's efforts to ensure that people have regular access to enough high-quality food to lead active and healthy lives. FAO has been leading efforts in ensuring that agriculture, particularly in the developing world, can help meet the demand for healthy diets and develop food production systems that are both economically and environmentally sustainable. *Promoting the production and consumption of fruits and vegetables and animal foods* (fish and poultry) that are rich in micronutrients is central to FAO's efforts to eradicate hunger, alleviate poverty and raise levels of nutrition and standards of living.

FAO advocates for and promotes the consumption of healthy diets, acknowledging the important role that dietary diversity can play in improving health and generating incomes for poor population groups. To enhance food and nutrition security in rural households, FAO promotes the production of vegetables and fruits, as well as animal foods (fishponds and animal husbandry), in home, community and school gardens. *Home and school gardening* projects are frequently linked with school feeding programmes, nutrition education and promotional campaigns to encourage consumption of micronutrient-rich foods. Owing to the rapid rise in the world's urban populations, FAO promotes urban gardening and agriculture as part of its Food for the Cities programme to make available fresh micronutrient-rich food and offer a means of self-employment and income generation for poor urban families.

Food and nutrition education plays a vital role in FAO activities aimed at promoting healthy dietary intake. There is ample evidence to show that programmes aimed at food and dietary diversification, such as home gardening and horticultural programmes, are most effective when they are combined with promotional and educational activities (32,33). Nutrition education and the promotion of healthy eating *in schools* is important as children's food habits and dietary patterns are formed when they are young, but it is equally necessary to reach adults and parents with clear messages that promote healthy food choices, food preparation and consumption. FAO promotes the development of *national food-based dietary guidelines* and provides technical assistance in the development and implementation of nutrition education programmes and campaigns in communities and schools. Educational materials that promote the production and consumption of a variety of foods, including indigenous ones, can be found on FAO's Nutrition and Consumer Protection Division website (http://www.fao.org/ag/agn/sitemap_en.stm).

Key initiatives through which FAO, in collaboration with governments, partners in the United Nations (UN) community, NGOs and civil society, promotes the production and consumption of micronutrient-rich foods and healthy diets include the following.

School gardens for better education and nutrition. School garden programmes have the potential to improve education of rural children and their families by making it more relevant to local needs. They enhance the quality of education and can serve as an outdoor laboratory for practical learning across a broad range of subjects. With wider community involvement, they can also address nutritional deficiencies by supplementing school feeding and adding nutritional value to school meals. Foods produced within school gardens focus on easy-to-grow micronutrient-rich vegetables and fruits, as well as animal foods, such as chickens and rabbits. A key function of school gardens is to encourage children to stay in school and to acquire a range of knowledge and skills, an aspect which is especially important in countries with a high prevalence of HIV/AIDS and a growing number of orphans. School gardens, in both urban and rural areas, can provide schoolchildren with hands-on experience in food production and natural resource management, as well as being a focus for education on good nutrition and healthy eating. New skills and techniques that students acquire in the school garden can be taken home to their family farms or household gardens. For their full potential to be realized, school gardens are best developed within the context of a carefully designed, comprehensive national programme which leaves ample room for local adaptation and promotes the full engagement of local communities. FAO collaborates with the Food for Education programme of the World Food Programme (WFP), the United Nations Children's Fund (UNICEF), national and international NGOs, as well as community-based organizations in the promotion and establishment of school gardens for children's better learning and nutrition worldwide. See FAO's school garden website (http://www.fao.org/schoolgarden/).

A WHO/FAO report (34) recommends as a population-wide intake goal the consumption of a minimum of 400 g of fruits and vegetables daily (excluding potatoes and other starchy tubers) for the prevention of chronic diseases such as heart disease, cancer, diabetes and obesity, as well as for the prevention and alleviation of several micronutrient deficiencies, especially in less developed countries.

Recognizing that fruit and vegetable intake plays an important role in the prevention and alleviation of micronutrient deficiencies and low intake could be a key risk factor for several non-communicable diseases, WHO and FAO launched a joint Fruit and Vegetable Promotion to increase fruit and vegetable consumption. This *WHO/FAO Global Fruit and Vegetable Initiative for Health (GlobFaV)* seeks to maximize synergies between WHO's global work on diet, physical activity and health and FAO's programmes on nutrition, food security and the horticultural supply chain. In concert with other UN agencies, the initiative will support national programmes in developing countries involving coalitions of stakeholders – from ministries of agriculture, health and transport, to farmers, extension services, schools and the food industry. See the WHO/FAO Global Fruit and Vegetable Initiative for Health (http://www.fao.org/ag/magazine/0606sp2.htm) and the framework document developed at the Kobe workshop (http://www.fao.org/ag/magazine/FAO-WHO-FV.pdf).

An *International Fruit and Vegetable Alliance (IFAVA)* has called for increasing fruit and vegetable consumption in order to help stem the rise of obesity and chronic diseases, arguing that this should be a primary goal within a health, food and agricultural policy. Health authorities in many countries support the '5-a-day' campaign which encourages people to eat at least five servings of fruits and vegetables daily. The reason why fruits and vegetables are so beneficial is because of their array of compounds. In addition to vitamins, minerals and trace elements, fibre and some food energy, fruit and vegetables also contain antioxidants and many other complex plant components (phytochemicals). It appears that the benefits stem not only from the individual components, but also from the interactions between these components. Dietary supplements containing isolated vitamins or minerals do not appear to have the same beneficial effects as fruit and vegetables themselves. Indeed, in some studies, supplements caused more harm than good. FAO is able to provide advice on strategies for increasing the production, availability, processing, preservation and consumption of micronutrient-rich foods.

Based on the understanding that effectively addressing the increasing global burden of malnutrition (both undernutrition and obesity and related chronic diseases) requires common policy options, the *Nutrition Friendly Schools Initiative (NFSI)* has been developed as a follow-up to the WHO Expert Meeting on Child Obesity in Kobe in 2005. The main aim of the NFSI is to provide a framework for designing integrated school-based interventions that address all forms of malnutrition that affect school-aged children, building on the ongoing work of various agencies and partners, including the FRESH Initiative (Focusing Resources on Effective School Health) coordinated by the United Nations Educational, Scientific and Cultural Organization, Child Friendly Schools (UNICEF), Essential Package (UNICEF/WFP), Health Promoting Schools (WHO) and Food and Nutrition Education Programmes (FAO). Improving the nutritional status of school-aged children is an effective investment for future generations. Pre-schools and schools offer many opportunities to encourage healthy eating practices and physical activity for children and engaging parents and community members in preventing child malnutrition in all its forms (i.e. undernutrition, micronutrient deficiencies and obesity and other nutrition-related chronic diseases).

Conclusions

Iron deficiency and iron deficiency anaemia are serious and widespread public health problems. Their global scale and magnitude, combined with their damaging physiological and harmful socio-economic effects, require the urgent adoption of known and effective measures to tackle this critical problem.

With the knowledge that the intake of foods rich in iron increase haemoglobin concentration and reduce the prevalence of anaemia significantly, much focus has been placed on iron fortification and supplementation programmes rather than on increasing food consumption and improving and diversifying diets. This partly is because governments, international agencies and donors have considered both fortification and supplementation programmes attractive for their apparent simplicity and cost-effectiveness. However, in practice, many such programmes are proving difficult to manage, more costly than expected to implement and less effective than promised.

With little success of anaemia reduction programmes to report, interest is turning to food-based approaches that have higher potential for achieving far-reaching and long-lasting benefits for the control of iron deficiency. Food-based approaches aim to improve nutrition through increasing the availability and consumption of a nutritionally adequate micronutrient-rich diet made up from a variety of available foods, and are recognized as an essential part of an urgently needed, more comprehensive strategy to combat iron and other micronutrient deficiencies.

There are a number of actions that may be taken by international agencies, governments, line ministries of agriculture, health and education, industry and the private sector, communities and households themselves that are feasible and practical and will increase the consumption and bioavailability of iron. As food-based strategies aim to improve the quality of the overall diet by increasing the availability and consumption of a wider range of foods, they address multiple nutrient deficiencies simultaneously. By so doing, food-based strategies are preventive, cost-effective and sustainable. They also encourage popular demand for safe, wholesome food and foster the development of sustainable agriculture that has positive knock-on effects for the rural economy.

The strategies proposed to promote dietary diversity need strong community-level commitment and their successful implementation requires advocacy to obtain community acceptance of and political support for programmes. Involving local people in programme assessment, analysis and actions will facilitate community acceptance. The support of local authorities and government may facilitate the implementation of such projects because these actions require economic resources which sometimes are beyond the reach of the neediest.

Success also depends upon well-financed food-based initiatives at country level. FAO can provide technical assistance to governments in concert with international agencies, NGOs, public and private institutions and the food industry to support planned and ongoing government food-based programmes for meeting a broad spectrum of micronutrient needs, including iron. By adopting food-based strategies on a broader scale as a matter of priority, we will have a balanced, more comprehensive approach that has the greatest potential for overcoming not only iron but also other micronutrient deficiencies.

Work in pursuit of this strategy includes continuing efforts to ensure that dietary diversification, food fortification, supplementation and public health measures are taken comprehensively to combat iron deficiency and specifically to:

- Increase the overall food intakes of those who are food-insecure, through support for enhanced food production, availability, processing, preservation and consumption.
- Increase the consumption of micronutrient-rich foods that meet dietary needs and food preferences.
- Explore ways to increase financial investments in food-based initiatives at country level, including through better quantifying the contribution that such interventions can make to demonstrate their efficacy.
- Draw up a list of best practices that households can adopt to prevent IDA based on local Trials of Improved Practices (TIPs) and design a communication strategy for effecting behaviour change.
- Research the content of phytate and iron-binding polyphenols in food, condiments and spices and in common meals and their usual variation in composition in order to make realistic recommendations about changes in meal composition, taking into consideration the effect of such changes on other nutrients (e.g. vitamin A).
- Evaluate the nutritive value of diets not only on energy and protein adequacy but also on micronutrient density.
- Explore home fortification of weaning foods.

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16 Human Micronutrient Deficiencies: Linkages with Micronutrient Deficiencies in Soils, Crops and Animal Nutrition

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Abstract
Micronutrient contents (trace elements and minerals) of foods are partially determined by the micronutrient content and availability of the soils on which the foods are grown. In principle, under conditions of soil micronutrient deficiency, micronutrient contents of food crops can be increased by the application of micronutrients as fertilizer. The first objective of this chapter is to analyse and document the occurrences and the strengths of the linkages between micronutrient deficiencies in soils, crops, animal and human nutrition. The second objective is to assess whether micronutrient application as fertilizer can be a realistic and feasible approach in addressing human micronutrient deficiencies.

Literature in the fields of soil science, agriculture, ecology, animal nutrition and human nutrition has been searched in order to document and analyse, as completely as possible, the relationships between micronutrients in soils, food crops, animal and human nutrition.

Evidence for direct quantitative relationships between micronutrient deficiency in soils and in human nutrition is most clearly available for iodine and selenium, and possibly also for zinc. For zinc and selenium, addition of these micronutrients to soils can substantially increase crop micronutrient content, and thus contribute to ameliorating human micronutrient deficiency.

When considering various approaches in addressing human micronutrient deficiencies, such as dietary diversification, micronutrient supplementation, micronutrient fortification of foods, developing new varieties through plant breeding and genetic manipulation, there appears to be, for some micronutrients, sufficient evidence to consider micronutrient fertilization as an alternative approach, with its own specific advantages. Currently, the most promising candidate for this approach is zinc.

Key words: micronutrient deficiencies, soils, agriculture, fertilizer, human nutrition, iodine, zinc, selenium, iron

Introduction

Dietary micronutrient deficiencies[1] affect a large part of the global population (1). The World Health Organization (WHO) estimates that some two billion people are affected by iron deficiency and that some 750 million people suffer from iodine deficiency (2,3). Also zinc deficiency is increasingly recognized as an important public health problem (4). In recent years, interest in the occurrence of human micronutrient deficiencies has been growing strongly, for several reasons. First, human micronutrient deficiencies appear to be much more widely spread than previously thought and

[1] In this chapter the term 'micronutrient deficiency' is used to indicate deficiencies in trace elements essential in human nutrition, such as iodine, zinc and iron, and also deficiencies in essential minerals such as magnesium and calcium, but vitamins are largely outside the scope of this chapter.

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information on their geographical distribution is increasing rapidly (5). Second, there is a considerable amount of new information on the adverse health effects of various micronutrient deficiencies. For example, over past decades it has become increasingly clear that iodine deficiency, apart from causing an enlarged thyroid gland (goitre), can seriously impair intellectual development of infants and children (6). Also, while some years ago there was only limited public health interest in zinc, it is now widely recognized that zinc deficiency is widespread and associated with suboptimal growth and reduced immunocompetence in children. Third, evidence is increasing that, for certain micronutrients, marginal intakes can have adverse health effects, with for example a suboptimal selenium intake playing a role in the aetiology of certain types of cancer (7,8).

There are various pathways which may lead to the development of dietary micronutrient deficiencies. First, among poor populations overall food intakes are often below requirements, and as a result not only the consumption of macronutrients (carbohydrate, fat, protein) but also the intake of micronutrients (minerals, trace elements and vitamins) can be inadequate. Moreover, among poor communities diets are often highly monotonous, which increases the risk that the dietary intake of one or more micronutrients is insufficient. For example, a diet which is very low in animal foods brings a higher risk that iron deficiency and anaemia will develop (9,10). A more specific situation arises when, in a country or region, the majority of locally produced foods have a low content of a particular mineral or micronutrient because the soils on which local foods are grown are low in their contents or availability of this nutrient. If, in such places, the people are largely dependent on locally produced foods, the intake of this nutrient will most likely be inadequate. The most well-known example of such type of deficiency is iodine. In various regions in the world (India, China) iodine-deficiency disorders, such as cretinism and goitre, are widely prevalent and directly related with low levels of iodine in local soils and, as a result, in foods grown on these soils, or in drinking water derived from groundwater (11). Finally, micronutrient deficiencies may also develop as a result of the presence of so-called 'anti-nutrients' in food, which are substances, such as phytic acid, that may inhibit or impair the absorption of micronutrients in the intestinal tract (12).

Also in agriculture, micronutrient deficiencies are an issue of increasing interest and concern. Trace elements such as zinc, manganese and copper are increasingly recognized as being essential for achieving higher yields, and much research is being undertaken which addresses the relationships between micronutrient provision to plants and associated crop growth (13–15). In addition, various studies indicate that improving the micronutrient supply to crops can result in more vigorous seedlings, lower vulnerability to plant diseases and possibly also improved drought resistance (12). Finally, also in animal husbandry the importance of an adequate supply of minerals and trace elements for achieving optimal growth and good animal health has been well recognized (16,17).

The main objective of this chapter is to analyse and document the occurrences and the strengths of the linkages between micronutrient deficiencies in soils, crops and human nutrition. It is presumed that, for areas where soils are very low in absolute content or bioavailability of certain micronutrients and where, at the same time, local people largely depend on these soils for the production of their foods, human micronutrient deficiencies are bound to occur. While micronutrient deficiencies are generally studied in separate disciplines, such as soil chemistry, agriculture, animal nutrition or human nutrition, this chapter discusses the connections between these various fields. It is expected that such a combined assessment will increase the overall understanding of micronutrient deficiencies, and can contribute in the design and selection of effective approaches aimed at eliminating or reducing human micronutrient deficiencies. With respect to the various possible strategies, specific attention is paid to the application of micronutrients as fertilizer to food crops and its effects, not so much on yields, but on the micronutrient densities of the foods produced.

Emphasis is on those micronutrients for which the occurrence of human deficiency has been recognized as a general public health problem. These micronutrients are iodine, zinc, selenium and iron. Where appropriate, reference is also made to other minerals and trace elements such as calcium, phosphorus, copper and magnesium.

Sources of Information and Methods

The present chapter is the result of combining information and insights from different scientific fields and disciplines, notably from human nutrition, agriculture and soil science. For retrieving information on various aspects of human micronutrient deficiencies, extensive use was made of the US National Center for Biotechnology Information's PubMed database, while also websites from international organizations active in the field of health and nutrition were consulted (Food and Agriculture Organization of the United Nations (FAO), WHO, United Nations Children's Fund, etc.). As regards agriculture and soil science, use was particularly made of the ISI Web of Knowledge database, as well as websites of agriculture-oriented international institutions and organizations, such as FAO, the International Food Policy Research Institute and the Consultative Group on International Agricultural Research. In addition to these sources of scientific and practical information, important information could also be identified and retrieved by making use of general Internet search engines such as Google and Yahoo!. Throughout the process of preparing the present chapter the emphasis has been on integrating research results, findings and perceptions from these various, but clearly interrelated, scientific fields. The main guiding principle herein has been to follow micronutrients in their successive presence and roles in soils, in crops and in human nutrition.

Micronutrients in Soils, Crops and Human Nutrition: Iodine, Zinc, Selenium and Iron

The uptake of micronutrients by plants from soils depends on a wide range of factors. First, soils vary in terms of chemical composition and therefore in their absolute contents of the various micronutrients. Second, a particular micronutrient may be present in the soil in different forms. Part of it may be readily available for plants from the soil solution, while another part may be unavailable for plants because it is strongly bound to or incorporated in soil particles. The proportion of a particular micronutrient that is available for uptake by plants depends on various physicochemical characteristics of the soil, such as pH, moisture status and particle size distribution. For example, the availability of copper and zinc increases with decreasing pH. On the other hand, availability of molybdenum and magnesium improves under alkaline conditions (13,18,19). Third, the uptake of micronutrients by plants is affected by interactions and antagonisms between nutrients, and also by interactions between nutrients and other substances present in soils. For example, a high concentration of phosphorus in soil reduces the availability of zinc for uptake by plants. And finally, plants may engage in symbiosis with other soil organisms in order to obtain scarce nutrients (20). For instance, mycorrhizal fungi can supply nutrients to plants in exchange for organic substances assimilated by the host plant. Thus, not only absolute soil contents, but a range of other factors affect the availability of the various micronutrients for uptake by plants.

The amounts of micronutrients which are taken up from soils by plants can affect crops in two ways. First, where it concerns micronutrients which are essential for plant growth, a deficiency generally results in reduced growth and lower yields. Second, and highly relevant for human micronutrient deficiencies, the amounts of micronutrients taken up by plants can be reflected in the micronutrient density in crops, including the edible parts.

It should be noted that human nutrition is analogous to plant nutrition in that the uptake of micronutrients from foods is often highly complex, with numerous interactions both among micronutrients and between micronutrients and other food components (21). Thus, also in humans, not only the absolute contents but also various other factors affect the uptake of micronutrients from foods.

Iodine

Soils vary widely in their iodine content. In areas close to the sea, soil iodine content tends to be relatively high, while more inland it is often much lower. Other factors, such as parent material, also affect soil iodine content or availability, while under conditions of repeated flooding, topsoils may become poor in iodine (6,22). Probably the most comprehensive available data set on soil iodine contents is the compilation by Johnson (23), who provides information on iodine content in over 2000 soil samples from a wide range of locations in different parts of the world, including large numbers of samples from New Zealand, Japan, the USA and Germany. However, for many places in the world, unfortunately particularly for less developed regions where iodine deficiency is much more common, only limited information on soil iodine content is available.

Although iodine is not an essential plant nutrient, it is generally assumed that there is a positive relationship between soil iodine content and iodine content of food crops.[2] Thus, in areas where soil iodine content is low, human intake of iodine, through foods and drinking water, will be low, and without some form of iodine supplementation iodine-deficiency disorders may develop. However, quantitative documentation on iodine content of foods in combination with information on soil iodine content is limited, and available data give mixed results (25–27). In fact, information on human intake of iodine is generally based on measurement of urinary excretion of iodine and rarely on the basis of analysis of foods consumed (6).

As regards agriculture, iodine is receiving only modest attention because iodine is not essential for plant growth. Yet, some studies report on the effect of the addition of iodine to soil on the iodine contents of plants. For example, in experiments with various types of vegetables, a positive relationship was observed between soil and crop iodine contents, and in greenhouse studies with rice, application of iodine resulted in an increased iodine concentration in straw but not in grain (28,29). In China, the addition of iodine to irrigation water resulted in up to threefold increases in soil iodine levels, which was accompanied by an improved iodine status of locally raised animals and of humans relying on local food crops and locally produced meat (30,31).

While a low iodine content of soil is a major causative factor in the development of goitre and other human iodine-deficiency disorders, there are other factors involved. For example, cassava and millet may contain goitrogens, which are substances that may negatively affect thyroid functioning and that can induce or aggravate iodine deficiency (32). Also, a number of studies report on physiological interactions between selenium and iodine, and in various regions in Asia and Africa a strong association between selenium deficiency and iodine deficiency has been reported (33–35). The interaction between iodine deficiency and selenium deficiency can be explained, at least partially, by the fact that both iodine and selenium are required for the synthesis and metabolism of thyroid hormone. This relationship between iodine and selenium metabolism also suggests that the efficacy of iodine supplementation in goitre prevention may be limited in selenium-deficient populations (36).

The most widely followed approach in addressing human iodine deficiency is fortification of table salt with iodine, and many countries have a long record of law-enforced salt iodination. However, coverage is not always complete, and in particular in

[2] Apart from uptake of iodine by plants from soil, there is also uptake of volatile iodine; according to Fuge, this is the most important route through which iodine enters plants (24).

developing countries, salt iodination has not fully eliminated iodine deficiency. For example, in India iodized salt is practically universally available, yet in some areas urinary iodine excretion is still below the minimum threshold level of 100 μg/day (37). In China, despite large-scale promotion of iodized salt, iodine deficiency remains a public health problem in some remote provinces such as Xinjiang, which can be explained by the fact that people use freely available rock salts which are very low in iodine (28,38). In Australia, re-emergence of iodine deficiency has been reported and partially ascribed to the fact that only about 10% of the population is using iodized salt (39).

In summary, there is a distinct positive relationship between low iodine contents in soils and foods and the occurrence of human iodine deficiency. Although iodine contents of food crops can, in principle, be increased through fertilization, other approaches, and in particular fortification of table salt with iodine, have proved to be the preferred choice in addressing human iodine deficiency.

Zinc

Zinc is an essential nutrient in plant, animal and human nutrition. For agriculture, zinc deficiency is the most widespread soil micronutrient deficiency in the world (40). Almost half of the agricultural soils of India, one-third of those of China and about half of the cultivated land in Turkey are considered zinc-deficient for plants (12). Other location-specific studies report low zinc content of soils in, for example, Nigeria, Malawi, Mali, Burkina Faso and the west coast of the USA (41–44). Problems of soil zinc deficiency may have been aggravated in the process of the green revolution (45). A comprehensive review on soil zinc availability and on various aspects of zinc physiology in crops is given by Alloway (46).

There is large variation in the zinc content of foods. Most green vegetables are relatively rich in zinc, but root crops such as cassava and yams are generally low in zinc. Within a single crop, zinc content may show wide variation depending on variety and place where it is grown. For example, modern varieties of rice and wheat are reported to have lower contents of micronutrients, including zinc, in comparison with traditional varieties (40,47–49).

The uptake of zinc by plants is complex. It is negatively affected by a high soil pH and by high soil concentrations of phosphate, calcium and magnesium (50). A considerable amount of research has been undertaken to assess the effects of zinc application on plant growth, and both greenhouse studies and field experiments have shown that fertilization with zinc can result in significant increases in yield (31). In field experiments in Turkey, application of zinc fertilizer resulted in wheat yield increases of up to 500% depending on local soil conditions and method of zinc application (40,51). While leaf application of zinc fertilizer (e.g. $ZnSO_4$) had the largest positive effect, simple addition of zinc fertilizer to soils also produced significant yield increases. For other crops, such as rice and maize, positive effects of zinc on yields have been demonstrated (51,52). In the USA, the micronutrient most widely applied to rice is zinc (53). An important but often unrecognized problem is the negative effect of phosphate fertilizer, when applied in large amounts, on zinc availability and zinc uptake by crops (44,54,55).

Apart from effects on crop yields, from a human nutrition point of view the relationship between the zinc status of soils and the zinc density of crops is equally important. Several studies report positive relationships between soil zinc content and zinc content of foods, and of fodder crops (56,57). Many studies have shown that application of zinc as fertilizer can result in marked increases in the zinc content of grains (31,40,51,52,58). For example, for wheat up to a tenfold increase in grain zinc concentration has been reported, in combination with increases in yield (31).

In human nutrition, zinc deficiency is increasingly recognized as a widespread nutritional risk, in particular in low-income countries. In children, zinc deficiency is associated with increased morbidity and mortality, for example from diarrhoea, possibly also from malaria, and with reduced child growth.

In pregnant women, a low zinc status may result in poor birth outcomes (59–62).

The intestinal absorption of zinc from food is complex and is affected by various factors. Dietary components such as phytic acid can have a strongly negative effect on the intestinal absorption of zinc (61,63). Phytic acid is a phosphorus-containing organic acid which can be present in rather high concentrations in cereals, particularly in unleavened bread, and zinc deficiency is known to be endemic among populations whose diet is predominantly cereal-based. In this context, it is important to note that fertilization with phosphate tends to increase crop phytic acid concentrations, thus further impairing zinc absorption (64). A considerable amount of research is currently being undertaken which aims at a reduction of phytic acid concentrations in food crops (65). Apart from phytic acid, micronutrients such as iron and copper can negatively affect zinc absorption in human nutrition (66).

A considerable number of studies report health improvements from zinc supplementation, such as better growth of children, reductions in morbidity or mortality, and also improvements in children's motor development (67–70). Some of these studies were undertaken in countries (Turkey, Iran) where soils are known to be poor in zinc (71,72). In one meta-analysis it is concluded that zinc supplementation has a significant positive effect on linear growth in children (73). On the other hand, in a recent large-scale study in Nepal, no positive effect of zinc supplementation could be established on child mortality or morbidity (74). At present, there is no consensus on whether mass-scale zinc supplementation would be the most appropriate approach for alleviating zinc deficiency, or whether other approaches to improve human zinc status are more likely to be successful (75).

There is little quantitative information on possible direct relationships between soil zinc deficiency and human zinc deficiency. An indirect indication of such a relationship can be drawn from data on Haryana, India. This region has a very high percentage of zinc-deficient soils (15), and it is one of the few regions for which, in a study in pregnant women, a high rate of human zinc deficiency has been reported (62). However, in another study in India, in Andra Pradesh, no distinct relationship between soil zinc content and human zinc status could be demonstrated (76). In north-east Thailand, the prevalence of stunting in children has been associated with low zinc contents of local soils and local foods, but also here conclusive evidence is not available (77). In Mexico, a much higher prevalence of poor zinc status in both children and adult women has been reported for the southern part of the country in comparison with the northern part. However, there are no studies available which report on zinc content of soils and food crops in different regions of Mexico (78). In West African lowlands, soils are reported to be severely zinc-deficient, but it is not known whether this is associated with the occurrence of human zinc deficiency (42). And finally, in Ethiopia, extremely low levels of dietary zinc intake in combination with low serum zinc levels have been reported for the southern parts of the country, but information on soil or crop zinc content is not available, nor on the occurrence of human zinc deficiency (79).

In summary, positive relationships between soil and crop zinc contents have been reported. Application of zinc as fertilizer may increase both crop yields and crop zinc density. To what extent soil zinc deficiencies in the world are directly related to human zinc deficiencies is less clear, although some observations point in that direction.

Selenium

Selenium is not an essential micronutrient in plant nutrition, but it has been classified under the group of beneficial elements (80). These are elements which, although not essential, can stimulate plant growth and improve plant health. Thus, applying selenium to selenium-deficient soils generally does not result in increased yields, but may provide some protection against certain plant diseases.

There is a considerable amount of information on the selenium contents of soils in different parts of the world (81,82). For China, there is an extensive database on soil selenium levels, and large areas of China have been identified as selenium deficient (11,38). Other countries or regions where soils are known to be low in selenium include Finland, Denmark, central Siberia, New Zealand and parts of Australia (82). For large parts of Africa, available information points to soils being relatively poor in selenium. Selenium is present in soils in various forms, such as elemental selenium, selenide, selenite, selenate or organically bound selenium. Of these different forms, selenate is most mobile and easiest taken up by plants. Selenium uptake by plants is negatively affected by high levels of iron and sulfur in soil, and also by a low pH.

There is a positive relationship between soil selenium content and selenium content of crops. Thus, foods with the lowest selenium content are found in those regions of China where soil selenium content is very low, while foods grown on high-selenium soils are generally high in selenium (36,83). Both laboratory studies and field experiments have shown that crop selenium concentrations can be increased by applying selenium as fertilizer (58,84). In China, the selenium content of rice could be considerably increased (approximately 20- to 25-fold) by the application of only 20 g of selenium (as selenate) per hectare (85). In Finland, nationwide compulsory addition of selenium to fertilizer resulted in a considerable increase in crop selenium content (82); this is the topic of Chapter 17 in this book.

Selenium is an essential micronutrient in human nutrition. There are two well-defined disorders that are caused by or at least associated with selenium deficiency: Keshan disease and Kaschin–Beck disease. Keshan disease, named after the Chinese province where it was first described, occurs mainly in children and women of childbearing age, and impairs cardiac functioning. Kaschin–Beck disease is an osteo-arthropathy, causing deformity of joints (82). In China, various studies reveal strong geographical linkages between soil selenium deficiency and the occurrence of human selenium deficiency (38).

Apart from clinical manifestations of selenium deficiency, marginal intakes of selenium may have adverse health effects, and in various studies suboptimal intakes of selenium have been associated with, among others, reduced immunocompetence and increased cancer mortality (7). For Europe and Australia, information suggests that over past decades there has been a decreasing trend in human selenium intakes, reaching levels below requirements for optimal health (7,82). As a possible explanation, it has been suggested that increased sulfur concentrations in soils, resulting from high global levels of fossil-fuel burning and related emissions of sulfur, are partially responsible for these decreasing levels of human selenium intakes (82). Suboptimal dietary intakes of selenium have also been reported for several other countries or regions in the world, including the Russian Federation, the Andes, New Zealand and parts of Africa (36,82,86). A comprehensive review on selenium and breastfeeding suggests that globally, for about 30% of women, the selenium concentrations in breastmilk are inadequate for satisfying the selenium requirements of their breastfed children (87).

