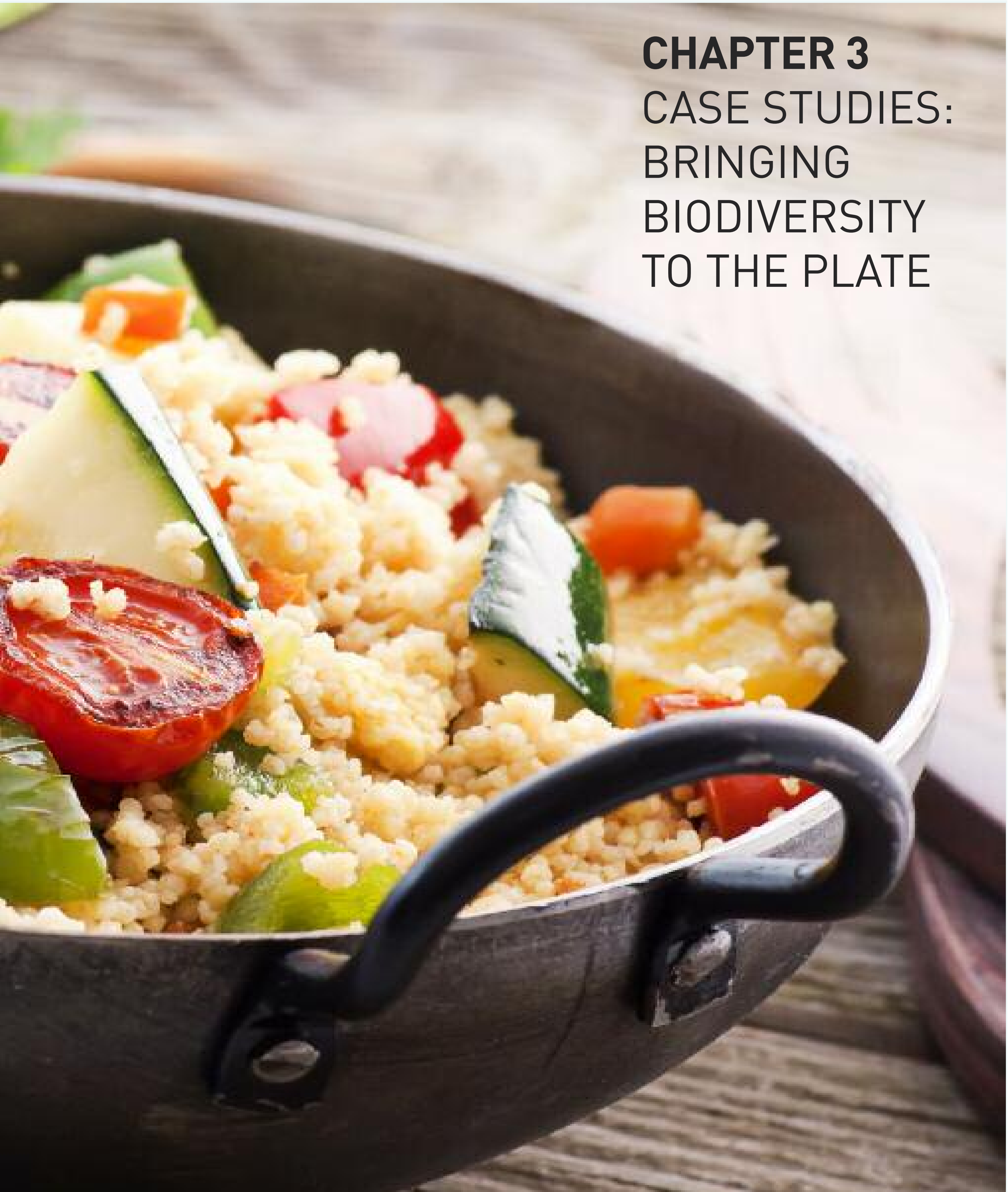
CHAPTER 3 CASE STUDIES: BRINGING BIODIVERSITY TO THE PLATE



BIODIVERSITY AND SUSTAINABILITY OF INDIGENOUS PEOPLES' FOODS AND DIETS

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Abstract

Indigenous Peoples living in their rural homelands and intact ecosystems retain a vast knowledge of biodiversity in food resources. Living in historical continuity over thousands of years implicitly recognizes the sustainability of their local food system. However, recent stresses to cultures and ecosystems, globalization of industrially produced foods, and simplification of diets have created commonalities for Indigenous Peoples for severe financial poverty, discrimination, disadvantage and challenges to nutrition and health. This report summarizes a ten-year programme of research and health promotion with 12 cultures of Indigenous Peoples in different parts of the world. Following methods development for documentation of local food systems of rural Indigenous Peoples, research highlighted a vast diversity in food species and their patterns of use. Dietary measures were used to evaluate improved use of local food resources that were emphasized in programmes and policy developments to sustainably improve diets and food and nutrition security in these areas. Effective cross-cutting strategies were participatory decision-making for research and intervention activities, focus on locally available cultural food species, capacity development and networking, educational activities with youth, and use of media to strengthen local perceptions of local food qualities. The interventions are ongoing, and several have been successful in scaling up their activities to other communities in the regions. Addressing threats to cultural and ecosystem sustainability and improving access to local traditional food will improve use of biodiverse food resources by Indigenous Peoples, enhance dietary quality, and improve sustainable food and nutrition security.

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1. Introduction

Indigenous Peoples are recognized by the United Nations as having historical continuity with ancestral territory and society, and as stewards of vast areas of biodiversity in their rural homelands. There are more than 370 million Indigenous Peoples in 90 countries, who speak more than 4 000 languages (Bartlett *et al.*, 2007; UNPFII, 2009). Sustainability of a local indigenous diet is presumed if a culture has occupied a territory for a very long time in harmony with nature, respecting and learning from the natural world and the bounty it provides to sustain community life and cultural ways of knowing and doing. If a culture survived through history to the present day, the diet was necessarily nutritionally complete; although recognition is given to the constant change and evolution experienced in natural ecosystems.

Our programme has been especially significant in its recognition that Indigenous Peoples in both developed and developing countries are often the most at risk populations within nations for issues related to both undernutrition and overnutrition, because they often experience the most severe financial poverty and disparities in health (Gracey and King, 2009; Reading, 2009). The transition to oversimplification of diets away from food resource diversity generated by healthy ecosystems is a global phenomenon that especially affects Indigenous Peoples dependent on ecosystems that are under stress (UNPFII, 2009).

In this context our research has focused on understanding the foods and diets of Indigenous Peoples in rural territories, and the treasures of knowledge these hold. Specifically, we focused on 12 long-evolved cultures in defined ecosystems in different parts of the world. Our objective has been to inquire into the food biodiversity, to understand the unique species and subspecies/varieties/cultivars known with traditional knowledge and how these continue to be cultivated, hunted, fished or gathered and then prepared and appreciated with cultural knowledge and techniques. The overall goal is to guide the use of this knowledge by communities for nutrition and health promotion activities that improve wellness.

2. Methods

Using participatory research methods created through the Centre for Indigenous Peoples' Nutrition and Environment at McGill University (CINE), Canada (Sims and Kuhnlein, 2003), staff from CINE in cooperation with the Nutrition Division of the Food and Agriculture Organization of the United Nations (FAO) developed a methodology with partners in Asian settings. This provided a framework to food systems documentation, structure to processes for scientific nomenclature, laboratory studies on nutrient composition, and qualitative methods to understand local food meanings and use (Kuhnlein *et al.*, 2006). Subsequently, in cooperation with the Task Force on Indigenous Peoples' Food Systems and Nutrition of the International Union of Nutritional Sciences (IUNS) the methodology was applied and adapted within 12 unique cultural case studies of Indigenous Peoples residing in different rural ecosystems in various global regions: Awajún (Peru), Ainu (Japan), Baffin Inuit (Canada), Bhil (India), Dalit (India, Gwich'in (Canada), Igbo (Nigeria), Ingano (Colombia), Karen (Thailand), Maasai (Kenya), Nuxalk (Canada), and Pohnpei (Federated States of Micronesia). In each area, communities of Indigenous People collaborated with in-country academic partners and CINE for research in two phases: 1) documentation of the food system including use of both local traditional food and imported market-sold food, food species and food component data; and 2) use of this knowledge to implement health promotion interventions using culturally sensitive and environmentally relevant elements of the local food systems. Team members communicated electronically and team leaders met annually over a ten year period (2001–2010) to discuss methods, results and strategies for implementing health promotion policies and activities (Figure 1) (Kuhnlein *et al.*, 2006). Funding from a variety of sources was obtained to develop and implement interventions to improve dietary intake and health by using elements of the diverse food systems of Indigenous Peoples in several of the case studies. Interventions were created with participatory methods with local teams from case studies working with the Nuxalk, Dalit, Gwich'in, Inuit, Ingano, Awajún, Karen and Pohnpei. The Ainu developed an education intervention that stressed cultural revival and traditional knowledge taught to youth.

Figure 1. Case study partners meeting in Bellagio, Italy, in 2008 to discuss research process, results and health promotion strategies (kp studios).

3. Results

Each case study completed a report of their findings and prepared a chapter for a book published and distributed widely by FAO (Kuhnlein *et al.*, 2009). In addition, several colourful food-system posters in recognition of the International Decades of the World's Indigenous Peoples were widely distributed by FAO (FAO and CINE, 2004-06). Eight 20-minute documentary films were created and are posted free on the internet (KP Studios, 2009).

3.1 Diversity of species documented and variation in extent of use

As anticipated, there is an astonishing diversity of species known and used, with up to 380 species used annually within one culture. There is also wide variation in the extent of use of these foods, varying from less than 10 percent to up to 95 percent of daily energy provided by local species in the ecosystem

(Table 1).

Indigenous Group	Energy %	No. of species/ varieties
Awajún (Peru)	93	223
Bhil (India)	59	95
Dalit (India)	43	329
Gwich'in (Canada)	33	50
Igbo (Nigeria)	96	220
Ingano (Colombia)	47	160
Inuit (Canada)	41	79
Karen (Thailand)	85*	387
Maasai (Kenya)	6	35
Nuxalk (Canada)	30*	67
Pohnpei (Micronesia)	27	381

* Estimated for adults.

Table 1. Adult dietary energy as local traditional food and number of species/varieties in the food system.
(Reproduced with permission from: Kuhnlein HV, in: Kuhnlein, Erasmus, Spigelski, 2009, pg 5)

Ways of cultivating, harvesting, processing and preparing the foods for families were shown to be fascinating. However, many species/varieties documented did not have scientific identifications and nutrition composition analyses completed (Kuhnlein *et al.*, 2009).

As shown in Table 1 the locally used food species numbers varied considerably depending on the ecosystem. Team members reported a low of 35 food species used in the arid, drought-prone zones of Kenya where Maasai reside, and up to more than 380 unique food species/varieties documented for tropical rain forests. The Karen in Thailand (387 species) and Pohnpei culture of the Federated States of Micronesia (381 species/varieties), Dalit in Zaheerabad region of India (329 species), Awajún in Peru (223 species) and Igbo of Nigeria (220 species) all had extensive, complex food systems and rich cultural traditions using them. However, the extent of use of species for providing daily energy consumption also varied (Table 1), with up to 100 percent of adult energy from local food resources for the Awajún and Igbo. Research with the Karen, Bhil, Maasai, Pohnpei and Dalit showed that commercial (or donated) refined staples replaced traditional foods in the diet; the Canadian Gwich'in, Inuit and Nuxalk peoples were using less than 45 percent of energy as traditional species with the commercial foods derived primarily from refined wheat flour, fats and sugar. The Ainu in Japan used very little traditional food in their daily diet, and could not recognize all the available species or record the extent of energy consumed from them (Kuhnlein *et al.*, 2009).

3.2 Indigenous Peoples' food and nutrition interventions for health promotion and policy

Eight interventions were developed with diverse resources from within the communities as well as from external sources. Funding and logistic constraints necessitated work with unique small populations where meaningful control groups were not available. This led to before- and after-intervention research designs using both qualitative and quantitative measures. Special considerations were needed to build local cultural pride, develop cross-sectoral planning and action, and create energetic and enthusiastic advocates for community goodwill. All interventions required several years to completion with evaluation documentation, even while the interventions were sustained and continued to build healthy diets in communities (Kuhnlein *et al.*, in press).

3.3 Cross-cutting themes of interventions

Leadership within the nine interventions agreed that activities targeting children and youth were crucial to build long-term change into community wellness. Not only were activities built to improve nutrition and health of young people, but to create the cultural morale and knowledge based in culture and nature for their learning in formal and informal settings. Traditional wildlife animal and plant harvest and agricultural activities based in local traditional crops were important in youth learning in case studies conducted with the Baffin Inuit, Gwich'in, Nuxalk, Inga, Pohnpei, Karen and Dalit. Ainu youth experienced classroom activities in traditional food preparation.

Broad-based education activities took place in intervention communities that stressed the local cultural food diversity and its benefits for understanding the ecosystem as well as for health in harvest, use and human nutrition. First steps were to use knowledge generated in Phase 1 to develop positive attitudes about local traditional food so that case study leaders could then foster behaviours at all levels to increase use of these foods. In the Pohnpei case study, for example, agricultural leaders provided training in agricultural practices and provided seedlings and young trees for planting in yards adjacent to community homes. In the Karen case study, school children were taught how to harvest from the forest, and also how to plant, cultivate and harvest their local traditional agricultural crops in village areas, which was followed by popular activities of harvesting and preparation of meals for their families. In the Gwich'in area, youth in middle school and high school prepared dried caribou meat and shared it with the elders in their community; and in the Inuit project elders made radio programmes that were shared for learning with youth in their school classes. These are just some of the examples showing how communities created their own meaningful activities.

Engagement with government offices was also an important cross-cutting theme. While some case study partners did not have regular communication with government offices, others did. When the communication was fruitful, it contributed a lot to the intervention. For example the Pohnpei case study worked well with ministries responsible for agriculture, health, education, and the public media to further their goals. People knew each other and connected easily. This was possible, in part, because of the pro-active leadership of the project, but also because both the state and national governments were in the same town on the same island in the Federated States of Micronesia. Another example is the good relationships the Karen project had with the Ministry of Health in Kanchanaburi Province, as well as the local border control officers who helped with activities in the schools. There was also good attention given by the Thai royal family to the project, which raised project profile with government agencies throughout Thailand. On the other hand, government offices are not always helpful to Indigenous Peoples if there is conflict over land or other resources and if there is systematic disadvantage based on discrimination; such discrimination is often manifest in lack of access to healthcare in rural areas where Indigenous Peoples live.

Throughout all intervention projects committed community leaders and academics became effective advocates dedicated to the success of the project and responsible for developing the capacity-building activities and empowerment of residents to use the local food systems based in culture to their best advantage. Capacity-building was the hallmark of the Dalit project in the Zaheerabad district of Hyderabad, India, where Dalit women were given opportunities for education, especially in media productions, and in finding education opportunities for their children. This resulted not only in increased literacy, but in building self-worth and commitment to using and showcasing their unique foods in many different ways, such as in culinary food fairs, computer cafes, and film festivals. All projects engaged project assistants to help with food activities and the research foundations of the interventions. A popular activity in most case studies was creation of photo-enhanced information books on the food system to share in schools, public places and to be distributed to village homes. Local assistants, primarily women, were leaders in networking, and in helping others to "learn by doing", and to gain participatory agreements on how to best move the projects forward. The best successes occurred in bringing together the community's social capital in the form of hunters, farmers, fishers, elders, political leaders, teachers and spiritual leaders to advance from the "bottom up" the local cultural principles of what is good food and how to harvest and best use it.

None of the interventions had focus in single nutrient solutions to single nutrient inadequacies. Rather, the strategies employed worked to improve food provisioning from local sources, and to improve dietary biodiversity for all age groups. All projects were in rural areas without access to large markets that stressed industrial food products. When market (store bought) food was discussed, it was in the context of how to increase the demand and supply of nutrient-rich, good quality foods with minimal processing.

4. Discussion

With positive attitudes and confidence that the local food is credibly healthy, local networks in these communities of Indigenous Peoples have developed a wide range of activities to create community empowerment for sustained use and food and nutrition security. However, sustainability of these foods for Indigenous Peoples depends on cultural and ecosystem sustainability. It depends on continued cultural expression; for example, to use food harvesting and appreciation as an avenue in youth education and fitness training, as well as guiding understanding of their natural surroundings. It also depends on ecosystem conservation to protect the food provisioning lands, waters, forests and other essential resources.

Measures of intervention programme success with small populations of culturally defined Indigenous Peoples preclude measurements that depend on large sample sizes and control groups. With the exception of improved underweight, changes in anthropometric measures, whether to improve stunting or reduce obesity, were not found within short time periods, as expected. More importantly, the root causes of being "big" or "small/short" were identified and addressed with expectation for long-term improvements in general community wellness. Measures of improved financial security were found within our case studies to be less important than perceptions of improved community wellness. In fact, in the Thai Karen case study, leaders expressed that "food is a part of happiness", and that it is meaningless to try to measure it with money.

Many policies that fostered improved food and nutrition security were developed, and are discussed more fully in Kuhnlein *et al.* (in press). It is crucial to maintain databases of health statistics that are disaggregated by culture and ethnic groups within nations to identify areas of health risks and to track change. Only by knowing the risks can they be addressed with multisectoral government agencies which logically include those responsible for health, human rights, education, agriculture, culture, commerce, environment and its conservation, energy and transportation – ministries that need to form cooperative partnerships to protect ecosystems and cultures against degradation and loss of biodiversity in both rural and other population areas where Indigenous Peoples live. Respecting and protecting indigenous knowledge and the peoples who hold this knowledge can lead to better understanding of research policies to use the genetic potential for crops to become resistant to pests, heat and drought.