Various approaches are being used to address human selenium deficiency. In China, the main strategies have been the fortification of table salt with selenium and the distribution of selenium tablets (38,88). A particular case in addressing human selenium deficiency is Finland (31,82). Already in the 1970s it was recognized that people's dietary intakes of selenium were very low and related to the low selenium contents of Finland's soils. In 1984, the Finnish government decided that all fertilizer (for food and fodder crops) had to be enriched with selenium. As a result, food content of selenium increased, and human dietary intake increased to a level where deficiency was no longer considered a public health concern (89,90). The success of this approach probably results from a combination of favourable conditions. One is that Finland's geochemical conditions are rather uniform, allowing for a standardized soil enrichment with selenium (90). Another positive factor is that soils in Finland are generally selenium-reducing, which prevents runoff of oxidized species of selenium into lakes and streams. That soil conditions can be less suitable for enrichment with selenium has been shown, for example, in Little Antilope Valley in

California, USA, where selenium fertilizers caused serious runoff of the element, resulting in its accumulation in the aquatic biota (36).

Finland is probably the first country where an agriculture-based approach was followed to remedy a nutritional micronutrient deficiency in humans. Nowadays, the use of fertilizer enriched with selenium has become common practice in many countries (36), while for other countries such intervention is being recommended.

In summary, for selenium there are positive relationships between low selenium content of soils and foods and the occurrence of human selenium deficiency. Adding selenium to fertilizer appears to be a feasible approach in addressing human selenium deficiency.

Iron

On a weight basis, on average between 3 and 5% of soil consists of iron, which makes it the fourth most abundant element in the geosphere (after oxygen, silicon and aluminium). However, most iron in soils is unavailable for absorption by plants (91). It is estimated that iron is poorly available for plant growth in about 30% of all the arable land in the world.

Iron is an essential nutrient in plant, animal and human nutrition. In crops, iron deficiency can be recognized by the occurrence of intraveinal chlorosis, the appearance of yellow or pale spots on the leaves of plants. Crops suffering from iron deficiency will grow more slowly than normal, are more susceptible to disease and yields may be reduced. As an example, in northern and central parts of the USA, iron deficiency is reported to be a major limiting factor in soybean production, resulting in production losses of the order of 300,000 (metric) tons per annum (92).

Iron content of crops shows wide variations, not only between different crop species (rice, wheat, maize, soybeans), but also within a particular crop species, depending on variety and place where it is grown (12,91). Green revolution cultivars tend to have lower iron content in comparison with traditional genotypes (93). The uptake of iron by plants is highly complex and affected by the presence or absence of various factors that promote or impair absorption. For example, copper, zinc, manganese and phosphorus are all iron antagonists, and high levels of these elements in soils (or in fertilizer) can seriously impair iron uptake by plants. Also, pH affects iron availability for uptake by plants, with generally less iron being taken up under alkaline conditions (12).

Yields of crops grown on iron-deficient soils can, in principle, be increased through fertilization with iron (94,95). However, in practice, improving crop yields through fertilization with iron has been shown to be difficult. For example, application of iron to soils in the form of ferrous sulfate ($FeSO_4$) has generally resulted in at most limited increases in crop yields (12). Other forms in which iron might be added to soils (e.g. as chelates) are more effective, but also expensive, and generally too costly for use on low-value staple crops (96). In fact, it is mainly through (repeated) foliar application of iron compounds that modest positive effects on cereal yields have been achieved (12,31).

With respect to possibilities to increase crop iron density through soil fertilization, available information is extremely limited. Among the few published results are pot experiments in which iron concentrations of leafy vegetables could be increased by enriching the soil with iron (97). Under field conditions, however, foliar application appears to be, again, the most feasible approach for achieving substantial increases in crop iron concentrations (12,31).

In human nutrition, the uptake of iron is complex, and there are many factors which either promote or inhibit the absorption of iron from food (98). For example, absorption of iron from plant foods is promoted by vitamin C, but impaired by phytic acid. Well known are the differences in bioavailability between iron in plant and animal foods, with iron absorption from animal foods generally being ten to 20 times higher than from plant products. As a result, a low consumption level of animal foods, which is common in low-income countries, tends to be associated with high levels of iron deficiency and anaemia and reduced growth in children (99).

The most common approach to improve human iron status, in particular of women of reproductive age, is the provision of iron supplements in the form of tablets, and there are many accounts of successful iron supplementation (98,100). Yet, selecting appropriate modes for effective iron supplementation, in particular as a preventive intervention, is still an issue of debate (59,101). One of the reasons is that adherence and compliance are often problematic, partially because of the adverse side-effects of iron tablets, such as nausea and abdominal distress (102). Supplementation with iron can even have adverse health effects. In a large-scale study in Zanzibar, in a region with very high malaria, supplementation of children aged 1–35 months with iron and folic acid (either with or without zinc) resulted in increased risks for morbidity and mortality of the order of about 10–15% (103). Only children with actual iron deficiency benefited from supplementation with iron and folic acid. In another large-scale study in Nepal, with similar forms of supplementation (iron and folic acid, with or without zinc) but where malaria was relatively low, there were no adverse effects on mortality and modest (but insignificant) beneficial effects on illnesses such as diarrhoea (74). These results stress that, for iron supplementation, appropriate targeting (e.g. following WHO guidelines) remains very important, and that under acute and severe disease conditions, iron supplementation could be detrimental and should be withheld, unless, at the same time, treatment of infectious disease (and in particular malaria) is well in place (104).

In summary, as regards iron, there are no accounts of direct positive relationships between, on the one hand, iron deficiencies in soils and crops and, on the other, iron deficiency in human nutrition. Increasing the iron density of crops through fertilization is possible in principle, but not easily achieved in practice.

Animal Nutrition

Not only in plant and human nutrition, but also in the nutrition of farm animals (cattle, pigs, poultry) has the importance of minerals and trace elements been fully recognized, with deficiencies in one or more micronutrients having negative effects on growth, susceptibility to disease, milk production or other aspects of animal health (16,17,105,106).

Various studies at different geographical locations have revealed direct linkages between micronutrient deficiencies in soils, forages and fodders and the nutritional conditions of animals (107–111). For example, in Haryana, India, low levels of zinc in buffalo milk could be directly related to low levels of zinc in local soils and in fodder produced on these soils (112). In Australia, the so-called ‘white muscle disease’ in calves, sheep and goats is known to be caused by low selenium of feed crops, possibly in combination with vitamin E deficiency, and in New Zealand livestock performance has been reported to be negatively affected by low soil levels of cobalt, selenium and copper (113–115). In Karnataka, southern India, linkages have been found between low levels of phosphorus in soils and the occurrence of symptoms of phosphate deficiency in cattle, while low calcium contents of fodders have been shown to be a limiting factor in milk production (116,117). Finally, in mountainous areas in the Czech Republic, soil deficiencies in zinc and copper were reflected in deficiencies in these micronutrients in both feed crops and animals (118). Thus, with respect to animal nutrition, there is ample evidence of direct relationships between soil micronutrient contents, micronutrient contents of forage and fodder, and micronutrient status of animals.

Various studies have shown that supplementation of farm animals with micronutrients can have positive effects on growth as well as on other health characteristics of the animals being raised. In addition, the micronutrient density of animal products, such as meat, milk and eggs, may be increased. In Germany, supplementation of animal feed with iodine resulted in higher iodine concentrations in meat and milk, and in Finland, the addition of selenium to fertilizer resulted in increased selenium intake of livestock and increased selenium content of animal products (89,119,120). In the Czech Republic, the elimination of human iodine deficiency has been partially attributed to iodine supplementation of livestock (121). Thus, not only through increased micronutrient contents of food crops, but also through increased micronutrient contents of animal products can human micronutrient deficiencies be addressed.

Other Micronutrients

For other micronutrients which are essential in human nutrition, such as copper, magnesium and manganese, there is only limited information on the occurrence of diet-related human deficiencies (59). As regards copper, deficiencies were reported in the 1960s in children in Peru, and more recently in children in Chile (122,123). Furthermore, low serum copper levels have been reported for severely malnourished children in Lucknow, India, and in Cape Town, South Africa (124,125). In human nutrition, there are complex interactions between absorption and metabolism of copper and iron, and it has been argued that the globally high levels of anaemia might be partially caused by a deficiency in copper (126). Among the few reports on dietary magnesium deficiency are accounts of its occurrence among pregnant women in Haryana, India, and among children in Egypt (59,127,128). For manganese, one study in Mexico revealed low serum manganese levels in severely malnourished children (129).

In agriculture, deficiencies in copper, magnesium and manganese, and other micronutrients such as boron and molybdenum, have been reported. For example, deficiency in copper has been established for wheat in Western Australia and for upland rice in Brazil (130,131). It has been shown that application of copper can give significant increases in yield. Magnesium deficiency occurs less frequently, but has been reported for banana and plantain in Puerto Rico and for rice in Bangladesh (132,133). In Ghana, application of magnesium to maize crops resulted in modest increases in yield (134). With respect to manganese, deficiencies have been reported in soybeans in the USA and in oil palm trees in Malaysia (135,136). Greenhouse and field studies in Brazil show that application of manganese as fertilizer can give yield increases for soybean and corn (14,137). No information is available on the effects of application of these micronutrients as fertilizer on their concentrations in food crops.

In animal nutrition, there are reports on deficiencies in micronutrients such as copper, magnesium and manganese (105,138,139). In Brazil, Ireland and Zimbabwe, copper deficiency is reported to occur in livestock (goats, sheep and cattle). In France, copper deficiency in goats has been attributed to excessive sulfur application on pastures (140). Grass tetany, resulting from magnesium deficiency, is another widely occurring micronutrient deficiency disease in animals, and has been reported to occur in livestock in many countries (110,141). Deficiencies in manganese are rarely reported in animal nutrition, but occur, for example, in cattle and sheep in some parts of Brazil (139). In many of these studies in animal nutrition, direct linkages were established between soil micronutrient contents, nutrient contents of forage and fodder, and animal micronutrient status (110,112,142,143).

Implications for Approaches in Alleviating Micronutrient Deficiencies

This chapter aims to analyse and document the linkages between contents and availability of micronutrients in soils, in foods and in human nutrition, and the consequences for the design and selection of intervention strategies aimed at alleviating human micronutrient deficiencies. Possible interventions include the promotion of a diversified diet, the provision of micronutrient supplements in the form of tablets, the fortification of common foods with micronutrients, and, in agriculture, the development of new micronutrient-dense food crops through plant breeding and genetic engineering (144). A relatively new approach, receiving specific attention in this chapter, is to increase the micronutrient density of food crops through the application of micronutrients as fertilizer.

The merits of the various approaches in addressing human micronutrient deficiencies are now discussed.

Dietary diversification

In poor rural communities, habitual diets tend to be monotonous (e.g. largely cereal-based), which brings specific risks for the development of micronutrient deficiencies (98,145). Therefore, in nutritional extension work it is common practice to stimulate households to bring more diversity in their habitual food consumption pattern. In several studies, a positive effect of dietary diversification on nutritional status of children has been established (146–148). However, what is the potential for diversification in areas where soils are deficient in one or more micronutrients and where the foods consumed are largely of local origin? An example is iodine deficiency, as it occurs in regions where soils are low in iodine. Under such conditions, diversification of the local diet is unlikely to have much impact on individual iodine intake. Similarly, for other micronutrient deficiencies, dietary diversification might not bring much improvement when low soil content or availability of the specific micronutrient is the primary cause.

Micronutrient supplementation

A common approach in addressing human micronutrient deficiency is the provision of micronutrient supplements in the form of tablets, capsules or injections. Micronutrient supplementation programmes are generally targeted at specific high-risk population groups such as pregnant women, infants and toddlers, or the elderly (149,150). In many cases, the provision of micronutrients has resulted in measurable health improvements, such as reduced morbidity, accelerated growth in children and lower perinatal mortality (60,69).

However, supplementation of micronutrients in the form of tablets, or in some other concentrated form, requires a well-functioning health system through which distribution takes place, and also commitment and understanding from those who participate (151). In low-income countries and in remote rural areas in particular, these requirements are not always easily met (152). In addition, with micronutrient tablets, there are always risks of over-consumption with associated adverse health effects (153). Furthermore, the formulation of micronutrient mixtures can be technically difficult, in particular when several trace elements need to be included. A number of studies have revealed negative interactions between iron and zinc when given simultaneously (154–156). It should be noted that, under certain conditions, micronutrient supplementation can even have adverse health effects, as has been the case with iron supplementation in highly malarious areas (98). On the basis of the above considerations, caution with large-scale micronutrient supplementation programmes seems warranted, and other approaches, depending on local conditions, might be more appropriate.

Fortification

Fortification of commonly consumed foods with one or more micronutrients is another widely used approach to address human micronutrient deficiencies. Examples are the provision of iodine-enriched table salt, iron-fortified sugar, iron-fortified milk, flours fortified with several micronutrients (iron, zinc, copper), etc. (151,157). However, fortification of food with micronutrients has its own limitations and is not without problems.

First, as a result of the fortification process, food characteristics such as taste, smell and colour may be changed, sometimes to such an extent that the acceptability of the product for human consumption is significantly reduced (158,159). A second issue is the bioavailability of micronutrients in fortified food as adverse interactions may occur when foods are fortified with more than one micronutrient (160,161). Third, fortification of a particular food will only be efficient and safe when the range of intakes is not too wide. When a considerable percentage of the population consumes on average a relatively low amount of the fortified food, then the health impact might be limited or even absent. On the other hand, when some people consume very large amounts of the fortified food, there will be risks for adverse health effects resulting from a micronutrient overload. On the basis of these considerations, the identification of foods suitable for fortification can be difficult, even more so in remote rural areas where food consumption is largely subsistence-based (162,163). Finally, it is important to note that in regular food processing the micronutrient contents of food products will generally be affected. For example, in the milling process of grains (wheat, rice) a significant part of the available micronutrients are lost (58,164), and products such as parboiled rice and bulgur wheat have been developed with the objective of restoring the original nutritional value of these products.

Plant breeding and genetic engineering (biofortification)

More recently, much research has been undertaken in the areas of plant breeding and genetic engineering[3] with the objective of improving crop characteristics such as yield, disease resistance, drought tolerance, etc., but also to increase the micronutrient density of staple foods (165,166). Between 1995 and 2005, large numbers of maize varieties were tested at the international maize research centre (CIMMYT) in Harare, Zimbabwe, for iron and zinc content. These studies have resulted in the identification of maize varieties with considerably higher iron and zinc contents compared with commonly used cultivars (167). As another example, plant breeding experiments at the International Rice Research Institute in the Philippines have resulted in the development of new rice varieties with iron contents which are four to five times higher than in commonly used varieties (168). However, it should be noted that, even for these iron-rich rice varieties, their contribution to total iron intake is still very modest. In a trial in the Philippines, consumption of this 'high-iron' rice resulted in improvements in women's iron stores, but not in a reduction in anaemia prevalence in the targeted group of women (169). In the domain of genetic engineering efforts are continuing to develop new cultivars of higher nutritional quality. One of the most well-known examples in this area is the development of so-called 'golden rice', a rice variety with significantly increased vitamin A content (170).

Thus, through plant breeding and genetic engineering new micronutrient-dense crop varieties are being developed which have the potential to contribute to the alleviation of human micronutrient deficiencies. However, what will be the response of such breeds or varieties when grown on micronutrient-deficient soils? When soils in a particular region are highly deficient in one or more micronutrients, even the best breeds or varieties will probably not be capable of incorporating these micronutrients in such amounts that human micronutrient deficiencies can be prevented.

Micronutrient fertilizer

The application of micronutrients to food crops to increase their micronutrient density has hitherto received little attention, except for selenium. A possible reason for this lack of interest is that traditionally agricultural research has focused mainly on increasing yields rather than on improving nutritional quality.

Addressing human micronutrient deficiencies through fertilization of food crops has a number of specific advantages. First, there are aspects of food safety. For certain micronutrients, the range between minimum human requirements and toxic levels is not very wide. While human selenium requirements are estimated to be of the order of 50 μg/day, toxicity begins at intakes at around 500 μg/day, which is only a factor of ten higher (171,172). When micronutrients are consumed in the form of tablets or other concentrated forms, there is always some risk of over-consumption with associated adverse

[3] While genetically modified organisms (GMOs) can have various advantageous characteristics, their application remains controversial in view of concerns about possible negative effects of GMOs on ecology as well as on human health.

health effects (173). However, when micronutrients are incorporated in staple foods or in other commonly consumed foods which have some degree of bulkiness, the risk that intakes become too high is much reduced.

Second, when micronutrients are added to fertilizer, the micronutrients are built into food crops through normal physiological processes. This implies there are certain physiological limits in respect to the amounts of micronutrients which can be incorporated in plants (174). A large part of naturally occurring micronutrients in foods is incorporated in enzymes, proteins or other high-molecular-weight organic compounds (e.g. iron as haem iron in animal foods or as ferritin in soybeans, zinc as casein in milk). In human nutrition, there are various complex and highly regulated mechanisms through which foods are digested and through which various nutrients, including organically bound micronutrients, are absorbed (175). However, in the case of micronutrient supplementation in the form of tablets, or in the case of food fortification, micronutrients are in the form of relatively simple chemical compounds which normally do not enter the human body. As a result, normal regulatory processes are partially bypassed, which may have negative interactions and undesirable side-effects. For example, when iron and zinc are combined in micronutrient supplements or in fortified foods, iron may reduce zinc availability. Such interactions are unlikely to occur between protein-bound forms of iron and zinc in natural foods. It is also for these reasons that for some micronutrients (zinc, selenium) absorption from regular foods is often more efficient than from supplements (176,177).

Thus, agriculture-based approaches have certain advantages in overcoming human micronutrient deficiencies. However, there are some complicating factors. Micronutrient application to soils needs to be site-specific. A standard mix and dose of a series of micronutrients is unlikely to be effective on all soils and indeed such approaches can, depending on the local soil chemical properties, sometimes do more harm than good. If soil conditions vary little, a single micronutrient strategy may be effective over large areas, whereas if soils are diverse over short distances, the situation is more complex. In such cases, farmers may choose to cultivate one soil type only, but if more than one soil type is cultivated, these are likely to require different micronutrient fertilizers. Preferences for particular soil types, while selecting cultivation sites, clearly require local knowledge on the environment. They imply the presence of local systems of land classification, which obviously cannot be based on soil chemical properties but rather on visible features at the surface, among which vegetation as an indicator of site conditions features prominently. Allan (178) observed that local knowledge can be scientifically precise and remarkably complete. Even across continents, local farmers consistently rate the same individual species as indicators of low and high fertility (179). Such local land classification systems have also been related to soil chemical composition (e.g. 180,181). In a recent study, the existence of local land assessment systems was shown statistically to be related to soil chemical conditions, including micronutrients (e.g. Angonia, Mozambique; Voortman and Spiers, unpublished observations, 2008). Thus, where soil patterns are complex, local ecological knowledge and land classification systems, as expressed in site selection for agriculture, can be used to establish site-specific micronutrient deficiencies. If human micronutrient deficiencies, confirmed by 'hunger signs' in crops, can be linked to local ecological knowledge, the complicating factors may prove to be a blessing in disguise. In this way, not only human micronutrient deficiencies can be addressed, but also crop yields are likely to be increased effectively. Furthermore, the shared common knowledge and experiences among local populations makes it possible that the message of what to apply to what type of land is likely to spread.

Table 16.1 reviews the merits of different possible approaches in addressing human micronutrient deficiencies under conditions where soils are deficient in one or more micronutrients, and where local diets depend to a very large extent on locally produced foods. The last column indicates whether micronutrients are incorporated in foods through normal physiological processes or not. Table 16.1 indicates that under conditions of soil micronutrient deficiency, dietary diversification will

Table 16.1. Potential effects of different strategies in addressing human micronutrient deficiencies in relation to soil micronutrient conditions.

Strategy	Potential effect under conditions where soil is deficient in one micronutrient	Potential effect under conditions where soil is deficient in several micronutrients	Micronutrients incorporated in food through normal physiological pathways
Dietary diversification	negative	negative	yes
Supplementation (tablets, etc.)	positive	positive/negative[b]	no
Food fortification	positive	positive/negative[b]	no
Plant breeding	?[a]	?[a]	yes
Genetic modification	?[a]	?[a]	yes[d]
Micronutrient fertilizer	positive	positive/negative[c]	yes

[a]New breeds and varieties are generally tested and developed under conditions where (micro)nutrients are not a growth-limiting factor. There is very little, if any, information on how these breeds will grow under conditions of soil micronutrient deficiency.
[b]Risks of adverse interactions between micronutrients and, as a result, a reduced bioavailability for intestinal absorption.
[c]Risks of adverse interactions between plant micro- and macronutrients in soils/fertilizer mixes.
[d]It can be contested whether an (increased) incorporation of micronutrients in genetically modified organisms is a normal physiological process or not.

not have much positive impact on human micronutrient intake as all foods are likely to be low in those micronutrients that are deficient in local soils. Similarly, for newly developed breeds or GMOs, micronutrient contents of food crops are likely to remain low when the micronutrients are not present in soil. It should be noted that new plant breeds and GMOs are generally tested under conditions where (micro)nutrients are not a growth-limiting factor. Thus, little information on micronutrient content of new breeds and GMOs, when grown on micronutrient-deficient soils, is available. Where soils are deficient in one micronutrient, it is generally feasible to improve human micronutrient intake by consuming foods grown in other areas, providing a micronutrient supplement in the form of tablets or by fortifying a commonly consumed food. Where soils are deficient in several micronutrients choosing the right approach is more complicated, in particular because of possible interactions between the various micronutrients, reducing their bioavailability. In summary, enriching foods by applying micronutrient fertilizer to crops is an alternative food-based approach which has the advantage that micronutrients are incorporated in food crops through physiological mechanisms, reducing the risks of adverse side-effects or unwanted interactions between micronutrients. Yet, further evidence of the advantages of this approach is needed.

Discussion and Conclusions

The two main objectives of the present chapter were to analyse and document the occurrences and strengths of the linkages between micronutrient deficiencies in soils, crops, animal and human nutrition, and to assess whether micronutrient application as fertilizer is a realistic and feasible approach in addressing human micronutrient deficiencies. With these objectives in mind, three factors which complicate the analysis need to be mentioned.

First, the assessment of micronutrient availability in soil is complex (182,183). Apart from visual inspection for plant symptoms which are indicative of micronutrient deficiency, soil micronutrient availability is generally assessed on the basis of laboratory analysis of soil samples, using extraction solutions such as DTPA (diethylenetriaminepentaacetic acid), EDTA (ethylenediaminetetraacetic acid), TEA (triethanolamine), Mehlich-3, etc. (44,184,185). Results obtained with different extractions methods may vary, and it is difficult to determine which procedure represents best the actual availability of a particular micronutrient for uptake by plants.

Second, quantitative data on micronutrient density of food crops grown on different types of soils are limited. In agricultural research, focus has been on yields, and consequently there is much literature on the relationships between micronutrient availability in soils and associated yields, but little information on crop micronutrient densities.

And third, also in human nutrition, the assessment of micronutrient status is not always straightforward (186). For example, the assessment of iron deficiency is generally based on information on anaemia prevalence, but other factors, such as intestinal worms, malaria, HIV, tuberculosis, high reproductive physiological demands of women, deficiencies in folic acid and copper or deficiencies in other vitamins and minerals, can also contribute to the development of anaemia. Therefore, anaemia prevalence is only an approximate indicator for iron deficiency. Also for zinc, there is no single reliable measurement on the basis of which a human deficiency can be diagnosed. Most commonly used is the measurement of serum zinc, but this measure is generally considered to be a weak indicator of human zinc status (187). A different approach for assessing people's micronutrient status is the estimation of dietary intake of micronutrients on the basis of food composition tables (FCTs). But food composition data as reported in FCTs are generally averages for a particular country, or even for a group of countries. Therefore, FCTs are not particularly suitable for assessing the micronutrient intake of population groups living in regions which have their own specific soil characteristics (188–190). In fact, only direct laboratory analysis of actually consumed foods will provide a reliable estimate of the dietary intake of micronutrients, but such analysis requires very high, generally prohibitive, inputs in terms of time, technical knowledge and costs (191,192). Despite these technical and methodological constraints, the results presented in this chapter indicate that there are, at least for some micronutrients, direct quantitative relationships between their levels and availabilities in soils, their densities in food crops, and the occurrences of human micronutrient deficiencies.

The classic example of a strong relationship between a micronutrient deficiency in soil, food and human nutrition is iodine. But also for selenium, it has clearly been shown that such relationships occur, particularly in China. For zinc, there are several regions in the world where soils are known to be poor in zinc and there are also many reports on the occurrence of dietary zinc deficiency in human nutrition, in particular in children. However, until now there are no studies where a direct relationship has been established between soil zinc status and human zinc status, and there is a need for more geographically based information on the occurrence of zinc deficiency in soils, crops and human nutrition. Finally, with respect to iron there is little information pointing towards direct relationships between soil iron availability and the occurrence of human iron deficiency, and factors other than low iron content of crops and foods are probably more important in causing iron deficiency in humans. Yet an increase in iron content of food crops might well contribute in reducing human iron deficiency.

Various intervention strategies are being used to address human micronutrient deficiencies. Under conditions of subsistence agriculture, the potentially beneficial effects of dietary diversification, plant breeding and genetic engineering are primarily dependent on soil micronutrient availability. Thus, when soils are deficient in one or more micronutrients, these approaches are unlikely to have a strongly positive impact on human micronutrient intake. Micronutrient supplementation and food fortification are two other approaches in addressing micronutrient deficiencies, but both methods have their limitations in terms of targeting and technical feasibilities. In particular, when several micronutrients are combined in the form of tablets or incorporated in fortified foods, there are risks of adverse interactions between micronutrients and reduced bioavailability for intestinal absorption. The application of micronutrients as fertilizer to crops is a relatively new approach in addressing micronutrient deficiencies (except for selenium). An important advantage of this approach is that micronutrients are incorporated in foods through normal physiological processes, which can have positive effects in terms of the absence of side-effects or improved bioavailability. At present, of all the micronutrients, prospects for food-based approaches are most promising for zinc, as application of zinc fertilizer to zinc-deficient soils may result in both increased yields and increased zinc contents of crops. For iodine, fertilization of feed crops has resulted in improved iodine status of animals and also increased the iodine content of animal products (meat, milk). With regard to iron, increasing its content in crops through fertilization is complex, but further studies are needed, in particular in view of the very high prevalence rates of human iron deficiency in the world.

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17 Nationwide Supplementation of Sodium Selenate to Commercial Fertilizers: History and 25-year Results from the Finnish Selenium Monitoring Programme

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Abstract

Selenium is unevenly distributed in soils worldwide. For climatic and geochemical reasons, Finland is one of the low-selenium regions in the world. To improve the quality of Finnish foods and animal health and to increase the selenium intake of the population, an official decision was made in 1984 to supplement compound fertilizers with selenium. Practically all fertilizers used in Finland have contained selenium since 1985. The objective of this chapter is to report the effects of the supplementation of selenium to commercial fertilizers on soils, feeds, basic foodstuffs, dietary selenium intake, human tissues and the environment.

Within a monitoring programme, sampling of cereals, basic foodstuffs, feeds, fertilizers, soils and human tissues has been carried out at least annually since 1985. The systematic error in selenium analyses has been followed annually by a quality assessment scheme involving seven participating laboratories.

The selenium concentration of spring cereals increased on average 15-fold compared with the level before the selenium fertilization practice. The mean selenium concentration in beef and pork increased six- and twofold, respectively, and in milk threefold, compared with levels before selenium fertilization. The average dietary intake increased from 0.04 mg Se/day to a plateau of 0.07 mg Se/day in the mid-2000s. Foods of animal origin in 2006 contributed over 75% of the total daily intake of selenium. The mean human plasma selenium concentration increased by 60% and the selenium status is optimal. Evident signs of selenium transport into natural waters have not been found.

In Finland, where the geochemical conditions are relatively uniform, the nationwide supplementation of fertilizers with selenium has proved to be an effective, safe and controlled way of bringing the selenium intake of the whole population to the recommended level. Moreover the well-being of animals has been secured.

Key words: selenium fertilizers, selenate, monitoring programme, soil, feeds, foods, dietary intake, human selenium status, environment, Finland

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Background

The history of active research on selenium started in 1957 when Schwartz and Folz (1) demonstrated the importance of selenium in rats. Coinciding with this, Mills *et al.* (2) detected the preventing nature of the enzyme glutathione peroxidase (GSHPx) in erythrocytes. Nevertheless, it took years before Rotruck *et al.* (3) demonstrated the function of selenium in GSHPx.

Finnish soils are naturally poor in selenium, although not exceptionally poor. In addition, the availability of selenium in Finnish soils to plants is poor due to soil properties, e.g. low soil pH and oxidation–reduction potential. Therefore, foods and feeds grown naturally in Finland are extremely low in selenium as was shown by Oksanen and Sandholm (4). The low selenium intake in animals resulted in a high incidence of diseases related to selenium deficiency, especially in fast-growing and young animals. To overcome this obstacle, various treatments against selenium deficiency diseases were tested after the role of selenium in nutrition was demonstrated (5). In the 1970s, the results of the extensive Mineral Element Study (6) showed that the selenium content in domestic agricultural products was also very low. The possible health effects of the very low levels of selenium in the average Finnish diet also attracted attention. To improve the quality of Finnish foods and to increase the selenium intake of the population, an official decision was made in 1984 to supplement compound fertilizers with selenium. A large amount of data has been collected and published during the 25-year period of selenium supplementation, and is summarized in this chapter.

Early selenium supplementation in Finland

Selenium has been successfully used as a treatment in preventing nutritional muscular degeneration since the early 1960s. In Finland, a decision to allow supplementing of mineral mixtures with inorganic selenium sources for feed purposes was made in 1969. This resulted in supplementing all commercial feeds with selenium, mainly sodium selenite, at the maximum allowed level of 0.1 mg Se/kg in total ration. This decreased the incidence of diseases related to selenium deficiency in farmed animals. However, in animals not commonly given commercial feed mixtures, there was no improvement in health.