It is well recognized that Indigenous Peoples experience challenges in expressing their human right to adequate food (Knuth, 2009). One serious challenge is that of climate change, which is expected to continue and threaten many ecosystems where Indigenous Peoples live. This then impacts the human rights of Indigenous Peoples who lack the physical, technological, economic and social resources to cope with resulting ecosystem damage which causes risk to biodiversity and sustainability of the diets that can be provisioned from it (Damman, 2010).

5. Conclusions

In all areas where our programme has been in effect, there are several threats to cultural sustainability and to ecosystem sustainability, which in turn threaten the biodiversity of sustainable diets of the resident Indigenous Peoples. Each case study and its intervention have impressive stories of challenges and successes that can inspire communities of Indigenous Peoples everywhere to become proactive in protecting their food systems. By documenting these unique food resources and their cultural and ecosystem requirements, we recognize the imperatives to protect these treasures of human knowledge to benefit Indigenous Peoples and all humankind now and into the future.

Understanding the challenges and successes of improving access to local food and improving dietary intakes and food and nutrition security of rural Indigenous Peoples provides important lessons. While it can be supposed that strategies with any group of disadvantaged people will bring success within a setting of Indigenous Peoples, this is not necessarily so unless the issues of rural inaccessibility, serious discrimination, and respect and protection of cultures and ecosystems that provide wellness are addressed. On the other hand, it is very likely that health promotion lessons based in local food systems that resonate with Indigenous Peoples will find a measure of meaning for practitioners who address public health in any community of disadvantaged people.

6. Acknowledgements

The many hundreds of scholars and community leaders and residents who contributed to the research and its publications represented in this report are sincerely appreciated. Special recognition is extended to Chief Bill Erasmus of the Dene Nation and Assembly of First Nations in Canada for his continuing inspiration, encouragement and support. The extensive collaboration with Dr Barbara Burlingame is acknowledged with thanks, as are the collaborators and project leaders associated with the International Union of Nutritional Sciences Task Force on Indigenous Peoples' Food Systems and Nutrition. Special appreciation is extended to the Canadian Institutes of Health Research and The Rockefeller Foundation's Bellagio Center.

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REVISITING THE VITAMIN A FIASCO: GOING LOCAL IN MICRONESIA

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Abstract
The term "vitamin A (VA) fiasco" refers to the global programme for universal VA supplementation, which has been challenged for its validity and wisdom. The Federated States of Micronesia (FSM) situation presents an example where VA supplementation has vied with food-based approaches for resources. The FSM has experienced many lifestyle changes since the 1970s, including a shift to imported processed foods and neglect of traditional foods. This led to serious health problems, including VA deficiency, diabetes, heart disease and cancer. In 1998 efforts were initiated to identify FSM foods that might alleviate VA deficiency. This led to discovering a yellow/orange-fleshed banana variety, Karat, containing 2 230 μg/100 g of the provitamin A carotenoid beta-carotene, 50 times more than in white-fleshed bananas. Other Micronesian yellow- and orange-fleshed carotenoid-rich varieties of banana, giant swamp taro, breadfruit and pandanus were later identified, also containing rich contents of vitamins and minerals. In a global health study led by the Centre for Indigenous Peoples' Nutrition and Environment, the Pohnpei, FSM traditional food system was documented. A two-year community-based, interagency, intervention was implemented, focused on increasing local food production and consumption. Multiple methods were used, including awareness, workshops, horticulture, cooking classes, mass media, posters, print materials, postal stamps, youth clubs, school activities, farmers' fairs, competitions, email and slogans: "Go Yellow" and "Let's Go Local". Results showed an increase in banana and taro consumption, varieties consumed, and improved attitudes towards local food. Carotenoid-rich banana varieties including Karat, which had not previously been marketed, became regular market items. Local food take-outs not previously sold became common sale items. The campaign stimulated great interest as an awareness success in FSM and throughout the region, stimulating interest to applying this approach to other Pacific islands. The campaign could, however, have a greater impact with greater allocation of resources to this food-based approach.

1. Introduction

1.1 Vitamin A fiasco

The term "the vitamin A fiasco" as discussed by Latham (2010) refers to the large global programme for universal VA supplementation, which has been challenged for its validity and wisdom. The rational of this programme was to decrease overall child mortality, but the article shows the weak scientific basis for this. No study has shown the proof of success of the vitamin A supplementation programmes. The programme has utilized huge amounts of funds in 100 countries. As funds were allocated to the vitamin A programme, this blocked food-based approaches for improving vitamin A status. This has also taken place in Micronesia, where there are limited resources plus the mentality that once the vitamin A supplements have been given, the problem has been dealt with.

This paper presents a success story of food. The areas covered are:

- How we first carried out food composition studies on Micronesian foods and identified yellow- and orange-fleshed varieties of local foods rich in provitamin A carotenoids and other nutrients that could be promoted to alleviate the serious problems of vitamin A deficiency and other health problems in Micronesia.
- How we developed our food-based "Go Local" programme with the aim to improve nutrition and health, and showing success in a target community.

1.2 Background to the situation in the Federated States of Micronesia

The Federated States of Micronesia (FSM), total population of 102 624, comprises four states: Pohnpei, Chuuk, Yap and Kosrae, altogether with 607 islands (FSM, 2010).

Since the 1970s, there have been great lifestyle and dietary changes in Micronesia. The traditional local foods include the starchy staples, including breadfruit, banana, taro, yam and pandanus, along with coconut, fish and seafood, and various fruits. There has been a great diversity of these staple foods. For example, there are 133 breadfruit, 171 yam, banana, and 24 giant swamp taro varieties (Raynor, 1991).

However in recent years there has been a shift to nutrient-poor imported processed foods, such as refined white rice, flour, sugar, fatty meats and other processed foods (Englberger *et al.,* 2003d).

Imported white rice, which is often not enriched, has become a major staple in the diet. This has changed the nutrient intake of the population as rice also contains no provitamin A carotenoids and is low in fibre, whereas local staples contain at least some carotenoids and are rich in fibre. Previously there was also little known about the differences in nutrient content between the many varieties of the staple crops as few food composition studies had been carried out on FSM foods.

The shift from traditional foods to imported processed foods and lifestyle changes in FSM led to a serious problem of vitamin A deficiency, which causes vision problems, increased infection and mortality. The first documentation of vitamin A deficiency in FSM was in Chuuk (Lloyd-Puryear *et al.,* 1989). Of 60 randomly selected children, 12 percent had night blindness and 5 percent had Bitot's spots, far exceeding the World Health Organization cut-offs for a public health problem (WHO, 1995). That study maintained that vitamin A deficiency was an emerging problem as there was no term for night blindness in the local language and old people did not know of the problem.

Following the identification of the problem in Chuuk, studies were done in the other three states, showing that over half of FSM under-5-year olds had vitamin A deficiency (Yamamura, 2004).

To alleviate the vitamin A deficiency problem, green leafy vegetables were first promoted as these vegetables are easy to grow and are rich in beta-carotene, the most important of the provitamin A carotenoids. Once consumed, beta-carotene is converted to vitamin A in the body. However, interviews with local members of the community revealed that green leafy vegetables had not been consumed previously as traditional foods, were not well accepted and were considered as food for the pigs.

It was clear that if people had not consumed green leafy vegetables in the past and did not have vitamin A deficiency, there must have been some traditional foods that had protected people against that health problem. This question led to the study to identify those foods that protected Micronesians from vitamin A deficiency in the past and could also alleviate the problem currently.

2. Methods

Overall an ethnographic participatory community-based and interagency approach was taken in assessing the foods, documenting the traditional food system and gaining insight on how to improve the situation. As vitamin A deficiency was diagnosed in the 1990s, efforts were first made in identifying local foods that are rich in provitamin A carotenoids or vitamin A and would alleviate vitamin A deficiency.

The results of the analyses were then used to promote the local foods and an overall approach was developed to awaken interest in local foods and the traditional food system. This was helped greatly by the involvement with a global health study led by the Centre for Indigenous Peoples' Nutrition and Environment. Pohnpei was selected as one of the 12 case studies in the CINE programme for documenting and promoting traditional food systems. Specific guidelines were followed (Kuhnlein *et al.,* 2005).

3. Results and discussion

3.1 Analyses of local foods

Karat, a yellow-fleshed variety of banana, was analysed and found rich in beta-carotene, the most important of the provitamin A carotenoids. Foods rich in provitamin A carotenoids protect against vitamin A deficiency (McLaren and Frigg, 2001). Karat contained up to 2 230 µg beta-carotene/100 g (Englberger *et al.,* 2006). An orange-fleshed banana, Utin Iap, contained 8 508 µg beta-carotene. This compares to 30 µg beta-carotene for common banana. It was shown that the carotenoid content was greater in those varieties with the greater yellow or orange flesh colouration. This led to the "Yellow Varieties" campaign and the slogan "Go Yellow". Both slogans helped to brand the movement and provide further interest.

A series of studies were conducted to analyse other banana, giant swamp taro, breadfruit and pandanus varieties, with potential for rich carotenoid content due to the yellow or orange flesh colouration. The results showed that the varieties with greater yellow or orange flesh colouration did have a greater carotenoid concentration (Englberger *et al.*, 2003a,b,c, 2008, 2009a, 2010d). These foods were also shown to be rich in vitamins, minerals including zinc, calcium, iron, and fibre.

Epidemiological studies also show that carotenoid-rich foods protect against cancer, heart disease and diabetes (WCRF/AICR, 2007; Kritchevsky, 1999; Coyne *et al.,* 2005). These non-communicable diseases have become the major health problems in the FSM. For example, in Pohnpei, 32 percent of adults now are afflicted with diabetes (WHO, 2008). Thus, the yellow-fleshed, carotenoid-rich foods and varieties can play a double role. They can help to protect against vitamin A deficiency disorders and also help against these non-communicable diseases.

3.2 Formation of a non-governmental organization

The Island Food Community of Pohnpei (IFCP) was chartered as a non-governmental organization in 2004, and adopted the Go Local slogan in 2005. With the formation of an organization devoted entirely to the promotion and research of local foods, important progress was made in going forward with local food promotion.

3.3 GO LOCAL slogan

One of the important parts of the intervention to increase production and consumption of local foods was the reviving of the slogan "Go Local", introduced first by a government officer Bermin Weilbacher in the 1980s (Englberger *et al*., 2010c). As many people were already familiar with the term and it captured the many broad aspects of what local foods involve, it caught on quite quickly. It provided "project branding" and gave a unifying aspect to the campaign.

The term refers to a food-based approach to improving health, and increasing food production and consumption. The term was changed slightly to "Let's go local" in order to soften the term and make it a group activity. Billboards, t-shirts, songs and promotional pens were made to present the slogan and it became well known and popular.

The term also refers to many other important benefits. This led to the development of an acronym "CHEEF" to describe the chief or many benefits of local food. These are Culture, Health, Environment, Economics and Food security. Thus, the campaign not only encouraged to "go local" but also emphasized the many reasons on why to go local.

3.4 Involvement with the CINE-led global health project

As part of the global health study led by the Centre for Indigenous Peoples' Nutrition and Environment, the traditional food system in Pohnpei, FSM, was documented (Englberger *et al.,* 2009b) and promoted (Englberger *et al.,* 2010a). A target community was selected, Mand Community, along with these criteria: around 500 in population, rural, accessible and willingness to participate. The first phase focused on the documentation (around three months) of the traditional food system, which is documented in Chapter 6 of the published book by CINE and Food and Agriculture Organization of the United Nations (Kuhnlein *et al.,* 2009; Englberger *et al.,* 2009b).

The second phase focused on the implementation of a two-year community-based, interagency, participatory intervention, aiming at increasing local food production and consumption.

Multiple methods were used, including awareness, workshops, horticulture, cooking classes, mass media, posters, print materials, on postal stamps, youth clubs, school activities, farmers' fairs, competitions, email (Englberger *et al.,* 2010b), slogans: "Go Yellow" and "Let's Go Local", and the use of local food policies.

The second phase also included the evaluation (Kaufer *et al.,* 2010).

The project showed these successes of promotion of local food:

- Increase in the frequency of consumption of banana and giant swamp taro.
- Increase in the number of banana varieties planted.
- Increase in dietary diversity, in particular, vegetables.
- A positive change in attitude towards local foods in the community.

3.5 Other documentations of island foods

Two chapters, one on banana and one on taro, were written for the book titled "Ethnobotany of Pohnpei: Plants, People and Island Culture" (Balick *et al.,* 2009), highlighting the rich content of the many varieties of banana and taro. The book also highlighted our involvement in the CINE-led case study and the "go local" campaign.

3.6 Local food policies

Local food policies were defined broadly and included community policies to use only local foods at meetings and workshops held by the Island Food Community of Pohnpei and by the community in Mand. Later this further developed into a policy that Mand Community adopted to ban soft drinks in their community meetings. Other Pohnpei communities also adopted bans on soft drinks in their events, including the Pingelapese Peoples' Organization, Inc. and the Kosrae Kolonia Congregational Church. A national policy was established with the FSM President signing a food security proclamation that all FSM national events use local food at their events. In order to help promote rare yellow- and orange-fleshed banana varieties, a general policy was also adopted by IFCP to buy just those varieties for their meetings and events, in place of the white-fleshed banana variety that is most commonly consumed in Pohnpei as a ripe eating banana.

4. Lessons learned

Our lessons learned were many. Some of these were:

- Community- and interagency-based approach was important.
- Walk the Talk: To promote local foods, it was essential to use local foods.
- Repetition: Messages needed to be repeated many times.
- Mass media (radio, newspaper, email, videos, television) helped a lot.
- Face-to-face encounters were also important.
- Multiple methods: It is important to use a variety of methods.
- Slogans (Go Local and Go Yellow): These are important for branding and unity.
- Scientific approach: Community people wanted a scientific approach.
- Food analysis was critical to establishing the value of their local food.
- Assessment and evaluation of the work was important to show progress.
- Acknowledgement of everyone's involvement increased motivation and interest.
- Local food policies: These were important and are still being further developed.

Many people were not aware of how their diet and physical activity affected their health, and innovative methods were needed to help them gain this understanding. On the other hand, many people were more interested in the other values of local foods. Protecting cultural identity through the preservation of the traditional food system was very important for many people.

The economic, environmental and food security benefits were important as well to help put forth the broad benefits that locally grown food provide. The use of the CHEEF acronym was very helpful for explaining why we should "go local", namely for Culture, Health, Environment, Economics and Food security. In addition, and perhaps most important of all, it was important that the leaders of the activity were passionate about their work, that the activities planned were fun and that people carrying out the activities also be involved in planning them.

5. Conclusions

To conclude, a food-based approach has many advantages to vitamin A supplementation in alleviating vitamin A deficiency in Micronesia. Heed should be taken of the paper by Latham *et al*. (2010) referring to the universal vitamin A supplementation programme as a "fiasco" and the need to question its wisdom and validity. Vitamin supplementation programmes can block food-based approaches.

It should always be remembered that whole foods can provide a wealth of nutrients, whereas supplementation programmes may focus only on one or a few nutrients. Food-based approaches and local foods are important for many benefits. The "CHEEF" acronym stresses the benefits of local food, which are: Culture, Health, Environment, Economics and Food security. So let's support food-based approaches and let's go local!

Acknowledgements

Warm thanks are extended to our many partners and support agencies, including the FSM National and State Governments, College of Micronesia-FSM, Mand and other communities, V6AH Radio, Kaselehlie Press, local NGOs and businesses, US Forestry/United States Department of Agriculture, Secretariat of Pacific Community, Center for Indigenous People's Nutrition and Environment (CINE), GEF Small Grants Programme, Papa Ola Lokahi, Pacific.German Regional Forestry Project, PATS Foundation, US Peace Corps Micronesia, Global Greengrants Fund, Bioversity International, CDC/UNICEF, Sight and Life, Food and Agriculture Organization of the United Nations, Japan Embassy, Japanese JICA, Australia, New Zealand Embassy, and German Embassy, University of Queensland, University of Adelaide, Emory University, University of Hawaii, University of Sydney, University of Arizona, Institute of Applied Sciences/University of South Pacific, New York Botanical Garden, and Project Eden. Warm thanks are also given to Professor Harriet Kuhnlein for her review of the manuscript.

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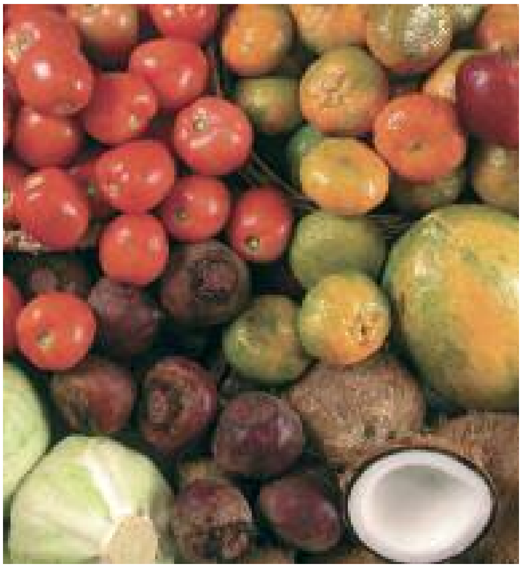

EXPLORING NEW METRICS: NUTRITIONAL DIVERSITY OF CROPPING SYSTEMS

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This book article is adapted from Remans et al. 2011 Assessing nutritional diversity of cropping systems in African villages. PLos ONE 6 (6) e21235

Abstract

Historically, agricultural systems have been assessed on the basis of a narrow range of criteria, such as profitability or yields. Yet, these metrics do not reflect the diversity of nutrients provided by the system that is critical for human health. In this study we take a step to demonstrate how ecological tools can play a role in addressing nutritional diversity as an overlooked ecosystem service of agricultural systems.

Data on edible plant species diversity, food security and diet diversity were collected for 170 farms in three rural settings in sub-Saharan Africa. Nutritional FD metrics were calculated based on farm species composition and species nutritional composition. Iron and vitamin A deficiency were determined from blood samples of 90 adult women.

Nutritional FD metrics summarized the diversity of nutrients provided by the farm and showed variability between farms and villages. Regression of nutritional FD against species richness and expected FD enabled identification of key species that add nutrient diversity to the system and assessed the degree of redundancy for nutrient traits. Nutritional FD analysis demonstrated that depending on the original composition of species on farm or village, adding or removing individual species can have radically different outcomes for nutritional diversity. While correlations between nutritional FD, food and nutrition indicators were not significant at household level, associations between these variables were observed at village level.

This study provides novel metrics to address nutritional diversity in farming systems and examples of how these metrics can help guide agricultural interventions towards adequate nutrient diversity. New hypotheses on the link between agrodiversity, food security and human nutrition are generated and strategies for future research are suggested calling for integration of agriculture, ecology, nutrition, and socio-economics.

1. Introduction

While great strides in reducing hunger through increases in agricultural productivity have been made worldwide, more than 900 million people are undernourished (FAO, 2010), over 2 billion people are afflicted by one or more micronutrient deficiencies (WHO, 2007) and over 1 billion adults are overweight (WHO, 2003). In addition to producing sufficient calories, a major, often overlooked challenge in agriculture and food systems is to provide an adequate diversity of nutrients necessary for a healthy life. A human diet requires at least 51 nutrients in adequate amounts consistently (Graham *et al.*, 2007). It has been argued that changes in agricultural production systems from diversified cropping systems towards ecologically more simple cereal-based systems have contributed to poor diet diversity, micronutrient deficiencies and resulting malnutrition in the developed as well as developing world (Graham *et al.*, 2007; Frison *et al.*, 2006; Negin *et al.*, 2009; Welch and Graham, 1999). Success of agricultural systems has historically been evaluated primarily on metrics of crop yields, economic output and cost-benefit ratios (IAASTD, 2009). Yet, these metrics do not reflect the diversity of nutrients provided by the system that is critical for human health. In this study we take a step to demonstrate how ecological tools can play a role in addressing nutritional diversity as an overlooked ecosystem service of agricultural systems.

In nutritional sciences, several methods have been developed that look beyond the single nutrient or food item to capture the broader picture of diet diversity (FAO-FANTA, 2008; Drescher *et al.*, 2007; Waijers *et al.*, 2007; Rose *et al.*, 2008; Kennedy *et al.*, 2010). Count measures are frequently applied to assess diet diversity, where the number of consumed food items and food groups is recorded (FAO-FANTA, 2008). Diet quality indices have also been developed that take into account consumption pattern and nutritional composition of food items

(Drescher *et al.*, 2007; Waijers *et al.*, 2007). Numerous studies have shown that nutritional quality of the diet improves as a higher diversity of food items or food groups is consumed (Shimbo *et al.*, 1994; Hatloy *et al.*, 1998; Moursi *et al.*, 2008; Steyn *et al.,* 2006; Kennedy *et al.*, 2005) and increased diet diversity has been associated with positive health outcomes such as lower rates of stunting, mortality and incidence of cancer (Arimond and Ruel, 2004; IFPRI, 1998; Kant *et al.*, 1993; Slattery *et al.*, 1998; Levi *et al.*, 1998; Bhutta *et al.*, 2008).

Approaches to quantifying diet diversity in nutrition research have direct analogues to approaches to quantifying biological diversity in ecology. Counting total number of food items or food groups is analogous to counting species richness and functional group richness. In ecology, there is increasing interest in quantitative measures of functional diversity, which take advantage of the wealth of information available on species' traits, particularly for plants, to overcome some of the drawbacks or lack of sensitivity of the simpler measures of diversity (Diaz and Cabido, 2001). Among these quantitative approaches is the functional diversity metric FD (Petchey and Gaston, 2002). FD is a metric that reflects the trait distinctiveness of a community and the degree of complementarity in traits of species within a community.

Here we explore a novel nutritional functional diversity metric (nutritional FD). The nutritional FD metric is based on plant species composition on farm and the nutritional composition of these plants for 17 nutrients that are key in human diets and for which reliable plant composition data are available (Table 1). We use this FD metric to summarize and compare the diversity of nutrients provided by farms in three sites in sub-Saharan Africa (SSA).

The nutritional FD value increases when a species with a unique combination of nutrients is added to a community, and decreases when such a species is lost. Changes in the presence or absence of species with identical nutritional composition do not change the value of FD, however such redundancy provides a buffer, in case other species are lost from the system. For example, changing climate conditions could prevent some plant species from being successfully cultivated, so having several species with similar nutritional composition means that such a shift in crop species composition would not necessarily impact the overall nutritional diversity at the farm or community level. The nutritional FD metric thus reflects the diversity of nutrients provided by the farm and the complementarity in nutrients among species on a farm or community.

Table 1. Nutrients and nutrient groups taken into account for calculation of FD metrics.

Macronutrients	Minerals	Vitamins
Protein	Calcium (Ca)	Vitamin A
Carbohydrates	Iron (Fe)	Vitamin C
Dietary fibre	Potassium (K)	Thiamin
Fat	Magnesium (Mg)	Riboflavin
	Manganese (Mn)	Folate
	Zinc (Zn)	Niacin
	Sulphur (S)	

From the 51 required nutrients for human diets, 17 nutrients that are key for human diets and for which reliable plant composition data were available in the literature were selected. Because plants are not a proven source for vitamin B12 and vitamin D, these were not included.

The three sites examined here, Mwandama in Malawi, Sauri in Kenya, and Ruhiira in Uganda, are part of the Millennium Villages Project (MVP), where food insecurity and undernutrition rates are high (Sanchez *et al.*, 2007; MVP, 2010; Nziguheba *et al.*, 2010). A principal goal of the MVP is to improve food security and nutrition through a set of interventions recommended by the United Nations Millennium Project Hunger Task Force (UN Millennium Project, 2005). The sites represent distinct but representative agro-ecosystems of SSA (Table 2), with maize (Mwandama, Sauri) or banana (Ruhiira) as the staple crop. Subsistence farming is the main livelihood strategy for over 75 percent of the households in these sites (Sanchez *et al.*, 2007; MVP, 2010; Nziguheba *et al.*, 2010). On average 50 percent of food consumed in the household comes from own production and 75 percent of food consumed in the village comes from production within the village (Table 2).

In this study we explore how nutritional FD metrics can provide insights in nutrient diversity of farming systems and can have potential to guide agricultural management. Data on plant species diversity, food security and diet diversity were collected for plots and home gardens of 170 farms in Mwandama, Sauri and Ruhiira and iron and vitamin A deficiency was determined from blood samples for 30 adult women per village. Four nutritional FD metrics were calculated: FDtotal describing diversity for all 17 nutrients of Table 1, FDmacronutrients for the four macronutrients, FDminerals for the seven minerals and FDvitamins for the six vitamins. Differences between farms and villages for species richness, nutritional FD, household food and health indicators were analysed as well as relationships between these different indicators.

Table 2. Site characteristics.

	Malawi, Mwandama	**Kenya, Sauri**	**Uganda, Ruhiira**
Farming system and Agro-ecological zone	Cereal root-crops mixed Subhumid Tropical	Maize mixed Subhumid tropical	Banana-based Highland perenial
Major crops	Maize	Maize, Beans	Banana
Rainfall pattern and annual average (mm)	Unimodal 1139	Bimodal 1800	Bimodal 1050
Altitude (m above sea level)	900-1200	1400	1350 - 1850
Average area cropped per household (ha)	1.0	0.6	1.9
Average % of food consumed by the household that comes from own production (calculated in $ values)	46%	35%	69%
Average % of food consumed in the village that comes from production in the village (calculated in $ values)	70%	75%	82%
Dominant soils and fertility conditions loam	Rhodustalfs, loamy to clayey	Rhodic Hapludox, clayey	Rhodic Hapludox and Acrisols, sandy clay
Soil pH	5.25 (± 0.60)	5.74 (± 0.37)	5.45 (± 0.85)
Soil Effective Cation Exchange Capacity (ECEC)	5.74 (± 2.34)	7.03 (± 1.96)	13.63 (± 4.34)
Soil % Nitrogen (N)	0.079 (± 0.026)	0.121 (±0.031)	0.260 (± 0.066)
Soil % Carbon (C)	1.098 (± 0.415)	1.461 (±0.332)	3.078 (± 0.742)
Soil C/N ratio	13.91 (± 2.18)	12.39 (±2.20)	11.96 (± 1.27)

Soil values represent average scores ± standard deviation based on 60 samples [29, 65]

2. Methods

2.1 Research sites

The Mwandama village cluster is located in the southern Zomba district of Malawi and covers an approximate population of 35 000 people. The region once characterized by native Miombo woodlands is now intensively cultivated. Smallholders grow mainly maize, pigeon peas, cassava and groundnuts, while commercial estates produce tobacco and maize. Livestock management is practised on a small scale and is restricted to chicken and goats.

The Sauri cluster is located in the Kenyan highlands in the western Nyanza Province and has a farm community of 63 500 people. The main occupations are subsistence farming, consisting primarily of maize, sorghum and cassava, and animal husbandry, including goats, chickens and cattle.

The Ruhiira cluster is situated in the Isingiro district in the hilly, dissected terrain of southwest Uganda and has a population of approximately 43 056 people. The agricultural system is predominantly a mixed system with livestock and cultivation of annual and perennial crops. The main crop is banana, which covers approximately 30 percent of the total cropland.

Further site characteristics are outlined in Table 2 (Sanchez *et al.*, 2007; MVP, 2010; Nziguheba *et al.*, 2010).

2.2 Sample selection and data collection

A random sample of 50 to 60 farms per site was selected based on demographic and geographic MVP data for 300 previously randomly selected households per cluster. For Ruhiira and Mwandama data for 60 farms were collected during June–September of 2009. For Sauri data for 50 farms were collected during November of 2009. The study procedures, purpose, risks and benefits were explained to participants during the informed consent process. The study received ethical approval from the Institutional Review Board at Columbia University.

2.3 Documentation of species diversity

For each of the 170 farms, all plots, including home gardens, cultivated by the household, were sampled to document all crop, plant and tree species, with different species and varieties according to local definitions. Plant species were confirmed with the help of local botany studies (Maundu *et al.*, 1999; Maundu *et al.*, 2005; Chewya and Eyzaguirre, 1999; Smith and Eyzaguirre, 2007; NRC, 1996, 2006, 2008). In addition, it was noted if these plants were edible and consumed by the household. Only plants that were edible and consumed in the village were considered for this study.

2.4 Nutritional trait data of plants

A database of plant nutritional composition data was developed based on existing studies and databases. When different parts of certain plants were consumed, both parts were listed and taken into account in further calculations. The nutritional composition data were standardized and weighted by converting values to the percentage of the Dietary Reference Intake (DRI) (NAS, 2009) for the specific nutrient provided by 100 g of the consumable product. So, for each nutrient, percentage of DRI provided by 100 g of that plant species were the values used to calculate the FD scores. Seventeen nutrients were selected based on data availability and the essential role they play in human diets (Table 1).

2.5 Calculation of diversity metrics

Species richness was defined by the number of identified and previously described edible species per farm. Petchey and Gaston's FD (Petchey and Gaston, 2002) was used as a measure of nutritional functional diversity, with 17 nutrients from 77 crops (Figure 1).
Functional diversity metrics begin with two data matrices: 1) a species by trait matrix, and 2) a farm or site by species matrix (Petchey *et al.*, 2009). In the method

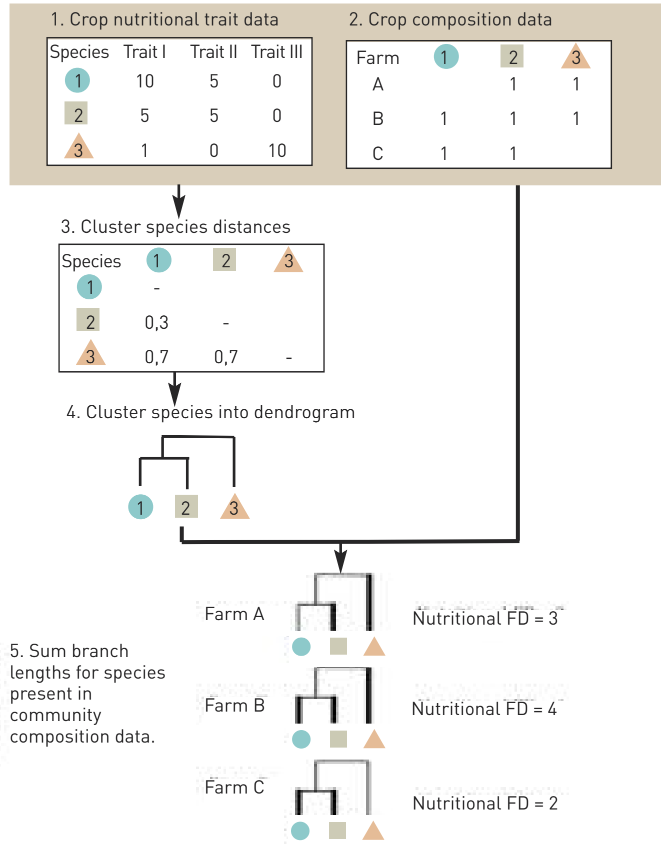

Figure 1. Schematic model of how to assess nutritional functional diversity.
Two data sets are required: a species by trait matrix (1), and a farm or site by species matrix (2). From the species x trait matrix, the multivariate distances between crop species are calculated (3), where distance is a function of distinctness in nutrient composition and content. The distances between species are used to cluster species into a dendrogram (4). Based on the crop species present in a given farm, the branch lengths of the dendrogram are summed (5). Example Farms A and C illustrate how nutritional functional diversity can differ even when species richness is identical, depending on the nutritional distinctiveness of the crop species present.

we used here, the species x trait matrix is used to calculate the multivariate distances between crop species, where distance between a pair of species determined by the distinctness in nutrient composition and content. Then the distances between species are used to cluster species into a dendrogram, which reduces the dimensionality of the diversity metric calculation. Finally, based on the crop species present in a given farm, the branch lengths of the dendrogram are summed, to give the FD value (Figure 1).

In the crop nutritional data set we use here, the species x trait matrix is composed by the percentage of DRI for a specific nutrient. The community composition matrix contains the presence or absence of each crop species for each of the 170 farms. We calculated nutritional FD in four ways: using all 17 nutrients, using just the four macronutrients, using the six vitamins, and using the seven minerals (Table 1), resulting in four respective FD metrics: FDtotal, FD-macronutrients, FDminerals and FDvitamins. Results were scaled by the maximum values to range from 0 to 100 for each FD metric separately.

2.6 Functional redundancy and observed versus expected FD

We assessed the degree of functional redundancy by simulations that model observed versus expected functional diversity for a given species richness (Figure 2) (Flynn *et al.*, 2009).

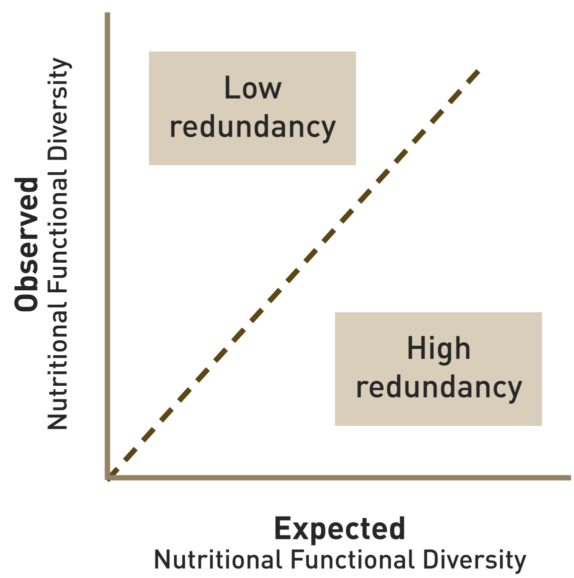

Figure 2. Schematic model to assess degree of redundancy by modelling observed versus expected functional diversity for a given species richness.
If a set of communities has a large range of species richness, but shows little variation in functional diversity, then the species pool in that set of communities has high functional redundancy. In contrast, a set of communities with low functional redundancy may exhibit large changes in functional diversity with only small changes in species richness.

To calculate "expected FD" scores, we used a simulation approach to create a null distribution of FD values for the observed number of species. Holding species richness constant for each of the 170 households, we randomly selected species without replacement from the species pool (the total number of species in the study) to calculate a null FD value for each household. We repeated this 5 000 times to produce a distribution of null values and tested whether the observed FD for each household was significantly higher or lower than the null FD distribution, at $\alpha = 0.05$ (Flynn *et al.*, 2009). For this study, "expected FD" is thus the mean of the functional diversity calculated from many possible species combinations for a particular number of species.

This approach allows us to determine if changes in FD across households simply reflect species richness, or if species composition and trait diversity vary in other ways, e.g. with village or other factors. If a set of communities has a large range of species richness, but shows little variation in functional diversity, then the species pool in that set of communities has high functional redundancy (Figure 2). That is to say, many species share similar traits and the loss of a few species has little impact on functional diversity. In contrast, a set of communities with low functional redundancy may exhibit large changes in functional diversity with only small changes in species richness (Figure 2) (Flynn *et al.*, 2009).