In humans, the dietary selenium supplementation of animals as inorganic selenium had only a minor effect, because transfer of inorganic feed selenium into animal products is poor. In the 1970s the per capita daily selenium intake of the Finnish population was generally about 30 μg, far below the US safe and adequate range of 50–200 μg (7). The low selenium content of domestic food products also resulted in speculations on the healthiness of locally produced food. In the years when grain was imported due to low domestic crop yield, human selenium intake increased to almost the level of the US safe and adequate range, as Varo and Koivistoinen calculated in 1981 (8). The Finnish authorities also considered the risk that the low selenium content of Finnish food products could become a trade barrier for food exports.

Rationale for increasing the selenium content in Finnish food

After the role of selenium in physiology became better understood, several studies in humans, e.g. studies of the group led by Salonen (9,10), were initiated in the late 1970s to study the potential health effects of low selenium intake. These studies brought up evidence of increased risk of cardiovascular diseases and cancer at low selenium intakes. This information resulted in extensive discussions in the Finnish media and led to dramatic increases in sales of selenium tablets and other special selenium preparations. From a public health point of view, this was not a sustainable solution, because the selenium intake was distributed extremely unevenly among different population groups. Those people not taking extra preparations were still subject to selenium deficiency and, on the contrary, some of those using these preparations in excess were facing a risk of overdosing, because the margin between the daily need for selenium and overdose is narrow.

Along with the increased awareness of the role of selenium, and as various studies had shown the necessity of selenium in nutrition, it became obvious that serious action should be taken to convince the Finnish population of the high quality of Finnish food and to remove obvious risks to public health. The basic principle was to make the action as comprehensive and safe as possible, so that the entire population would have a sufficient selenium intake without risk of overdosing.

An extensive research programme was launched to study the best way to increase the dietary intake of selenium of the Finnish population. Yläranta (11) investigated the selenium transfer to plants through various means of selenium application in his extensive experiments carried out in 1979–1983, and the transfer of selenium from feeds to animal products was studied in various experiments launched in 1982 and continuing to the late 1980s (12–14).

Transfer of fertilizer selenium to plants

Although foliar application of selenium, either as sodium selenate or sodium selenite, was found to be taken up by plants several times more efficiently than the selenium added to fertilizers, there are several risks with this method. In foliar application, selenium uptake by the crop is dependent on spraying conditions, stage of growth of the plants as well as climatic conditions during and after the spraying. The application of selenium through spraying needs an extra field operation, consequently resulting in extra costs, and could result in that not all the crop would have selenium applied. Accurate dosing of such small quantities of selenium as is needed in foliar application cannot be guaranteed under farm conditions.

In contrast to foliar application, fertilizer application is a rather safe method for selenium supplementation, because selenium is mixed into the commercial fertilizers under controlled industrial conditions and the level of fertilizers applied to the crops under farming conditions is well controlled. Under acidic soil conditions, common in Finland, selenium from sodium selenate is more readily taken up by the plants than selenium from sodium selenite. Based on this, it was obvious that sodium selenate is the most appropriate form of selenium to be used in fertilizers. In the soil, selenium is rapidly reduced to insoluble forms and therefore the risk for leaching of selenium into the environment is negligible.

To define the proper level of selenium in fertilizers, different efficiency in uptake between various crops needs to be considered. Selenate-Se from fertilizers is several times more efficient in increasing the selenium content in grasses than in cereal crops. In Finland, the common practice is to use multi-nutrient (NPK) fertilizers for all field and horticultural crops, and for many of the crops there are specifically formulated fertilizers.

Transfer of plant selenium to animal products

The most important selenium sources in the human diet in Finland are milk and meat products, accounting altogether for nearly 70% of the total selenium intake, both before and after applying selenium in fertilizers, as calculated by Eurola *et al.* (15). Organic plant-incorporated selenium was chosen as the major target for the research, because studies in the 1970s indicated inefficiency of inorganic selenium in raising the selenium content of animal products.

The target estimated by the research group (12), to have in fresh milk 20 μg Se/l, can be reached either by supplementing the ration of cattle by approximately 1 mg Se/kg feed dry matter (DM) as sodium selenite or with 0.1 mg Se/kg feed DM as selenium-fertilized feed. The latter equals the dietary requirement of cattle. A similar pattern between inorganic and organic selenium sources occurs in transfer of feed selenium to meat. At a high organic selenium intake level, milk content tends to reach a plateau at the level of 43 μg Se/l, i.e. only a level twice the desired level in milk (12).

Therefore, it is unlikely that there would be a risk of detrimentally high levels of selenium in milk at conventional dietary selenium levels in cattle feeding. Nevertheless, there are some conflicting results in experiments using selenized yeast as a selenium source, because a stable plateau in milk selenium content was not found in the study of Givens *et al.* (16). Therefore, some caution should be considered when applying selenized yeast as a selenium source.

Decisions and monitoring for increasing the selenium content of agricultural crops

In December 1983, the Ministry of Agriculture and Forestry set up a Selenium Working Group to draft a proposal concerning the addition of selenium to general fertilizers. Another task of the Working Group was to draw up a research and monitoring plan for observing the impacts of the selenium added to the soil, plants, feeds and foodstuffs of plant and animal origin. The selenium intake of humans and animals was also studied and monitored. The Working Group was responsible for assessing the impacts of the added selenium and, where necessary, to give proposals for revising the quantities of selenium to be added.

In accordance with the proposal of the Selenium Working Group, selenium was added to multi-nutrient fertilizers used in agriculture and horticulture. At first, the quantity added was 16 mg Se/kg fertilizer for cereals and 6 mg Se/kg fertilizer for grasses. In spring 1990 the Ministry of Agriculture and Forestry decided, based on a proposal of the Selenium Working Group, to lower the quantity to be added to solid multi-nutrient fertilizers to 6 mg Se/kg fertilizer, and the addition of selenium to other fertilizers was prohibited. This was done because the increase in the selenium content in cereals and the selenium intake were higher than expected. There was also some uncertainty as to the possible environmental impacts of the selenium added to fertilizers. The reduction led to a considerable decrease in the selenium content of feeds, fodder cereals and domestic foodstuffs.

The Finnish Fertilizer Act was amended in 1993, and the Decision of the Ministry of Agriculture and Forestry issued under the Fertilizer Act in 1994 also adjusted the maximum allowable quantity of selenium in fertilizers. Now 6 mg Se as selenate could be added to multi-nutrient and inorganic compound fertilizers intended for agriculture and horticulture. However, the decision did not concern EU fertilizers.

In 1998, the Ministry of Agriculture and Forestry decided to commission the Agricultural Research Centre of Finland (later MTT Agrifood Research Finland) to carry out monitoring of selenium. The legislation on fertilizers was amended on the basis of a proposal of the Selenium Working Group in 1998, when the quantity of selenium to be added to inorganic compound fertilizers for agriculture and horticulture was raised by a decision of the Ministry of Agriculture and Forestry from 6 mg to 10 mg selenate-Se/kg fertilizer. This decision did not concern EU fertilizers, but was based on observations which showed that the selenium intake of domestic animals and humans had decreased, first as a result of the reduction in the quantity of selenium in fertilizers in 1990 and then due to the decrease in the use of multi-nutrient fertilizers. The conditions for environmental support and restrictions on the use of phosphorus had already clearly reduced the use of multi-nutrient fertilizers, so that the selenium quantity per hectare of arable land had been decreasing.

The Selenium Working Group justified the increase in selenium content of fertilizers by the fact that selenium intake had been decreasing in Finland for quite some time – even if in recent years it had been satisfactory, about 70 μg Se/day. One obvious reason for the decrease was the constant reduction in the use of fertilizers and changing fertilization practices. Food imports from the EU continued to grow, which also reduced selenium intake. Raising the selenium content in fertilizers would influence its intake in Finland but, according to the Selenium Working Group, this was not likely to reach the levels seen in 1988–1991 or exceed 130 μg Se/day. This meant that increasing the selenium level in fertilizers would not lead to an excessive rise in selenium intake, but the intake would remain within the range of sufficient and safe intake. As regards foodstuffs, there was no reason why the selenium level in fertilizers could not be raised. Increased selenium content in fertilizers would also ensure its content in animal feed, so that animal welfare could be safeguarded in the variable conditions prevailing on different farms.

Exceptions to a satisfactory selenium status in Finland are products from organic farms. The regulations in organic farming do not allow the use of such fertilizers fortified with selenium. Because organic products, in general, are regarded as safe and healthy products, low selenium content affects their image adversely. This constraint still remains to be solved.

The monitoring of selenium continues in Finland and in 2006, the Selenium Working Group proposed adjusting selenium quantities of inorganic fertilizers when the new Fertilizer Product Act (539/2006) entered into force. In the Ministry of Agriculture and Forestry Decree on fertilizer products (12/07), selenium may now be added as selenate at 15 mg Se/kg DM to a fertilizer to which the addition of selenium is permitted according to the type designation. The maximum quantity in fertilizers is 20 mg Se/kg DM and it must not be added to the surface of the fertilizer grains. The addition of selenium must also be stated in the product description.

As an exception, selenium as sodium selenate may also be added to fertilizers sold to livestock farms and to farms accepting manure with the conditions described above at 25 mg Se/kg DM. Fertilizers may contain a maximum 30 mg Se/kg DM. The permitted end use of the fertilizer is supplementary fertilizing of grass and corn for a stated need when the main fertilizer used for arable land is manure. The fertilizer manufacturer and vendor are obliged to check in advance that the farm accepting fertilizer is a livestock farm or a farm accepting manure. In addition, farms using fertilizer must indicate the arable land plots where the fertilizer is spread by plot accounting records of their arable land.

According to the Selenium Working Group, the reason for the derogation is the abundant use of animal manure as plant fertilizer on livestock farms. Because of the use of manure, the amount of inorganic fertilizers applied on these farms is much lower than on cereal farms and thus the amount of selenium originating in fertilization is also below the average. In its report, the Selenium Working Group also refers to the similar trend in the content of selenium in animal feed in cases where animal manure is used as the main fertilizer. This indicates that the selenium contained in feed mainly comes from inorganic fertilizers which contain selenium.

In conclusion, selenium has been added to fertilizers in Finland for over 20 years. This has been founded on comprehensive, long-term research and monitoring as well as measures undertaken based on a large body of data. The addition of selenium to fertilizers in Finland may be considered an excellent example of good collaboration between companies, research and authorities which has improved the quality of Finnish food and raised selenium intake from food to a sufficient level in human and animal health.

Occurrence and Chemistry of Selenium in Finnish Soils

The main source of selenium in biological systems and the food chain is soil. Because soil selenium is ultimately derived from the parent material in the bedrock, its content is markedly dependent on the origin and geological history of the soil and dictated by the mineralogical characteristics of the parent material, weathering degree of mineral constituents and soil formation processes. Because no systematic mapping of selenium in Finnish bedrock and soils has been carried out, this overview is a synthesis of rather limited published data and conclusions based on general biogeochemical and chemical principles.

Origin of selenium in parent material

The mode of occurrence of selenium is dictated by its close relationship with the element sulfur. Selenium can replace sulfur in sulfides commonly formed with metals such as iron, zinc, copper, nickel, etc. The high-selenium soils largely come from sedimentary deposits whereas the low-selenium soils are typically derived from igneous rocks typical of the bedrock in Finland (17). Scattered geochemical studies on ores and minerals (18–22) indicate, however, that areas of moderate or rather high concentrations may be found.

Distribution of selenium in Finnish soils

In Finland, the bedrock is covered by a thin glacial till layer and, in places, by glaciofluvial deposits. On coastal areas, late- and postglacial marine- and brackish-water clay and silt deposits are common. Inland, fine-textured sediments are mainly of lacustrine origin. A typical feature is the abundance of peatlands which cover about one-third of the land. These facts form a general frame for the occurrence of selenium in Finnish soils. Soils of contrasting texture differ in their concentrations of elements. This is attributable to the various particle size classes which differ in mineralogical composition and sorption components. Clay consists markedly of micas, e.g. biotite, and related clay minerals. Biotite is a black mineral relatively high in selenium (21). The coarser fractions are dominated by light-coloured quartz and feldspars. As a rule of thumb, the dark minerals are higher in selenium than the light ones. Furthermore, the clay fraction is also much richer in aluminium and iron oxides, the main sorption components for selenium, than are the coarse particles. These factors explain the distribution pattern found by Sippola (23) and Yläranta (24), that Finnish clay soils are higher in selenium than the coarser ones. In organogenic soils, the native selenium concentration varies depending on the origin of the soil. Peat soils are very poor in selenium (22,23). Similarly, gyttjas formed in calcareous environments are low in selenium because of a shortage of adsorbing metals.

Bioavailable selenium

As with many other soil-borne elements, total selenium is not a useful index of plant-available selenium and cannot be used as a reliable parameter in risk assessment or in determination of selenium supplementation need. This was seen in the study of Oksanen and Sandholm (4), who did not find any correlation between forage crops and soil type in various parts of Finland. On the contrary, correlations between selenium in plants and soil can be found if the relationship is investigated within various types of soils as done by Sippola (23). In organic soils, total selenium correlated much better with selenium in plants than acid ammonium acetate–Na_2EDTA-extractable selenium. A smaller difference in the correlation coefficients was found in clay soils.

The mobility and plant availability of selenium in soils is controlled by a number of chemical and biochemical processes: sorption, desorption, formation of inorganic and organic complexes, precipitation, dissolution and methylation to volatile compounds.

Selenite and selenate decisively differ in their reaction mechanisms: selenate is mobile in the soil profile, whereas selenite is efficiently retained to oxide surfaces (formed during weathering of minerals) and, consequently, is less available to plants. A low pH, typical of Finnish soils, enhances the sorption reactions. That is why liming increases the mobility of selenite. Also a high salt concentration in the soil solution favours sorption reactions. Organic matter in the soil does not retain anions directly even though some retention to humic compounds can take place through their organometallic complexes possibly present. In soils low in gaseous oxygen, selenate is reduced to selenite, which decreases the mobility of this element. Finnish soils provide a good environment for the reduction reactions, because they are high in organic matter that consumes oxygen in decomposition reactions. Furthermore, especially in the fine-textured soils, the gas exchange between soil pores and the atmosphere is often limited because of soil compaction or wet conditions, which contributes to the formation of reductive conditions. This means that selenate added with fertilizers will be reduced to selenite and retained in soil particles. The findings made in practice agree with the theory: selenium fertilization should be repeated every growing season, because plant availability cannot be maintained for long. On the other hand, the reduction tendency of selenate diminishes the risk of selenium leaching. However, selenium may be transported to surface waters with the eroded soil particles. According to Yläranta (25), the volatile losses of selenium from Finnish soils are very small. However, he noticed that liming and addition of organic matter enhanced selenium volatilization through enhanced microbiological activity.

Acid sulfate soils – special problem areas

Veterinary reports about the spread of nutritional muscular degeneration in Finland since 1933 provide indirect information about bioavailable selenium. Isolated cases of the disease occurred in the 1950s throughout the country, but it was most frequently observed in the coastal areas of the Gulf of Bothnia (5) where acid sulfate soils are common. The soils are marine in origin (sediments of the ancient Littorina Sea) and high in sulfide precipitates, and also in selenium. Thus, the most frequent occurrence of selenium problems in domestic animals found on these soils seems to disagree with their geological history. It is likely, however, that this contradiction is apparent and attributable to the chemistry of selenium dictating its bioavailability. The typical edaphic properties of acid sulfate soils (very low pH, high content of iron and soluble electrolytes) are known to increase the retention tendency of selenium. However, an additional factor contributing to the deficiency symptoms in these soils could be the high sulfate concentration found to depress the uptake of selenium by plants (Keskinen *et al.*, unpublished data). Thus, numerous environmental factors control the availability of selenium to plants and, consequently, selenium intake by animals and humans.

Materials in the Monitoring Programme

Sampling

The majority of items collected within this programme have been systematically sampled at least annually since 1985.

Cereals

Flours and silo samples of bread grain cereals (rye, spring and winter wheat) were obtained from the largest commercial mills in Finland: Fazer, Raisio Group and Helsingin Mylly Oy. The flour samples were taken directly from the production lines at the mills. The farm samples of wheat, rye, barley and oats were obtained from the Plant Production Inspection Centre Grain Laboratory, which has been collecting samples from farmers for its grain quality monitoring project since 1966.

Bread, milk, cheese, fish

Samples of bread, milk, cheese, Baltic herring and eggs were purchased four times annually from eight retail food stores. The sampling areas varied: samples were taken from Forssa every sampling period, while the cities of Helsinki, Turku and Tampere alternated as a pair with Forssa (four stores per city). The samples were pooled in pairs to make four samples per sampling period. This amounted to 24 samples per food item annually. Rainbow trout, potato and white cabbage were collected only once each year. Occasionally some other food items such as carrot, strawberry, onion and broccoli were also collected. Samples were freeze-dried, homogenized with a blender and stored in a freezer prior to analysis.

Meat and liver

Samples from pig and cattle were obtained from a Finnish slaughterhouse. The samples were collected regularly every month according to an annual residue control plan from animals selected randomly from the slaughter line. The samples were packed separately and sent to the laboratory within 24 h in temperature-controlled chambers containing coolant canisters frozen before dispatch.

Fertilizers and feeds

The selenium content of fertilizers was analysed at the Plant Production Inspection Centre in the form of normal control inspections set by the fertilizer legislation. As an example, 33 samples were analysed in

2000–2001. Feed samples were collected according to the European Commission Regulation 138/1998.

Environmental samples

Tapwater, groundwater, lake and river waters, and lake and river sediments were collected during 1990–1992. Ten samples of perch from 26 lakes were obtained through fishing associations (26–29). A follow-up study was done in 1997–1999 in which 14 rivers and seven lakes were sampled (30).

Human blood and tissues

Plasma samples have been obtained annually from healthy subjects in urban Helsinki (n = 30–35) since 1984, and both plasma and whole blood samples from rural Leppävirta (n = 35–45) since 1985. The participants in Helsinki were members of staff of the National Public Health Institute, while those residing in Leppävirta were mostly the same subjects recruited in 1985 for the purposes of following their selenium status. Their ages in the year 2000 ranged from 26 to 62 years in Helsinki and from 25 to 77 years in Leppävirta. The inclusion criterion is apparent health and exclusion the use of supplements containing selenium. All subjects filled in a questionnaire regarding their health status and use of dietary supplements (selenium) on each blood-sampling occasion. An annual blood sample was drawn into a vacuum tube and plasma and whole blood were stored at –20°C before analysis (within 6 months). Sampling of other human tissues, toenails and autopsy liver samples is described in detail elsewhere (31,32).

Analytical methods for measuring selenium

Cereals, milk, cheese, vegetables, fish

The selenium concentration was analysed by an electrothermal atomic absorption spectrometric (ETAAS) method (33). The dried samples were digested in a mixture of concentrated HNO_3, $HClO_4$ and H_2SO_4. Selenium was reduced to Se(IV) with hydrochloric acid, chelated with ammonium pyrrolidine dithiocarbamate (APDC) and extracted into methyl isobuthyl ketone (MIBK) for AAS measurement. Certified (Table 17.1) or in-house

Table 17.1. Results (mean±standard deviation) for selenium of the Certified Reference Materials analysed at the Finnish Food Safety Authority Evira (National Veterinary and Food Research Institute until 2006), MTT Agrifood Research Finland and University of Helsinki, Department of Food and Environmental Sciences.

Certified Reference Material	Certified value (mg Se/kg DM)	Present results (mg Se/kg DM)	*n*
Finnish Food Safety Authority			
BCR184 Bovine muscle	0.183 ± 0.012	0.175 ± 0.020	81
BCR 185R Bovine liver	1.68 ± 0.014	1.67 ± 0.021	5
BCR 185 Liver	0.446 ± 0.013	0.475 ± 0.035	75
NIST Bovine liver	0.71 ± 0.07	0.76 ± 0.05	80
MTT Agrifood Research Finland			
ARC/CL Wheat flour	0.057 ± 0.005	0.057 ± 0.006	366
ARC/CL Milk powder	0.082 ± 0.008	0.076 ± 0.011	96
Dorm-2 Dogfish muscle	1.40 ± 0.09	1.41 ± 0.13	51
NIST Bovine liver	0.73 ± 0.03	0.75 ± 0.02	9
ARC/CL Diet	0.181 ± 0.017	0.183 ± 0.03	3
University of Helsinki			
BCR 189 Wholemeal flour	0.132 ± 0.010	0.124 ± 0.007	8
BCR 185 Bovine liver	0.446 ± 0.013	0.445 ± 0.025	6
NIST 1549 Milk powder	0.110 ± 0.010	0.108 ± 0.006	5
NIST Bovine liver	0.71 ± 0.07	0.672 ± 0.026	15

reference materials of a suitable matrix were analysed in every batch of samples. The Finnish Centre of Metrology and Accreditation accredited the method for selenium in 1999.

Meat and liver

Two methods were used for analysing meat and liver: a fluorimetric method (until 1990) and thereafter selenium concentrations were measured by a hydride-generation atomic absorption spectrometric (HGAAS) method with digestion in a muffle furnace (34). The Finnish Centre of Metrology and Accreditation has accredited the method for selenium and the laboratory fulfils the requirements of the SFS-EN ISO/IEC 17025 standard.

Certified Reference Materials (Table 17.1) were analysed together with each sample series. Calibration was continuously checked using standard samples with different concentrations. The recoveries in different sample materials were 80–105%. The amounts added were selected so as to be close to the amounts normally found in meat and liver.

Fertilizers and feeds

Selenium was analysed by an HGAAS method. Feed samples were wet-digested and fertilizers diluted with an acid solution prior to the AAS measurement. The method used was MKO number P08261.

Soils

At Viljavuuspalvelu Oy, soil selenium was analysed by an in-house method. Selenium was extracted with boiling water (soil:water 1:3 w/v) for 30 min and dry-ashed with the aid of $Mg(NO_3)_2$. The selenium concentration was measured by an HGAAS–flow injection analysis system method.

Plasma, whole blood and tissues

Plasma selenium concentration was determined by an ETAAS method (35). The precision between series was 4.4% and the accuracy was, on average, within 5% of external quality-assurance plasma standards (36). Whole blood, toenails and liver selenium concentrations were determined by an acid-digestion fluorimetric method (37). The precision of the method between series was 3.5%, and the mean bias compared with external quality assurance samples was +1% (38).

Environmental samples

Water selenium concentration was determined by an acid-digestion fluorimetric method after a pre-concentration step (28). Sediment and fish samples were dried and then subjected to the acid digestion.

Quality control

The seven laboratories participating in the selenium monitoring programme used their own quality control schemes in the sampling and the selenium analyses. Most of the laboratories participate regularly in international comparison tests. In addition, the University of Helsinki organized inter-laboratory comparison tests 21 times during the years 1985–1997, and MTT Agrifood Research Finland has continued these by organizing four since 1998. The samples (four or five) represent different food and feed matrices, with selenium concentrations ranging from very low to high.

In 1999 and 2001, the *Z* scores of the laboratories varied in the range 0–1.8. The statistical analyses proved that there were no significant differences in selenium levels between the selenium monitoring laboratories and the results from different laboratories were comparable with each other.

Results from the Monitoring Programme 1985–2010

Selenium in foods

Grains

The effect of selenium-supplemented fertilization on cereal grains was distinct. The selenium content of spring cereals (spring wheat, oats and barley) increased 20- to 30-fold during the years when two supplementation levels were in use. After using only the lower of the original supplementation levels since 1991, the selenium content of spring cereals decreased to about a tenth compared with the level common before the selenium fertilization. Since the raising of the supplementation level to 10 mg Se/kg fertilizer, the selenium level of spring cereals increased to a level that is 15-fold higher than before the selenium fertilization practice (Fig. 17.1). The increase in winter cereals (rye and winter wheat) was considerably less, the concentrations varying between 0.02 and 0.07 mg Se/kg during the years 1985–1995, which was two- to sevenfold higher than the level common before the selenium fertilization. The reason for this difference is that winter cereals are usually given only light selenium-supplemented multi-mineral fertilization in the autumn during sowing, while nitrogen fertilizers without selenium are applied in the spring. Selenate is reduced to selenite during the winter when the soil is covered by snow and thus bound to the soil. The selenium content of winter cereals has increased to the average value of 0.1 mg Se/kg DM since also nitrogen fertilizers are supplemented with selenium (Fig. 17.1).

The selenium concentrations of flour and bread are quite similar. Finland occasionally imports grain because of an inadequate or low-quality harvest, and domestic grain and imported grain are mixed for milling. For this reason, the selenium content of grains sometimes differs from that of flours and breads. The selenium content of European cereals usually varies between 0.02 and 0.050 mg/kg DM and that of North American cereals between 0.2 and 0.5 mg/kg (8).

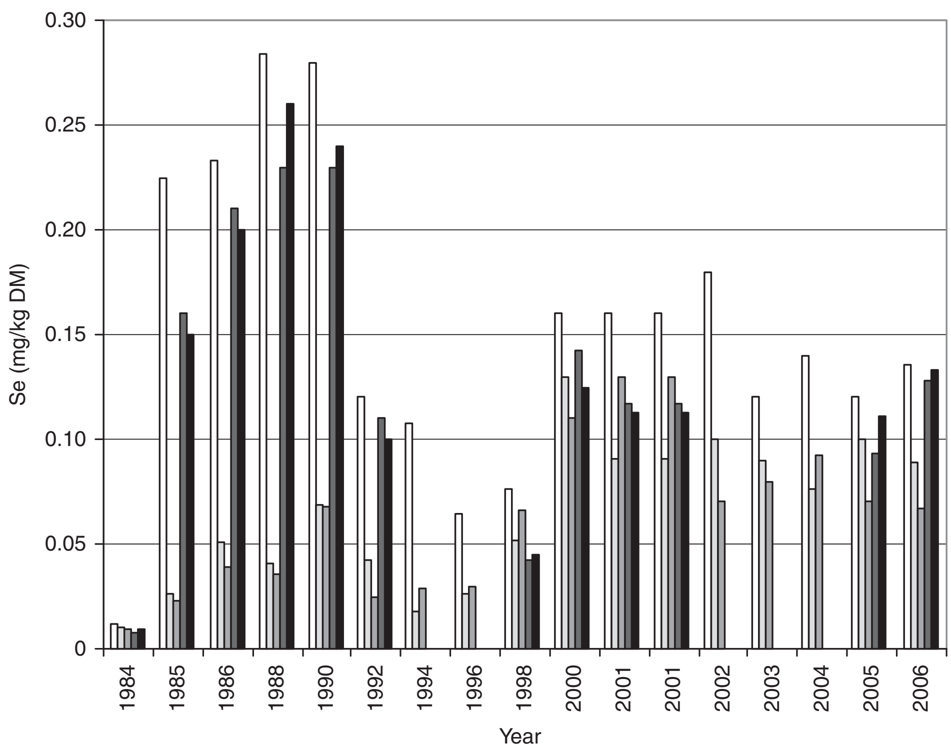

Fig. 17.1. Selenium concentration of cereal grains (□, spring wheat; ■, winter wheat; ■, rye; ■, barley; ■, oats) in Finland, 1984–2006. DM, dry matter.

In 1985–1990, cereal products contributed about 20% of the total daily selenium intake of the population. Adjusting the amount of selenium in fertilizers has affected the selenium content of grains, and the contribution of cereals to selenium intake has decreased to 16%. In 2006, the proportion of cereals and cereal products was 19% of the average daily selenium intake.

Meat

The selenium concentration of beef produced in Finland in the mid-1970s was low; an average concentration of about 0.05 mg/kg DM. Pork contains generally more selenium than beef. In Finland, the average level in the 1970s was about 0.2 mg Se/kg DM. Even this level was low compared with reported values from other countries.

The effect of selenium fertilization on the selenium concentration of beef and pork was very clear. During 1985–1990, beef contained an average of 0.16 mg Se/kg fresh weight, which was about 13-fold higher than the value for 1975–1977. The average selenium concentration of pork during 1985–1990 was about four times higher than during 1975–1977. Reduction in the amount selenium in fertilizers decreased the selenium contents of beef and pork meat significantly. The selenium concentration of beef and pork in 2004 was about sixfold and twofold lower, respectively, compared with the common level before the beginning of the selenium fertilization (Fig. 17.2).

Meat and meat products are an important dietary source of selenium in Finland. The contribution to the total selenium intake was about 40% in the beginning of the 1990s and about 31% in 2006.

Dairy products and eggs

In the mid-1970s the selenium concentration of milk was very low, about 0.003–0.004 mg/l fresh weight. It slowly increased in the early 1980s, probably because of increasing use of selenite-containing commercial feeds and mineral concentrates and selenium medication of cattle. The effect of selenium-supplemented fertilizers on milk composition was rapid and substantial. Selenium-supplemented fertilizers were used for the first time in May 1985. Milk samples collected in June 1985 already contained nearly twice as much selenium. During the first years of selenium fertilization,

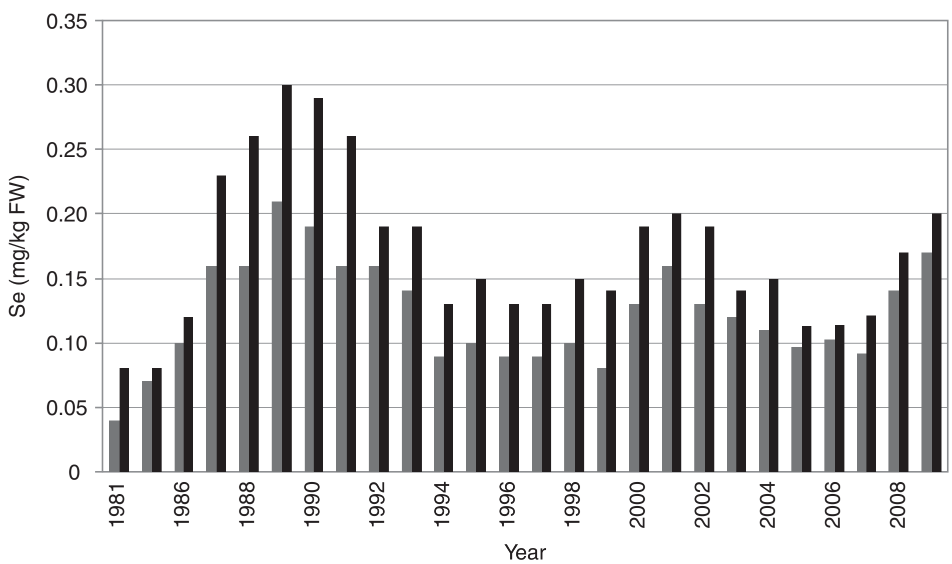

Fig. 17.2. Selenium concentration of beef (■) and pork (■) in Finland, 1981–2009. FW, fresh weight.

the selenium concentration of milk fluctuated with the season, being about 15% lower in the outdoor season than in winter. The seasonal variation became smaller in later years, and in 1990 it was almost undetectable. During recent years, about 20% seasonal variation was seen again. After adjusting the fertilizer selenium levels, the changes in the selenium concentration of milk were also seen very quickly (Fig. 17.3).

The selenium concentration of eggs was relatively high, about 0.45 mg/kg DM in the mid-1970s, because of the use of selenium-enriched feeds. After 1985, the concentration gradually rose to the level of 1.2 mg Se/kg DM and decreased again to 0.8 mg Se/kg DM. The contribution of dairy products and eggs to the total selenium intake was over 25% when the selenium concentration of cereals was higher. The present contribution to the total selenium intake is about 35%. Foods of animal origin contribute over 75% of the total selenium daily intake. The significance of animal foods for selenium intake has increased remarkably.

Dietary intake

The per capita average daily selenium intake in the mid-1970s, when grain was not imported, was as low as 0.025 mg. In the early 1980s, when grain was imported, the intake was 0.04–0.05 mg Se/day. However, most of the time, selenium intake was below the lower limit of the Recommended Daily Allowance (RDA) considered as safe and adequate. The selenium supplementation of fertilizers affected the average intake substantially. A high plateau was reached during the years 1986–1990 of between 0.11 and 0.12 mg Se/day. During 1992 and 1997, intake was 0.079 mg Se/10 MJ on average and the trend was decreasing. In 1998, the amount of selenium in fertilizers was increased and that also increased the average daily selenium intake. In the 2000s, average daily intake has been about 0.07–0.08 mg Se/10 MJ (Fig. 17.4). Due to the third amendment in fertilizer selenium in 2007, the average daily intake is expected to reach a new higher level within a few years. The Finnish selenium intake can be considered to meet well with the Nordic, EU and US recommendations, 0.055 mg/day (39–41). The estimated selenium intake is calculated for a diet where all foods are of domestic origin. The use of imported foods may decrease selenium intake. The proportion of imported foodstuffs is, however, so small that this estimation can be considered valid (42).

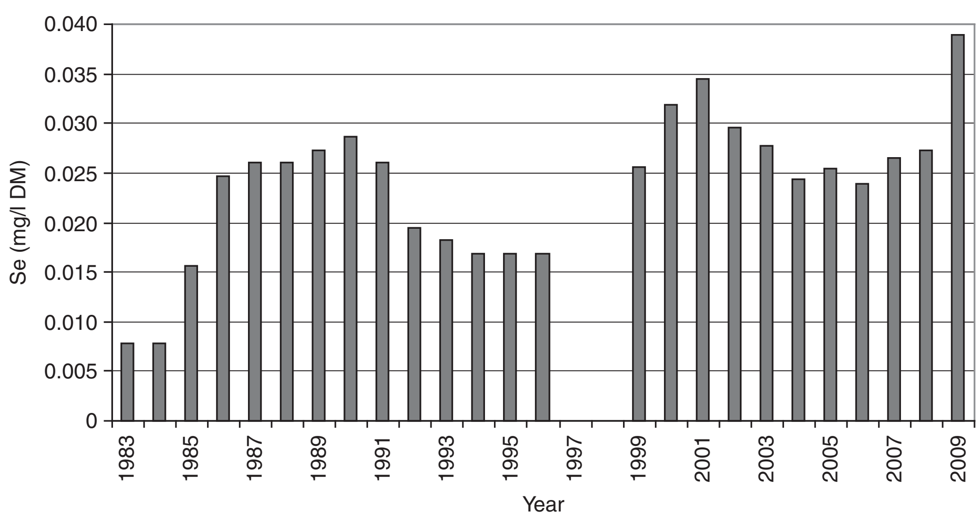

Fig. 17.3. Selenium concentration of milk in Finland, 1983–2009. DM, dry matter.

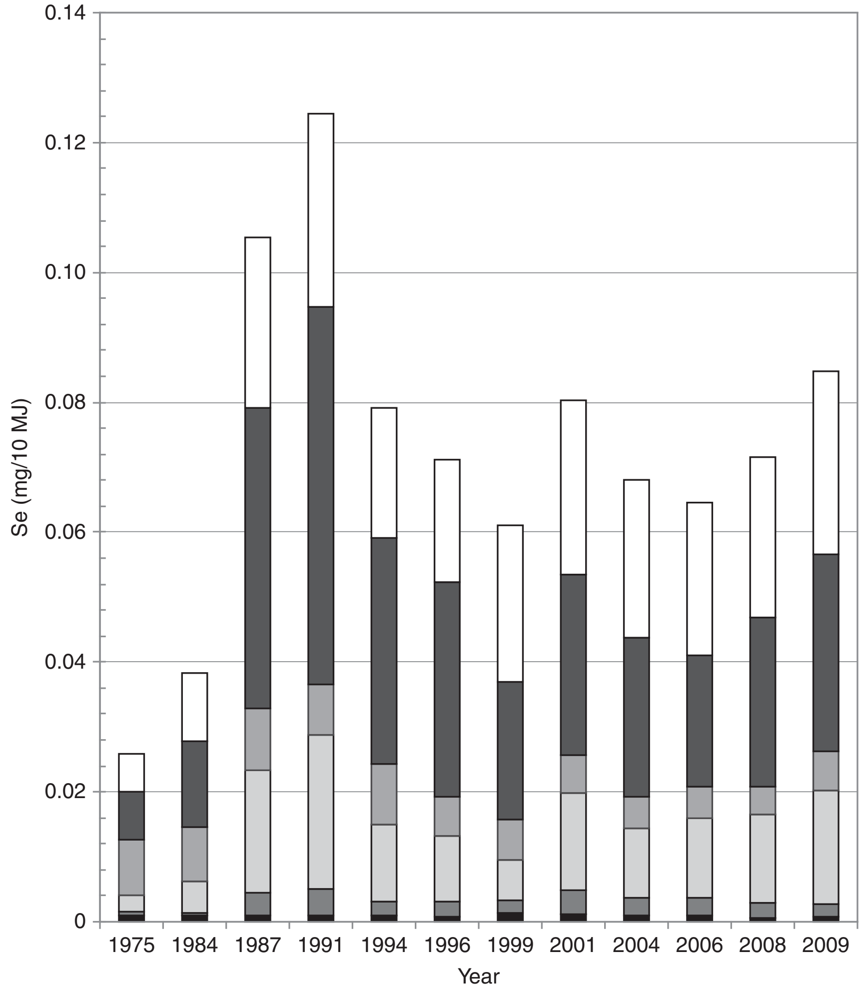

Fig. 17.4. Average daily selenium intake from different sources (□, milk; ■, meat; ■, fish; □, cereals; ■, vegetables; ■, other) in Finland, 1975–2009.

Selenium in animal feeds

Selenium requirement of animals

The importance of selenium in animal nutrition was first discovered in the 1950s when it was shown that most myopathies in sheep and cattle, as well as exudative diathesis in chicks, could be prevented by adding selenium or vitamin E to the diet (43). Selenium is a component of the GSHPx enzyme, which explains its interactive role with vitamin E and the sulfur-containing amino acids. Selenium deficiencies are well known in the form of white (nutritional) muscular disease in ruminants and other animals (44). However, the line between the requirement and harmfulness of selenium is narrow, since selenium is a highly toxic element. Therefore, the total amount of selenium in animal diets has to be monitored constantly.

Selenium takes part in essential functions in living organisms and is necessary for growth and fertility in all animals. The dietary requirement for selenium Se differs between animal species depending on their digestive system and type of production. For a given species, the minimum requirement of selenium varies mainly with the form of selenium ingested and dietary composition, especially its content of vitamin E (45).

In spite of the fact that the nutritional bioavailability of selenium varies according to the criteria, population and individuals chosen, in general the bioavailability of inorganic selenium, mostly as selenite, is lower than that of the organic form of selenium (46). When assessing the selenium requirement of animals, the vitamin E supply should be assumed to be normal, because vitamin E deficiency enhances the requirement for selenium.

Ruminants seem to absorb selenium less efficiently and more variably than non-ruminants. Rumen microorganisms reduce selenium to unavailable forms (47), and only one-third of inorganic selenium is absorbed. The apparent absorption of selenium has been shown to be greater from concentrate than from a lucerne–hay diet (52.8% versus 41.8%) (48).

Feed intake of sheep is greater per unit body weight compared with cattle, which may create a higher burden on antioxidant defences and therefore lead to greater need for selenium. Wool production in sheep affects selenium requirement (49) and high milk yield of dairy cows also increases their selenium requirement (45).

The Finnish recommendation for cattle is 0.1 mg Se/kg feed DM, for pigs 0.2 mg Se/kg DM, for poultry 0.1–0.2 mg Se/kg DM and for fur animals 0.6–0.9 mg Se/kg DM (50). In Norway, the dietary requirement for rainbow trout is reported to be 0.15–0.38 mg Se/kg DM.

Animal feeds

The amount of selenium in feeds of plant origin is variable depending on the plant species, the part of the plant sampled, the growing season and soil on which they grow (45). The selenium content in Finnish soils is known to be low, but availability to plants is limited because of climatic and geochemical reasons (11). This is reflected directly in feeds (and foods). Since 1984, fertilizers produced in Finland have been supplemented with sodium selenate, which has increased the overall selenium content of feed materials grown in Finland on average from 0.02 mg/kg DM to 0.2 mg/kg DM (15). Consequently this has increased the level of selenium in foods of animal origin and helped humans to meet their dietary selenium recommendations.

Soils containing less than 0.5 mg Se/kg are likely to lead to crops and pastures with inadequate selenium concentrations (<0.05 mg/kg DM). The main form of selenium in feed materials of plant and animal origin is organic protein-bound selenomethionine, together with small amounts of selenocysteine and selenite (45).

The natural concentration of selenium in forages varies according to the soil selenium status. According to the Finnish monitoring programme, grass silages contained on average 0.2 mg Se/kg DM (range 0.12–0.3 mg Se/kg DM) during the years 1985–2005. In 1984, the concentration in grass silage was 0.03 mg Se/kg DM (Fig. 17.5). Grass silages

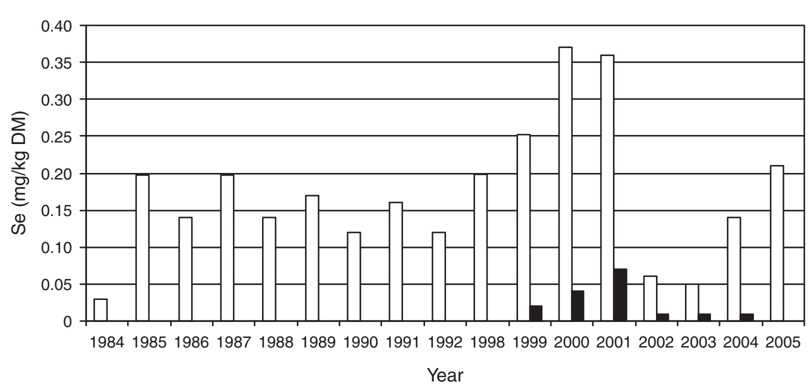

Fig. 17.5. Selenium concentration of grass silage (□, conventional; ■, organic) in Finland, 1984–2005. DM, dry matter. (Adapted from Root (52).)

from the organic production system contained nearly ten times less selenium than conventionally produced silages (51). Silages from the spring harvest seemed to have a higher selenium concentration than the summer and autumn harvests. Legumes tend to contain less selenium than grasses (45).

The selenium concentration of wheat can be higher than that of barley and oat grains (53). In Finland, the selenium concentration of feed oats and barley reached a stable mean level of 0.10–0.14 mg/kg DM in the early 2000s (15) (Fig. 17.6).

The best selenium sources of animal protein feeds are of marine origin. Salmon and herring meals have been shown to be rich in selenium (1.9 mg/kg DM) (53). Tuna fish meal can, however, contain even higher amounts (5.1 and 6.2 mg Se/kg DM) (55). Based on the EU Commission Regulation 1234/2003, fish meal is not allowed in the feeding of ruminants in the EU, but it still provides a good protein and selenium source for pigs and poultry as well as for fish and fur animals.

Animal diets can be supplemented with both inorganic selenium (sodium selenite, sodium selenate) and organic selenium (selenium yeast) added to feeds as feed additives. The maximum permitted concentration in complete feed is 0.5 mg Se/kg feed with 12% moisture content, which consists of both naturally occurring selenium in feed materials and added selenium (Ministry of Agriculture and Forestry Regulation 43/2005). In Finland the Finnish Food Safety Authority, Evira (formerly Plant Production Inspection Centre, KTTK) monitors commercial feeds, and during the years 2000 and 2001, 36% of the analysed samples exceeded the permitted selenium value (15). In 2005, only 6% of the analysed samples of both domestic and foreign commercial feeds exceeded the permitted maximum selenium value. In 12% of the samples the analysed selenium content differed compared with the given value on the feed labelling (56,57). In 2006, the figures were 17% and 14%, respectively (51). Most of the exceeding values were analysed in fish feeds, which did not contain added selenium but are naturally high in selenium. It is challenging for feed manufacturers to estimate the amount of selenium deriving from different feed materials used in compound feeds.

Selenium in agricultural soils

In the 1970s and 1980s, few basic studies on the selenium content of Finnish agricultural soils were performed (11,23,58,59). Yläranta (11) found mean total selenium content in the plough layer of 0.21 mg/kg. The coarse mineral soils studied by Yläranta (11) contained lower selenium concentrations than clay soils, and the highest concentrations (1 mg/kg) were found in organogenic soils. The total selenium content in Finnish soils is not exceptionally low.

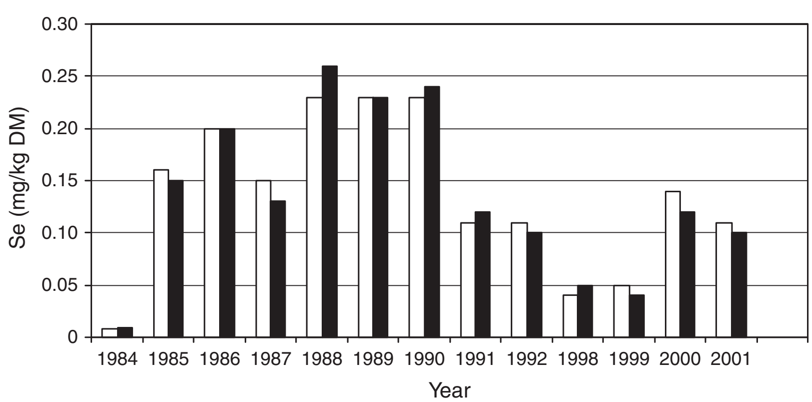

Fig. 17.6. Selenium concentration of barley (□) and oats (■) in Finland, 1984–2001. DM, dry matter. (Compiled with data from the Ministry of Agriculture and Forestry (54), Eurola and Hietaniemi (30) and Eurola *et al.* (15).)

However, for climatic and geochemical reasons, selenium is poorly available to plants. The amount of hot-water-extractable selenium can be used as an indicator of selenium availability to plants. About 4% (range 1.5–10.2%) of the total selenium has been found to be extractable in hot water from various soil types (11).

Viljavuuspalvelu Oy has analysed hot-water-extractable selenium from farming samples. Since selenium-supplemented fertilization began, the number of samples received has decreased considerably, so the Selenium Working Group had a soil selenium study carried out by Viljavuuspalvelu Oy in 1990 (54). The mean hot-water-extractable selenium content of the agricultural soils (n = 450) was 0.006 mg/l. According to Sippola (23), the mean total selenium content of soil samples was 0.201 ± 0.019 mg/kg (n = 250, range 0.005–1.241 mg/kg). Clay and mull soils contained higher selenium concentrations than coarse mineral soils. MTT Agrifood Research Finland monitored soil quality in 1998 (60), and found that the mean soluble (extracted to hot water) selenium content of soils was 0.010 ± 0.005 mg/l (n = 705), with concentrations decreasing northwards. The mean result obtained in 1990 is within the confidence limits of the results by Sippola (23) and Mäkelä-Kurtto and Sippola (60). Therefore, on the basis of these two large studies, it seems that there is no marked increase in the concentration of hot-water-extractable selenium in agricultural soils of Finland after the addition of selenium to fertilizers.

Recently, the number of selenium analyses by Viljavuuspalvelu Oy has been as low as nine to 12 samples per year. In 2000, the hot-water-extractable selenium content varied between <0.01 and 0.12 mg/l (n = 10), and in 2001, between <0.01 and 0.13 mg/l (n = 9). These and the literature data indicate that selenium fertilization has not increased the amount of hot-water-extractable selenium in agricultural soils. However, the total selenium content of soils has not been monitored during the selenium fertilization programme. Utilization of fertilizer selenium by the crop is usually <10%. It can be assumed that most of the added selenium not taken up by the crop is immobilized in the soil. A rough calculation suggests that, since 1984, the content of total selenium has increased about 70 g/ha. If all of it remains in the soil and is distributed evenly throughout a 20 cm-thick plough layer, it can be estimated that the total selenium in Finnish agricultural soils has increased on average by about 20% in about 20 years.

Selenium in human blood and tissues

Selenium requirement of humans

Selenium is an essential trace element necessary for the well-being of animals and humans. A very low dietary intake of selenium, <10 μg/day, is associated with Keshan disease, a cardiomyopathy particularly affecting children and young women. Keshan disease can be prevented by prophylactic dosage with sodium selenite (61). This disease has not been described outside China. At suboptimal intakes, 10–40 μg Se/day, there is an increased risk for heart disease, some forms of cancer and other diseases (62). Recommended dietary intakes globally take into account the daily intake required to saturate the activity of the selenium-dependent enzyme, GSHPx in plasma. The Nordic Nutrition Recommendations are 50 μg Se/day for men and 40 μg Se/day for women (39). The EU (40) and US (41) RDAs are 55 μg Se/day for both men and women. For lactating women, the RDA is slightly higher.

The supplementation of fertilizers with sodium selenate in Finland is a nationwide experiment aimed at increasing the selenium status of both animals and humans. The window for optimal intake of selenium is narrow, with the risk for deficiency very low and toxicity at excessive levels. Systematic monitoring of the selenium status of the population is necessary for safety reasons and also for research purposes.

Plasma selenium

Plasma selenium concentrations in healthy Finnish urban and rural adults have been monitored regularly since the 1970s. During the 1970s, the low dietary intake of selenium, 25 μg/day (63), corresponded to a plasma selenium level of 0.63–0.76 μmol/l (64), being among the lowest values reported in the world (65). Since 1985, the plasma selenium concentration of the same healthy adults has been monitored systematically in urban Helsinki and rural Leppävirta. The intake of selenium has been ascertained to be solely from foods and not supplements.

In the first half of the 1980s, before supplementation of selenium to fertilizers became effective in 1985, the mean plasma selenium concentration ranged between 0.75 and 1.23 μmol/l. The large variation was due to the import of high-selenium wheat (64). One year before selenium supplementation of fertilizers was started, the mean plasma selenium concentration was 0.89 μmol/l and it reached its highest level four years later at 1.5 μmol/l, one of the highest values in Europe (Fig. 17.7). Following the decrease in the amount of fertilizer selenium in 1990, plasma selenium decreased to a new level of 1.10 μmol/l in 1999. This plasma selenium level was still above the mean plasma selenium value for Europe, but lower than is generally found in Canada or the USA (65). After the second change in the amount of fertilizer selenium in 1998, a new plasma selenium plateau at about 1.4 μmol/l was reached by 2006.

Plasma selenium concentrations in subpopulations thought to be at risk of suboptimal selenium intake have also been studied before and during the selenium fertilization (66). The mean plasma selenium concentrations of mothers giving birth and their neonates from 1983 to 1996 followed the trend of adult plasma selenium levels at a lower level. Neither exceptionally low nor exceptionally high individual values were observed during this period.

Since 1985, whole-blood selenium has been monitored systematically only in the rural population group. Whole-blood selenium reached its peak mean value approximately one year later than plasma selenium. Before supplementation of fertilizers with selenium, the mean value was 1.15 μmol Se/l, and in 1990, a maximal value was reached at 2.60 μmol Se/l. After 1992, the decrease paralleled that of plasma selenium, levelling off at 1.85 μmol Se/l by 1999. As a consequence of the second change in the amount of fertilizer selenium, the mean whole-blood selenium concentration seems to have reached a stable level of 1.70 μmol/l by 2006.

Tissue selenium

Toenails reflect the integrated intake of selenium over a period of 6 months to 1 year (67). Toenail data for the period 1984 to 1995 have been compiled from different Finnish studies on healthy subjects (68–70). Before supplementation of fertilizers with selenium started, the mean toenail concentration was 0.45 mg Se/kg. The maximum level, 0.91 mg Se/kg, was observed in 1992 about two years later than for whole-blood selenium. In accordance with plasma and whole-blood selenium, a clear downward trend was seen after the first change in the amount of fertilizer selenium

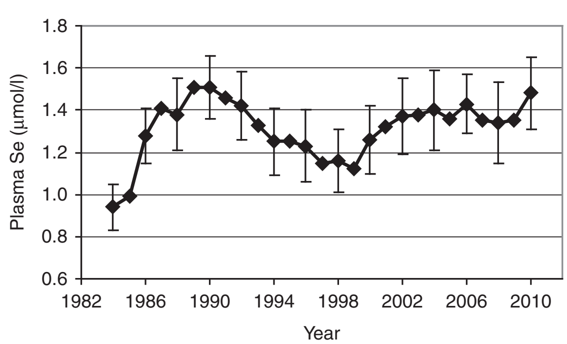

Fig. 17.7. Mean annual plasma selenium concentration in healthy Finns before and during the selenium fertilization.

and the latest value, from 1995, is 0.72 mg Se/kg. The inter-individual variation in toenail selenium was typically 10–12%. In a European multicentre study comprising eight countries, the toenail selenium concentration of 59 middle-aged Finnish men sampled during 1990–1992 was the highest, 0.84 mg/kg (71).

The largest fraction of body stores selenium is situated in the liver. Its selenium is mobile and reflects dietary selenium intake over a time span of weeks (72). Selenium has been determined in human liver samples obtained at autopsy from men who died in traffic accidents both before (1983–1985) and during (1988–1989) the selenium supplementation of fertilizers. Initially, the mean value was 0.95 ± 0.27 mg Se/kg DM. The mean selenium concentration of liver tissue obtained three to four years later had increased to 1.58 mg/kg (66).

Plasma, red blood cell and platelet glutathione peroxidase activity

The activity of the selenium-dependent GSHPx is associated with selenium intake only up to moderate intake levels. At higher selenium intakes, the activity of the enzyme in plasma and whole blood reaches a plateau and cannot be stimulated further. The plateau, in terms of plasma selenium, is below 50 μg/day, and for whole blood, approximately 60–80 μg/day (73–75). Saturation of plasma GSHPx activity has been regarded as a measure of optimal selenium intake and has been the basis of the current US RDA (74).

Two placebo-controlled supplementation studies have been carried out in central Finland on the same 50 middle-aged healthy male blood donors (69,76). The aim of the studies was to find out to what extent platelet GSHPx activity could be increased by selenium supplementation and the qualitative effect of organic/inorganic selenium supplementation on GSHPx activity. The first study was performed in 1981 and the second in 1987, i.e. before and during selenium fertilization. Common to both studies, ten men were supplemented with 200 μg of selenium as organic selenium in the form of selenium-enriched yeast or with 200 μg selenium as sodium selenate. The third group received a placebo. At baseline in 1981, the mean plasma selenium concentration was 0.89 μmol/l and in 1987 1.40 μmol/l, which corresponded to mean dietary selenium intakes of 39 μg/day and 100 μg/day, respectively.

The percentage increase in platelet GSHPx activity for men supplemented with either selenate or yeast-Se was calculated in relation to the activity of the placebo groups. Before the addition of selenium to fertilizers, selenate and yeast-Se supplements increased the enzyme activity by 104% and 75%, respectively. During fertilization the effects of selenate and yeast-Se were much lower, 41% and 6%, respectively. The results suggested that an intake of 100 μg Se/day was still not sufficient to completely saturate GSHPx activity in platelets. Extrapolation of platelet data, including the two Finnish studies and six other studies with a similar design, suggests that maximal stimulation of platelet GSHPx activity would occur at a plasma selenium level of 1.3 μmol/l (36). The current data indicate that the selenium status of Finns is at an optimal level.

Human health

The supplementation of fertilizers in Finland is a nationwide experiment affecting all individuals, not a placebo-controlled clinical trial. Therefore, it is impossible to measure in exact terms the health outcomes of the intervention. Apart from Keshan disease which can be prevented by prophylactic administration of sodium selenite (61), the role of selenium in human disease in unclear. Judging from the results of epidemiological studies, mortality and morbidity in cardiovascular diseases (9) and cancer (10,77) are endpoints that might have been affected by increasing the selenium intake in Finnish people. If it is anticipated that selenium exerts its effects via the antioxidant activity of the selenium-dependent enzyme, GSHPx, then the intervention should have been successful, since it resulted in near-maximal stimulation of GSHPx activity in all blood components (36,69).

Age-adjusted mortality from coronary heart disease has declined continuously in Finland since the end of the 1960s (Fig. 17.8). Most of the decline can be attributed to

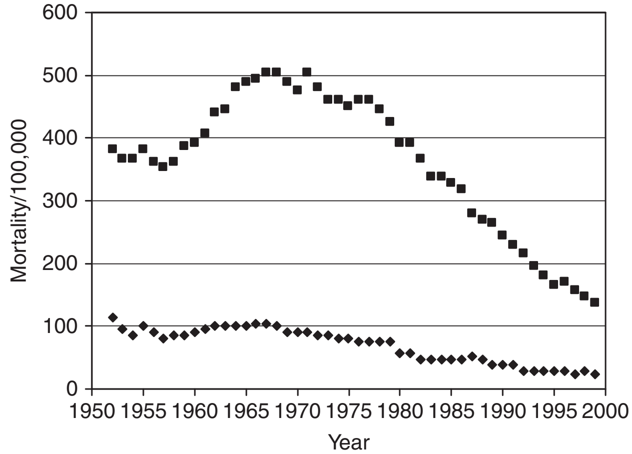

Fig. 17.8. Age-standardized mortality from coronary heart disease in Finland, 1952–1999; deaths per 100,000 of the population (◆, women; ■, men) aged 35–64 years. (Compiled with data from Statistics Finland.)

favourable changes in the levels of classical risk factors such as plasma cholesterol, smoking and blood pressure and, since 1985, it has been impossible to find any change in the declining trend that could be attributed to selenium supplementation (78). Neither do the data on cancer incidence in Finland suggest any specific effects due to increased dietary selenium intake in the late 1980s (Fig. 17.9). For example, lung cancer incidence in males shows a downward trend from the mid-1970s to 1985, with no change in the rate thereafter up to 2005. On the other hand, the incidence of prostate cancer increased sharply in the early 1990s. These diseases are affected by numerous different medical (prostate-specific antigen diagnostics in prostate cancer), lifestyle (cessation of smoking in lung cancer) and dietary factors and it will be extremely difficult to determine whether the increased selenium intake resulting from supplementation of fertilizers has influenced the health of the nation. The most important reason for this is the lack of a reference population, since the entire population of Finland (5.2 million) is affected equally by the increased selenium intake. Cultural, dietary and genetic differences between Finnish and neighbouring populations prevent any meaningful comparison. Conclusions on the effects of increased selenium intakes should be based on controlled clinical trials.

Selenium in the environment

Various components of artificial fertilizers may leach into natural waters and cause harmful effects for the environment, like eutrophication. Selenium in the form of sodium selenate has been added to artificial fertilizers in Finland since 1985. The amounts of selenium used annually in fertilizers during 1985–1990, 20 tonnes, and during 1991–1998, 7.6 tonnes, are comparable with the total fallout of selenium from precipitation, estimated to be 18 tonnes in 1989 (79). Concern about possible bioaccumulation of selenium in the water ecosystem gave rise to monitoring of waters in Finland. Studies on selenium in waters commenced in 1990, and thus had not been done before the selenium fertilization started.

Selenium concentrations of tapwater, groundwater, lake and river waters, and lake and river sediments collected during 1990–1992 disclosed no obvious environmental effects which could be ascribed to selenium fertilization (26–29). Comparison of the total selenium levels in environmental samples

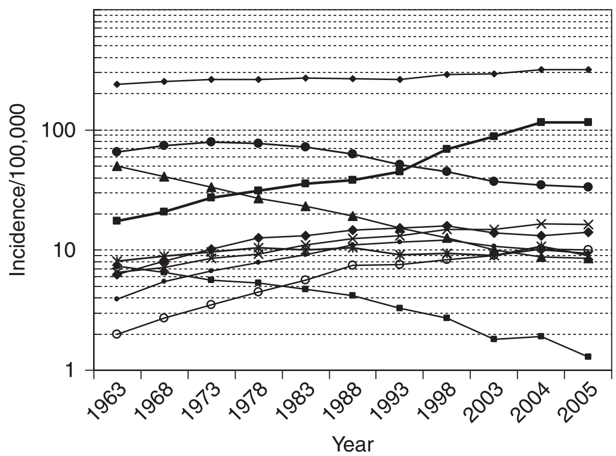

Fig. 17.9. Age-standardized incidence of cancers (—◆—, all cancers; —■—, lip; —▲—, stomach; —✕—, intestine; —✳—, pancreas; —●—, lung; —○—, skin melanoma; —■—, prostate; —●—, kidney; —◆—, bladder) in males in Finland, 1963–2005. (Compiled with data from the Finnish Cancer Register.)

showed them to be generally lower than in other European countries. A follow-up study was done in 1997–1999 on the seasonal variation of water selenium from 14 rivers and lake sediments from seven lakes (30).

During 1997, the mean selenium concentration of river waters was lowest in June (92 ng/l) and highest in August (119 ng/l), although not statistically different. The mean values were similar to those measured in 1990 to 1992. The results for both water and sediment selenium concentrations are shown for samples taken in 1992 and 1999 in Table 17.2. The mean water selenium concentration did not differ between the two sampling years. The mean selenium concentrations of the sediment top layers sampled in 1999 were only slightly lower than in 1992. In five of the lakes, the selenium concentration in sediments was higher in the top layers than the bottom layers, approximately corresponding to the time after and before fertilization started, but the selenium concentration had already started to increase during the first half of the 20th century (29).