2.7 Household food indicators

Recommendations of the Food and Nutrition Technical Assistance (FANTA) project were used to develop questionnaires for the months of inadequate household food provisioning (MIHFP, range 0–12; adapted from months of adequate household food provisioning (Bilinsky and Swindale, 2007), household food insecurity access scale (HFIAS, range 0–21) (Coates *et al.*, 2007) and household diet diversity score (HDDS, range 0–15) (FAO-FANTA, 2008) based on a 24-hour recall for consumption of 15 food groups: cereals; vitamin A rich vegetables and tubers; white tubers, roots and plantains; green leafy vegetables; other vegetables; vitamin A rich fruits; other fruits; legumes and nuts; oils and fat; meat; fish; eggs; milk; sweets; spices and tea (FAO-FANTA, 2008). The surveys were first pre-tested and adapted to local conditions and language.

2.8 Iron and vitamin A deficiency

Individual serum samples were collected from 30 women between the ages of 13 and 49 per site (90 in total) to determine iron and vitamin A deficiency.

Iron was measured by a colorimetric assay using the Hitachi 917 analyser (Roche Diagnostics, Indianapolis, IN). Under acidic conditions, iron is liberated from transferrin. Ascorbate reduces the Fe^{3+} ions to Fe^{2+} ions, which then react with FerroZine re-agent to form a coloured complex. The colour intensity is directly proportional to the iron concentration in the sample and is measured photometrically. Iron at the concentration of 46, 93 and 138 ug/dL has a day-to-day variability of 1.8%, 1.1% and 0.6%, respectively. Iron deficiency was defined as a level less than 15 ng/mL (FAO-WHO, 1988). The levels of vitamin A were measured by high performance liquid chromatography (Shimadzu Corporation, Kyoto, Japan). Vitamin A is de-proteinized from the serum/plasma sample using ethanol and extracted with hexane. The extract is dried, re-dissolved with ethanol and injected into the chromatograph. Retinyl acetate is used as the internal standard. This assay is standardized using calibrators from the National Institute of Standards and Technology. The minimum required volume for this assay is 150 microlitres. Vitamin A deficiency was defined as a level $\leftarrow$ 20 micrograms/dL (FAO-WHO, 1988).

All calculations, as well as general linear models and analysis of variance, were done in the statistical programming environment R (2.11.0, www.r-project.org).

Table 3. Indicator outcomes per site

		Malawi, Mwandama	Kenya, Sauri	Uganda, Ruhiira	p-value
Edible plant diversity in village	Edible species richness of village (number of unique species for that site)	42 (11)	49 (11)	55 (13)	
Edible plant diversity per household farm	Edible species richness	11.15 ± 3.66	15.22 ± 4.29	18.25 ± 4.82	←0.001
	Nutritional FDall [0–100]	49.25 ± 17.96	64.56 ± 16.32	68.44 ± 15.82	←0.001
	Nutritional FDmacronutrients [0–100]	46.73 ± 9.75	52.7 ± 13.15	72.23 ± 14.54	←0.001
	Nutritional FDminerals [0–100]	32.21 ± 10.56	52.52 ± 16.14	70.88 ± 16.2	←0.001
	Nutritional FD vitamins [0–100]	41.97 ± 24.48	46.91 ± 17.92	45.78 ± 18.08	0.41
Household food indicators	HHDDS	7.57 ± 2.58	8.22 ± 2.05	9.2 ± 3.18	←0.001
	HHFIS	11.65 ± 5.80	7.62 ± 5.01	10.27 ± 4.96	←0.001
	MIHFS	4.37 ± 2.27	2.56 ± 2.18	3.97 ± 1.67	←0.001
Nutritional health indicators	Vit A deficiency women	0.00%	3.30%	6.70%	0.563
	Fe deficiency women	23.30%	6.70%	6.70%	←0.001

Values represent total number for indicators at the village level and average scores for indicators at the household (= farm) or individual level ± standard deviation. P-values are shown for ANOVA test of village effect on farm/household/individual level indicators. HHDDS: Household Diet Diversity Score; FIS: Household Food Insecurity Score, MIHFS: Months of Inadequate Household Food Supply.

3. Results

3.1 Species diversity

Across the 170 farms of the three sites, a total of 77 edible, previously described plant species were identified. Twenty-seven of these 77 species were common among all three sites. The average number of edible species per farm differs significantly between villages, ranging from 11 in Mwandama to 18 in Ruhiira (Table 3).

Farm species richness was found to be independent from farm landholding size (r2 = -0.0017, p = 0.366), also when corrected for village. The five most commonly grown crops across all three sites are bananas (on 93% of the farms), maize (91%), beans (75%), cassava (75%) and mango (69%). Examples of unique species for one of the sites include several green leafy vegetables such as *Corchorus olitorius* (apoth) and *Crotalaria brevidens* (mito) for Sauri in Kenya; tamarillo or tree tomato (*Solanum betaceum*) and some spices, e.g. ginger and cardamom, for Ruhiira in Uganda; certain fruits such as peaches, figs and pomegranates for Mwandama in Malawi.

3.2 Nutritional FD and relationship with species richness

Four nutritional FD metrics (FDtotal, FDmacronutrients, FDminerals and FDvitamins) were calculated for each of the 170 farms (Table 3). This approach allows us to investigate the nutritional diversity across all nutrients and within each of the major nutrient groups. For three out of these four FD metrics, average values for farms differ significantly between the sites (p←0.001) (Table 3), with equivalent values only for FDvitamins (p=0.41). Similar to species richness, all FD metrics were found to be independent from farm landholding size (p→0.1).

Figure 3 plots FD values against species richness for each of the 170 farms.

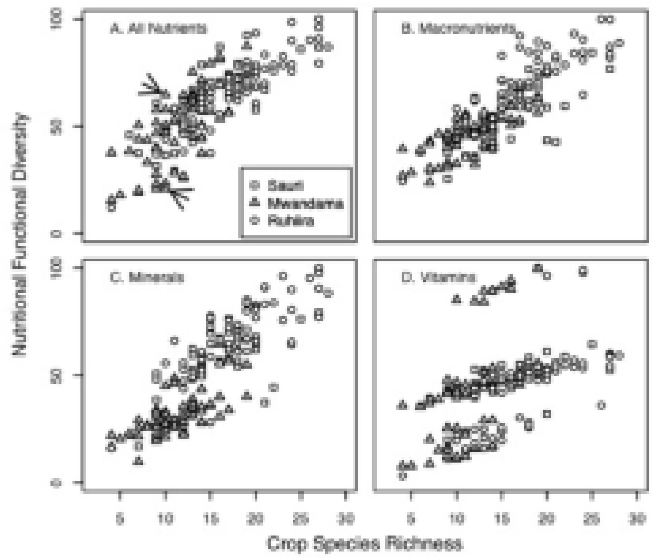

Figure 3. Nutritional functional diversity values are plotted against species richness for 170 household farms.
A: Nutritional FD = FDtotal, summarizing functional diversity for all 17 nutrients listed in Table 1; B: Nutritional FD = FD-macronutrients for the four macronutrients; C: Nutritional FD = FDminerals for the seven minerals; D: Nutritional FD = FDvitamins for the six vitamins (Table 1). Farms in Mwandama are shown as triangles, farms in Sauri as squares, and farms in Ruhiira as circles.

Regression of FDtotal (Figure 3A) against species richness reveals several patterns. First is a strong positive correlation ($p \leftarrow 0.001$; $r2=0.68$) between FD-total and species richness, independent of village. Thus, as the number of edible species increases, the diversity of nutrients that farm provides also increases. Second, at a level of around 25 species per farm, the relationship between FDtotal and species richness starts levelling off, meaning that additional species to a farm, with around 25 or more species, increases nutritional diversity very little. Third, although species richness and FDtotal are correlated, farms with the same number of species can have very different nutritional FD scores.

For example, two farms in Mwandama (indicated by arrows on Figure 3A) both with 10 species show an FDtotal of 23 and 64, respectively. The difference in FD is linked to a few differences in species nutritional traits. Both of these example farms grow maize, cassava, beans, banana, papaya, pigeon pea and mango. In addition, the farm with the higher FD score grows pumpkin, mulberry and groundnut, while the farm with lower FD score has avocado, peaches and black jack (in Malawi, black jack leaves are consumed). Trait analysis shows that pumpkin (including pumpkin leaves, fruits and seeds which are all eaten) adds diversity to the system by its relatively high nutritional content in vitamin A, Zn and S-containing amino acids (methionine and cysteine) compared to other species; mulberry by its levels of vitamin B complexes (thiamin, riboflavin) and groundnut by its nutritional content for fat, Mn and S. The black jack, avocado and peaches found in the lower FD farm add less nutritional diversity to the system than pumpkin, mulberry and groundnut since they do not contain the vitamin B or S complexes, and thus are less complementary to the other plants in the system for their nutritional content. This example shows how different crop species compositions can result in very disparate nutritional FD even with identical numbers of crops planted in a field.

When considering the FD values based on the nutrient subgroups, i.e. macronutrients, minerals and vitamins, the pattern of the relationship between species richness and FD differs among subgroups (Figure 3B, C and D).

While FDmacronutrients increases nearly linearly with increasing species richness, FDvitamins shows abrupt changes and is highly dependent on the presence of few species. For example, addition of mulberry or guava species strongly increases the FDvitamins value of the farm because of their unique high values for vitamin B complexes and vitamin C, respectively. This uniqueness attributed to a few key species results in a stepwise pattern of different FDvitamins levels instead of a gradual increase with number of species and indicates high species sensitivity (see also below). For FDminerals, the group of farms in Mwandama differs significantly from the Ruhiira and Sauri farms, by lower FDminerals values and a lower slope in the FDminerals – species richness relationship ($p \leftarrow 0.001$). This suggests that the species on the Mwandama farms are not contributing as much mineral diversity to the system as species in the Kenya or Uganda village (see also below).

3.3 Functional redundancy

A crucial component of FD is functional redundancy (Petchey *et al.*, 2007), which reflects the degree of overlap in the traits of species in a community. We assessed the degree of functional redundancy by simulations that model observed versus expected functional diversity for each of the 170 farms and the four nutritional FD metrics (Figure 4).

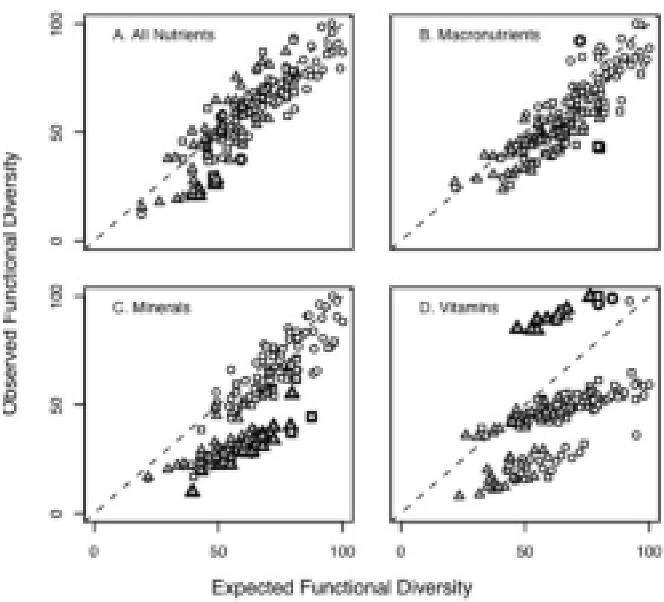

Figure 4. Observed values for nutritional diversity are plotted against simulated expected nutritional FD values for 170 household farms.
Farms that have observed FD values significantly different from expected FD values are marked in bold. Farms in Mwandama are shown as triangles, farms in Sauri as squares, and farms in Ruhiira as circles.

When observed FD is higher than expected, it indicates low functional redundancy, or that species are more distinct from one another than expected by chance (Figure 2) (Flynn *et al.*, 2009).

Figure 4 illustrates that functional redundancy patterns differ among nutrient groups. For FDtotal and FDmacronutrients no strong redundancy patterns are observed (Figure 4A, B). For FDminerals, a group of farms (in bold in Figure 3C) with an observed FD significantly lower (at α=0.05) than the expected FD was identified, meaning there is high functional redundancy, with several species having similar nutrient traits. Most of these farms are of the Mwandama site, and in contrast to other farms, they are entirely lacking a set of species identified as most influential for mineral diversity including *Sesamum calycinum* (onyulo) which is particularly rich in Fe, *Eleusine coracana* (finger millet) with high Ca and Mn levels, *Glycine max* (soybean) rich in Fe, Mg and Mn, *Helianthus anuus* (sunflower) which seeds have high levels of Zn, Mg and S, and *Solanum nigrum* (black nightshade) rich in Fe and Mn.

In contrast to the pattern of high redundancy for FDminerals, for FDvitamins a group of farms (in bold in Figure 4D) can be identified with significantly higher observed FD than expected FD, meaning there is low functional redundancy on those farms as only a few species provide certain combinations of vitamins (Figure 4D). What these farms have in common is that they all contain the species *Morus alba* (mulberry). As mentioned above, mulberry, especially the leaves, contain vitamins B complex and C, in higher levels than most other plants. Addition or loss of mulberry as one of the few species in the community providing vitamin B complex, can increase or reduce FDvitamins significantly.

3.4 Linking to food and health indicators

In addition to agrobiodiversity data, data on household food indicators including a household food insecurity access scale (HFIAS), number of months of inadequate household food provisioning (MIHFP) and household diet diversity scores (HHDDS) were obtained for each of the 170 farms (Table 3). Significant differences between villages for these indicators reflect different levels in food security and diet diversity, with lower food security and diet diversity in Mwandama as compared to Ruhiira and Sauri (Table 3). Average village data indicate that low species richness and FD scores at the village level are paired with low diet diversity, high food insecurity and number of months of inadequate food provision of the village community (Table 3).

Analysis of correlations between these household food indicators and farm species richness and nutritional FD metrics indicate that for each of the food indicators, correlation coefficients are slightly higher for FD metrics than for species richness. But none of these correlations are significant and significance does not change when corrected for village and/or land size (data not shown).

The patterns for iron and vitamin A deficiencies at the village level (Table 3) are similar to patterns for FDminerals and FDvitamins respectively: while Mwandama shows significantly higher rates of Fe deficiency than Ruhiira and Sauri, average FDminerals of Mwandama farms is significantly lower compared to FDminerals in Ruhiira and Sauri. No significant differences between sites are found for vitamin A deficiency and similarly, FDvitamins is the only FD metric for which the three sites score equally.

4. Discussion

Sub-Saharan Africa faces pressing challenges, with 40 percent of children chronically undernourished or stunted (UNICEF, 2009). As new investments and attention galvanize much-needed action on African agriculture, a vigorous debate is required to ensure that agricultural progress is evaluated based on metrics that go beyond economic cost/benefit ratios and calories per person and that can also address the complexity of nutritional diversity required for human health. In this study, we demonstrate how an ecological concept, the FD metric, has potential to summarize nutritional diversity of cropping systems and thereby provide new insights on provisioning ecosystem services across farms and villages in sub-Sahara, Africa.

The strengths of the study lie in the development of a systems approach that is able to consider the large variety of species available in the system together with their nutritional composition and in the step it takes towards integrating agriculture, nutrition and ecology studies (Deckelbaum *et al.*, 2006; Remans *et al.*, 2011). By applying the FD metric on nutritional diversity, it was possible to identify variability in nutritional diversity across farms and villages (e.g. low diversity for minerals in the Mwandama cluster compared to Sauri and Ruhiira) as well as to identify species that are critical for ensuring the provisioning of certain nutrients (e.g. mulberry for vitamin B complexes). The results also emphasize that the species nutritional composition and redundancy available in the system determine if introduction or removal of certain species will have critical impacts on the nutritional diversity of the community (e.g. addition of species to farms with around 20 species does not cause much change to FDtotal, high species sensitivity for FDvitamins, high redundancy for FDminerals).

While in the past, food-based interventions in developing countries have focused mostly on a single nutrient (Frison *et al.*, 2006), the approach described in this study can help guide agricultural interventions towards diversity of nutrients and/or towards nutrient redundancy or resilience of the system. In particular, this work provides means to identify potential crops, varieties or groups of plants that add nutritional value (diversity or redundancy) and can be introduced, promoted or conserved taking into account the functional diversity of species already available in the system. The single nutrient approach of the past, varying from various recommendations for high-protein diets (Brock *et al.*, 1955) and later for high-carbohydrate diets (McLaren, 1966, 1974), to more recent efforts directed at the elimination of micronutrient deficiencies, was in part linked to a lack of knowledge in earlier years about the interactions among nutrients in human physiology and metabolism (Frison *et al.*, 2006). The roles of micronutrients in health and well-being and the synergies in their physiologic functions are now being increasingly recognized, supporting the notion that nutrient deficiencies rarely occur in isolation and calling for dietary diversification (Frison *et al.*, 2006; Latham, 2010; McLean *et al.*, 2009). These advances in nutritional sciences also create a demand for applying a more holistic approach to the nutritional diversity of agricultural systems as described here.

This study is, however, limited and offers room for improvement on several fronts. First, no data were collected on the quantities produced or on species evenness. Cropping area or yield data would further strengthen the study by allowing calculation of an abundance-weighted FD metric, several of which have been developed in community ecology (Mouchet *et al.*, 2010; Laliberté and Legendre, 2010). While this is planned as a next step in future work, presence/absence-based FD metrics are valuable as predictors of ecosystem functioning (Flynn *et al.*, 2011). The nutritional FD metric of this study gives thereby valuable insights on the diversity of nutrients provided by the cropping system, particularly on the complementarity and redundance of species in the system and on the potential of species to contribute nutritional traits to the existing composition of species (on farm or in the village).