Xenobiotics accumulate in aquatic organisms and especially in predatory fish. We studied the relationships between selenium in

Table 17.2. Lakewater and sediment selenium in the 20th century.

Lake	Trophic level	Water 1999 (ng/l)	Water 1992 (ng/l)	Sediment, bottom 1999 (mg/kg DW)	Sediment, top 1999 (mg/kg DW)	Sediment, top 1992 (mg/kg DW)
Pyhäjärvi	+	115	81	0.18	0.23	0.23
Villikkalanjärvi	+	162	113	0.23	0.16	0.27
Kyöliönjärvi	+	116	59	0.31	0.45	0.35
Onkivesi	+	91	58	0.26	0.37	0.26
Pääjärvi	±	99	143	0.71	0.49	1.05
Iso-Hietajärvi	–	40	34	1.16	2.06	2.03
Pesosjärvi	–	52	89	2.95	2.82	3.64
Mean		96	82	0.82	0.94	1.12

DW, dry weight; +, eutrophic; ±, mesotrophic; –, oligotrophic.
Bottom sediment 1999 is mean of sediment layers below 20 cm representing the 19th century.

perch, water and sediments according to the trophic state of 26 lakes (29). The selenium concentrations of perch and surface and pre-industrial sediments were strongly interrelated and associated with trophic state of the lakes (Fig. 17.10). The total water selenium concentration was not associated with any of the other factors.

In conclusion, obvious effects on the water ecosystem from selenium supplementation of fertilizers have not been observed to date. However, transport and distribution of selenium in the aqueous environment is complex and data should be interpreted with caution.

Guidance, lessons and other micronutrients

An advantage in adding selenium to fertilizers is that, in Finland, its manufacturing takes place in a well-controlled industrial environment and risks for overdosing are minimal. This has been easier in Finland than it probably would be in most other countries because in Finland fertilizer markets have been controlled mainly by one single company committed to selenium fortification. The marketing and distribution system in Finland is also efficient and recommendations for application of fertilizers are generally followed at the farming level. The local climate and soil conditions are important factors that should be taken into account if a similar fortification pattern were to be considered in another country. In areas where soil conditions vary strongly, achieving uniform target products would be more challenging. Even in Finland under relatively uniform soil conditions, quite large variations in cereal selenium concentrations have been documented.

One difficulty encountered is the effect of the unpredictable mixed use of feed fertilizers (6 mg Se/kg) for cereals and cereal fertilizers (16 mg Se/kg) for feeds during 1985–1990. Such a practice resulted in a large variation of the selenium concentration of the end products. An adjustment was made towards the same amount (6 mg Se/kg) in both fertilizer types. The efficient monitoring programme with a short temporal delay enabled a rapid nationwide response. Such a response requires well-developed farming systems and overall infrastructure in agriculture and in the entire food distribution chain. It is not likely to work as well in countries having less developed or more diverse farming systems. For countries that may wish to fortify other minerals or micronutrients via fertilization for the whole population, account must be taken of the chemical nature, industrial safety and possible environmental effects, and the overall impact should be assessed locally by field studies.

Most of the other essential micronutrients are not as toxic as selenium and therefore risks with them are lower. However, to be cost-efficient, the uptake rate of such a nutrient in the food chain should be high and its behaviour in plants and animals should be similar if a comprehensive fortification regime is sought.

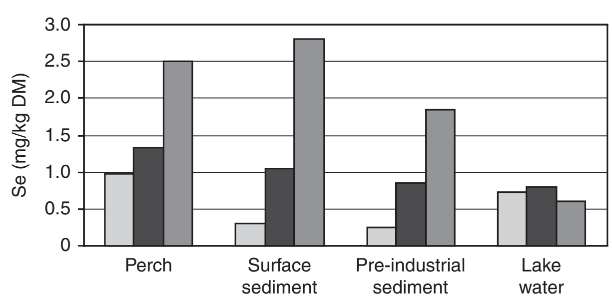

Fig. 17.10. Selenium concentration of perch and lake water and sediments according to trophic state of lake (■, eutrophic; ■, mesotrophic; ■, oligotrophic). DM, dry matter. Note: the unit for water Se concentration is ng/l and is not shown.

The authors conclude that a similar fortification pattern with selenium or some other nutrient may be feasible in other areas, providing that the precautions discussed here are considered and thorough analyses of any prevailing risks are conducted. Nevertheless, under current competition in world markets, any extra cost in production may need a public intervention to encourage fortification, because fertilizer producers should have an incentive for such an action.

Summary and Conclusions

For geochemical reasons, Finland has been a low-selenium area. Based on studies of the selenium concentration of foods, epidemiological associations and field trials of selenium supplementation, it was decided in 1984 to increase the selenium concentration of foods and the selenium intake of the population by supplementing multi-mineral fertilizers with selenium in the form of sodium selenate. Within two years, a threefold increase of selenium intake was observed to levels of 100–120 μg/day in 1989–1991. The supplementation affected the selenium concentration of all major food groups with the exception of fish. Plasma and whole-blood selenium concentrations of people increased concomitantly, by 70% and 125%, respectively. In 1990, the amount of selenium added to fertilizers for grain production was reduced by about 60%. This reduced the selenium intake by 30% and mean plasma and whole-blood selenium levels by 20% and 40%, respectively, from the highest levels observed in 1989 and 1991. Plants take up part of the supplemented selenate and convert it into organic selenium compounds, mainly selenomethionine. This affects human nutrition by increasing the selenium concentration of foods of both animal and vegetable origin. It also reduces the need to supplement animal feeds with inorganic selenium.

In Finland, where the geochemical conditions are relatively uniform, the supplementation of fertilizers with selenium has proved to be an effective, safe and controlled way of bringing the selenium intake of the whole population to the recommended level (80). Since most of the supplemented selenium is derived from foods of animal origin, supplementation of animal feeds with organic selenium would be an alternative way of increasing the selenium concentration in foods and the selenium intake of people (81).

Whichever way selenium fortification is chosen, a monitoring programme must be implemented to ensure the health of animals and humans and take steps to protect the environment, especially as this is a nationwide intervention.

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18 Leaf Concentrate and Other Benefits of Leaf Fractionation*

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Abstract

Leaf concentrate is an extremely nutritious human food, containing approximately 50% (dry weight) high-quality protein, together with numerous micronutrients, principally β-carotene, vitamins B_6, B_9, E and K, plus iron, calcium and magnesium. Many studies have shown that those consuming it recover quickly from nutritional anaemia and have a significantly improved general state of health. Today, over 40,000 people receive a daily serving of 10g of dried lucerne leaf concentrate.

The fractionation of leaves was first reported over 200 years ago and has been the subject of extensive research and application since the 1940s. The process breaks down the original leaves into three products: residual fibre, 'whey' and leaf concentrate. The whey and the fibre are effective fertilizers, substrates for fermentation and/or animal feed. Through the use of all three products, leaf fractionation can be more productive, in terms of edible protein per hectare of land, than any other known agricultural method.

This chapter presents the history and nutritional qualities of leaf concentrate, provides technical details of leaf fractionation at domestic and intermediate (community/semi-industrial) scales of production, and reviews studies that provide evidence for the effectiveness of leaf concentrate in improving human nutritional status. It concludes by reviewing the factors that have hitherto hindered the widespread adoption of leaf concentrate and leaf fractionation. The authors suggest how these may be overcome, and discuss the potentially wider role of leaf concentrate in alleviating human malnutrition, including its use in a locally produced ready-to-use therapeutic food.

Key words: leaf concentrate, leaf fractionation, food security, nutrition, micronutrient deficiency, β-carotene, vitamin A, iron, anaemia, child and maternal health, HIV/AIDS

Introduction

Here is just one example of a subject that I believe deserves to be better known and investigated, and whose benefits for undernourished children – and adults – are potentially immense. This is leaf concentrate. (John Waterlow, FRS,

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It is widely accepted that food security and maintaining the social fabric of communities help alleviate and prevent malnutrition (2). Also well recognized is the role of good nutrition in preventing infection and in aiding not only the physical but also the psychological and emotional recovery from illness (3).

Increasingly acknowledged, too, is the brake on economic development caused by malnutrition: almost everyone will know, from personal experience, how lack of food adversely affects strength and the ability to concentrate on a task.

However, still underestimated are the long-term effects of a deficient diet on a mother during her pregnancy and while breastfeeding, and also on the child, especially from weaning to the age of 6 years. The consequences for children's physical development and nervous system can be permanent and limit their ability to learn and later obtain skilled employment. This can significantly impede the evolution and economic progress of countries where nutritional deficiencies afflict a sizeable proportion of the population, particularly the young.

The production of leaf concentrate through the process of leaf fractionation offers a considerable contribution to the alleviation of the problems mentioned above.

All life depends, directly or indirectly, on the products of photosynthesis. Leaf fractionation produces not only a highly nutritious human food – leaf concentrate – that can be made in the home or mass-produced, but also offers a highly efficient way of using agricultural land.

When perennial forage crops are repeatedly harvested on the point of flowering and fractionated, their yield (per unit area) of protein and associated micronutrients is greater than from any other known method of farming (4–6). Because of this, land used for the production of protein-rich crops can be released for growing staple crops, thereby increasing the overall production (per unit area) of a balanced diet.

Such economy of land use, while desirable in any circumstances, is becoming more urgent and important in the current context of increasing pressure on arable land and water resources from a growing global human population, combined with soil impoverishment and erosion and the erratic rain patterns and potentially rising sea levels associated with global warming. Leaf fractionation is a powerful tool to help manage this changing global situation.

Brief History and Current Status of Leaf Concentrate in Human Nutrition

The following summary is a brief overview of past and present work involving leaf concentrate in human nutrition. For comprehensive details of the biochemistry of leaf concentrate and the technicalities of its preparation, storage and use in human and animal nutrition, readers are directed to what are considered to be the standard texts on the subject (4,7). Details of projects are available through the organizations concerned or in cited references.

The nutritional value of leaf concentrate has been recognized for over 200 years. Its existence was first reported by Rouelle in 1773 (8), who described the curd that he obtained by heating leaf juice as an 'animal–vegetable' substance. Shortly afterwards, Beddoes suggested that it should be made into human food (9). Over the next 150 years there was occasional research, but it was not until the early 20th century that serious work began into the nature of the curd, the methods of separating it from the fibre and the nutritional value of both (10–12).

For over 50 years, from the early 1940s, the leading researcher in the UK was N.W. Pirie, FRS, based at Rothamsted Experimental Station. His team investigated many aspects of leaf concentrate, including biochemistry, toxicology and production. Much of this research, from the late 1960s to the early 1990s, was cross-fertilized by leaf concentrate projects run by 'Find Your Feet', a small British non-governmental organization (NGO), in partnership with local community organizations in Africa, Bangladesh, India and Sri Lanka. From the late 1980s, 'Leaf for Life', based in the USA, began working with leaf concentrate in Latin America, principally in Bolivia, Mexico and Nicaragua.

Throughout the 1950s, 1960s and 1970s, Kohler and Bickoff, at the US Department of Agriculture in Albany, California, led work on leaf fractionation aimed primarily at reducing the energy costs of high-temperature crop drying. They developed the ProXan registered process, which was adopted by Batley-Janss Enterprises, whose leaf concentrate was shipped in bulk to Japan for incorporation in poultry feed. This operation shut down in 1973 when increases in oil prices rendered shipping costs prohibitive.

In parallel, at the University of Wisconsin, Bruhn, Koegel, Straub and Stahmann investigated the use of leaf concentrate as food in cooperation with F.H. Shah in Pakistan. Members of this group formed the NGO 'Leaf Nutrient, Inc.' to provide equipment and training for village-scale production of leaf concentrate in villages in the neighbourhood of the city of Saltillo, Mexico.

In 1982, a United Nations report concluded that leaf concentrate was safe and nutritious and that sites for its incorporation into traditional foods should be found (13).

Find Your Feet and Leaf for Life initiated over 30 projects, the majority of which were at the lower end of the intermediate scale of production described below. Some of these projects were set up solely to establish the nutritional benefits of consuming leaf concentrate; others had a wider aim of developing economically viable models of leaf concentrate production and consumption that could be adapted as needed for use in other locations with widespread malnutrition. Two projects in particular indicated the potential for local production of leaf concentrate to be self-sustaining: the relevant aspects of these are described below under 'Previous experience of intermediate-scale production' (pp. 351–352).

Since 1975, France-Luzerne, a group of French agricultural cooperatives, has been producing dried leaf concentrate from lucerne (alfalfa) on an industrial scale (currently 12,000 tonnes per annum) using a development of the Pro-Xan process. The leaf concentrate is mainly sold as poultry feed. In the early 1990s, France-Luzerne adapted its process to make a human food-grade leaf concentrate; since 1994 it has supplied over 480 tonnes of this to local NGOs in over a dozen countries via the French NGO 'Association pour la Promotion des Extraits Foliaires en nutrition' (APEF). This makes it possible for researchers anywhere to obtain uniform samples of dried lucerne leaf concentrate for study, without needing to be involved in setting up and running their own small-scale production plant. In this way, the collection of robust data demonstrating the effects of leaf concentrate in human nutrition has been greatly facilitated. At the time of writing, the cost of food-grade leaf concentrate, ex-works in France, is 1€/kg; thus the cost ex-works of providing a daily 10 g serving of leaf concentrate for one year is less than 4€.

In October 2009, the Commission of the European Communities authorized the sale of dried lucerne leaf concentrate within the European Union (14). Currently over 40,000 people worldwide, mainly children, pregnant and breastfeeding women, the elderly and those affected by HIV/AIDS, receive a daily serving of 5 g (young children) to 10 g (older children and adults) of dried lucerne leaf concentrate.

For over 20 years, Michael Cole has been operating a small fractionation plant at Coombe Farm, Cove, Tiverton, Devon, UK (www.leafcycle.co.uk), developing processing technology and producing leaf concentrate from a wide variety of leaves for organoleptic appraisal and local marketing exercises, selling either direct to the public or through health-food stores. Among the principal findings of Cole's work are the following:

- Confirming Pirie's view that unconventional crops should be investigated (4), Cole's preferred crop is the stinging nettle (*Urtica dioica* L.), a hardy perennial weed, for its vigorous regrowth and yield and the taste of its leaf concentrate.
- The leaf concentrate is well accepted both alone (dried and granulated) and in a novel food, 'Leafu-Tofu', a co-precipitate of leaf and soybean curds (approximately 1:4, dry weight), which is sold vacuum-packed and refrigerated for cold-chain distribution. Leafu-Tofu is green, with the texture of tofu, and analysis indicates that the two curds are complementary as

sources of micronutrients. Funds are being sought for an *in vivo* trial.
- Comparison of the performance of small/intermediate-scale (up to 400 kg/h) pulper and press prototypes with that of one of France-Luzerne's industrial units, using the same raw material (lucerne leaves), indicated that the quality of the prototypes' leaf concentrate was even higher. Funds are being sought to develop these prototypes and increase capacity to 500 kg of leaf crop per hour.

Leaf Fractionation in a Food-based Approach to Combating Micronutrient Deficiencies

Almost all food is derived from the green leaves of plants. There are always losses when that food is translocated to other parts of the plant such as tubers, fruits and seed. The losses are far greater when the food formed in the green leaves is fed to animals. When animals digest the food created by plants, it is upgraded, resulting in new foods that are generally of a higher quality for the human diet, but in far smaller quantities. Thus, simple biology determines that plant-based foods will always be more plentiful than animal-based foods.

Green leaves, particularly those of legumes, are rich sources of many minerals and vitamins, and are an integral part of traditional diets in many parts of the world, including those where malnutrition and undernutrition are prevalent. Leaf fractionation is a means of improving year-round human access to most of the nutrients present in green leaves. At the same time, it removes most of the anti-nutritional components. In this way, it is analogous to separating grains from chaff or peeling a potato (4).

However, in leaf fractionation, all the products are utilized, whereas cereal chaff or potato peel is typically discarded. The process of fractionation creates three products from the original leaves and consists of mechanically separating the leaf juice from the leaf fibre, heating the juice to over 90°C and then separating the resulting green curd – the leaf concentrate – from the brown whey on which it floats. The precise proportions of the three products will depend on the production method and on the leaf type, condition and volume but, as a rough guide, they are by weight:

- Leaf concentrate (moist) – 5% (~50–60% moisture content).
- Whey – 50% (~93–98% moisture content).
- Fibre – 45% (~50–60% moisture content).

Leaf concentrate is an extremely nutritious human food. It is approximately 50% (dry weight) high-quality protein, containing all essential amino acids, together with numerous micronutrients, principally β-carotene and iron. Various anti-nutritional components are largely removed by the fractionation process.

The fibre, either on its own or mixed with the whey, is a very effective animal feed: on a dry-weight basis, the fibre has a nutritional value roughly equal to, or sometimes better than, the original leaf crop (15,16). Both the whey and the fibre are effective fertilizers, while the whey can also be used as a substrate for fermentation.

Studies over many years have shown that a daily serving of 10 g of dried leaf concentrate has proved effective in alleviating deficiencies in vitamin A and iron (see 'Review of Evidence' below, pp. 357–361), while more recently, in Burkina Faso, communities have found that the incidence of noma (*Cancrum oris*, an oral gangrene) has been eliminated when leaf concentrate is consumed regularly (17,18). Observations of medical professionals are also consistent in noting, in those consuming leaf concentrate, the following effects (19–23):

- A reduction in the incidence of, and improvement in recovery from, diarrhoea and infections of the skin and upper respiratory tract, together with, in many cases, elimination of the need for associated medication.
- Improved post-operative recovery and healing of wounds.
- Rapid improvement in the general condition of various vulnerable groups, including
  - pregnant or nursing mothers (increase in breastmilk and rapid postnatal recovery);

- infants from the start of weaning;
- severely malnourished children, with anaemia and/or kwashiorkor and marasmus;
- sufferers of HIV/AIDS, malaria and tuberculosis, where the leaf concentrate is used as a nutritional adjunct to specific treatment; and
- the elderly.

Fresh, moist leaf concentrate has the consistency of a crumbly cheese and is bright to dark green in colour; it can be used fresh or may be preserved, usually by granulating and drying, after which it is ground to a flour for use.

Several decades of experience in many countries have demonstrated that leaf concentrate, fresh or dried, is highly acceptable and can be easily incorporated into local diets, in main meals, snack foods and drinks. Projects have varied significantly in their level of sophistication, from preparation at home, through distribution in social programmes to the marketing of retail products. The emphasis has always been on the importance of good nutrition for childhood and maternal health. Some examples now follow, together with aspects that were found to be important to their success.

As part of its wider programmes of building food security, nutritional education and child and maternal health, the Nicaraguan NGO 'Soynica' has been using leaf concentrate as a source of home fortification since 1989, initially with leaf concentrate made from local leaves and, since 1994, with dried lucerne leaf concentrate supplied by APEF. As well as providing powdered leaf concentrate for incorporation into families' normal diets and organizing 'community kitchens' to help mothers prepare meals with leaf concentrate, Soynica has developed a range of commercial products, including cereal mixes and teas enhanced with soy and leaf concentrate. Since the first Soynica/APEF study on 174 children and 15 pregnant women in 1995, Soynica's programme has grown to distribute leaf concentrate to over 22,000 children and 10,000 adults in urban and rural areas.

Since 2002, the French NGO 'Enfants du Monde' (EdM) has been distributing leaf concentrate in Burkina Faso in a programme of home fortification. Initially, mothers were supplied with sachets on a weekly basis, each sachet containing 10 g of dried lucerne leaf concentrate, to be mixed into their children's normal diet at home, typically millet or sorghum balls. The programme has grown from a few tens of children in 2002 to over 7000 in 2009, including 5000 children in 52 schools. The leaf concentrate is delivered to the schools in bulk and given to children directly in its powdered form. The children receive 5 g/day for the first two weeks, after which they are given the full 10 g/day. As noted above, the programme has resulted in the elimination of noma (*C. oris*) when leaf concentrate is regularly consumed (17,18). Its success has been due to extensive awareness and education campaigns, the local populations' recognition of the health benefits of consuming leaf concentrate and the ease with which leaf concentrate can be eaten 'as is' or incorporated into traditional foods. EdM also distributes leaf concentrate to over 7000 children in Madagascar and to nearly 1000 children and pregnant and lactating women in Senegal.

In hot climates, cold, sweetened drinks enriched with leaf concentrate are well received: *atole* (a thin, drinkable porridge common in much of Latin America) and lemonade have proved particularly popular. Drinks are normally easy to prepare, as they only require the leaf concentrate to be measured out and stirred in. Experience has shown that drinks tend not to be regarded by families as 'meals', which is often beneficial for the children receiving them: even a small amount of solid food, such as a biscuit given at school or in a day care centre, may mean that a child receives less food than usual at home.

In Mexico, the NGO 'Asociación Franco, Mexicana, Suiza y Belga de Beneficiencia' has worked with local food manufacturers to develop a range of products – candy bars, candy powder, *atole* mix and baby food – under the trademark 'Fortiplus', all containing dried lucerne leaf concentrate. The products are distributed by a variety of organizations to the children, aged 6 months to 6 years, in their care. The programme has been running for 8 years and, in 2009, comprised 79 institutions with 130 establishments in five states; over 6 million portions have been served. In 2009, the number of beneficiaries increased from 15,000 to 25,000.

In several countries in Latin America, small cooperatives of local women, usually with support from a government agency, church or civic organization, have made their own leaf concentrate, incorporating it into a range of retail products. The normal requirements of attractive presentation, packaging, good shelf-life and value for money apply to foods and drinks containing leaf concentrate as to most other products. In addition, the green colour imparted by the leaf concentrate to some products may be unfamiliar.

The most successful products have been pasta, lemonade syrup and *churritos* (a spicy, fried, maize-based snack). Snack foods are often better accepted than foods intended for primary meals, as people are more adventurous about trying them than integrating a new staple into the traditional diet at home. Snack foods also appeal more to the young, are identified with fun, and are usually sold in small units, all of which encourage people to try them. In addition, leaf concentrate-enriched pasta has been well received, particularly by those familiar with green pasta commonly found in developed countries.

One of the advantages of leaf fractionation is that it can be undertaken on a range of scales (domestic and intermediate, as described further below); some important differences between the scales are now highlighted, as they are fundamental to the understanding of the different ways in which leaf fractionation can play its part in a food-based approach to combating micronutrient deficiencies.

At the *domestic* or small group level, leaves can be fractionated using equipment commonly found in the kitchen and can be integrated with other activities. Domestic leaf concentrate is typically consumed fresh, which simplifies production and eases incorporation into local diets. The quantities of leaf used are small – 2 kg of leaves per day will provide enough leaf concentrate for a family of four – and hence they can often be obtained from a home garden or even collected from the wild. The fibre and the whey will normally be used within the family or group setting to fertilize a home garden or provide fodder for domestic animals. In this way, domestic leaf fractionation may be undertaken almost entirely outside the cash economy, a feature that reinforces community resilience in times of hardship.

In certain circumstances, increasing the scale of leaf fractionation may be the preferred option. In this chapter we refer to this as *intermediate-scale production*, or ISP. ISP aims to realize the full economic value of all the products of leaf fractionation in order to provide sustainable production. ISP leaf concentrate is dried, which facilitates storage and transport from production sites to areas of need, which may include neighbouring communities. ISP's benefits of improved efficiency will outweigh the demands of increased complexity.

Where local conditions, be they climatic, agronomic, social or economic, do not permit the production of leaf concentrate, for example in emergency or disaster situations or in arid areas, imported leaf concentrate from the existing industrial units in France can provide an essential source of various micronutrients to a human population in need. It can also provide a source pending the establishment of a local leaf fractionation capability.

Nutritional Qualities of Leaf Concentrate

This section summarizes the most important nutritional constituents of leaf concentrate and describes some aspects that make it particularly effective in combating micronutrient deficiency malnutrition, including that of those affected by HIV/AIDS. Evidence for the effectiveness of leaf concentrate in combating micronutrient deficiencies is extensive (see 'Review of the Evidence' for more details, pp. 357–361).

The three deficiencies that are considered to be of greatest global public health significance are those of vitamin A, iron and iodine (24). As shown in Tables 18.1 to 18.4, leaf concentrate is rich in the first two of these – β-carotene (provitamin A) and iron – while also containing a high-quality protein and many other micronutrients. The iodination of

Table 18.1. Dried lucerne leaf concentrate: general composition and comparison with whole milk powder (Adapted from Bertin (25).)

	Mean composition (%)	
	Leaf concentrate	Whole milk powder
Water	8	3
Protein	50.8	26
Lipids	10.2	26
PUFA	4.7	0.9
ω-3 PUFA	3.5	0.2
Minerals	10.6	8
Fibre	2.5	–

PUFA, polyunsaturated fatty acids.

salt is a widely used, cheap and effective solution to the third.

The consumption of whole foods, such as fruit and vegetables, appears to have greater beneficial effects than taking dietary supplements containing isolated vitamins or minerals (27). Studies with leaf concentrate, a food that similarly combines a wide range of nutrients and micronutrients, support these observations, particularly with regard to the absorption of iron to alleviate iron-deficiency anaemia. For example, a recently published trial (28) found that 'daily servings of leaf concentrate, containing 5 mg iron and 13 μg folic acid, are as effective as daily supplements containing 60 mg iron and 500 μg folic acid for treating anaemia in adolescent girls. Similar improvements in the blood parameters of the participants were seen in both arms of the trial, suggesting that the lower iron content of leaf concentrate may be offset by better bioavailability of iron in leaf concentrate and/or synergistic effects of other components of leaf concentrate'.

Infection with HIV increases a person's nutritional needs to fight infection, rebuild muscle tissue and gain or at least maintain weight. These needs increase as the HIV/AIDS symptoms develop. However, for various reasons, such as reduction in appetite, digestive system problems and lack of income, the food intake and absorption of nutrients of those affected with HIV declines. All these factors increase preference for a concentrated food containing proteins (for rebuilding muscle tissue), vitamins and minerals (to support the immune system) and carbohydrates and fats (for energy). Several small trials with lucerne leaf concentrate have shown favourable early results (e.g. in Burundi (29) and Cameroon (APEF, 2007, internal document)) and support field observations elsewhere (18,19).

Table 18.2. Dried lucerne leaf concentrate: essential amino acid composition and comparison with other foods. (Adapted from Bertin (25).)

Essential amino acid (g/100 g food)	Leaf concentrate	Eggs	Whole milk	Beef (steak)	Chicken	Cooked rice
Valine	3.1	0.8	0.2	1.6	1.3	0.2
Leucine	4.7	1.1	0.3	2.6	2.0	0.2
Isoleucine	2.6	0.7	0.2	1.5	1.4	0.1
Methionine	1.0	0.4	0.1	0.8	0.7	0.1
Cysteine	0.5	0.6	0.0	0.8	0.7	0.1
Tryptophan	1.2	0.2	0.1	0.2	0.3	0.0
Threonine	2.4	0.6	0.1	1.3	1.1	0.1
Lysine	3.1	0.9	0.1	2.7	2.3	0.1
Histidine	1.2	0.3	0.1	1.0	0.8	0.1
Phenylalanine	3.0	0.7	0.1	1.3	1.1	0.1
Tyrosine	2.2	0.5	0.2	1.0	0.9	0.1
Methionine + cysteine	1.5	0.7	0.1	1.3	1.1	0.1
Phenylalanine + tyrosine	5.2	1.2	0.3	2.3	2.0	0.2
Total essential amino acid content	25.0	6.8	1.5	14.8	12.6	1.2
% Moisture	8.0	74.0	88.0	56.0	65.0	23.0

Table 18.3. Dried lucerne leaf concentrate: principal vitamin content and contribution to children's Recommended Nutrient Intake (RNI). (Adapted from Bertin (25).)

Vitamin	Mean content per 10 g	% of RNI for child aged 4–6 years (26)
A (β-carotene)[a,b]	767 μg RE	170
B_1 (thiamin)[b]	0.022 mg	4
B_2 (riboflavin)[b]	0.044 mg	7
B_3 (niacin)[b]	0.042 mg	1
B_5 (pantothenate)	~0 mg	0
B_6	0.58 mg	97
B_8	1.5 μg	–
B_9 (folate)[b]	13.4 μg	7
B_{12}[b]	0.21 μg	18
C[b,c]	6 mg	20
D	~0 μg	0
E[b]	9.9 mg	198
K	0.08 mg	400

[a]Because vitamin A is supplied in the form of β-carotene, there is no risk of an excess of vitamin A; 1000 μg of β-carotene = 167 μg retinol equivalents (RE).
[b]Identified as important vitamins and minerals for people living with HIV/AIDS (3).
[c]Vitamin C is added by France-Luzerne during the production of leaf concentrate at a concentration of 60 mg/100 g leaf concentrate.

Table 18.4. Dried lucerne leaf concentrate: principal mineral and trace element content and contribution to children's Recommended Nutrient Intake (RNI). (Adapted from Bertin (25).)

Mineral/trace element	Mean content per 10 g (25)	% of RNI for child aged 4–6 years (26)
Calcium[a]	338 mg	56
Magnesium[a]	14.8 mg	20
Phosphorus	79.1 mg	–
Potassium	80.1 mg	–
Sodium	1 mg	–
Copper	0.076 mg	
Selenium[a]	0.5 μg	2
Iodine[a]	3 μg	3
Iron[a]	5.4 mg	135[b]
Zinc[a]	0.2 mg	6[c]

[a]Identified as important vitamins and minerals for people living with HIV/AIDS (3).
[b]At 15% bioavailability.
[c]High bioavailability.

While retaining the greater part of many of the nutritional components of the original leaf, the process of making leaf concentrate also largely removes many anti-nutritional elements. Their residues in leaf concentrates, such as phytates, saponins, L-canavanine and phyto-oestrogens, including coumestrol, are present in concentrations that are insignificant owing to the small quantities of leaf concentrate consumed (25).

Tables 18.1 to 18.4 summarize the principal nutritional components of leaf concentrate, based on routine analyses of lucerne leaf concentrate produced industrially in France. In Tables 18.3 and 18.4, values for selected nutrients are compared with recommended daily intakes for children (26) as indicated and those vitamins and minerals identified as important for people living with HIV/AIDS are highlighted (3).

Domestic-scale Leaf Concentrate Production

This section describes the production and use of leaf concentrate within a family, a small group of families or a small institution such as a school. Although at the upper end (in quantity of leaf crop processed per day) there may be some overlap in machinery with the intermediate-scale production described in the next section (pp. 349–357), it should be noted that small group production in this context is quite separate: in general, all of the products – the leaf concentrate, fibre and whey – would be utilized by the group of families, or organization, producing them; if any income could be generated through the sale of any of the products, this would be a bonus, rather than a primary objective.

Long-term solutions to malnutrition require local control of a diverse food supply. While it may be reasonable to import some occasional luxury items, dependence on importing basic daily foods makes a community inherently vulnerable.

The production of leaf concentrate through domestic-scale leaf fractionation offers a simple and inexpensive means of upgrading the nutrient availability from green leaves for individual families or small groups of families, thereby improving their ability to control their own nutrition. It improves self-reliance for those on a low income and, in situations of unemployment and underemployment, enables a family to make economic use of available labour outside the cash economy as it can be easily integrated with other activities. In addition, the cultivation of leaf crops for fractionation, particularly leguminous crops, can enhance the productivity of available land, while reducing the need for, and therefore the cost of, chemical fertilizers, herbicides and pesticides.

Production can be scaled according to need, so that there is no need to store excess leaf concentrate that is not to be consumed the same day, although leaf concentrate can be readily incorporated into a wide variety of dishes for later use. In addition, the quantities of fibre and whey are small and can generally be used (for feeding and watering domestic animals) by the family producing the leaf concentrate.

Crop selection, management and harvesting

Two kilograms of leaf will produce about 100 g of fresh, moist leaf concentrate, which is sufficient to provide significant insurance against most micronutrient shortfalls for a family of four. This quantity of leaf can be obtained in various ways, for example from a home-garden, by children weeding a cornfield (e.g. pigweed (*Amaranthus retroflexus*) or lambsquarters/Fat Hen (*Chenopodium album*)), or it can be acquired from a market as fresh forage crop (e.g. lucerne).

To have fresh leaf concentrate daily over the course of an eight-month growing season, a family of four would therefore need to obtain a total of about 500 kg of fresh leaves. Although the yields of leaf crops vary greatly with climate, soil, variety, planting density and cultivation techniques, there are several crops that can produce over 50 tonnes of fresh leaf per hectare, and some that can produce more than double that (e.g. amaranth or lucerne). This means the entire leaf crop needed for the year could be raised on less than 100 m^2 of land. Some of the best crops for leaf concentrate production are listed in Box 18.1.

The first five plants listed in Box 18.1 are legumes capable of both high leaf yields and

Box 18.1. Preferred crops for leaf fractionation.

- *Medicago sativa* (lucerne or alfalfa)
- *Vigna unguiculata* (cowpea)
- *Trifolium alexandrium* (berseem clover)
- *Lablab purpureus* (lablab or hyacinth bean)
- *Clitoria ternatea* (butterfly or Kordofan pea)
- *Brassica oleracea* (collards or kale)
- *Brassica juncea* (mustard)
- *Beta vulgaris* var. *cicla* (Swiss chard)
- *Atriplex hortensis* (orach, mountain spinach)
- *Triticum×aestivum* (wheat)
- *Hordeum vulgare L.* (barley)
- *Amaranthus tricolor* (amaranth)

good fixation of atmospheric nitrogen; the latter helps to reduce the need for artificial fertilizer.

Leguminous leaf crops also lend themselves to intercropping. For example, cowpeas or lablab beans can be grown in between rows of maize, sorghum, millet, cassava, yams or bananas, helping to reduce the growth of weeds.

Intercropping is, moreover, mutually beneficial: two hectares of maize and cowpeas intercropped will usually produce about 30% more than one hectare of maize and one hectare of cowpeas. Three hundred square metres of maize, cassava or bananas intercropped with cowpeas could reasonably produce enough cowpea foliage for a family's leaf concentrate, without competing with the other crops. Furthermore, cowpea leaves can be harvested at least once without significantly affecting the yield of beans.

In addition to intercropping, fast-growing crops for leaf concentrate can be grown before or after a grain crop. Cowpeas, lablabs, bell beans, field peas and butterfly peas are well suited because they fix enough nitrogen to benefit the crop that follows or to replace the nitrogen used by the grain crop. In this way, the entire growing season can be economically utilized. Some non-leguminous leaf crops such as amaranth are enormously productive (up to 170 tonnes of leaf per hectare per annum under intensive cultivation) and ready for a first harvest in less than 30 days. Lucerne and perennial clovers do well as an undercrop in fruit or nut orchards. The multiple uses for many of the best leaf concentrate crops provide the small grower or part-time farmer with much flexibility.

Preparation of fresh leaf concentrate

The preparation of leaf concentrate in the home is straightforward. Domestic production can be integrated with other activities: for example, a mother grinding leaves for her family can simultaneously watch over her children and can cook beans with the same fire that heats the leaf juice.

The steps are described in Box 18.2, based on information taken from 'The Domestic Method of Making Leaf Concentrate', a guide produced by the Nicaraguan NGO Soynica (30). As with most food processing, quality control throughout is critical to acceptance – burning of the curd, spoilage of leaves or curd, and inadequate pressing of the whey can all lead to leaf concentrate with unacceptable flavour.

Consumption and storage of leaf concentrate

Although dried leaf concentrate can be stored for 6 months or more if it is kept in an airtight container and out of the light, a significant advantage of domestic-scale production is that all of the product can be used fresh. This greatly simplifies packaging and storage, as well as eliminating the steps involved in preserving the leaf concentrate.

Food and drink preferences vary enormously between and within cultures, countries and communities. In many parts of the world, the consumption of leaves that are suitable for fractionation is already part of the traditional diet. For example, cowpea leaves are used as a potherb vegetable in many parts of Africa and southern Asia, while the Sri Lankan dish *kola kanda* is made by pounding leaves and coconut in a mortar, squeezing out the juice and adding it to boiled rice.

Fresh leaf concentrate is best used the same day it is made or the next day, unless it can be refrigerated, in which case it may last up to a week. It disperses more readily in liquids than its dried alternative and can be easily added to soups, stews and porridges or be incorporated into a variety of sweets and other dishes. One of the most popular options, which is also a good method of preserving the fresh leaf concentrate, is to add it to a syrup of lemon juice and sugar. This has the advantage for those suffering from anaemia of supplying vitamin C, which significantly improves absorption of the iron from the leaf concentrate. Also easy to make and with a good shelf-life is pasta: at flour to leaf concentrate ratios of 10:1 (dried) or 4:1 (fresh), a 100 g serving of pasta will provide the recommended daily portion of leaf concentrate. Box 18.3 contains a list of

Box 18.2. Domestic-scale leaf fractionation: production steps. (Adapted from Soynica (30).)

1. *Gather the leaves*: use very young leaves, before, or just after, the plant starts flowering. Choose tender leaves, rejecting any that are tough or dry. Immediately after harvest start the following steps.
2. *Wash the leaves* in clean water to remove mud or dust and foreign objects.
3. *Sorting*: strip away any tough stalks by hand or with a knife. Shred the leaf blades to make pulping easier.
4. *Pulping*: this is the most difficult part but very important to ensure a good yield of leaf concentrate; if the leaf cells are not thoroughly ruptured, yields of leaf juice and consequently leaf concentrate will be adversely affected. A manual meat mincer is suitable, as is a pestle and mortar. If electricity is available, a kitchen mixer or an electric grinder makes the process easier. A little extra water may be needed to help leach out the protein, but often the residual water left on the leaves after washing is enough. Added water increases the cooking fuel required to bring the juice to boiling point.
5. *Pressing*: wrap the pulped leaves in a previously moistened, open-weave cloth and use convenient objects – stones or boards – to press the pouch as well as possible, catching the green leaf juice in a suitable vessel. It is important to keep the layer of pulp thin: if the initial layer of pulp is more than 2–3 cm thick, some of the protein molecules will be trapped in the tightly compacted fibre, thus reducing the yield and quality of the leaf concentrate. Pressing the fibre should take no more than 5 min.
6. *Heating*: heat the green juice quickly while stirring to prevent it from sticking; slow heating can damage the nutritive value, but burning the curd may adversely affect its taste. Coagulation occurs from 45 to 75°C but it is essential to go on heating just to boiling point to achieve:

- the virtual elimination of bacteria;
- the minimization of undesirable components, and
- improvement of the texture of the curd, facilitating filtration.

7. *Filtration*: filter the hot juice through a previously wetted, tightly woven cloth, such as denim or twill, to separate the green curd from the whey.
8. *Pressing*: when pressing the curd, pressure should be applied more gradually than when pressing the fibre, and for longer, if necessary overnight. Remove as much whey as possible: what stays in the cloth is moist green leaf concentrate, ready to eat. When it has been adequately squeezed it will peel cleanly from the cloth and will have the consistency of a crumbly cake.

25 recipes tested for their acceptability in several countries. Full details are given elsewhere (6).

Fresh leaf concentrate can also be preserved by pickling or drying, for example with a simple solar dryer with good airflow. It dries faster and more evenly if it is granulated first, for example by rubbing it through a screen. The leaf concentrate must be kept out of direct sunlight and the maximum drying temperature is about 55°C.

Use of fibre and whey

One of the advantages of leaf concentrate production is that there should be no waste: the whole above-ground plant is used. As a general guide, taking into account some water added for cleaning and processing, 2 kg of leaf will produce:

- Leaf concentrate (moist) – 0.1 kg (~50–60% water content).
- Whey – 1 litre (~93–98% water content).
- Fibre – 1 kg (~50–60% water content).

The fibre has two principal uses: as animal feed and as green manure.

- Cattle, horses, sheep, goats, rabbits and guinea pigs have all been successfully raised using the fibre as a primary or secondary feed. Some care must be exercised, however. For example, residual fibre from lucerne is likely to have too much calcium to be a good choice for feeding rabbits more than 6 months old. The manure that is produced by animals eating the fibre can also be used to enrich soil.
- Research in India has shown that yields of wheat were greatly increased when it was sown 30–40 days after a

Box 18.3. Recipes for foods containing leaf concentrate.

Recipe	Main country/area of consumption (if applicable)
Leaf concentrate syrup	
Lemonade concentrate syrup	
Pasta	
Soup nuggets	
Atole	Latin America
Porridge	
Soymilk shake	
Frozen banana/milk snack	
Laddu	India
Tortillas (corn/wheat flatbread)	Latin America
Tamales	Latin America
Uchepos	Mexico
Kola kanda	Sri Lanka
Curried potato soup	
Lemon trail bars	
Barfi	India
Leaf concentrate rice	India
Tikki	India
Tamarind jelly	Nicaragua
Green salsa	Mexico
Churritos	Latin America
Potato/carrot pancakes	Mexico
Swedish vegetarian meatballs	
Leaf burger	
Vegan leaf burger	

green manure crop of *Sesbania sesban* or *Crotalaria juncea* had been fractionated before its fibre was tilled in (31).

Other potential uses for leaf concentrate fibre include making biogas for cooking (the slurry remaining from making biogas also improves soil fertility) and enriching the soil through improving soil structure and the availability of soil minerals.

The whey is also a very useful by-product. It can be re-mixed with the fibre prior to use as animal feed, or used diluted with water as a garden fertilizer, as it contains enough nitrogen and potassium to be effective in this capacity.

From domestic to small group production

Single-family production can readily be extended to a small group of families: for example, five or six families could rotate responsibility for making the leaf concentrate. On the next level, a school, church, orphanage or social club could make leaf concentrate for up to 100 children with a modest investment in equipment. This would require processing about 40 kg of fresh leaf daily, for which a manual meat grinder driven by a small geared-down electric motor would be suitable. Box 18.4 contains a sample of small-scale leaf processing equipment, together with country of use.

It is important to note that processing more than 10–20 kg of leaf crop per day will normally require some form of non-manual power, and also to emphasize the importance of reliable, efficient machinery (32).

Intermediate-scale Leaf Concentrate Production

Introduction

This section addresses the production of leaf concentrate on an 'intermediate' scale,

Box 18.4. Examples of domestic-scale leaf processing equipment.

Description	Capacity (kg leaves/h)	Countries of use	Function	Advantages	Disadvantages
Pedal-powered combined screw pulper and press	15–20	India Sri Lanka	Pulping and pressing leaves	Continuous operation; human-powered; combines pulping and pressing	Requires human power so can be tiring
Mechanized combined pulper and press	Up to 100	Bangladesh Ghana	Pulping and pressing leaves	Continuous operation; powered by electric motor or internal combustion engine; combines pulping and pressing	Can be noisy; requires non-human power
Electric-powered blender: scaled-up version of domestic blender with 20-litre vessel and 0.74 kW electric motor	100	Mexico Nicaragua	Pulping leaves	Effective pulper; easy to manufacture and use	Requires water to be added to vessel; requires electric power; seals on motor can leak; batch operation
Vertical-axis rotational pulper ('impact macerator')	>150	Mexico	Pulping leaves	Effective pulper; easy to manufacture and use; continuous operation	Can be noisy

i.e. larger than the domestic operation discussed in the previous section, but much smaller than the existing industrial scale in France.

While domestic production operates mostly outside the cash economy, ISP functions mostly within it. Raw materials are bought, and production sold, in order to balance its budget and be sustainable.

The philosophy underlying ISP is that its size and nature can adapt to the needs of the communities that it is serving. The correct scaling of leaf concentrate production between domestic and larger systems is a crucial consideration in terms of feasibility and sustainability. An appropriately scaled project is more likely to achieve synergies with existing socio-economic activities. It limits wastage, secures in-kind benefits and/or recycles cash benefits in the local economy. It offers some independence from fluctuations in markets for food supplies, livestock feeds and soil fertilizers, and contributes to community social stability and security.

Where circumstances are favourable, it is possible to achieve higher productivity with larger schemes which require and benefit from greater complexity. In such circumstances, production can probably exceed local needs and any surplus thus becomes available for neighbouring communities.

The optimal ISP size will vary with the context. Daily processing capacity can range from 300 kg of leaves for a village of 600 people to 30 tonnes for a region with a population of 60,000; feasibility tends to be limited upwards by the number of livestock that can reasonably be concentrated in one place (for organizational and ecological considerations) and downwards by the minimum productivity required to balance capital investment and labour.

ISP can develop synergies with existing food systems in the following areas:

- Improving human nutrition.
- Maximizing productivity of available land.
- Improving, conserving and fertilizing the soil.
- Improving livestock feed.
- Providing employment opportunities for local people.
- Contributing to ecological sustainability.

The following subsections describe the key elements of ISP; then a case study of an ISP scheme is presented, illustrating the combination of learning from both smaller- and larger-scale production.

Fundamentals of intermediate-scale production

The fundamentals of ISP are derived from the experience of many, mostly village-scale, projects in Africa, Asia and Latin America, combined with learning from over 35 years' continuous industrial production of leaf concentrate in France.

Previous experience of intermediate-scale production

Village-scale ISP has been the subject of over 20 studies of various durations, mainly run by the NGOs Find Your Feet and Leaf for Life, in partnership with local organizations in Africa, Bangladesh, India, Latin America and Sri Lanka. Together they have provided a large amount of information regarding crop selection and management, machinery, organization and logistics and the development of markets in different cultural environments. Two of these projects are now described briefly.

1. *Kpone Bawaleshie, Ghana*. In the early 1980s, a cooperative operated in Kpone Bawaleshie, near Accra, Ghana, producing leaf concentrate, silage and potable alcohol from a variety of local leaves (33). The leaves were collected by villagers, either from their cultivated plots or the wild, and paid for in cash, thus offering a source of income even for those without the time or ability to grow suitable crops. The leaf concentrate, fresh or preserved moist with salt, was sold within the village and incorporated into the mid-day meals of pre-school children. The silage and alcohol were sold outside the community to provide a net financial income. A preliminary economic assessment indicated that the operation was potentially viable, even though income from the sale of silage had not, at that stage, been calculated: leaf concentrate could be sold at a price that would cover the direct purchase of the leaves, while the sale of the alcohol just exceeded all other costs, to provide a net profit of just over 6%.

2. *Bidkin, India*. The project at Bidkin, near Aurangabad, India, which ran in the late 1970s and early 1980s, carefully examined the economics of leaf concentrate production using equipment handling up to 150 kg of fresh lucerne per hour (34,35). The study concluded that it would be viable at a processing capacity of 500 kg/h. The leaf concentrate was sold in enriched wheat flour and in a milk replacement formula for calves, while the fibre, after mixing with some of the whey, was fed fresh to local cattle, ensiled, or incorporated into a dry cattle fodder mix. The proposal was to extend the operation to provide local farmers with an alternative to growing sugarcane or bananas, the most profitable local cash crops. For the farmers, a significant advantage of growing lucerne was that it provided cash flow: they received income each time it was harvested, on average every 3 weeks, rather than only after a year, as was the case with the other crops, thus reducing their need to borrow money. However, suitable machinery for processing leaves at this rate was not available at the time, and the funds could not be found to develop it.

Over the past 15 years, there have been developments in machinery that would make such a study feasible. A vertical-axis rotational pulper has been developed in the USA and was successfully used for 8 years by a cooperative of women in Zacapu, Mexico (D. Kennedy, 2007, report from Leaf for Life to APEF). The most recent prototype combines a development in the UK of this pulper with a new design of screw press, which has performed well up to a level of approximately 400 kg of fresh leaf crop per hour (see 'Brief History' above, p. 341). While facilitating studies such as that proposed by the Bidkin researchers into higher production rates, more efficient processing is likely to make leaf fractionation sustainable at lower levels as well.

Industrial production of leaf concentrate

France-Luzerne's current units are capable of processing up to 150 tonnes of freshly cut lucerne per hour to produce high-quality dried cattle feed – made from de-watered leaf fibre mixed with concentrated whey – and a dried, granulated leaf concentrate, for use in poultry diets and (since 1994) human nutrition. The processing machinery is custom-designed and the operation is fully integrated with the surrounding agricultural economy, involving thousands of hectares of nearby fields dedicated to the cultivation of lucerne and thousands of beef and dairy cattle in other regions and abroad.

The considerable volumes produced by the very large industrial plants necessitate the dehydration of press-cake and whey at high cost before their transportation to distant livestock-raising areas, which is a concern in terms of both rising energy costs and ecological impact. One distinctive feature of ISP is the absence of the high-temperature drying of the leaf concentrate's by-products. Instead, they are mainly mixed together and fed immediately as the main component of the diet to a local herd of cattle (or other herbivores). Some of the by-products will be conserved in the cheapest possible way for use out of season. Depending on climate, they will be sun-dried or ensiled.

Key elements of sustainable intermediate-scale production

Although the industrial scale of operation is substantially larger than any envisaged within ISP, there are important principles underlying its continued success – and therefore sustainability – that apply to ISP. Experience of both village-level ISP and industrial production has identified the principal requirements and benefits of ISP as described below.

REQUIREMENTS *Crop specialization and intensification.* Different leaves have different processing qualities, so the selection of a single crop allows the pulping and pressing equipment to be designed to work optimally with one type of leaf. In addition, whether the crop is grown within an integrated operation or provided by external suppliers, a single crop type makes harvesting easier to plan and undertake. Lucerne, a crop particularly suited to leaf concentrate production, also has wider agricultural benefits, which are discussed below. In addition, the nutritional qualities of lucerne leaf concentrate have been extensively demonstrated (see 'Nutritional Qualities of Leaf Concentrate' (pp. 343–345) and 'Review of Evidence' (pp. 357–361)). For these reasons, it is recommended as a starting crop, where suitable, for any new ISP; with experience, other crops better adapted to specific soils and climates will offer further opportunities.

Coordination of harvesting and production schedules. Harvesting needs to be planned in order to: (i) maximize the time that the production plant is operational; and (ii) ensure that the leaves are at the optimum state of maturity to maximize both the yields of leaf concentrate and the quality of the fibre.

Integration of livestock. The direct feeding of livestock incorporated into an ISP scheme is essential to accommodate any mismatch between harvesting schedules and production unit operation.

- Some of the fibre will routinely be conserved for the off-season as sun-dried 'hay' or, mixed with some of the whey, as

silage; integrating cattle into the scheme allows this quantity to be adjusted to herd size, crop production and relative length of wet and dry seasons.
- When the volume of crop ready for harvesting exceeds the plant's processing capacity, e.g. during the first cut or after rains, the surplus can still be harvested in peak condition but 'bypass' the extraction plant and be sun-dried or ensiled.

Appropriate processing technology. Typically, larger-scale production is more efficient but also carries higher capital cost. ISP covers a wide range of processing capacities, and different machinery is appropriate at different levels. The case study reported below utilizes technology developed from both village and industrial levels.

Creation/establishment of markets for all products. Experience at both village and industrial levels has shown that realizing the economic value of all the products – the leaf concentrate, fibre and whey – by developing markets for them, preferably in the project area, is a prerequisite for the sustainable establishment of ISP, so a scheme can only be realistically considered in areas acquainted with the raising of livestock. Some examples of successful marketing approaches and products are provided above (see 'Leaf Fractionation in a Food-based Approach' (pp. 342–343) and 'Previous experience of intermediate-scale production' (pp. 351–352)). In Mali, women's groups are also incorporating leaf concentrate into fruit pastes. Local government support and funding are likely to be required to help develop these markets.

BENEFITS *Improvement in human nutrition.* The nutritional qualities of leaf concentrate have been discussed above ('Nutritional Qualities of Leaf Concentrate', pp. 343–345) while the evidence for its effectiveness is presented below ('Review of Evidence', pp. 357–361). The dried leaf concentrate produced in ISP stores well and is neither bulky nor heavy, easing transport to areas in need. It can be consumed either on its own or incorporated into a wide range of snacks, meals and drinks (see 'Consumption and Storage of Leaf Concentrate', pp. 347–348). In this way, ISP provides an additional option at an affordable price for sourcing proteins, phytochemicals, vitamins and minerals where the capacity of a community to produce this variety in its food may be challenged by climatic, economic, social or other disorders (33).

Maximizing productivity of available land. Two factors contribute to maximizing the productivity of available land:

- Because leaf fractionation of a forage crop produces more protein per hectare than any other use of the land, ISP reduces the area required for production of protein sources and thus releases arable land for the cultivation of staple foods (4–6).
- Extensive experience with lucerne in many countries has shown that it is particularly suited to leaf concentrate production in a variety of climates. It is high-yielding, typically producing over 50 tonnes of fresh leaf per hectare in six harvests in an 8-month growing season; under certain conditions, for example those described by Joshi *et al*. (34) near Bidkin, India, annual yields can be as high as 160 tonnes in 15 cuts, if irrigation allows cultivation throughout the year.

However, the opportunity cost of implementing an ISP in a zone experiencing competition with other food crops should also be considered (see Bidkin project under 'Previous experience of intermediate-scale production', pp. 351–352).

Soil improvement, conservation and fertilization. Lucerne brings the following additional agricultural benefits (some are shared by other legumes):

- Year-round soil cover and a strong root system help prevent leaching and loss of topsoil, thus improving soil structure, favouring organic activity and encouraging biodiversity. Through reducing soil erosion, lucerne also helps to prevent downstream irrigation canals and streams from silting up. This protection against erosion extends to intercropping periods when techniques such as direct seeding or seeding under vegetal cover may be employed.

- As a legume, lucerne fixes atmospheric nitrogen in its root nodules, thus reducing its need for artificial fertilizer. This also benefits subsequent non-leguminous crops, as lucerne roots can take up to 18 months to degrade. Moreover, lucerne will preferentially use soil nitrogen when it is in excess, thus helping to regulate the soil nitrate level and protect groundwater from leaching.
- Lucerne is drought-resistant, thanks to its long roots, and hence well suited to surviving the dry season, although it is not suited to arid conditions, requiring approximately 50 mm of water per tonne of leaf.

However, lucerne is not suited to acidic soils: if the soil pH is 6.5 or less, it will need to be adjusted, for example by addition of lime or dolomite.

Improvement in livestock nutrition. Limited availability of cattle fodder is the norm in many countries in the dry season. An inadequate diet significantly reduces, and may terminate, milk production with serious economic consequences for rural families, as this activity represents one of their few cash-raising opportunities. The implementation of ISP contributes to solving that problem as follows:

- On a dry-matter, weight-for-weight basis, the fibre and whey, when mixed, have nutritional characteristics similar to (or sometimes better than) those of the original forage (15,16). The fibre alone, with moisture content lower than that of the original leaf crop, is more amenable to sun-drying for use as hay or may be ensiled with minimal losses, using some of the whey to ensure anaerobic conditions and add water-soluble carbohydrates, thus enhancing the silage.
- Where the weather is too damp for sun-drying during the growing season, ensiling is a highly valuable option, both for fibre and for any surplus unextracted crop, preferably in combination with other crops such as whole maize or residues such as bagasse and straw (6).
- Some of the whey can be used to water livestock.

In some areas, livestock security problems can restrict extensive grazing, thus exacerbating the feeding problem by increasing the concentration of cattle. ISP is consistent with penning, which also facilitates the recovery of manure for use as fertilizer (after composting).

Provision of employment opportunities. Any ISP scheme will require management and labour for production. In addition, marketing and sales will be necessary for the operation to establish itself. These will all depend on the scale of the ISP scheme. The case study in the next section, for example, would provide employment for seven people, just on the production side. In certain circumstances, labour-intensive methods of harvesting may be appropriate, which would offer substantial employment opportunities for most of the year.

Ecological sustainability. The direct agricultural benefits of the nitrogen-fixing properties of lucerne, and legumes in general, are mentioned above. The cultivation of forage crops for leaf fractionation has further advantages (4):

- Regular harvesting, typically at intervals of between 3 and 6 weeks, reduces the time available for pest communities to become established, thereby almost eliminating the need for pesticides.
- As mentioned above (see 'Crop selection, management and harvesting, p. 347), the dense leaf cover of forage crops helps to prevent the growth of weeds, thus reducing the need for herbicides.

Apart from the cost savings already mentioned, the diminution in the use of chemically produced fertilizers, herbicides and pesticides induces wider ecological benefits, such as the protection of groundwater from chemicals and the lessening of atmospheric carbon. The Rodale Institute, which has been carrying out a continuous comparison of organic and conventional agricultural methods for more than 23 years in the USA, has found that legume and manure-based approaches (36):

- Emit one-third fewer greenhouse gases than conventional methods (use of

chemical fertilizer and pesticide applications) by eliminating the energy inputs required to produce pesticides and fertilizers.
- Remove atmospheric carbon in a way that conventional methods do not, sequestering up to 4000 kg CO_2/ha in the soil per annum.

Nitrous oxide, a gas released by the application of nitrogen fertilizers, is another greenhouse gas contributing to global warming that is not produced by the cultivation of lucerne or other legumes.

Intermediate-scale production: case study

This section presents a case study of what a particular ISP scheme might look like in practice. It has been chosen to illustrate the use of equipment developed from both smaller and larger leaf concentrate production units, as the pulper is a development of the latest village-scale design while all other components are miniaturizations of the France-Luzerne industrial technology. The selected scheme benefits from the continuous production of the industrial operations and is based on a unit capable of processing up to 2 tonnes of fresh lucerne per hour, producing approximately 500 kg of dried leaf concentrate daily, for an expected 240 working days per year. This would provide enough leaf concentrate for 47,000 children, at an average of 7 g/day. This level of production is presently considered to be the smallest at which the improved efficiency of the industrially based equipment would outweigh its extra complexity and greater capital cost.

The production steps are described in Box 18.5 and shown schematically in Fig. 18.1. Box 18.6 presents the production potential of such a unit. In tropical or subtropical latitudes, where harvesting might be possible for 8 months per year, there is a realistic maximum of about 3500 hours of production per year, given ideal conditions. This would involve harvesting during daylight for 12 hours in two shifts, with an additional 2.5 hours of processing a 5-tonne stockpile of leaves at the end of the day.

The establishment of a scheme such as this, if no smaller leaf concentrate production or market were in existence beforehand, would initially need some external support, such as a government grant, and a partner organization, such as an agricultural school or research station, with a sufficiently large herd of dairy cows. Subsequently, operations could be extended to farms in the immediate surrounding area in order to reach the 'critical mass' required for sustainability in terms of land area, herd size and consequent economics. The best approach, or approaches, for encouraging engagement will naturally depend on local conditions; one method might be an arrangement between production plant and farmers to exchange fresh fodder for sun-dried or ensiled fibre/whey (stored on site) plus some remuneration.

Box 18.5. Intermediate-scale leaf fractionation: production steps.

1. Fresh leaf crops are harvested and transported to the production plant in a trailer.
2. A conveyor belt carries the chopped leaves to a vertical-axis rotational pulper.
3. The pulped leaves fall directly from the pulper into a screw press.
4. On being expelled from the screw press, the fibre is collected in a container, where it is subsequently mixed with the leaf concentrate whey before being used as ruminant feed.
5. The green leaf juice is collected and its pH is adjusted to 8.5, to slow down the action of phenyloxidase and to improve the structure of the curd.
6. As it is pumped to a continuous horizontal centrifugal decanter, the juice is brought to a temperature of >90°C by steam injection.
7. The curd and whey are separated in the centrifuge, the whey is re-mixed with the leaf fibre before being directly fed to the cattle (alternatively, some of the leaf fibre will be sun-dried or remixed with some of the whey before being ensiled for use during the dry season).
8. The curd is dried on a fluidized-bed dryer, cooled and bagged at about 6% moisture.

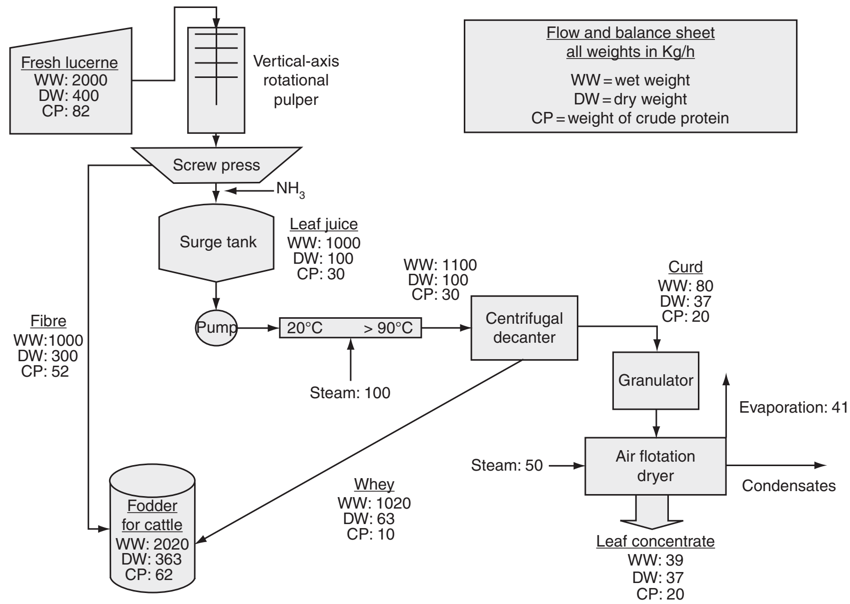

Fig. 18.1. Intermediate-scale leaf fractionation: schematic process diagram.