Second, the nutritional composition data and FD metric calculations were based on available species level data. It is known that a large diversity in nutritional composition exists among different varieties of species as well as among different environments in which plants are cultivated (Bates, 1971; Kennedy and Burlingame, 2003; Davey *et al.*, 2009). For example, certain varieties of *Phaseolus vulgaris* L. (common bean) are significantly higher in iron and zinc than other *P. vulgaris* varieties (Graham *et al.*, 2007; Blair *et al.*, 2010), and addition of zinc fertilizer to the soil can further increase the concentration of trace elements in edible parts (Graham, 2008). Also, the FD calculation used here does not take into account the level of neutriceuticals and phytochemicals, that play a beneficial role for human health, nor the level of antinutritional factors (e.g. phytate, oxalate, tannins) that reduce the bioavailability of certain nutrients (e.g. Ca, Fe, proteins). Efforts to acquire more data at the species and subspecies level on nutritional composition across different environments, will allow fine-tuning of the proposed FD metrics. In addition, including livestock diversity and number will provide a more complete picture of the nutritional diversity available on farm.

No significant correlations at the farm level were found between nutritional FD of crops grown and household food consumption indicators. This might be partly due to limitations of the proposed FD metrics or the relatively simple household food indicators used in this study, but also to the complex pathway between agricultural production and food consumption (World Bank, 2007; Rose *et al.*, 2009). While most households in the studied villages are considered subsistence farmers, farm households are not closed systems.

Food consumption and expenditure data (Table 2) show that the average proportion of food consumed coming from own production is around 50 percent. Also, a significant correlation was found between the number and value of food items bought and sold on local markets and the household food indicators at each of the three sites (FIS, HHDDS, MHIFS) (Lambrecht, 2009). These findings emphasize the importance of local markets and support the notion that these farm households are not closed systems. The most appropriate scale to link nutritional FD metrics to food consumption and nutrition indicators, would be the “foodshed”, defined as the geographic area that supplies a population centre with food (Peters *et al.*, 2008). Village level data show that for example for Ruhiira 82 percent of food consumed is derived from production within the village

(Table 2). This indicates that in the case of these villages, the foodshed, largely overlaps with the village. It is therefore interesting to note that certain associations between nutritional FD and food and nutrition indicators were observed at the village level: the correspondence in patterns between FD-minerals and Fe deficiency, FDvitamins and vitamin A deficiency and FDtotal and diet diversity, food insecurity and number of months of insufficient food supply. These findings generate new hypotheses on the link between nutritional diversity of the farming system and nutrition outcomes at the village or in particular the foodshed level such as: Can the high rate of Fe deficiency among adult women in Mwandama be due partly to a lack of species that contribute more significantly to mineral diversity, particularly those high in Fe? Also, does the high crop species richness in Sauri and Ruhiira play a role in their relatively lower level of food insecurity? In addition, the study triggers new questions as to what are the determinants or filters of nutritional diversity on farms, villages and agro-ecological zones. For example, it is clear that mineral diversity of species in the Mwandama village is lower than in Sauri and Ruhiira, and even when species richness increases, FDminerals in Mwandama remains relatively low. Several potential barriers for growing species that add more to FDminerals can be hypothesized and could be categorized under ecological (e.g. climate, soil, altitude, water availability), dispersal (large distance to origin of seeds) or anthropogenic determinants (e.g. cultural preference, limited economic access to seeds, lack of knowledge). In this context, it is interesting to note that soil fertility measures in the Mwandama village (Table 2) show very low values for effective cation

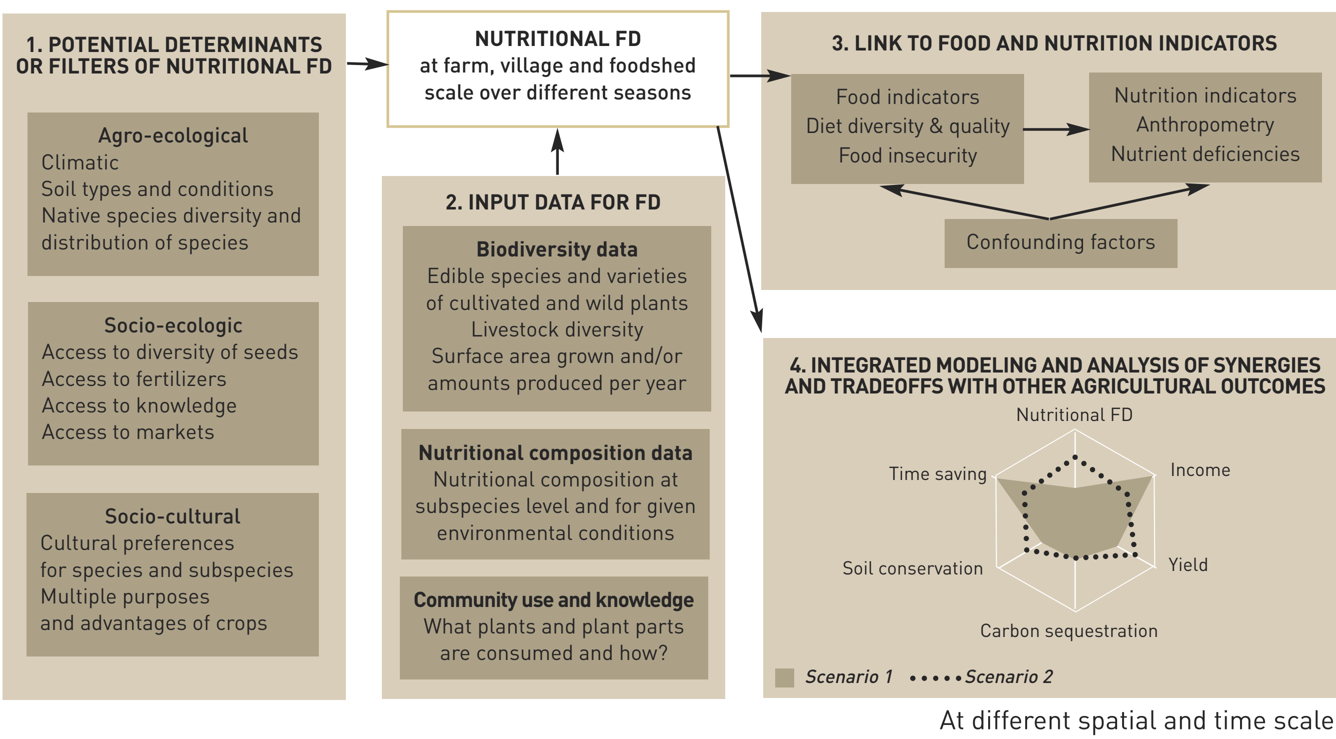

Figure 5. Suggested strategy for future research on nutritional functional diversity.
The overall objective of the strategy is to guide agricultural and landscape interventions towards more balanced nutritional outcomes. Three major fronts for research are suggested: study of potential determinants and barriers of nutritional FD and identify the ones that can be controlled (1); collection of new and mobilization of existing data that enable a more comprehensive calculation of nutritional FD and this at a landscape and village level (2); establishing linkages with consumption and human health outcomes of agricultural systems through integrated data sets that include health and socio-economics (3); and integrated modelling and analysis of potential synergies and trade-offs between nutritional diversity and other outcomes from agriculture (4).

exchange capacity (ECEC) and percentage of total nitrogen (N), two factors that are critical for soil fertility. It can be hypothesized that the soil conditions in Mwandama restrict successful cultivation of crops to only those adapted to lower soil fertility conditions or it might be that farmers' preference for certain crops or soil management strategy has impacted soil fertility over time.

Based on the findings and new questions raised, a strategy for future research is outlined in Figure 5, with an overall objective to guide more balanced nutritional outcomes from agricultural systems.

The strategy emphasizes four major fronts for expanding the research presented here: 1) study on potential determinants and barriers of nutritional FD in different settings; 2) collection of new and mobilization of existing data that enable a more comprehensive calculation of nutritional FD across different villages; 3) establishing linkages between nutritional diversity of farming systems and consumption and human health outcomes, particularly at the foodshed scale (Peters *et al.*, 2008; Niles and Roff, 2008); and 4) integrated modelling and analysis of potential synergies and trade-offs between nutritional diversity and other outcomes from agriculture, e.g. income generation, risk reduction, greenhouse gas emissions, water quality, labour intensity and social well-being. Such modelling can be done at different scales (farm, village, country, region, global) and across agro-ecological zones to identify how complementary different agro-ecosystems are for providing the necessary nutritional diversity.

In conclusion, this study delivers novel work on addressing nutritional diversity of agricultural systems. We show that applying the ecological functional diversity metric on nutritional traits of plants in agricultural systems gives insights on the diversity of nutrients provided by cropping systems. Application of this metric can help guiding management decisions towards increased nutrient diversity for a given number of species, as well as towards increased redundancy or buffer of species for a specific set of nutrients.

In addition, new hypotheses on the link between agrobiodiversity and nutrition are generated and a cross-disciplinary research framework is suggested. Nutritional FD is thereby a tool that bridges agriculture, human nutrition and ecology studies and offers an entry point for integration of other scientific disciplines (economics, anthropology, human health, landscape ecology) (Remans *et al.*, 2011; Rumbaitis del Rio *et al.*, 2005; DeClerck *et al.*, 2006). Assessing the multiple outcomes of agricultural systems across agro-ecological zones is critical for making progress towards more sustainable and nutritious food systems (Sachs *et al.*, 2010).

Acknowledgements
We would like to thank the Millennium Villages Project staff and villagers for their efforts and participation in project implementation and research.

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NUTRIENT DIVERSITY WITHIN RICE CULTIVARS (ORYZA SATIVA L) FROM INDIA

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Abstract
Rice research in India has focused mainly on increasing yield and little is known of the nutrient composition of many of the country's rice varieties. This study investigates the variations in the nutrient content of 269 high-yielding Indian rice cultivars. Protein content ranged from 6.92 to 12.98 g/100 g with a mean of 9.43 ± 1.22 g/100 g. The majority of the samples (51%) had protein content between 9 and 12 g/100 g. Mean crude fat content was 2.38 ± 0.46 g/100 g and as many as 30 cultivars had more than 3 g/100 g. Moderate levels of total dietary fibre (3.99–4.71 g/100 g) were observed in the brown rice samples. Mean ash content was 1.39 ± 0.18 g/100 g and 36 percent of the samples had ash content between 1.5 and 2.0 g/100 g indicating mineral abundance in many rice varieties. High concentrations of macro-elements such as phosphorus (330 ± 81 mg/100 g), potassium (253 ± 27.81 mg/100 g) magnesium (129 ± 16 mg/100 g) and calcium (13.12 ± 2.66 mg/100 g) were observed. Grain iron content ranged from 0.57 to 4.04 mg/100 g with an average of 1.36 ± 0.59 mg/100 g. The coefficient of variation observed for grain iron content was as high as 43 percent. Grain zinc content ranged from 1.46 to 3.87 mg/100 g with a coefficient of variation of 19 percent. Essential amino acids made up 39 percent of the total amino acids. The amino acid score ranged from 59 to 73 (mean 65 ± 3.42) and Lysine was the limiting amino acid. Palmitic (range 20–26%), oleic (30–37%) and linoleic acids (33–42%) accounted for more than 92 percent of the total fatty acids in rice. The study has revealed diverse rice varieties with wide-ranging nutrients that can be utilized in breeding programmes to effectively increase protein and micronutrient content in rice.

1. Introduction
Rice is rich in genetic diversity with thousands of varieties cultivated in more than 100 countries around the world. Nearly all cultivated rice is Oryza sativa L. with a small amount of O. glaberrima grown in Africa. It is estimated that there are 120 000 different cultivars ranging from traditional rice varieties to the commercially bred elite cultivars (Londo et al., 2006). In its natural state, rice comes in many different colours prized for their nutrient and health properties. Rice is tied to cultures and livelihoods symbolizing life and prosperity for billions of people playing a fundamental role in the world food security and socio-economic development. To emphasize the importance of rice, the UN General Assembly declared 2004 the International Year of Rice under the slogan "Rice is Life" (FAO, 2004).
India is the largest rice-growing country accounting for one-third of the world acreage under rice cultivation. Rice is grown in almost all the Indian states covering more than 30 percent of the total cultivated area in the country. India's food production is projected to touch 235 million tonnes during 2010–11, of which rice will account for 94.5 million tonnes (Directorate of Economics and Statistics, 2010). Each year an estimated 408 661 million tonnes of rice is consumed across the globe accounting for 20 percent of the world's total calorie intake. The biggest public health challenge both globally and in rice-consuming countries comes from micronutrient deficiencies of iron, zinc, vitamin A and iodine affecting more than 3 billion people worldwide (WHO, 2002). The proportion of the global population suffering from micronutrient deficiencies has increased over the last four decades largely due to the increase in acreage under rice and wheat cultivation at the expense of pulse crops (a much richer source of micronutrients) and to changing dietary habits (Graham et al., 2007). India has the highest incidence of undernutrition in the world, and of the micronutrient deficiencies, iron deficiency anaemia is the most serious public health problem in the country (NNMB, 2006).
In the past, generic food composition data were considered sufficient for most purposes but today the usefulness of cultivar-specific composition data is becoming increasingly acknowledged for understanding diet-related morbidity and mortality. Significant cultivar-specific differences have been

observed in the nutritional content of rice (Kennedy and Burlingame, 2003). Many factors, such as climate, geography and geochemistry, agricultural practices, post-harvest conditions and handling, as well as genetic composition of the cultivar are known to affect the nutrient composition of rice. Among these factors cultivar-specific differences have received the least attention.

Rice research in India has traditionally focused on ways of increasing yield to match the country's burgeoning population and trade. The importance of enhancing nutritional quality to improve human health through rice breeding is only now coming in focus. In 2002, the International Rice Commission recommended that the existing biodiversity of rice varieties and their nutritional composition needed to be explored and that nutrient content must be among the main criteria used for selection of rice cultivars for use in areas of food insecurity. Rice is an important source of nutrients and breeding rice crops with particularly enhanced nutrient concentration requires knowledge of the variation in the trait among the available germplasm. Therefore this study was initiated in order to document the nutrient composition of 269 high-yielding rice cultivars cultivated in India. Nutrient analysis was carried out using brown rice, the raw material for white rice.

2. Methodology

2.1 Sample processing

All varieties (indica subspecies) of rice were supplied by the Directorate of Rice Research (ICAR), Rajendranagar, Hyderabad in the form of brown rice. Samples were powdered using cyclone mill (UDY Corporation, USA) and stored in clean polyethylene bottles from where aliquots were taken for analysis.

2.2 Proximate composition

Moisture, ash and dietary fibre content were assayed using the Association of Official Analytical Chemists (AOAC, 2006) methods 934.01, 942.05 and 985.29, respectively. Protein content (N X 5.95) was determined by the AOAC Kjeldahl method (984.13). Total fat was determined by the AOAC method after acid digestion (996.01). Carbohydrate content was determined by calculating the difference (100 – moisture+fat+protein+ash+total dietary fibre).

2.3 Mineral analysis

Approximately 0.5 g of sample was accurately weighed into a Teflon PFA digestion vessel to which high purity acid mixture (3.0 mL HNO3 and 1.0 mL H2O2) was added. Each sample was taken in duplicate, sealed and digested in a microwave digestion system (CEM, Corp. MARSXpress). After completion of the digestion, vessels were cooled, carefully removed and transferred to a 25 ml volumetric flask. Analysis of calcium, copper, iron, magnesium, manganese, potassium and zinc was carried out after appropriate dilutions in an Atomic Absorption Spectrometer (iCE 3300 Thermo Scientific). Phosphorus was estimated by the Fiske and Subbarow method as described in AOAC method (931.01).

2.4 Quality control

For mineral estimation a blank and a Certified Reference Material (NIST 1568a or 1547) were included in each digestion batch for quality assurance. A comparison of the mean content values for each of the analyte in this study and that given in the CRM certificate is presented in Table 1. The precision data shows good agreement reflecting good data quality.

Table 1. Analysis of Certified Reference Material

Minerals	CRM No.	Sample	Measured Value (mg/kg)	Certified Value (mg/kg)
Fe	NIST-1568a	Rice Flour	7.57 ± 0.16	7.4 ± 0.9
Zn	NIST-1568a	Rice Flour	19.22 ± 0.35	19.4 ± 0.5
Cu	NIST-1568a	Rice Flour	2.4 ± 0.155	2.4 ± 0.3
Mn	NIST-1568a	Rice Flour	18.52 ± 0.376	20.0 ± 1.6
Ca	NIST-1568a	Rice Flour	118 ± 2.3	118 ± 6
Mg	NIST-1568a	Rice Flour	560 ± 3	560 ± 20
K	NIST-1568a	Rice Flour	1280 ± 3.2	1280 ± 8
P	NIST-1547	Peach Leaves	1360 ± 16	1370 ± 70

2.5 Amino acid composition

Amino acid analysis was carried out by hydrolysing the samples in sealed ampoules in vacuo with 6 N HCl and incubated at 110ºC for 22 hours (Darragh, 2005). Excess acid was removed in a flash evaporator under reduced pressure at a temperature of less than 40ºC. The sample was then dissolved in a citrate buffer (pH 2.2) and loaded into an automatic amino acid analyser (Biochrom-30, Cambridge, UK). Methionine and cysteine was determined separately after performic acid oxidation (Moore, 1963). Tryptophan was quantified after barytic hydrolysis of the samples according to the method described by Landry and Delhaye (1992). Each amino acid was identified and quantified using authentic standards (National Institute of Standards and Technology, SRM 2389). The amino acid score was calculated using the FAO/WHO/UNU suggested pattern of amino acid requirement for pre-school children (2–5 years) (FAO/WHO/UNU, 1985).