Box 18.6. Intermediate-scale leaf fractionation: production potential.

Crop:	Lucerne (alfalfa)
Total crop cultivation area:	100 ha yielding 15 t dry matter/ha
Growing/harvesting season length:	8 months/240 days
Production schedule:	14.5 h/day (+ washing down = 2 shifts of 8 h, 7 days/week)
Processing capacity:	2 t/h (leaf)
	29 t/day
Leaf concentrate production:	35 kg/h (dried leaf concentrate)
	500 kg/day
	120 t/year at most (at 240 days' production)
No. of daily portions:	17 million/year at 7 g/day (average per portion) i.e. daily supply for 47,000 children
Fibre/whey animal feed production:	2 t/h
	30 t/day (including added steam)
Energy requirements:	70 kW (mechanical), 150 kg of steam/h
Water requirements:	200 l/h, washing included
No. of dairy cows & heifers:	400
Potential milk production:	1.5–2 million l/year depending on the breed of livestock and its husbandry

Table 18.5 presents an estimate of a number of budget items. The figures are based on the following assumptions.

- Total capital cost: €600,000. This cost is for equipment produced in France. If the equipment were made locally or elsewhere, it is possible that this cost could be reduced.
- Depreciation costs only are taken into account. It is assumed that the cost of initial equipment is donated or

Table 18.5. Intermediate-scale production: example outline of budget items.

Item	€/kg leaf concentrate	%
Depreciation on capital investment (10 years)	0.50	23
Maintenance	0.08	3
Cost of forage minus income from by-products	0.23	11
Transport	0.00	0
Electricity for machinery at €0.10/kWh	0.20	9
Gas for steam generation at €0.10/ kWh	0.40	19
Salaries for one manager and two shifts of three staff each	0.23	11
Miscellaneous costs at 10%	0.16	8
Profit at 20%	0.36	17
Selling price	2.16	100

covered by a grant and no repayment is required.

- Leaf crop raw material is not purchased but produced within the ISP organization. Consequently, all costs attached to existing raising livestock, crop harvesting and transportation, drying/ensiling and storing for the off-season are not considered here; only additional workshop costs are listed.
- A conservative estimate of 9% yield (dry matter) of leaf concentrate. It should be possible to improve this performance with careful management of harvesting at optimal crop maturity.
- Gas is used as the fuel to produce the steam. Other energy sources, such as coal, wood or rice husk, could result in significant savings.
- The residual fibre/whey mix has the same value (per kg dry weight) as the original leaf crop. The cost indicated corresponds to the lost dry matter due to leaf concentrate production.

These are representative costs and it is recognized that they have the potential to vary considerably depending on location. However, they indicate the potential feasibility of such a project.

Review of Evidence

This section reviews, in chronological order, studies and trials that have provided evidence of the effectiveness of consuming leaf concentrate in improving human nutritional status.

Between 1960 and 1990, there were more than a dozen studies aimed at estimating the effects on malnourished children and adults of consumption of leaf concentrate from a variety of species of plant. With a few exceptions, the leaf concentrate used was prepared with small-scale equipment from local crops. The serving was typically one or two tablespoons of fresh moist leaf concentrate incorporated in the normal diet. Such a serving adds 4–8 mg β-carotene and 5–10 mg iron, together with 5–10 g protein, 3–6 mg vitamin E, 25–50 μg folic acid, 175–350 μg zinc and 300–600 mg calcium. Most of the trials compared the effectiveness of leaf concentrate with that of conventional alternatives such as cow or buffalo milk and/or pulses.

In the early 1960s, three papers by Waterlow and co-workers (37–39) described nitrogen-balance studies on malnourished infants undergoing rehabilitation in hospital. These compared freeze-dried canned leaf concentrate (made from several types of leaf at Rothamsted Experimental Station, UK) with liquid milk as protein sources. Nitrogen absorption and retention from leaf concentrate were respectively 90% and 93%, compared with 93% and 91% from milk. On an equal protein intake basis, weight gain on a leaf concentrate/milk mix (in which one-half to one-third of the protein came from the leaf concentrate) was as good as on milk alone.

A possible allergic reaction to leaf concentrate in two children was reported. One such reaction was also found in a short study in India in 1971 (40). It was believed that pheophorbide might have been the cause, and consequently the coagulation temperature for the preparation of food-grade leaf concentrate was raised from 75–80°C (sufficient to coagulate the protein) to a minimum of 90°C to inactivate chlorophyllase. No further cases have been reported of allergy or of any other serious adverse side-effects.

The first long-term (6-month) feeding trial, conducted by the Central Food Technology Research Institute in Mysore, India, used leaf concentrate produced locally from lucerne and compared four groups of 20 children aged 6–12 years (41). The control group followed their normal diet based on ragi (*Eleusine coracana*), while two groups received an additional 10 g protein from either sesame flour or leaf concentrate, and the fourth group received 0.5 g lysine. The leaf concentrate group gained height and weight more than any other group (height gain in leaf concentrate group: 4.84 cm versus 2.20 cm in control group, 3.51 cm in sesame group and 4.25 cm in lysine group; weight gain in leaf concentrate group: 1.28 kg versus 0.47 kg in control group, 0.86 kg in sesame group and 1.05 kg in lysine group; t test $P < 0.001$ for comparisons of leaf concentrate height and weight gain with all other groups). Although the traditional basal ragi diet was rich in iron, there was a greater increase in mean haemoglobin (Hb) in the leaf concentrate group: 0.87 g/dl versus 0.29 g/dl in the control group (t test $P < 0.001$), 0.64 g/dl in the lysine group (t test $P = 0.08$) and 0.71 g/dl in the sesame group (t test $P = 0.3$).

In 1972, the results of a study in Nigeria were published (42) in which 26 children with kwashiorkor attending a hospital outpatients' clinic were given leaf concentrate to be added to their home diet. Their mothers were provided with cans of freeze-dried leaf concentrate and instructed to stir a tablespoonful into each of their three daily meals. Within 10 days oedema had subsided in all children, as had diarrhoea, and there was spontaneous remission of anaemia, attributed by the authors in part to the folic acid in the leaf concentrate. Appetite and alertness also quickly improved. There was no comparison group in this study.

There followed a series of trials with children aged 2–5 years in Coimbatore, India (43–45) and children aged 7–14 years in Lahore, Pakistan (46,47). These trials lasted from 6 months to 2 years and compared the incorporation in the diet of leaf concentrate with various conventional alternatives including cereal/pulse mixes, skimmed milk powder and whole fresh buffalo milk. All resulted in very satisfactory growth patterns together with improvements in Hb and vitamin A status and diminished morbidity. For example, in the second Coimbatore trial (44), after 18 months the mean increases in Hb and serum retinol in the leaf concentrate group were 3.4 g/dl and 1.34 μmol/l respectively, compared with 2.5 g/dl and 0.80 μmol/l in the control group (who received an isoenergetic tapioca supplement).

A subsequent trial of leaf concentrate for pre-school children in Sri Lanka, which was intended to replicate the favourable findings of the trials in Coimbatore and Lahore, was largely unsuccessful (48). This was principally due to problems with the local production of leaf concentrate (incorrect manufacture of machines) (32) and to the target population being generally well-nourished (no iron, folate or protein deficiencies) (49). However, it was reported that leaf concentrate was highly acceptable to children, and almost all of their mothers perceived benefits from its consumption (32).

Devadas and Murthy, in a 4-month trial (50), attempted to assess the biological utilization of β-carotene from leaf concentrate. They compared three sources: amaranth leaves, leaf concentrate prepared from amaranth leaves and a standard β-carotene solution. The subjects were 15 children aged 3–5 years, attending a nursery school where, in addition to their home diet, they received a daily snack formulated after a weighed food survey. During the first month they received this snack as control. In each of the next three months the daily snack had added to it, in turn, 40 g amaranth, 8 g dried leaf concentrate and then 1 ml standard solution, each supplying 1200 μg β-carotene. During the last three days of each month, faeces were collected to estimate excretion of β-carotene and hence utilization from each source. They found that amaranth leaves, amaranth leaf concentrate and standard solution had percentage utilization (mean ± standard deviation (SD)) of respectively 61.4 ± 9.4%, 76.7 ± 7.5% and 85.4 ± 6.1%; thus amaranth leaf concentrate was better utilized than the unprocessed amaranth ($P < 0.001$). This finding was replicated in a more recent study, which reported a retinol equivalence (i.e. how much of the 'provitamin A' in the substance under examination was required to provide 1 μg of retinol) of 6.9 μg for leaf concentrate from spinach, compared with 13.6 μg for the unprocessed leaf (51), the latter figure being consistent with recent work by others (52). These results support studies in which serum retinol was measured in children and adults who had received leaf concentrate; it has invariably been found that hypovitaminosis A diminished or disappeared (43–45).

In a trial with predominantly anaemic children aged 4–9 years in a primary school in Maharashtra, India (53), two groups of 30 children were given a 100 g snack (providing 1674 kJ (400 kcal) and 12 g protein) six days each week for 9 months. The snacks in one of the groups were fortified with 9% by weight of dried leaf concentrate made from lucerne on a village farm (34). A green vegetable dye was added to the control group's snack in an attempt to blind participants to their allocation. Measurements were made of weight, height and Hb status, all of which showed a larger mean increase in the group which received 9% leaf concentrate compared with the control group (mean ± SD: 2.5 ± 0.5 kg versus 2.0 ± 0.4 kg, $P < 0.001$; 6.3 ± 0.9 cm versus 5.2 ± 0.9 cm, $P < 0.001$; 1.7 ± 0.9 g/dl versus 0.5 ± 0.9 g/dl, $P < 0.001$, respectively). The proportion of children with anaemia (Hb < 12 g/dl) in the 9% leaf concentrate group was reduced from 100% to 36%, compared with no change in the control group (90% to 87%).

Leaf concentrate has also been evaluated in a hospital setting with sick and elderly patients. A study of 30 patients with end-stage renal disease in the chronic haemodialysis programme at St John Hospital, Bucharest, Romania (54), included only patients with Hb = 7–8.5 g/dl. For 3 months they received 15 g dried leaf concentrate daily; Hb was measured fortnightly. Initial mean Hb of the group was 7.9 g/dl, after 1 month 8.0 g/dl and finally 8.4 g/dl ($P < 0.05$). A shorter study (55) on 50 hospitalized subjects aged 50–86 years (40 female, ten male) receiving 15 g dried leaf concentrate each day for 15 days, added to soup or by spoon, concluded that iron-deficiency anaemia and sideremia in the elderly may be corrected by leaf concentrate in the absence of iron therapy; increases in levels of serum retinol, calcium and magnesium were also observed.

The effects of leaf concentrate on the health of pregnant women, and on the birth weight of their babies, were studied in Jaipur, India (56). The participants were 105 women from the slums of Jaipur. The women were recruited from among attendees at eight primary health centres involved in a government programme. This programme provided a 120 g industrially produced cereal-based snack, rich in phytates but low in micronutrients. The women were 18–35 years of age and they were enrolled in the 14th–16th week of their pregnancy and divided randomly into two groups. The control group continued to take the regular snack (six days each week), while the experimental group received a similar snack in which dried leaf concentrate, made locally from lucerne, at 6% by weight, had replaced the standard ingredients in such a way that the control and experimental snacks were isoenergetic and isoproteinaceous. This had the effect of significantly raising the micronutrient content of the snack, particularly in iron, calcium, β-carotene and folic acid. The two groups were monitored monthly and one week after delivery. In the experimental group there was a reduction (from 52% to 38% at term) in the proportion of women with moderate or severe anaemia (Hb ≤ 8.5 g/dl), compared with an increase in the control group (from 60% to 83% at term). Mean Hb in the experimental group was unchanged (8.8 g/dl at baseline, 9.0 g/dl at term) compared with a decrease in the control group (from 8.4 g/dl to 7.8 g/dl at term, $P = 0.02$). Mean ± SD birth weight in the experimental group was higher than in the control group (2695 ± 322 g versus 2540 ± 299 g, $P = 0.02$). A subsample of 20 infants (ten from each group) was followed for 6 months. Those from the experimental group all gained weight faster than those from the control group, and their mothers reported better and quicker recovery after delivery. A number of these mothers chose to continue taking the leaf concentrate snack throughout their lactation, but no further outcomes were measured.

In the same setting, at Jaipur, the relative effectiveness of leaf concentrate compared with iron and folic acid supplements for treating anaemia in adolescent girls has been studied (28). The study was a randomized controlled two-arm trial (n = 102) over 3 months: one group received a daily iron and folic acid supplement (60 mg iron, 500 μg folic acid); the other group received a daily serving of 10 g of dried leaf concentrate supplied by APEF (providing 5 mg iron, 15 μg folic acid). Hb, mean red cell volume, serum ferritin, serum iron and total iron-binding capacity were measured pre- and post-intervention. At the start of the trial, of the 102 girls, four (3.9%) were severely anaemic (Hb < 7 g/dl), 28 (27.5%) were moderately anaemic (Hb ≥ 7 g/dl and <10 g/dl) and 70 (68.6%) were mildly anaemic (Hb ≥ 10 g/dl and <12 g/dl). In the iron and folic acid group, 11 girls (20.4%) withdrew due to side-effects of the supplement, compared with one girl (2.1%) in the leaf concentrate group. At the end of the trial, none of the remaining 86 girls was severely anaemic, nine (10.5%) were moderately anaemic and 26 (30.2%) were mildly anaemic; 51 (59.3%) had normal Hb levels (≥ 12 g/dl). These proportions were comparable in both groups. After adjustment for baseline values, the effectiveness of leaf concentrate in improving serum iron parameters was comparable with iron and folic acid, and the authors concluded that leaf concentrate was a viable, and more palatable, alternative to iron and folic acid supplements for treating anaemia in adolescent girls in this setting.

Another randomized controlled trial using dried leaf concentrate supplied by APEF was conducted in Lima, Peru, involving two groups each of 30 chronically malnourished children aged 3–5 years (57). One group received for 12 months a daily 10 g serving of leaf concentrate and the other group 15 g of skimmed milk powder with equivalent protein content. The children were monitored clinically (weight, height, morbidity) and biochemically (serum protein, albumin, transaminase and creatinine). The leaf concentrate and milk were taken daily in the children's homes, mixed into a maize porridge, and their intake was monitored. The two groups of children had similar characteristics at entry to the study (body mass index, age, sex, Hb), except for serum protein and albumin which were, respectively (mean ± SD), 59.3 ± 4.5 g/l and 27.8 ± 1.1 g/l for the leaf concentrate group compared with 62.2 ± 5.3 g/l and 28.6 ± 0.8 g/l for the skimmed milk group. The leaf concentrate was well accepted by the children (consumption 91%) and produced no digestive, kidney or liver complaints. Losses to follow-up were fewer in the leaf concentrate group (four children at 3 months and six children at 12 months) compared with the skimmed milk group (nine and 16 children, respectively). Growth estimated by mean increases in weight and height was similar for the two groups. Leaf concentrate improved Hb levels (33% anaemic at entry, 0% after 12 months) whereas this proportion was unchanged in the skimmed milk group. No untoward effects were recorded that could be attributed to the leaf concentrate, nor were there abnormal increases in transaminases and creatinine. Biological markers for protein deficiency (serum protein and albumin) were similarly corrected in the two groups at 12 months. The investigators concluded that leaf concentrate was as effective as skimmed milk in treating protein malnutrition in children, with the additional benefit of treating anaemia. These findings were replicated in a subsequent study carried out in the same district with similar methodology but on a larger sample (70 children in each group) over 6 months, and with powdered whole (instead of skimmed) milk given to the control group (E. Bertin, F. Vitry and J. Adnet, 2010, paper submitted to *Journal of Human Nutrition and Dietetics*).

A 3-month trial in the Democratic Republic of the Congo (DRC), in partnership with the DRC Research Centre for Health Sciences, compared the effects of 10 g of dried leaf concentrate versus 15 g of skimmed milk powder on growth and measures of malnutrition (e.g. albuminaemia) in two groups each of 30 children aged 3–5 years. Acceptability of leaf concentrate was similar to that of milk powder, as were the effects of the two nutritional supplements on gains in height and weight, and improvements in measures of malnutrition (E. Bertin, 2008, report to APEF).

A wealth of observational and anecdotal evidence for the apparent benefits of leaf concentrate has been accumulated from programmes in more than a dozen countries (17–23). Although inadmissible in a systematic review of evidence, these reports (mainly observational case series and testimonials by medical professionals) are supported by the findings of the randomized controlled trials summarized above. Programmes in several countries have instigated randomized controlled trials in order to provide rigorous evidence. Most notably, in Burundi and Cameroon, two randomized controlled trials involving the consumption of leaf concentrate by people living with HIV/AIDS have shown promising results, following very favourable case-series reports from programmes in these countries ((29) and APEF, 2007, internal document).

Leaf Concentrate, Past and Future

The previous sections have described some of the applications and benefits of leaf fractionation within a food-based approach for combating micronutrient malnutrition. This section briefly reviews the major factors that have hitherto hindered the widespread adoption of leaf concentrate and leaf fractionation, explains how these may be overcome, and discusses the potentially wider role of leaf concentrate in alleviating human malnutrition.

Over the past 40 years, the use of leaf concentrate in human nutrition has had a chequered history, with three main cyclical factors inhibiting its more general use:

- A lack of public awareness of the existence of leaf concentrate and its benefits has resulted in a lack of 'demand' for it.
- The lack of such 'demand' has discouraged the initiation of production.
- The lack of production (supply) has meant that there has been little public awareness.

Until recently, there have been two further, connected, obstacles:

- Lack of efficient, village-level, intermediate-scale processing machinery (up to 500 kg of leaf per hour) enabling consistent and profitable production of locally made leaf concentrate.
- Lack of robust, comparable scientific data on the effectiveness of leaf concentrate in combating malnutrition based on the consumption of a consistent product.

In addition, the vast majority of potential beneficiaries of leaf concentrate are severely impoverished, struggling even to afford the extremely low 'cost price' of the industrial product (currently €1/kg, ex-works in France, i.e. just over €3.5/year at 10 g/day per person); this has made leaf concentrate an unattractive option for commercial investors seeking a rapid return on their investment.

The availability of the French industrially produced leaf concentrate is now permitting the accumulation of an increasing body of evidence regarding the nutritional effectiveness of leaf concentrate (see previous section), not only in directly combating specific deficiencies (e.g. iron or vitamin A) but also in improving general health, resisting infection and accelerating recovery; of particular interest are the positive effects observed in people living with HIV/AIDS (18,19,29,58).

The French leaf concentrate also offers the potential for the creation of a local demand for leaf concentrate pending the establishment of a local ISP scheme, while the development of a new village-scale combined pulper and press, which has performed well in trials, would widen the range of scales at which ISP might be started, bringing to a larger number of people the benefits of leaf fractionation outlined earlier.

Although the first ISP scheme may require a relatively high initial capital investment, experience of manufacturing outside Western Europe indicates that costs may be substantially reduced (F.-C. Richardier, 2009, personal communication).

Possibly outside the immediate scope of the current work, but closely linked, are two further potential uses of leaf concentrate.

- As part of emergency food stocks held by the World Food Programme, as there is increasing testimony to the benefits of leaf concentrate in the field (17–23).
- Incorporated into a ready-to-use therapeutic food (RUTF) formulation. The general health benefits noted when leaf concentrate is incorporated into a variety of diets judged to be deficient in micronutrients (see 'Leaf Fractionation in a Food-based Approach', pp. 341–342) bear strong similarities to those attributed to pro- and prebiotics (59). A formulation has been developed using the French leaf concentrate (Dibari, 2007, internal report, Valid International), with which initial trials will be undertaken. In the long term, a locally produced RUTF containing leaf concentrate from an ISP scheme could be produced, independently of imported mineral–vitamin mixes (S. Collins, 2009, personal communication).

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19 Disability-adjusted Life Years (DALYs): a Methodology for Conducting Economic Studies of Food-based Interventions such as Biofortification

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Abstract
Micronutrient deficiency is a public health problem in many developing countries despite the food-based approaches such as conventional supplementation and fortification programmes to combat it. Therein lies the importance of programmes such as biofortification, which could complement these efforts; but their applicability and continued development would be strengthened with an accurate assessment of cost effectiveness and economic impact. The disability-adjusted life years (DALYs) methodology could be a good approach for such a purpose. The objective of this chapter is to explain the DALYs methodology used to evaluate interventions in health and nutrition (e.g. biofortification) in economic terms and then apply it to the case of iron-biofortified beans in Nicaragua.

Based on the relationship between micronutrient deficiency and health, the impact and cost of biofortification are estimated in economic terms based on the years of productive life lost (DALYs) as related to the biofortification of beans with iron in Nicaragua. The introduction of iron-biofortified beans in Nicaragua may save 252 to 989 years of productive lives in that country, at a unit cost ranging from US$96 to US$379 (cost-effectiveness). In monetary terms this represents a saving of US$246,000–969,000 (economic impact).

The DALYs could be a useful approach for the economic assessments of nutritional interventions such as biofortification as it considers the interrelationships existing among nutrition, health and well-being. The principal constraint is the availability and quality of the information required for its application.

Key words: disability-adjusted life years, iron deficiency, biofortification, cost effectiveness, economic impact, Nicaragua

Introduction

Malnutrition due to micronutrient deficiencies has gained priority on the agenda of many governments and development aid organizations, given the enormous impact that these deficiencies have on the socio-economic development of countries, especially those in the developing world (1). Due to the increased incidence of diseases stemming from these deficiencies, the consequences of which include temporary and permanent incapacities and the death of those who are afflicted by them, the future development of these countries is at risk because the potential productivity of their populations is compromised (2).

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For decades, attempts have been made to combat this form of malnutrition with programmes such as conventional fortification and supplementation, among others; but their impact and effectiveness have been limited (3). In the case of supplementation, this is related to the lack of coverage, inadequate logistical and financial support, as well as the fact that the beneficiaries often forget the instructions on how much and how many times to take the supplements. Lack of control or supervision of tablet consumption could be a cause of the limited effectiveness of iron supplementation programmes (4) and non-compliance, especially on the part of pregnant women, can be a significant factor for this failure as well (5). On the other hand, the reduced impact of fortification programmes is attributed to low nutrient bioavailability in the diet, especially in developing countries, because very few deficient people consume a sufficient amount of the fortified product that would permit them to absorb the necessary amount of the micronutrient (3). Additionally, one of the main technical barriers to successful iron fortification is overcoming the inhibitory effect on iron absorption of dietary components such as phytic acid which is present in cereal grains, such as wheat flour that is widely used as a fortification vehicle in many fortification programmes in the developing world (6). For these reasons, micronutrient deficiencies such as iron, zinc and vitamin A continue to be a problem that affects millions of people, especially in the most marginal regions of Africa, Asia and Latin America. According to the World Health Organization (WHO) (7), anaemia, used as a proxy for iron-deficiency anaemia, affects 1.62 billion people in the world, which corresponds to 24.8% of the global population. The highest prevalence is in children of pre-school age (47.4%) and the lowest prevalence is in men (12.7%). The population group with the greatest number of individuals affected is non-pregnant women (468.4 million). In the case of vitamin A deficiency, there are more than 7 million pregnant women afflicted by it each year (1). Hotz *et al*. (8) estimate that 25–33% of the population in developing countries is at risk of suffering from zinc deficiency. In view of the worsening situation of food security and nutrition in the world, resulting from problems such as climate change and the increasing scarcity of basic staples such as maize and wheat (given their enormous demand by the growing industry for producing biofuels), there has been a consequent increase in the level of prices to the consumer (9), so that foods are often unaffordable for many people, especially those with limited resources. Thus, it is indispensable to complement efforts to reduce micronutrient malnutrition through the implementation of sustainable and more efficient, cost-effective programmes such as biofortification, which consists in enriching crops with micronutrients via techniques for agronomic improvement (10). Given the above, it is important to design and apply theoretical and practically applicable methodologies that permit the analysis, selection and application of the best alternatives in terms of viability and nutritional and socio-economic impact.

Preliminary studies using the disability-adjusted life years (DALYs) methodology have shown that the introduction of iron-biofortified beans in Nicaragua can result in a 44–49% reduction in the DALYs lost annually due to iron deficiency (11). According to estimates made by HarvestPlus (12), the cost per DALY saved by the biofortification of beans with iron is high for all of Latin America when compared with the value in other regions. In other words, the cost-effectiveness of this strategy is lower in Latin America than in the other regions studied (12). This means that the investment in biofortification in Latin America is not as effective as in Africa or Asia. In Nicaragua, for example, the value per DALY saved can range from US$64 to US$439 and in north-eastern Brazil from US$20 to US$134, while in India and Pakistan the cost per DALY saved by an intervention with iron-biofortified wheat can be from US$1.10 to $9.80 and US$3.10 to $13, respectively (12). In Latin America and the Caribbean, compared with iron supplementation (whose cost is US$70 per DALY saved), iron biofortification is a cost-effective intervention. However, compared with iron fortification in the region, iron biofortification is not cost-effective (12).

The DALYs methodology can be applied for economic assessments of health interventions as it takes into account the interrelationships existing among nutrition, health and well-being (13). At the same time, the DALYs methodology estimates the health benefits, expressing them in just one index, which can be compared with those of other alternatives as well as monetized, facilitating their analysis and economic interpretation. Thus, the methodology is used by organizations including WHO (14) and projects such as HarvestPlus (12) and AgroSalud, which are currently working to mitigate micronutrient deficiencies through biofortification. The DALYs methodology applied to biofortification is based on the work of Zimmermann and Qaim (15), who used the concept of DALYs for the first time to measure the potential benefits of the biofortification of basic crops.

The purpose of this chapter is to explain the DALYs methodology in its application to nutrition-related interventions such as biofortification, by means of a practical example of its utilization in the case of the introduction of iron-biofortified beans in Nicaragua, a current undertaking of the AgroSalud Project.

Biofortification, A Food-based Approach for Combating Micronutrient Deficiencies

Biofortified crops can be developed in two ways: through genetic modification (16) or through a breeding procedure where crosses are made between different varieties of the same traditional plant until the variety with the desired traits is produced (17). Ideally, biofortified crops will not have any variation in their texture, flavour or appearance. An exception will be crops with greater β-carotene content, which have a yellower colour that distinguishes them from white-fleshed varieties, such as yellow maize and orange-fleshed sweet potatoes (18).

Biofortification can be cost-effective, given that with just one investment in the research and development of germplasm, multiple flows of benefits are obtained by disseminating these new varieties in other regions and countries (13). Moreover, farmers can multiply the seed for use in the next production cycle, making this a sustainable alternative in the long term (13). Comparing the cost–benefit ratios of the interventions with iron-biofortified rice and wheat in India, results were more promising than those for increasing iron intake in other Asian countries. The average cost–benefit for biofortification ranged from US$186 to US$2180 (13) versus US$176 to US$200 for interventions with fortification and from US$6 to US$14 for supplementation (14).

Currently the HavestPlus Project is working on the biofortification of cassava, maize and sweet potatoes with β-carotene, as well as the biofortification of beans, rice, cassava, maize, sweet potatoes and wheat with iron and zinc. Its work is centred primarily in Africa and Asia (12). In the case of Latin America and the Caribbean, the AgroSalud Project has been working with the same micronutrients and crops, except wheat and cassava, in 14 countries of the region (18).

Methods

The disability-adjusted life years methodology

The commonly expected benefits resulting from biofortification are improvement in health via improvement in nutrition. These improvements have been observed with iron-biofortified rice (19) and β-carotene-biofortified orange-fleshed sweet potatoes (20). To carry out an analysis of cost-effectiveness, economic impact, cost–benefit ratio and other studies that involve the quantification and assessment of these benefits, a method of measurement should be used that permits the results to be compared with benefits obtained by other interventions.

The World Bank introduced the concept of DALYs in 1993 (15). The advantage of the DALYs methodology is that it captures the permanent or partial incapacities caused by death or illness in just one index, DALYs lost (15), equation (19.1):

$$\text{DALYs lost} = \text{Years of productive life lost by death} + \text{Years of productive life lost due to incapacity} \tag{19.1}$$

The impact of biofortification can be determined by the difference between the DALYs lost due to a micronutrient deficiency with and without biofortification (15). This comparison can also be made with other interventions such as supplementation and conventional fortification. The present analysis is focused on biofortification with the results yielding the number of productive years that society would save thanks to biofortification, years that would otherwise be lost as a consequence of the diseases stemming from the greater prevalence of the micronutrient deficiency in a scenario without biofortification. If, upon consuming the biofortified crop, micronutrient intake is increased, the micronutrient deficit is decreased and the incidence of micronutrient deficiency-related illnesses is decreased, the number of DALYs lost in the scenario with biofortification would be lower than that lost in the baseline scenario or without biofortification, resulting in a positive impact, equation (19.2):

$$\text{Impact of biofortification} = \text{DALYs lost with biofortification} - \text{DALYs lost without biofortification} \qquad (19.2)$$

Once the number of DALYs is estimated that the society would save due to biofortification, cost-effectiveness may be calculated by comparing the costs invested in research, development and dissemination. The contribution of biofortification to the country's Gross National Product (GNP) and the level of return on the investment made or the Internal Rate of Return (IRR) of biofortification can also be estimated. The methodology makes it possible to estimate the impact that the greater intake of micronutrients would have on health by reducing the rate of incidence of the diseases related to the deficiency studied, as can be seen in equation (19.3) (15):

$$\text{DALYs lost} = \sum_j T_j M_j \left(\frac{1 - e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1 - e^{-rd_{ij}}}{r} \right) \qquad (19.3)$$

where

T_j is the total number of people in target group j

M_j is the rate of mortality associated with the deficiency in target group j

L_j is the average life expectancy remaining in target group j

I_{ij} is the rate of incidence of illness i in target group j

D_{ij} is the weight of the incapacity due to illness i in target group j

d_{ij} is the duration of illness i in target group j (for permanent disability d_{ij} is equal to the average of the remaining life expectancy L_j)

r is the rate of discount for years of future life.