2.6 Fatty acid composition

The fatty acid composition was determined after direct methylation of the samples according to the method of O' Fallon et al. (2007). The fatty acid methyl esters were analysed in a Shimadzu 2010 GC equipped with Flame Ionization Detector (FID) and SP2560 column (100 m x 0.25 mm x 0.2 mm). Injection was achieved by splitless mode and the injection port and detector were maintained at 250°C. Nitrogen was used as carrier gas and the temperature programme was from 140°C to 230°C with a ramp rate of 4°C/min. Individual peaks were identified by retention time using SupelcoTM37 component FAME MIX. Fatty acid composition was expressed as a percentage of total fatty acids.

2.7 Statistical calculations

Data analysis was carried out using SPSS (Version 18: Chicago, IL). Descriptive statistics, namely mean, range and standard deviation, were calculated. Pearson correlation coefficients were carried out among the different nutrients of interest. P values were two-tailed and two significant levels (P← 0.05 and 0.01) were used.

3. Results and discussions

3.1 Proximate composition

The macronutrient composition of all the rice varieties is listed in table 2.

Table 2. Proximate composition and dietary fiber content of 269 high yielding Indian rice varieties

Parameter	N	Mean ± SD	Range
Moisture (g/100g)	269	9.69 ± 1.37	6.15 – 12.66
Protein (g/100g)	269	9.47 ± 1.22	6.92 – 12.98
Fat (g/100g)	269	2.36 ± 0.46	1.23 – 3.77
Ash (g/100g)	269	1.39 ± 0.18	0.90 – 1.99
Insoluble dietary fibre (g/100g)	205	3.62 ± 3.64	3. 13.90
Soluble dietary fibre (g/100g)	105	0.79 ± 0.06	0.66 – 0.92
Total dietary fibre (g/100g)	105	4.41 ± 0.17	3.99 – 4.71
Carbohydrate (g/100g)	105	71.79 ± 1.37	68.04 – 75.77
Energy (kcal)	105	347 ± 3.64	340 - 356

All samples had moisture content varying between 6.15 and 11.91 g/100 g within the limit of 12 g/100 g normally recommended for safe storage of processed rice. Brown rice protein content in 269 cultivars studied ranged from 6.92 to 12.98 g/100 g. The width between the highest and the lowest protein content was 6 g/100 g. The average rice protein content of 9.43 g/100 g found in the present study was much higher than the reported value of 6.88 g/100 g in the Indian Food Composition Tables (Gopalan et al., 1989) indicating a general increase of protein content in Indian rice varieties. Factors such as environmental condition, soil fertility, fertilizer use and post-harvest processing can influence the protein content of rice; however, the present study examines only the varietal difference and not the other factors that can influence protein content in rice.

Protein content in rice due to varietal differences has been reported to be in the range of 4.5 to 15.9 g/100 g (Juliano and Villareal, 1993). Compared to the present study, Chandel et al. (2010) has reported lower protein content ranging from 6.95 to 10.75 g/100 g with an average of 8.07 g/100 g while Basak et al. (2002) reported a much lower protein content of 6.6–7.3 g/100 g in Indian rice genotypes. Chinese and North American wild rice samples had a relatively higher protein content of 12–15 g/100 g (Zhai et al., 2001). Frequency distribution showed that 45.2 percent of the samples had protein content below 9 g/100 g while only 3 percent of the samples were above 12 g/100 g. The highest protein content of 12.98 g/100 g was observed in Phoudum, a traditional high-yielding variety. The majority of the samples (51%) had a protein content of between 9 and 12 g/100 g.

Brown rice crude fat content in 269 Indian rice cultivars ranged from 1.23 to 3.77 g/100 g with a mean of 2.38 ± 0.46 g/100 g which is comparable to that reported by other investigators (Juliano, 1985; Scherz et al., 2000). Similar fat content ranging from 1.81 to 2.24 g/100 g and from 2.1 to 3.2 g/100 g has been reported in Italian rice varieties (Brandolini et al., 2006). The highest fat content of 3.77 g/100 g found in Kavya variety is substantially high even though it is within the range of 1 – 4 g/100 g reported for brown rice (Juliano, 1985). Frequency distribution of brown rice fat content showed that the 73 percent of the samples had fat content between 2 and 3 g/100 g while as many as 30 cultivars had more than 3 g/100 g. Though rice is not a rich source of fat, the study revealed that considerable variations exist within rice cultivars with some cultivars having substantially higher content that can be utilized to marginally increase fat intake.

The total dietary fibre content analysed in 105 rice varieties ranged from 3.99 to 4.71 g/100 g, with MLT-ME6 having the highest content. The average insoluble fibre and soluble fibre content was 3.62 ± 0.16 g/100 g and 0.79 ± 0.06 g/100 g, respectively. In all varieties, the content of insoluble dietary fibre was significantly greater (p←0.001) than that of soluble dietary fibre. Compared to the present study, Cheng (1983) has reported a much lower total dietary fibre content of 1.36 – 2.83 g/100 g in brown rice. Rice appears to be a moderate source of dietary fibre; however, milling or polishing to produce white rice drastically reduces the dietary fibre content in rice. In Asian countries where higher intake of white rice has been associated with increased risk of metabolic diseases and type 2 diabetes, substitution with brown rice has shown to lower the risk of type 2 diabetes, CVD and mortality (Katcher et al., 2008; Villegas et al., 2007). Therefore using brown rice to overcome current physiological effects in human health due to its high fibre and other bioactive compounds appears to be an advantage.

Brown rice ash content in 269 rice cultivars ranged from 0.9 g/100 g in Pantdh to 1.99 g/100 g in IR36 variety. Mean brown rice ash content was 1.38 g/100 g, comparable to brown rice from Brazil (1.21 g/100 g) and wild rice varieties from China (Heinemann et al., 2005; Zhai et al., 2001). Frequency distribution showed that 64 percent of the samples had ash content between 0.9 and 1.5 g/100 g, while 36 percent had ash content between 1.5 and 2.0 g/100 g reflecting mineral abundance in many rice varieties.

3.2 Mineral Content

The concentration of elements in 269 brown rice genotypes is summarized in table 3.

Table 3. Mineral content of high yielding Indian rice varieties (mg/100g)

Min.	N	PRESENT STUDY		Juliano and Bechtel (1985)	Marr et al (1995)	Scherz et al (2000)
		Mean ± SD	Range			
Fe	236	1.23 ± 0.53	0.52 – 3.75	0.2 – 5.2	0.5 – 5.7	2 – 3.6
Zn	236	2.38 ± 0.45	1.01 – 3.46	0.6 – 2.8	1.3 – 2.1	0.8 – 2
Cu	236	0.31 ± 0.10	0.13 – 0.78	0.1 – 0.6	0.14 – 1.3	0.24 – 0.30
Mn	236	1.41 ± 0.31	0.75 – 2.46	0.2 – 3.6	2.5 – 6	3.74
Ca	236	12.27 ± 2.59	8 – 19	10 – 50	3 – 11	11 – 39
Mg	236	116 ± 14.04	69 – 150	20 – 150	100 – 130	110 – 166
P	236	297 ± 71.18	113 – 4987	170 – 430	240 – 310	250 – 383
K	104	253 ± 27.81	162 - 347	60 - 280	210 – 300	150 – 260

The sum of nutritionally important minerals assayed in this study represents 36 percent of the total ash content. In general, high concentrations of macro-elements such as phosphorus (330 ± 81 mg/100 g), potassium (253 ± 27.81 mg/100 g), magnesium (129 ± 16 mg/100 g) and calcium (13.12 ± 2.66 mg/100 g) was observed in the Indian rice cultivars. The levels of macro-elements found in the present study was comparable with the values obtained by Zeng et al. (2009) in 28 indica brown rice from China. Phosphorus content was highest in T. Basmati (465 mg/100 g) and lowest in Aathira (195 mg/100 g). More than 80 percent of the total phosphorus content in rice occurs as phytate that functions in chelating and storing phosphorus in the seed (Oatway et al., 2001). Magnesium content ranged from 86 mg/100 g in MLT-E-2 to 149 mg/100 g in Chageli variety. The variation in calcium content was from 6.8 mg/100 g in Aanashwara to 17.11 mg/100 g in Pantdhan-12. Mean ± SD content of manganese and copper was 1.56 ± 0.35 and 0.34 ± 0.11 mg/100 g respectively. Copper content was low ranging from 0.14 to 0.84 mg/100 g. Manganese content was lowest in Aathira (0.77 mg/100 g) and highest in MLT-M-11 (2.13 mg/100 g). Element transfer from soil to brown rice has been studied and inter-regional differences in the concentration of various elements were not found to be substantial in many cases (Jung et al., 2005). The order of the concentrations of elements in brown rice in this study was phosphorus → magnesium → calcium → zinc → manganese → iron → copper. Similar trends have been observed by other investigators conducting studies on different rice varieties (Ogiyama et al., 2008).

Grain iron content ranged from 0.57 mg/100 g in Aathira to 4.04 mg/100 g in MLTE-5 with an average of 1.36 ± 0.59 mg/100 g on dry weight basis. Frequency distribution of iron content showed that 46 percent of the samples had less than 1 mg/100 g, 48 percent had 1 – 2 mg/100 g and 6 percent had more than 2 mg/100 g. Rice grain iron content has been reported to be in the range of 0.2 – 5.2 mg/100 g by Juliano and Bechtel (1985). A much lower iron content has been reported in wild rice accession (1.25 – 2.27 mg/100 g), advance breeding lines (0.81 – 1.28 mg/100 g) and landraces (0.48 – 1.62 mg/100 g) in 46 Indian rice genotypes by Chandel et al. (2010). Compared to the present study higher iron content in the range of 0.70 – 6.35 mg/100 g with an average of 2.28 mg/100 g on dry matter basis was reported for 95 Chinese varieties (Wang et al., 1997). Similarly high iron content in the range of 0.5 – 6.7 mg/100 g has been reported in 90 Australian rice varieties (Marr et al., 1995) while Korean rice varieties showed low content of 0.16 – 1.4 mg/100 g (Kim et al., 2004). Interestingly high iron content of 5.06 ± 1.05 mg/100 g has been reported in improved indica cultivar from China (Zeng et al., 2009). On the other hand low iron content of 1.2 mg/100 g was reported in Vietnamese rice (Phuong et al., 1999). The coefficient of variation observed for grain iron content in the present study was as high as 43 percent which indicates ample room for improving rice iron content.

Grain zinc content ranged from 1.46 mg/100 g in Lalat to 3.87 mg/100 g in MLT-M-14 with a coefficient of variation of 19 percent. Frequency distribution showed that 73 percent of the samples had zinc content in the range of 1 – 2 mg/100 g and 14 percent had more than 2 mg/100 g. Varying grain zinc content in 46 rice genotypes from India was found to be 2.96 – 4.17 mg/100 g in wild rice accession, 1.67 – 3.01 mg/100 g in advance breeding lines and 2.07 – 2.96 mg/100 g in landraces (Chandel et al., 2010). Zeng et al. (2009) found zinc content of 2.57 ± 0.67 mg/100 g in improved Indian cultivars which is comparable to 2.64 ± 0.50 mg/100 g found in the present study though higher zinc content of 3.34 mg/100 g has also been reported in 57 Chinese rice varieties (Wang et al., 1997). Increased nitrogen fertilizer application did not produce significant increases in grain iron and zinc content in rice (Chandel et al., 2010). The width between the lowest and highest zinc content in the present study was 2.41 mg/100 g while that of iron was much higher at 3.47 mg/100 g. Rice is not a rich source of iron and zinc but it remains the major source of intake for these micronutrients in the rice-eating population.

3.3 Correlations among the contents of ash and eight mineral elements in brown rice

Results of the Pearson's correlation performed among eight mineral element content and ash in brown rice is given in table 4.

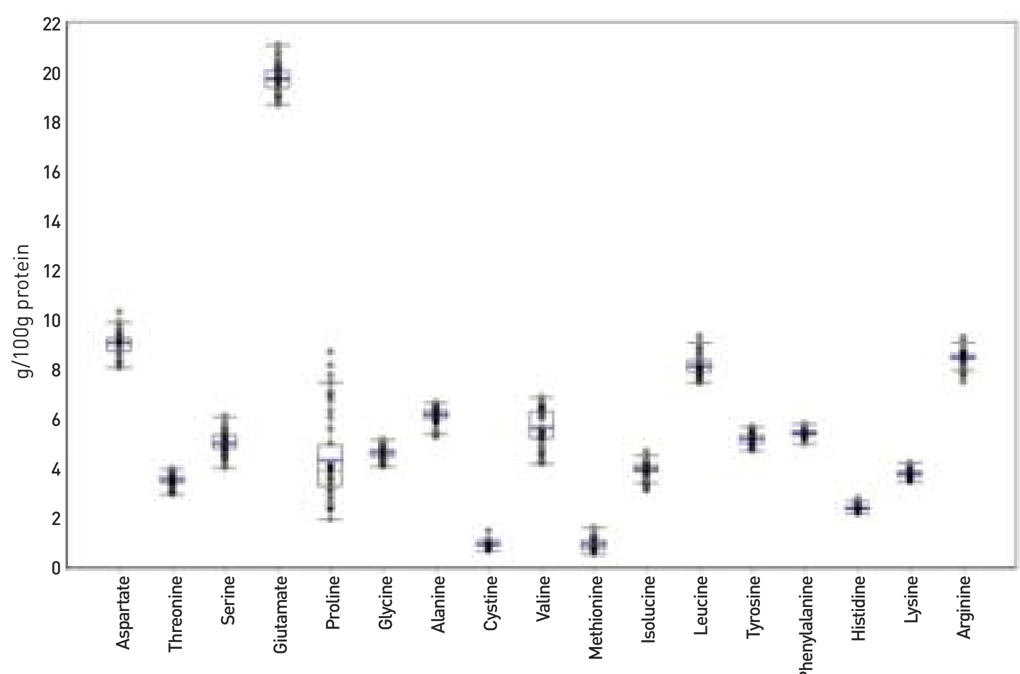
Table 4. Correlation among eight mineral contents in 269 high yielding Indian rice cultivars

El.	Ash	Fe	Zn	Cu	Mn	Ca	Mg	P
Fe	0.192**							
Zn	0.235**	0.187*						
Cu	0.71	0.432**	0.209**					
Mn	-0.097	0.058	-0.120	0.167*				
Ca	-0.018	0.159*	-0.148*	0.057	0.135*			
Mg	0.286**	0.166*	0.410**	0.191**	-0.008	-0.226**		
P	0.152*	0.205**	-0.159*	0.010	0.287**	-0.103	0.156*	
K	0.212*	0.082	0.108	0.118	0.103	0.292**	0.215*	-0.100

* Significant at 0.05 probability level
** Significant at 0.01 probability level

Ash correlated positively with Fe or Zn or Mg or P or K but showed no correlation with Cu or Mn or Ca indicating that all the mineral content in rice is not positively correlated with its ash content. Among the minerals, close positive correlation was observed between the contents of Zn and Fe, Cu and Fe or Zn, Mn and Cu, Ca and Fe or Mn, Mg and Fe or Zn or Cu, P and Fe or Mn or Mg, K and Ca or Mg, while negative correlation was observed between the content of Ca and Zn, Mg and Ca, P and Zn. Jiang et al. (2007) also observed positive correlation between Fe and Zn suggesting that high iron content is accompanied by high zinc content in rice. There were differences in the correlations among other elements between the Chinese rice genotypes and the present study which may be due to the fact that Jiang et al. (2007) used polished rice whereas brown rice was used in the present study. Significant positive correlation was observed between Mg and all other elements studied except Mn. This may be explained by the fact that Mg regulated the uptake of all other essential elements and thus the Mg content of rice grain assumes importance (Tucker, 1999). The mineral contents in the Indian rice varieties are very diverse which can be explained by the genetic characteristics of varieties and other agri-

Figure 1. Box plot showing the distribution of various amino acids in 42 high Yielding Indian rice varieties



cultural practices that can influence its contents.

3.4 Amino acid content and Amino acid score

Box plot showing distribution of various amino acids in 42 high yielding rice cultivars is shown in Figure 1. The total essential amino acids made up 39% of the total amino acids. Lysine content ranged from 3.42g/100g in AP 41 Kanchana to 4.2g/100g in AP 71 Pratap with a mean of 3.76 ± 0.20 g/100g protein. Shekar and Reddy (1982) has also reported wide variation in lysine content (2.82 to 4.86g/100g protein) in scented rice varieties. In contrast low lysine content (2.8g/100g protein) was observed in Mexican and Malaysian rice varieties (Roohinejad et al 2009; Sotelo et al, 1994). In the present study besides AP71 Pratap another two varieties AP 85 Sarala and AP106 also had lysine content above 4 g/100g protein. Wide genetic variability for lysine content in Indian rice varieties has been reported (Banerjee et al, 2011). The mean ± SD of threonine content, the second limiting amino acid in rice was 3.45 ± 0.21 g/100g protein. The lowest threonine content of 3.03 g/100g protein was observed in IR 64 while the highest content of 3.86 g/100g protein was found in AP 85 Sarala. After lysine and threonine, isoleucine is the only amino acid that can sometimes be limiting in rice protein. Isoleucine content ranged from 3.02 – 4.59 g/100g protein with mean content of 3.91 ± 0.39 g/100g protein. The savoury amino acids glutamate and aspartate was the major amino acids constituting 19.36 ± 0.39 and 8.91 ± 0.38 g/100g protein respectively. The sweet amino acids glycine and alanine was as high as 4.51±0.20 and 6.01±0.29 g/100g protein respectively. The range of the different essential amino acids expressed in g/100g protein was 1.32 – 1.54 for tryptophan, 1.51 – 3.04 for cysteine, 4.05 – 6.92 for valine, 1.11 – 2.40 for methionine, 7.23 – 8.73 for leucine, 5.12 – 5.75 for phenylalanine, 2.23 – 2.73 for histidine and 7.53 – 8.62 for arginine. There was reasonable level of variation for all the amino acids indicating that genetic gain by means of selection is likely.