Results

The DALYs methodology was used to assess the cost-effectiveness and economic impact of biofortifying beans in Nicaragua as part of the AgroSalud Project. This analysis updates information used previously to calculate the DALYs from iron-biofortifed beans in Nicaragua (11). Anaemia is widespread in this Central American country (21), where beans are a basic staple in the diet, reaching a daily per capita consumption of 72 g according to the Food and Agriculture Organization of the United Nations (22). The varieties of beans that are consumed in Nicaragua contain an average of 50 μg iron/g and, at the end of the 3 years of research and development, it is expected that the iron content of beans will reach between 80 μg/g (pessimistic) and 100 μg/g (optimistic) (S. Beebe, Leader of Bean Breeding Unit at International Center for Tropical Agriculture (CIAT), 2007, personal communication).

A Model for Assessing the Impact of Nutritional Interventions (MAIN) was created by CIAT (23), developed in Visual Basic for Applications (VBA) and coded in Microsoft Excel 2000 (23).The first step is to identify the conditions related to micronutrient deficiencies which cause incapacity and loss in productivity. For zinc, the consequences include diarrhoea, pneumonia and stunted growth. For vitamin A, they include night blindness, cataracts, total blindness, measles and an increase in mortality. Consequences of iron deficiency may include anaemia, which can cause damage in motor functions and psychological development, maternal mortality, increases in stillbirths and infant mortality (8).

The second step is to identify the population group (j) affected and to estimate its size according to the different age ranges based on national population censuses (Table 19.1). For example, the damage in motor functions caused by anaemia due to iron deficiency can affect the entire population, independent of age and gender, although its incidence will vary (24,25). A distinction is made between children of 5 years of age and less, children aged 6–14 years, women over 15 years and men older than 15 years. Damage in psychological development can affect boys and girls 5 years or younger, while maternal mortality can affect women of reproductive age (15–49 years).

Given that not all of the population will develop one or all of these illnesses, it is necessary to estimate the number of new cases that could occur for each condition and population group at the current levels of micronutrient deficiency (I_{ij}). Based on this information, the number of potential cases that could develop each illness is estimated by multiplying the population by the incidence within each age group (Table 19.2).

The average age at which these conditions or illnesses commonly occur, the life expectancy of the Nicaraguan population at birth and the duration of illness (d_{ij}) were used to estimate the years during which those affected would live with illnesses or the incapacities stemming from such illnesses. In the case of the damage to motor functions due to moderate anaemia related to iron deficiency among children 5 years or less, this appears in the first 6 months of life and its effects are permanent, affecting the child the rest of his/her life (13), or 69.5 years, based on an average life expectancy at birth of 70 years (26). By multiplying 69.5 by the weight of the incapacity due to damage in motor functions in the specific population range (D_{ij}), the number of productive years that would be lost as a result of such an ailment (DALYs lost) is calculated. In Nicaragua, it was estimated that the rate of incidence of the damage in motor functions due to moderate anaemia related to iron deficiency was 1.25% in children 5 years or younger (Table 19.2). As the population within this age range equals 858,000 children (Table 19.1), then the population potentially affected by this ailment would be 10,725 children, who would suffer from its repercussions for the rest of their lives; the extent of which depends on the severity of the anaemia caused by the iron deficiency. The degree of incapacity due to motor-function damage in children 5 years or less is estimated at 1.1% for moderate anaemia and 8.7% for severe anaemia (27). Applying the weight of the incapacity to the number of years that the children would live with the consequences of anaemia, the number of DALYs lost without biofortification was estimated (Table 19.3).

The next step is to simulate the scenario once the biofortified varieties have been released and adopted by producers and consumers. Given that the majority of these varieties being developed have not been disseminated, much less adopted or consumed by the target population, a series of assumptions was made to simulate a scenario with biofortification.

First, we need to determine the size of the micronutrient deficiency based on average intakes. For this, it is necessary to know the average daily consumption per person of all the crops to be biofortified and for each of the age ranges analysed. A food composition table is used to estimate the level of individual consumption for each micronutrient, thereby characterizing the overall diet of the groups under analysis (13). The principal bottleneck in estimating the DALYs is obtaining information on individual daily consumption of nutrients (12). The Living Standards Measurement Studies (LSMS) of The World Bank (28) can be used for this purpose, but they are not available for all countries.

Table 19.1. Population by age range in Nicaragua.

Population group[a]	Population[b]
Children ≤5 years	858,000
Children 6–14 years	1,278,000
Women ≥15 years	1,754,000
Men ≥15 years	1,654,000
Total population	5,544,000

[a]Data from Stein *et al.* (13).
[b]Data from The World Bank (26).

Table 19.2. Diseases related to iron deficiency, degree of incapacity generated, average age at which the illness appears, expected duration of illness, rate of incidence and number of people affected by iron deficiency in Nicaragua according to age range: without biofortification.

		Children		Children (≤5 years)			Children (6–14 years)		
Diseases related to ID	Level of ID	Degree of incapacity (%) (D_{ij})[a]	Average age at which illness appears (years)[b]	Rate of incidence (%) (I_{ij})[c]	No. affected (000s)[d]	Duration of effects of illness (000s)[b]	Rate of incidence (%) (I_{ij})[a]	No. affected (000s)[d]	Duration of effects of illness (000s)[b]
Damage in motor functions	Moderate	1.1	0.5	1,250	10.7	5.5	0.250	3.2	8.0
	Severe	8.7	6.0	0.023	0.2	5.5	0.004	0.1	8.0
Damage in psychological development	Moderate	0.6	5.0	0.100	0.9	65	N/A	N/A	N/A
	Severe	2.4		0.002	0.0	65	N/A	N/A	N/A
		Adults		Women (≥15 years)			Men (≥15 years)		
Damage in motor functions	Moderate	1.1	15	0.120	2.1	55	0.090	1.5	53
	Severe	9.0	15	0.004	0.1	55	0.001	0.0	53

ID, iron deficiency; N/A, not applicable.
[a]Data from Alderman and Horton (25).
[b]Data from Stein *et al.* (13).
[c]Data from World Health Organization for 2006 (14).
[d]Result of multiplying the population of said target group by the incidence.

Table 19.3. Years of productive life lost due to iron deficiency in Nicaragua: without biofortification.

DALYs lost	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years	Total DALYs lost
Due to mortality[a]	179	0	507	0	686
Due to incapacity[b]	844	282	794	474	2393
Total	1023	282	1300	474	3079

DALY, disability-adjusted life year.
[a]Estimate based on the rates of maternity- and birth-related death due to iron deficiency, the rate of infant mortality and the rate of births, given that the other illnesses are not considered fatal.
[b]Estimate based on calculating the numbers affected by illness and the extent of the incapacity attributed to illness.

In Latin America, they are available for Brazil, Ecuador, Nicaragua, Panama and Peru. National nutrition surveys (Colombia (29), Cuba (M. Hernandez, personal communication, 2007) and Mexico (30)) are another source for these data.

The amount of iron that the target group would ingest from the biofortified beans is estimated from the additional amount of iron that the crop would have once it is biofortified and the farmers' level of adoption, given that not all farmers will adopt the variety or dedicate the entire area planted to the biofortified variety. Similarly, the total crop amount consumed by the target population will not be biofortified, given that non-biofortified varieties will also be available in the market. Information about the amount of micronutrient lost due to postharvest activities such as handling, cooking, etc., is taken into account. Two scenarios are simulated (Table 19.4): (i) a pessimistic one, where iron content in beans is increased by only 30 μg/g, with 10% losses of iron due to postharvest activities and a 20% coverage rate of the biofortified variety; and (ii) an optimistic one, where iron content in beans is increased by 50 μg/g, there are no losses due to postharvest activities and the level of coverage is 50%. In both scenarios, iron bioavailability is assessed to be unchanged.

Table 19.4. Additional iron in biofortified beans, iron losses due to postharvest activities and crop coverage rate.

Assumption	Pessimistic scenario	Optimistic scenario
Additional iron content (μg/day)	30	50
Postharvest losses (cooking, handling, etc.) (%)	10	0
Crop coverage rate (%)	20	50

Data from S. Beebe, Head of Bean Programme at Centro Internacional de Agricultura Tropical (CIAT), 2007, personal communication.

To estimate the amount of additional micronutrient that people would ingest once they consume the biofortified crops, micronutrients coming from the diet without the biofortified product are added to that supplied by the biofortified crops, multiplied by the amount of crops consumed. For example, in the pessimistic scenario, when multiplying the additional iron content on beans (30 μg/g) by 90% (–10% of postharvest losses) and this result is multiplied by the current consumption of beans (45 g/day), the additional iron intake supplied by biofortifed beans is calculated as 1620 μg/day. Adding this result to the current intake of iron from all food sources (4870 μg/day), the total consumption of iron with biofortifed beans is 6490 μg/day (Tables 19.5 and 19.6).

Once the average amount of micronutrients consumed by each population group is estimated, as well as the micronutrient contribution of the crop, the micronutrient deficit in the diet is estimated. This was done by comparing micronutrient intake levels with the Recommended Dietary Allowance (RDA) for the USA and Canada (31). In Nicaragua, the RDA for children under 5 years old is 11,000 μg/day and the current iron intake in all meals is 4870 μg/day, thus the deficit of iron in the diet is 6130 μg/day (Tables 19.5 and 19.6).

Once the scenario with biofortified beans consumption is simulated and the new iron

Table 19.5. Characterization of iron intake in the diet, estimate of the deficit in its intake and the contribution of biofortified beans in Nicaragua: pessimistic scenario.

Parameter	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years
Current intake of iron in all meals (μg/day)[a]	4,870	5,850	6,540	6,050
Recommended iron intake (μg/day)[b]	11,000	14,000	18,000	12,000
Deficit of iron in the diet (μg/day)[c]	6,130	8,150	11,460	5,950
Current consumption of beans (g/day)[a]	45	53	57	52
Iron intake from biofortified beans (μg/day)[d]	1,215	1,431	1,539	1,404
Increase in iron intake with biofortified beans (μg/day)[e]	6,085	7,281	8,079	7,454

[a]Data from The World Bank for 2001 (26).
[b]Institute of Medicine Dietary Reference Intakes (2000) (31).
[c]Current intake of iron in all meals minus recommended iron intake.
[d]Result of multiplying current consumption of beans with new iron bean content.
[e]Result of adding the iron intake with biofortified beans with the current intake of iron in all meals.

Table 19.6. Characterization of iron intake in the diet, estimate of the deficit in its intake and the contribution of biofortified beans in Nicaragua: optimistic scenario.

Parameter	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years
Current intake of iron in all meals (μg/day)[a]	4,870	5,850	6,540	6.050
Recommended iron intake (μg/day)[b]	11,000	14,000	18,000	12,000
Deficit of iron in the diet (μg/day)[c]	6,130	8,150	11,460	5,950
Current consumption of beans (g/day)[a]	45	53	57	52
Iron intake from biofortified beans (μg/day)[d]	2,250	2,650	2,850	2,600
Increase in iron intake with biofortified beans (μg/day)[e]	7,120	8,500	9,390	8,650

[a]Data from The World Bank for 2001 (26).
[b]Institute of Medicine Dietary Reference Intakes (2000) (31).
[c]Current intake of iron in all meals minus recommended iron intake.
[d]Result of multiplying current consumption of beans with new iron bean content.
[e]Result of adding the iron intake with biofortified beans with the current intake of iron in all meals.

intake estimated, the new incidence for the illnesses related to iron deficiency is estimated (13), based on the minimum iron intake required for them to appear. With the new incidence, the number of new cases of ailments stemming from iron deficiency was estimated for both pessimistic and optimistic scenarios (Tables 19.7 and 19.8).

Having the number of new cases of the resulting ailments that would occur, as well as data on the severity of the incapacity, its duration and average age of occurrence, the number of productive years that would be lost are estimated in the pessimistic and optimistic biofortification scenarios. In Nicaragua, for children under 5 years of age, 156 DALYs will be lost by mortality and 771 DALYs by incapacity in the pessimistic scenario for a total of 926 DALYs lost; and 95 DALYs and 557 DALYs will be lost in the optimistic scenario due to mortality and incapacity for a total of 652 DALYs lost (Tables 19.9 and 19.10).

The DALYs that would be lost in the biofortification models (Tables 19.9 and 19.10) are compared with those obtained in the model without biofortification (Table 19.3) in order to estimate the number of productive years that society would lose due to the micronutrient deficiency studied. This is the amount of time expressed in additional productive years that the members of a society would be able to contribute to their

Table 19.7. Incidence and number of those affected by illnesses stemming from iron deficiency in Nicaragua: pessimistic scenario.

Diseases related to ID	Level of ID	Children (≤5 years) New rate of incidence (%) (I_{ij})[a]	Children (≤5 years) New no. of those affected (000s)[b]	Children (6–14 years) Rate of incidence (%) (I_{ij})	Children (6–14 years) No. of those affected (000s)
Damage in motor functions	Moderate	1.141	9.8	0.230	2.9
	Severe	0.021	0.2	0.004	0
Damage in psychological development	Moderate	0.091	0.8	N/A	N/A
	Severe	0.170	1.5	N/A	N/A
		Women (≥15 years)		Men (≥15 years)	
Damage in motor functions	Moderate	0.112	2.0	0.081	1.3
	Severe	0.004	0.1	0.001	0.0

ID, iron deficiency; N/A, not applicable.
[a]Result of multiplying the expected additional iron content in beans with the estimated coverage rate and adding this value to the value of iron intake without biofortification.
[b]Result of multiplying the population of said group by the new rate of incidence.

Table 19.8. Rate of incidence and number of those affected by illnesses stemming from iron deficiency in Nicaragua: optimistic scenario.

Diseases related to ID	Level of ID	Children (≤5 years) New rate of incidence (%) (I_{ij})[a]	Children (≤5 years) New no. of those affected (000s)[b]	Children (6–14 years) Rate of incidence (%) (I_{ij})	Children (6–14 years) No. of those affected (000s)
Damage in motor functions	Moderate	0.825	0.987	0.230	2.92
	Severe	0.015	0.1	0.171	0.0
Damage in psychological development	Moderate	0.066	0.6	N/A	N/A
	Severe	0.001	0.0	N/A	N/A
		Women (≥15 years)		Men (≥15 years)	
Damage in motor functions	Moderate	0.088	1.5	0.056	0.9
	Severe	0.003	0.1	0.001	0.0

ID, iron deficiency; N/A, not applicable.
[a]Result of multiplying the expected additional iron content in beans with the estimated coverage rate and adding this value to the value of iron intake without biofortification.
[b]Result of multiplying the population of said group by the new rate of incidence.

economies if they did not lose their physical and intellectual capacities, partially or totally, due to the micronutrient deficiency under study. Tables 19.11 and 19.12 show the DALYs gained in the pessimistic and optimistic scenarios, respectively, of the iron-biofortified beans in Nicaragua. In the pessimistic scenario, 57 DALYs are saved by mortality reduction and 195 DALYs by incapacity reduction for a total of 252 DALYs lost (Table 19.11). In the optimistic scenario where the iron content of beans is increased by 50 μg/g, 221 DALYs are saved by reductions in mortality and 768 DALYs by reduction of incapacity, for a total of 989 DALYs lost (Table 19.12).

Upon dividing all the DALYs that would be gained from iron biofortification

Table 19.9. Years of productive life lost with iron-biofortified beans in Nicaragua: pessimistic scenario.

DALYs lost	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years	Total DALYs lost
Due to mortality	156	0	473	0	629
Due to disability	771	259	740	428	2198
Total	926	259	1213	428	2827

DALY, disability-adjusted life year.

Table 19.10. Years of productive life lost with iron-biofortified beans in Nicaragua: optimistic scenario.

DALYs lost	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years	Total DALYs lost
Due to mortality	95	0	370	0	465
Due to disability	557	192	579	297	1625
Total	652	192	948	297	2090

Table 19.11. DALYs gained due to biofortification of beans with iron in Nicaragua: pessimistic scenario.

DALYs gained	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years	Total DALYs gained
Due to reduction in mortality[a]	23	0	34	0	57
Due to reduction of disability[b]	74	23	53	46	195
Total	97	23	87	46	252
In monetary terms (millions of US$)[c]	0.1	0.0	0.1	0.0	0.2
Result due to reduction in mortality[d]					8.3%
Result due to reduction of incapacity[e]					8.2%
The burden of illness is reduced by[f]	9.5%	8.0%	6.7%	9.7%	8.2%

DALY, disability-adjusted life year.
[a]Subtraction of the DALYs lost due to mortality with biofortification in the pessimistic scenario from the DALYs lost due to mortality in the scenario without biofortification.
[b]Subtraction of the DALYs lost due to incapacity with biofortification in the pessimistic scenario from the DALYs lost due to incapacity in the scenario without biofortification.
[c]Multiplication of the total DALYs gained by the per capita Gross National Product of Nicaragua (US$980).
[d]Division of the DALYs lost due to mortality with biofortification in the pessimistic scenario by the DALYs lost due to mortality in the scenario without biofortification.
[e]Division of the DALYs lost due to incapacity with biofortification in the pessimistic scenario by the DALYs lost due to incapacity in the scenario without biofortification.
[f]Division of the total DALYs lost with biofortification in the pessimistic scenario by the total DALYs lost in the scenario without biofortification.

by the DALYs that would be lost without biofortification, the extent to which the burden of illnesses stemming from iron deficiency would be reduced by introducing the biofortified beans would be obtained. According to these results, upon increasing the amount of iron contained in the beans by 30 μg/g in the pessimistic scenario, the weight of the diseases stemming from iron deficiency in Nicaragua could be reduced by 8.2% on average for all age groups; but if the optimistic scenario of increasing iron content by 50 μg/g is reached, the reduction in the burden of such diseases would be 32.1% (Tables 19.11 and 19.12).

The intervention with iron-fortified beans in Nicaragua would represent savings ranging from 252 to 989 productive years for the economy of that country. Expressing these years in monetary terms by multiplying them

Table 19.12. DALYs gained due to biofortification of beans with iron in Nicaragua: optimistic scenario.

DALYs gained	Children ≤5 years	Children 6–14 years	Women ≥15 years	Men ≥15 years	Total DALYs gained
Due to reduction in mortality[a]	84	0	137	0	221
Due to reduction of disability[b]	287	89	215	177	768
Total	371	89	352	177	989
In monetary terms (millions of US$)[c]	0.4	0.1	0.3	0.2	1.0
Result due to reduction in mortality[d]					32.2%
Result due to reduction of incapacity[e]					32.1%
The burden of illness is reduced by[f]	36.2%	31.7%	27.1%	37.3%	32.1%

[a]Subtraction of the DALYs lost due to mortality with biofortification in the optimistic scenario and the DALYs lost due to mortality in the scenario without biofortification.
[b]Subtraction of the DALYs lost due to incapacity with biofortification in the optimistic scenario from the DALYs lost due to incapacity in the scenario without biofortification.
[c]Multiplication of the total DALYs gained by the per capita Gross National Product of Nicaragua (US$980).
[d]Division of the DALYs lost due to mortality with biofortification in the optimistic scenario by the DALYs lost due to mortality in the scenario without biofortification.
[e]Division of the DALYs lost due to incapacity with biofortification in the optimistic scenario by the DALYs lost due to incapacity in the scenario without biofortification.
[f]Division of the total DALYs lost with biofortification in the optimistic scenario by the total DALYs lost in the scenario without biofortification.

by the average income or product generated annually per capita GNP (13), it is estimated that the savings for the country would range from US$246,960 (2007 US$) to US$969,220, based on a per capita income of US$980 (26).

Having estimated the benefits obtained from biofortification or DALYs gained, they can be related to the costs incurred in this intervention with biofortification; that is, the costs of research and development and the dissemination of the biofortified bean varieties in Nicaragua, which in the AgroSalud Project total US$95,424. Based on this information, it was estimated that saving one DALY or year of productive life via iron-fortified beans in Nicaragua would cost from US$379 in the pessimistic scenario to US$96 in the optimistic scenario. These data serve as a basis for comparison with the results from other types of interventions to help select the most efficient intervention; that is, the one that achieves the same benefit at the lowest cost.

Discussion

The DALYs methodology is a useful approach for the economic assessment of interventions in health and nutrition such as food-based approaches, given that it permits the measurement and monetary assessment of benefits obtained in health via an improvement in the conditions of a target population group. This methodology has been applied for the economic assessment of interventions with biofortification, supplementation and conventional fortification for different countries over different periods of time. According to some studies (12), biofortification is cost-effective in southern Asia, where iron-biofortified rice saves one DALY at a cost of US$3–4; in the case of iron-biofortified wheat, this cost is around US$1. For iron supplementation and iron fortification in Asia, the cost per DALY saved is US$70 and US$43, respectively, making biofortification the most cost-effective intervention. In Latin America, the cost per DALY saved by iron biofortification is much higher according to these studies, except for north-east Brazil, where the cost for saving one DALY with iron-fortified beans ranged from US$20 to US$134. The difference in the estimates between the continents is said to be primarily due to the larger rural populations and the relatively more efficient seed distribution systems in Asia and Africa.

In an analysis for Nicaragua, Honduras and north-east Brazil, supplementation and conventional fortification with iron cost US$487 and US$215, respectively, per

DALY saved (11). In a previous analysis of iron-biofortified beans in Nicaragua, the cost per DALY saved was US$64 for the optimistic scenario and US$439 for the pessimistic one, assuming a 50% adoption rate in both scenarios (12). This is not the same case for the interventions with zinc or vitamin A, where the cost per DALY saved ranges from US$27 to US$79 for supplementation and fortification with zinc, and from US$43 to US$90 for similar interventions with vitamin A. In comparison with zinc, biofortification was not lower than US$150 per DALY saved in Honduras, Nicaragua and north-east Brazil (12).

When comparing the results of these studies with those obtained in the analyses for the intervention with biofortified beans in Nicaragua presented here, biofortification was more cost-effective than iron fortification and supplementation in the optimistic scenario and with respect to supplementation in the pessimistic scenario. Nevertheless, it must be kept in mind that the type and quality of the information and assumptions must be similar for all analyses if they are to be comparable across the board, given that comparison is based on the optimistic scenario, where a 50% adoption rate was assumed in both analyses.

The complexity and differences between the assumptions and the information used to estimate the DALYs or different nutrition interventions mean that there can be different studies on the same intervention, with the same crop and nutrient in the same country, and the results could be different; the credibility of those results depends on the coherence and foundation of the assumptions, as well as the sources of information used.

The complexity of the information and the number of assumptions required for estimating the DALYs mean that this methodology is not always applicable, especially for analyses at a sub-national level, given that information on the incidence of illnesses and level of intake per person per day of the crop being analysed, as well as the characterization of the diet by population groups, is difficult to collect.

On the other hand, many of the assumptions on which this methodology is based are not exempt from criticism despite the level of agreement with which they were determined (13). Consequently, the credibility of these results has been questioned by those critics who consider it a complex methodology that is not readily understood by those people who are neither scientists or nutritionists nor economists.

Despite these criticisms, the DALYs methodology is useful for simultaneously comparing multiple interventions in health and nutrition. It is used by multilateral and international entities such as The World Bank and WHO, because of its theoretical coherence for relating and quantifying the changes in people's state of health as a result of changes in their nutritional status.

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Index

Page numbers in **bold** refer to illustrations and tables

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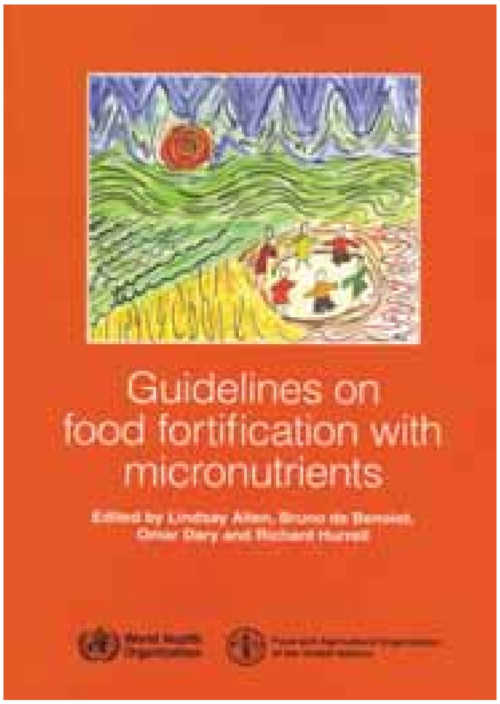
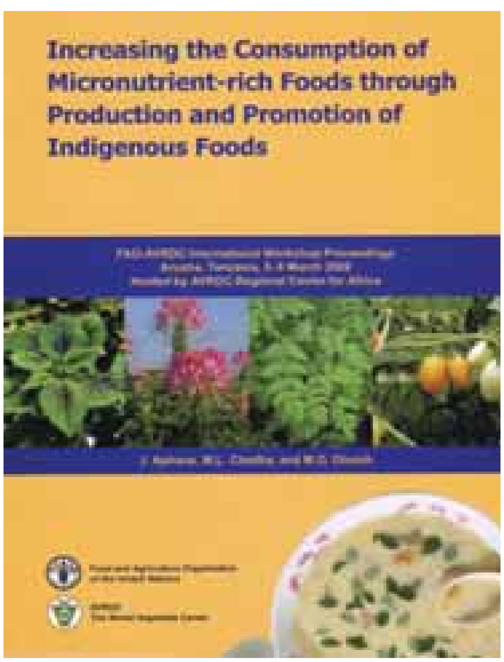


L. Allen, B. de Benoist, O. Dary, R. Hurrell
Guidelines on food fortification with micronutrients
World Health Organization and Food and Agriculture Organization of the United Nations
France, 2006, 341 pg with 1 CD-ROM
ISBN 92 4 159401 2
English only:
http://www.who.int/nutrition/publications/micronutrients/guide_food_fortification_micronutrients.pdf



J. Aphane, M.L. Chadha, M.O. Oluoch
Increasing the Consumption of Micronutrient-rich Foods through Production and Promotion of Indigenous Foods
Food and Agriculture Organization of the United Nations and The World Vegetable Center- AVRDC
2003, 77 pg
ISBN 92-9058-130-2
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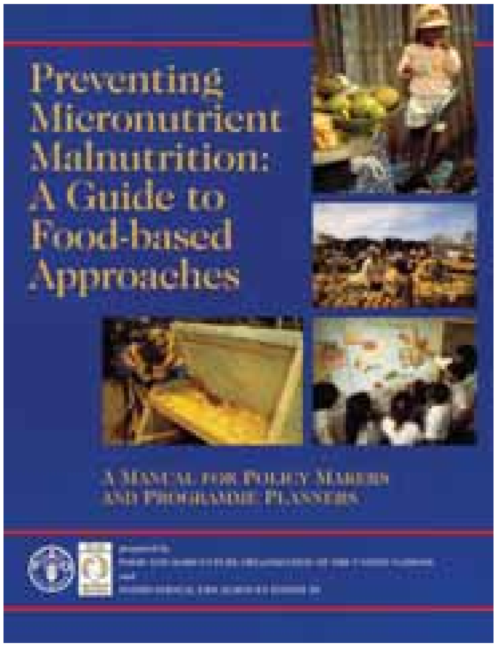
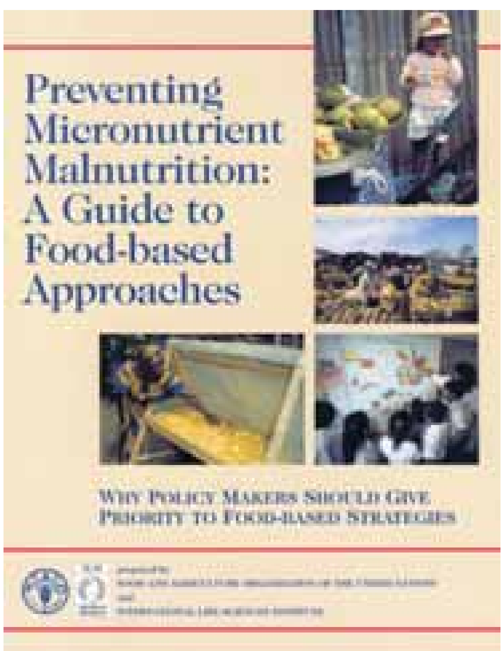


Preventing Micronutrient Malnutrition: A Guide to Food-based Approaches
A manual for policy makers and programme planners
Food and Agriculture Organization of the United Nations and International Life Sciences Institute
International Life Sciences Institute, Washington DC, USA, 1997, 105 pg
ISBN 0-944398-89-8
English only:
http://www.fao.org/docrep/X5244E/X5244E00.htm



Preventing Micronutrient Malnutrition: A Guide to Food-based Approaches
Why policy makers should give priority to food-based strategies
Food and Agriculture Organization of the United Nations and International Life Sciences Institute
International Life Sciences Institute, Washington DC, USA, 1997, 11 pg
ISBN 0-944398-94-4
English only:
http://www.fao.org/docrep/X0245E/X0245E00.htm

Combating Micronutrient Deficiencies: Food-based Approaches

Edited by

Brian Thompson and Leslie Amoroso

Food and Agriculture Organization of the United Nations

Micronutrient deficiencies affect more than two billion people in the world today. With long-ranging effects on health, learning ability and productivity, they contribute to the vicious cycle of malnutrition, underdevelopment and poverty. Food-based approaches, which include food production, dietary diversification and food fortification, are sustainable strategies for improving the micronutrient status of populations and raising levels of nutrition. *Combating Micronutrient Deficiencies: Food-based Approaches* focuses on practical, sustainable actions for overcoming micronutrient deficiencies through increased availability, access to and availability and consumption of adequate quantities and appropriate varieties of safe, good quality food. This volume brings together the available knowledge, success stories and lessons learned from country-level activities to help demonstrate that food-based approaches are viable, sustainable and long-term solutions for overcoming micronutrient malnutrition.

This book is a useful resource for policy makers, agronomists, food and nutrition security planners, programme implementers and health workers.

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