Compared to the WHO/FAO/UNU (1985) amino acid requirement for 2-5 years old child the amino acid score ranged from 59 to 73 with a mean of 65 ± 3.42. Compared to lysine content in rice varieties from other studies (Hegsted and Julaino 1974; Sotelo et al 1994; Tobekia et al, 1981), generally higher lysine content was observed in the present study. Despite observing

Table 5. Correlation among amino acids and protein content in 42 high yielding Indian rice cultivars

	Try	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys	Val	Met	Ile	Ley	Tyr	Phe	His	Lys	Arg
Asp	0.368*																	
Thr	0.175	0.800**																
Ser	0.215	0.756**	0.845**															
Glu	0.126	0.137	0.146	0.390*														
Pro	0.222	-0.076	-0.054	0.115	0.264													
Gly	0.199	0.742**	0.816**	0.581**	0.009	-0.214												
Ala	0.149	0.711**	0.832**	0.681**	0.227	-0.224	0.794**											
Cys	0.466**	0.513**	0.412**	0.455**	0.147	0.042	0.332*	0.412**										
Va	-0.033	-0.549**	-0.490**	-0.521**	0.060	0.211	-0.357*	-0.391*	-0.143									
Met	0.329*	0.558**	0.524**	0.446**	0.141	0.200	0.512**	0.450**	0.330*	-0.264								
Ile	0.145	-0.274	-0.249	-0.488**	-0.155	-0.012	-0.040	-0.090	0.060	0.735**	-0.042							
Ley	0.012	0-.503**	-0.487**	-0.375*	0.280	0.261	-0.474**	-0.381*	0.002	0.905**	-0.309*	.564**						
Tyr	0.434**	0.313*	0.169	0.228	0.373*	0.120	0.139	0.264	0.313*	-0.208	0.286	0.138	-0.073					
Phe	0.303	0.022	-0.071	-0.067	0.347*	-0.025	0.150	0.102	-0.011	0.453**	0.049	0.420**	0.416**	0.364*				
His	0.190	0.430**	0.486**	0.193	-0.123	-0.200	0.570**	0.403**	0.277	0.094	0.336*	0.435**	-0.012	0.032	.0208			
Lys	0.044	0.343*	0.333*	0.081	-0.354*	-0.075	0.413**	0.199	0.257	0.234	0.278	0.419**	0.041	-0.134	0.127	0.603**		
Arg	0.242	0.204	0.241	0.200	-0.025	0.159	0.357*	0.047	0.101	0.108	0.353*	0.188	-0.010	0.248	0.186	0.251	0.405**	
Protein	-0.281	-0.789**	-0.676**	0-.475**	0.173	0.225	-0.658**	-0.620**	-0.310	0.843**	-0.557**	0.286	0.881**	-0.452**	0.206	-.0332*	-0.169	-0.174

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

increased lysine content in some cultivars, this amino acid still remains the first limiting amino acid in all varieties. Milling does not induce any dramatic changes in the amino acid composition of rice and thus the amino acid score is unlikely to change significantly due to polishing (Sotelo et al, 1994; Tobekia et al, 1981).

Table 5 shows the correlation among the different amino acids including protein content. Significant negative correlations was observed between protein content and Asp or Thr or Ser or Gly or Ala or Met or Trp or His indicating that increase in protein content will result at the expense of these amino acids. A positive correlation was observed between Lys and Asp or Thr or Gly or Iso or His while a negative correlation was seen between Lys and Glu. The second limiting amino acid threonine showed significant correlation with Ser or Gly or Ala or Cys or Met or His or Lys. Negative correlation was also observed between Thr and Val or Leu. Significant correlations was observed between many combinations of amino acid in the Indian rice cultivars. The results suggest that many Indian rice varieties possess better amino acid profiles and exhibit superior nutritional qualities which could be utilized in breeding varieties with improved amino acid composition.

3.5 Fatty acids composition

Box plot showing the distribution of various fatty acids in 85 Indian rice cultivars is presented in Figure 2. The major fatty acids were palmitic (range 20 – 26%), oleic (range 30 – 37%) and linoleic acids (33 – 42%) which accounted for more than 92% of the total fatty acids. Studies on non-glutinous rice cultivars from Japan also showed similar content of the major fatty acids palmitic, oleic and linoleic acids (Kitta et al, 2005). The Mean ± SD content of myristic , stearic and α-linolenic acids was 0.32 ± 0.06, 2.63 ± 0.50 and 1.52 ± 0.23 respectively. α-linolenic content ranged from low of 0.93 to as high as 2.19%. Capric acid was detected at very low levels ranging between 0.02 – 0.32 % in the present study. There is no report on the presence of Capric acid in rice and this is the first report of the kind. A sample chromatogram of one rice fatty acid profile showing distinct peak of capric acid is depicted in Figure 3. Detection of capric acid was achieved by

Figure 2. Box plot showing the distribution of various fatty acids in 85 high yielding Indian rice cultivars

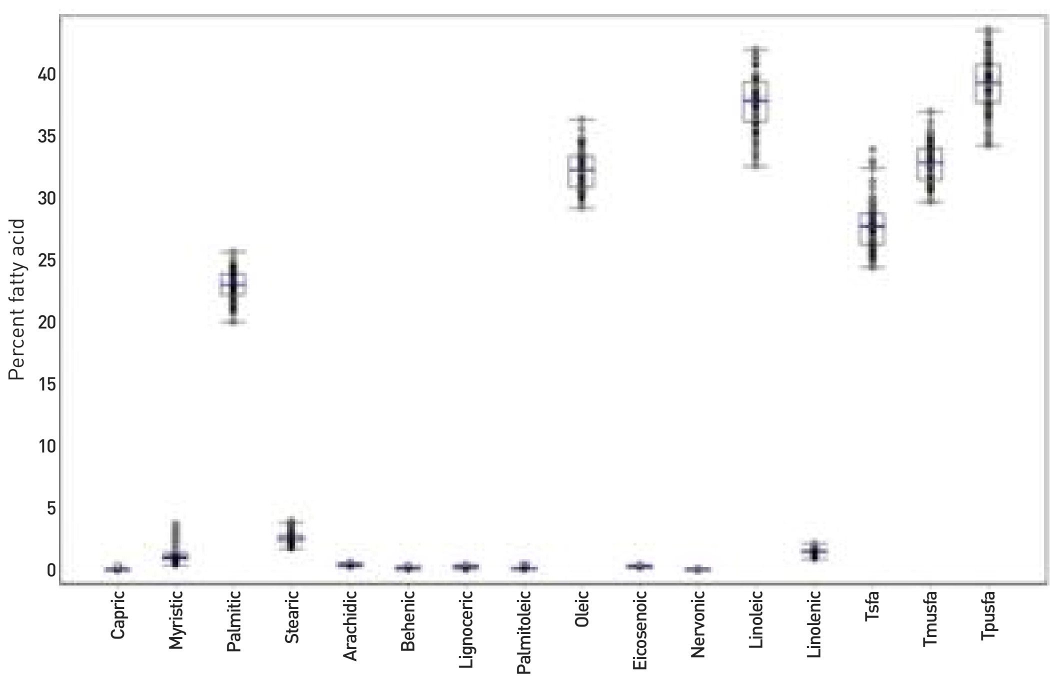
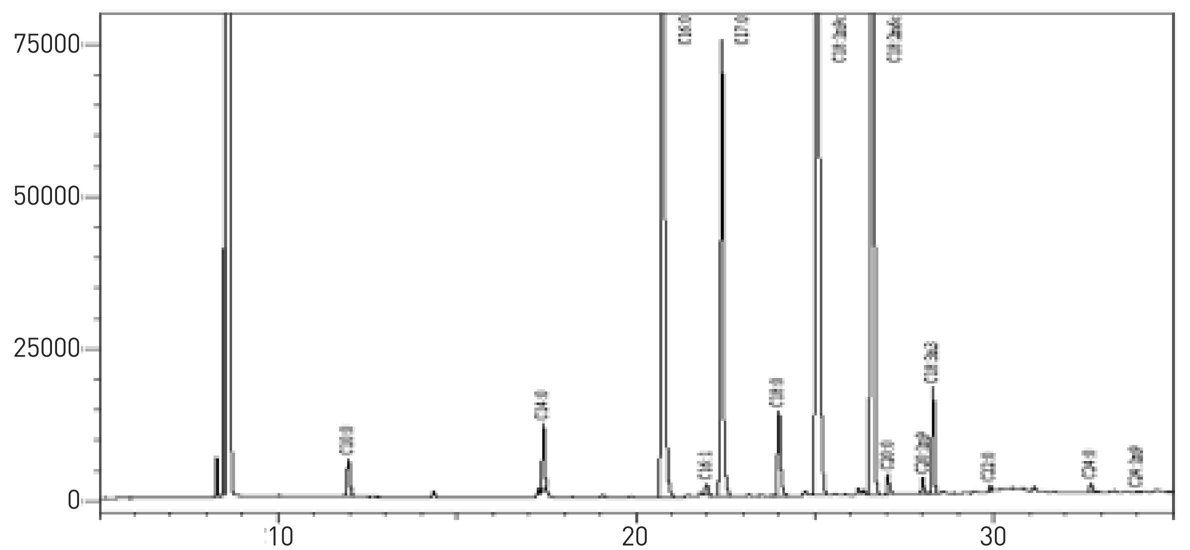


Figure 3. Fatty acids chromatogram of rice sample



using direct fatty acid methylation of samples and using SupelcoTM SP2560 column which provided clear separation of the fatty acids including Cis and Trans isomers. Low levels of arachidic (0.45 ± 0.07), behenic (0.19 ± 0.06), lignoceric (0.27 ± 0.12), nervonic (0.07 ± 0.02) and eicosenoic (0.32 ± 0.06) acids were also observed in all the rice samples studied here. Most studies on fatty acids composition in rice (Khatoon and Goapalakrishna, 2004; Mano et al, 1999; Taira and Chang 1986; Yhoshida et al, 2010; Zhou et al, 2003) failed to detect and report these minor fatty acids which together accounts for about 1.6% of the total fatty acids. The wide range of individual fatty acids in the diverse rice varieties shows that rice breeding can be designed to increase individual fatty acid of interest for improved health benefits.

Correlations were observed between many combinations of fatty acids is shown in table 6. The major fatty acid palmitic showed significant correlation with capric or myristic acids while oleic showed sig-

Table 6. Correction among the fatty acids is high yielding Indian rice varieties

	Capric	Myristic	Palmitic	Stearic	Arachidic	Behenic	Lignoceric	Palmitoleic	Oleic	Eicosenoic	Nervonic	Linoleic
Myristic	0.659**											
Palmitic	0.503**	0.454**										
Stearic	0.627**	0.493**	0.424**									
Arachidic	0.60	0.056	0.139	0.494**								
Behenic	0.348**	0.267*	0.120	0.589**	0.598**							
lignoceric	0.486**	0.206	0.057	0.473**	0.208	0.640**						
Palmitoleic	0.617**	0.858**	0.288**	0.393**	-0.061	0.330**	0.342**					
Oleic	-0.212	-0.215*	-0.316**	0.052	0.212	0.096	0.011	-0.0113				
Eicosenoic	0.323**	0.008	0.097	0.313**	0.187	0.358**	0.633**	0.138	0.184			
Nervonic	0.024	-0.318**	0.076	0.155	-0.023	0.057	0.397**	-0.251*	-0.047	0.407**		
Linoleic	-0.524**	-0.524**	-0.566**	-0.690**	-0.396**	-0.430**	-0.306**	-0.458**	-0.478**	-0.339**	0.20	
Linolenic	-0.084	-0.102	-0.083	-0.0355**	-0.243*	-0.211	-0.169	-0.117	-0.368**	-0.143	-0.137	0.352**

**. Correlation is significant at the 0.01 level) 2 tailed). *. Correlation is significant at the level (2 – tailed).

nificant negative correlation with myristic acid. Negative significant correlation was observed between linoleic acid and all other fatty acids except linolenic and nervonic acid. Palmitic acid also showed significant negative correlation with Oleic and linoleic acids. The data exhibited negative correlations between polyunsaturated fatty acids and saturated or monounsaturated.

Many important rice landraces with diverse genetic composition are grown and consumed all over the world. However, modern hybrid rice varieties have replaced the more nutritious and diverse rice varieties leading to a decline in nutrient diversity within rice species. Decline in rice diversity can adversely affects the nutrient security of the people in rice consuming populations where nutrient diversity in rice has been fundamental to the food and nutrient security of the people.

Modern biotechnology is being explored for improvement of nutrients and its bioavailability in rice, however, the purpose of using genetic engineering for food purpose is still being debated. Fortification of foods with micronutrients may have short term gains but for long term, biofortification strategy taking advantage of the consistent daily consumption of large amount of rice by all family members provides a feasible means of reaching the malnourished populations in remote areas. Increasing protein and micronutrient content like iron and zinc content in brown rice by 20% would mean a substantial increase in the protein and micronutrient intake especially in rice consuming country like India.

Conclusion

The study has revealed diverse rice varieties with wide range of nutrients within rice cultivars in India. The various agro climatic regions in India offers immense opportunity for proper selection of rice cultivars for certain regions which combine high mineral levels with low levels of inhibitors for improved bioavailability in order to combat micronutrient deficiencies in the country. The importance of nutrient diversity in rice is being understood now with the realization that biodiversity is fundamental to food and nutrient security of the people. With the sharp increase in lifestyle-related health issues and diseases, scientists should look at quality traits that place greater focus on their antioxidant properties, glycemic index, and mineral content in the vast pool of indigenous rice varieties available in the country.

Acknowledgements

The technical assistance of K. Subhash, P.S. Prashanthi and O. Kiran Kumar are gratefully acknowledged.

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CANARIUM ODONTOPHYLLUM MIQ.: AN UNDERUTILIZED FRUIT FOR HUMAN NUTRITION AND SUSTAINABLE DIETS

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Abstract

Canarium odontophyllum Miq. or locally known as "dabai", is one of the popular underutilized fruits of Sarawak, Malaysia. Local community consumes a significant amount of dabai during the fruiting season without much knowledge about its nutritional composition and health-promoting properties. Nutritional composition and antioxidant properties of dabai fruits from different growing areas in Sarawak were investigated. Lipid was the major macronutrient in dabai fruit, while the predominant minerals were magnesium and calcium. The fruit is a source of unsaturated fatty acids, with 38–42% oleic acid, 15–18% linoleic acid and traces of linolenic acid. The total anthocyanin content in dabai fruit (2.05–2.49 mg/g dried weight) was comparable to blackberry, blueberry and grape. Fifteen types of phenolic compounds have been identified from this fruit. Several products like mayonnaise, sauces, chips, pickles and soap have been developed from this fruit. This fruit has also been used by local restaurants as an ingredient in their dishes.

1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) in its effort working with its members and the entire international community for achievement of the Millennium Development Goals (MDGs), has declared year 2010 as the International Year of Biodiversity. The integration of biodiversity and nutrition is important for the achievement of MDGs. With this, the conservation and sustainable use of biodiversity for food and agriculture play a critical role in the fight against hunger, by ensuring environmental sustainability while increasing food production.

Sarawak has the richest diversity of flora in Malaysia and offers an excellent source of indigenous fruits and vegetables to the rural communities. *Canarium odontophyllum* Miq. is one of the popular indigenous fruits potentially to be developed as a speciality fruit of Sarawak. The fruit is known as "dabai" among the local community and has been dubbed "Sibu olive" because of its physical appearance, smooth texture and rich flavour (Lau and Fatimah, 2007). Dabai fruits are similar in appearance to olive fruits and turn dark purple when they are fully ripe. The fruits are ovoid drupes, weigh 10.0–18.0 g, 3.0–4.0 cm long and 2.2–3.0 cm in diameter. Dabai fruit contains a single seed with hard and thick endocarp (2.5–3.5 cm long and 1.6–2.0 cm in diameter). The seed is sub-triangular with three chambers. The purple peel and pale yellow fleshy pulp of this fruit (3.0–5.0 mm thick) is edible, while the seed is discarded. The whole ripe fruit is soaked in warm water for 3–5 minutes to soften the pulp and eaten as such or with sugar, salt, pepper or sauce. Dabai fruits are traditionally consumed as highly nutritious fruit rich in energy and fat by local community during fruiting season.

Dabai fruits are rarely eaten, unfamiliar and unknown elsewhere apart from Sarawak. They are sometimes viewed by outsiders as nutritionally inferior fruit. The current usage of dabai fruits is still limited to human consumption. Therefore, there is an urge for scientific evidence to realize the full potential of dabai fruits. To the best of our knowledge, only few reports on nutritional composition and antioxidant properties of dabai fruits are available. Voon and Kueh (1999) has reported the proximate composition including mineral and vitamin content of dabai fruit, while oils extracted from the fruit pulp and kernel were studied for their fatty acids composition and vitamin E content by Azlan *et al.* (2010). Carotenoids profiles of peel, pulp and seed of the fruit and their related antioxidant capacities have been studied by Prasad *et al.* (2011). Extracts of peel, pulp and kernel of dabai fruit have consistently shown antioxidant capacities (Azrina *et al.*, 2010; Prasad *et al.*, 2010; Shakirin *et al.*, 2010).

Previous studies have indicated that geographical conditions and botanical aspects such as variety can significantly affect nutritional values and health beneficial attributes of fruits qualitatively and quantitatively. Influence of geographical conditions on the nutritional composition and antioxidant properties of dabai fruits is unknown. Moreover, apparently there are two varieties of dabai fruits found: the commonly available purple dabai fruit and the less common red dabai fruit. This study was therefore designed to determine and compare the nutritional composition and antioxidant properties of dabai fruits from different divisions of Sarawak, as well as between the two varieties. Thus, this study plays a significant part in the achievement of the MDGs, especially to eradicate extreme poverty and hunger (Goal 1) and to ensure environmental sustainability (Goal 7) in developing countries like Malaysia. This study contributes to the enhancement of livelihood and income of the rural poor. Scientific evidence for the health benefits of dabai fruits in addition to their nutritional quality will provide added value to the fruits. Moreover, this study contributes to the mitigation of environmental degradation by conserving and safeguarding the genetic resources with sustainable use of the natural resources.

2. Proximate composition

Proximate composition (g/100 g FW) of dabai fruits from different growing areas is given in Table 1. Lipid was the major macronutrient of dabai fruits and did not differ among fruits from different growing areas (21.16–25.76 g/100 g FW). Moisture accounted for 50.44–51.91 percent by FW while ash content was 1.66–1.89 g/100 g FW. Both moisture and ash contents did not differ among dabai fruits collected from different growing areas. Results also demonstrated that the red variety showed no difference from the purple variety in terms of their lipid, moisture and ash contents.

Table 1. Nutritional composition of dabai fruits from different growing areas.

Nutritional composition*	Purple dabai fruits			Red dabai fruits
	Kanowit	Kapit	Song	Sarikei
Moisture	51.30±0.93a (50.13–52.97)	51.11±1.10a (49.26–53.08)	50.44±0.76a (48.78–51.70)	51.91±0.88a (50.92–52.60)
Total available carbohydrate	4.45±0.83b (3.57–5.50)	5.07±0.82b (3.89–5.84)	8.97±2.21a (6.11–12.51)	9.16±0.15a (8.99–9.27)
Protein	5.20±0.87a (3.75–6.22)	4.56±0.87a,b (3.08–5.65)	4.35±1.15a,b (2.69–6.68)	3.45±0.64b (2.78–4.04)
Lipid	25.76±3.03a (22.30–29.51)	21.16±4.71a (14.57–26.01)	24.47±2.76a (20.91–29.04)	23.72±1.11a (23.08–25.01)
Ash	1.89±0.08a (1.77–1.95)	1.88±0.42a (1.46–2.42)	1.66±0.26a (1.34–2.00)	1.78±0.17a (1.66–1.90)

*g/100 g fresh weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at $p \leftarrow 0.05$ within the same row.

Table 2. Minerals composition of dabai fruits from different growing area.

	Purple dabai fruits			Red dabai fruits
Minerals*	Kanowit	Kapit	Song	Sarikei
Magnesium	80.31±3.97a (76.51–84.51)	74.67±15.36a (56.26–93.23)	76.09±24.07a (50.04–102.07)	62.72±0.38a (62.38–63.25)
Calcium	28.47±1.56a (26.87–30.08)	40.52±16.66a (22.90–61.94)	43.72±22.72a (16.00–67.88)	40.60±0.11a (40.50–40.74)
Sodium	8.77±0.34b (8.47–9.50)	12.05±3.45a (7.26–15.91)	10.77±0.31a,b (10.13–11.19)	9.36±0.05b (9.28–9.41)
Potassium	6.80±0.21a,b (6.50–7.19)	6.93±1.71a (4.84–9.06)	5.29±1.10b,c (3.64–6.76)	5.02±0.13c (4.85–5.16)
Iron	3.10±0.49a (2.58–3.60)	3.14±0.26a (2.76–3.44)	2.10±0.09b (1.93–2.18)	2.80±0.04a (2.76–2.84)
Zinc	0.78±0.18b (0.61–0.95)	0.81±0.05a,b (0.74–0.86)	0.77±0.09b (0.66–0.87)	0.92±0.01a (0.91–0.93)
Copper	0.47±0.06a (0.42–0.53)	0.35±0.14 (0.24–0.55)	0.39±0.04aa (0.32–0.44)	0.21±0.00b (0.20–0.21)

*mg/100 g fresh weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.

Protein content varied to a greater extent among dabai fruits. While the highest protein content was found in purple dabai fruits from Kanowit (5.20 g/100 g FW), the lowest was in red dabai fruits from Sarikei (3.45 g/100 g FW). It was observed that total available carbohydrate content in the red variety and in purple dabai fruits from Song (9.16 and 8.97 g/100 g FW, respectively) were almost twofold higher than purple dabai fruits from Kapit and Kanowit (5.07 and 4.45 g/100 g FW, respectively). Red dabai fruits were richer in available carbohydrate but with reduced amount of protein as compared to the purple variety.

3. Mineral composition

Mineral composition of dabai fruits varied considerably from one division to another, as well as varying between the red and purple varieties (Table 2). The predominant minerals in dabai fruits were magnesium (62.72–80.31 mg/100 g FW), calcium (28.47–43.72 mg/100 g FW), sodium (8.77–12.05 mg/100 g FW) and potassium (5.02–6.93 mg/100 g FW). Iron, zinc and copper were detected in appreciable amounts in dabai fruits of the present study. It was noted that dabai fruits from Kapit distinguishably had the highest contents of sodium, potassium and iron in every 100 g FW of fruits.

4. Amino acids composition

The amino acids composition of dabai fruits is given in Table 3. Considerable variation was observed from one growing area to another; similarly, variation was

Table 3. Amino acids composition of dabai fruits from different growing areas.

	Purple dabai fruits			Red dabai fruits
Amino acids*	Kanowit	Kapit	Song	Sarikei
Essential				
Isoleucine	2.64±0.13a (2.51–2.75)	2.39±0.29a (1.99–2.69)	2.55±0.07a (2.43–2.63)	2.75±0.11a (2.67–2.83)
Leucine	7.40±0.30a (6.95–7.62)	7.24±1.07a (6.13–8.80)	7.29±0.42a (6.64–7.78)	8.23±0.29a (8.02–8.43)
Lysine	5.61±0.22a (5.38–5.91)	5.43±0.78a (4.32–6.14)	5.86±0.28a (5.49–6.41)	5.77±0.16a (5.65–5.88)
Methionine	0.90±0.01b (0.89–0.92)	0.91±0.09b (0.81–1.04)	0.95±0.07a,b (0.85–1.04)	1.09±0.08a (1.03–1.15)
Phenylalanine	4.82±0.16a (4.65–4.95)	4.64±0.65a (3.61–5.29)	5.16±0.35a (4.71–5.64)	5.09±0.44a (4.78–5.40)
Threonine	3.39±0.06a (3.30–3.43)	3.24±0.34a (2.69–3.64)	3.84±0.55a (3.35–5.04)	3.64±0.17a (3.52–3.76)
Valine	3.66±0.21a (3.41–3.84)	3.07±0.34a (2.70–3.62)	3.57±0.39a (2.73–4.02)	3.60±0.24a (3.43–3.77)
Non-essential				
Alanine	4.93±0.21a (4.79–5.25)	4.82±0.51a (4.21–5.55)	5.12±0.56a (4.56–6.13)	4.89±0.30a (4.68–5.10)
Arginine	2.54±0.17a (2.31–2.66)	3.15±0.54a (2.52–3.83)	2.87±0.05a (2.81–2.95)	2.82±0.07a (2.77–2.87)
Aspartic acid	27.18±1.33a (26.24–29.06)	30.91±6.05a (25.43–40.14)	26.37±1.93a (22.65–28.83)	25.34±0.11a (25.26–25.41)
Cystine	0.60±0.19a (0.40–0.76)	0.75±0.27a (0.44–1.09)	0.63±0.50a (0.10–1.55)	0.32±0.45a (0.10–0.63)
Glutamic acid	19.58±0.34a (19.29–19.90)	18.32±1.18a (16.64–19.44)	19.01±0.65a (18.18–19.89)	19.61±0.55a (19.22–20.00)
Glycine	4.32±0.17a (4.10–4.52)	3.94±0.46a (3.25–4.55)	4.44±0.39a (4.05–5.21)	4.32±0.16a (4.20–4.43)
Histidine	2.37±0.14a (2.16–2.46)	2.02±0.21b (1.76–2.31)	2.28±0.13a,b (2.12–2.48)	2.39±0.17a (2.27–2.51)
Proline	4.29±0.17a (4.12–4.52)	4.40±0.55a (3.57–4.99)	4.68±0.37a (4.21–5.30)	4.73±0.23a (4.57–4.89)
Serine	2.89±0.43a (2.49–3.26)	2.41±0.14a (2.23–2.57)	2.62±0.30a (2.31–3.04)	2.72±0.01a (2.71–2.72)
Tyrosine	2.90±0.10a (2.79–2.98)	2.38±0.31b (1.96–2.64)	2.79±0.11a (2.63–2.97)	2.73±0.17a,b (2.61–2.85)

*% of total amino acids. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at $p \leftarrow 0.05$ within the same row.

noted between the two varieties investigated. Seventeen amino acids were detected, including seven essential (isoleucine, leucine, lysine, methionine, phenylalanine, threonine and valine) and ten non-essential (alanine, arginine, aspartic acid, cystine, glutamic acid, glycine, histidine, proline, serine and tyrosine) amino acids. Fruits were especially rich in aspartic and glutamic acids, constituting 44.95–49.23 percent of total amino acids. Essential aminoacids were present at lower concentrations (26.9–30.2%), of which methionine was the limiting amino acid (0.90–1.09%).

5. Fatty acids composition

Dabai fruit pulp oil contained mainly palmitic (37.1–39.5%), stearic (1.3–3.7%), oleic (38.1–42.4%) and linoleic (15.3–18.4%) acids (Table 4). The oil was a source of unsaturated fatty acids (57.94–59.08%).

Table 4. Fatty acids composition of dabai fruits from different growing areas.

Fatty acids*	Purple dabai fruits Kanowit	Kapit	Song	Red dabai fruits Sarikei
C14:0 Myristic acid	0.23±0.03a,b (0.21–0.26)	0.20±0.01b (0.20–0.21)	0.21±0.04b (0.17–0.27)	0.28±0.00a (0.28–0.28)
C16:0 Palmitic acid	38.15±0.76a (37.48–38.82)	37.12±0.45a (36.54–37.48)	38.11±3.18a (34.39–42.67)	39.48±0.01a (39.47–39.48)
C17:0 Margaric acid	0.03±0.00a (0.03–0.03)	0.03±0.00a (0.03–0.03)	0.03±0.00a (0.03–0.04)	0.04±0.01a (0.03–0.04)
C18:0 Stearic acid	2.72±0.26b (2.50–2.95)	3.51±0.15a,b (3.41–3.70)	3.68±0.63a (3.19–4.68)	1.33±0.00c (1.33–1.33)
C24:0 Lignoceric acid	0.03±0.01b (0.02–0.03)	0.05±0.01a (0.04–0.06)	0.03±0.01a,b (0.01–0.05)	0.04±0.02a,b (0.02–0.05)
SFA	**41.16±0.53a (40.69–41.63)**	**40.92±0.54a (40.23–41.36)**	**42.06±2.69a (39.29–46.13)**	**41.16±0.04a (41.13–41.18)**
C16:1 Palmitoleic acid	0.76±0.12b (0.66–0.86)	0.76±0.07b (0.67–0.80)	0.62±0.12b (0.48–0.79)	1.69±0.00a (1.69–1.69)
C18:1 n9c Oleic acid	41.04±0.70a,b (40.43–41.65)	42.36±0.22a (42.10–42.61)	40.88±3.06a,b (36.78–44.79)	38.06±0.01b (38.05–38.07)
C20:1 Eicosenoic acid	0.03±0.00a,b (0.03–0.03)	0.04±0.01a (0.03–0.04)	0.04±0.01a (0.03–0.05)	0.02±0.00b (0.02–0.02)
MUFA	**41.83±0.58a (41.32–42.34)**	**43.15±0.28a (42.81–43.45)**	**41.54±3.02a (37.47–45.32)**	**39.77±0.01a (39.76–39.78)**
C18:2 n6c Linoleic acid	16.40±0.01b (16.38–16.41)	15.30±0.34b (14.96–15.72)	15.73±1.24b (14.55–17.60)	18.40±0.04a (18.37–18.43)
C18:3 n6 Linolenic acid	0.58±0.05a (0.54–0.62)	0.60±0.03a (0.57–0.64)	0.64±0.12a (0.49–0.80)	0.67±0.01a (0.66–0.67)
C18:3 n3 Linolenic acid	0.03±0.00a (0.03–0.03)	0.03±0.01a (0.02–0.03)	0.03±0.00a (0.03–0.03)	0.02±0.00b (0.02–0.02)
PUFA	**17.01±0.06b (16.95–17.06)**	**15.93±0.32b (15.62–16.33)**	**16.40±1.13b (15.38–18.12)**	**19.09±0.04a (19.06–19.11)**

*% of total fatty acids. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.

Almost even proportion of saturated fatty acids (40.9–42.1%) and monounsaturated fatty acids (39.8–43.2%) was observed. Results of the present study are in good agreement with that of Azlan *et al.* (2010) which the ratio of saturated (SFA): monounsaturated (MUFA): polyunsaturated (PUFA) fatty acids reported was 44.4: 42.8: 12.8. A notable finding was that the percentage of PUFA in red dabai fruits from Sarikei (19.1%) was higher than the purple variety (15.9–17.0%).

6. Phenolic constituents

Total phenolics content and TFC of dabai fruits were found to be varied from one growing area to another; and significantly different between the red and purple varieties. Purple dabai fruits collected from Kapit had the significantly highest TPC and TFC ($p < 0.01$), while the significantly lowest TPC and TFC ($p < 0.01$) were found in red dabai fruits. The TPC of purple dabai fruits from Kapit was three times higher than red dabai fruits. Purple dabai fruits from Kapit also had the TFC which was five times higher than red dabai fruits. It was observed that cooking the fruits at 60°C for 3–5 minutes resulted in increases of TPC and TFC (Tables 5 and 6).

Dabai fruits from Kapit, Kanowit and Song were all of the purple variety, formed a homogeneous group with no significant difference in their TAC, ranged 2.05–2.49 mg anthocyanins pigment/g DW.

In contrast, red dabai fruits from Sarikei had the significantly lowest TAC (0.08 mg anthocyanins pigment/g DW) ($p < 0.01$). Contrarily to the previous two observations, cooking of dabai fruits at 60°C for 3–5 minutes resulted in decreases of TAC (Table 7).

Table 5. Total phenolics content of dabai fruits from different growing areas.

		Purple dabai fruits		Red dabai fruits
TPC	Kanowit¥	Kapit¥	Song¥	Sarikei
Cooked fruit	19.44±2.90b (15.40–22.01)	33.21±6.11a (27.25–42.57)	22.81±5.91b (15.11–32.13)	9.50±0.42c (9.17–9.97)
Uncooked fruit	13.79±1.18b (12.38–15.59)	27.02±5.20a (22.24–33.97)	14.12±3.97b (10.95–21.02)	9.10±1.20b (8.18–10.46)

TPC, total phenolics content expressed as mg gallic acid equivalent (GAE)/g dried weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.
¥ indicates significantly different at p ← 0.05 within the same column.

Table 6. Total flavonoids content of dabai fruits from different growing areas.

		Purple dabai fruits		Red dabai fruits
TFC	Kanowit¥	Kapit	Song¥	Sarikei
Cooked fruit	55.46±9.11b (44.38–67.14)	103.92±24.60a (76.24–139.33)	53.31±12.15b (31.10–70.29)	20.46±5.62c (14.81–26.05)
Uncooked fruit	33.06±5.60b (28.24–41.10)	86.06±21.71a (62.38–122.71)	37.59±16.03b (22.62–73.00)	14.08±3.23b (12.10–17.81)

TFC, total flavonoids content expressed as mg rutin equivalent (RE)/g dried weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.
¥ indicates significantly different at p ← 0.05 within the same column.

Table 7. Total anthocyanins content of dabai fruits from different growing areas.

TAC	Kanowit	Purple dabai fruits Kapit¥	Song¥	Red dabai fruits Sarikei¥
Cooked fruit	2.06±0.53a (1.49–2.74)	2.49±0.60a (1.73–3.41)	2.05±0.30a (1.55–2.51)	0.08±0.00b (0.08–0.09)
Uncooked fruit	2.54±0.25a (2.32–2.81)	3.54±0.94a (2.29–4.61)	3.20±0.83a (2.45–4.69)	0.18±0.01b (0.17–0.18)

TAC, total anthocyanins content expressed as mg anthocyanins pigment/g dried weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.
¥ indicates significantly different at p ← 0.05 within the same column.

Table 8. Trolox equivalent antioxidant capacity of dabai fruits from different growing areas.

TEAC	Kanowit¥	Purple dabai fruits Kapit¥	Song¥	Red dabai fruits Sarikei¥
Cooked fruit	0.45±0.05b (0.40–0.50)	0.68±0.09a (0.57–0.85)	0.38±0.06b (0.31–0.47)	0.20±0.00c (0.20–0.21)
Uncooked fruit	0.21±0.04b,c (0.17–0.24)	0.32±0.04a (0.28–0.39)	0.25±0.03b (0.20–0.30)	0.18±0.01c (0.18–0.19)

TEAC, trolox equivalent antioxidant capacity expressed as mmol trolox equivalent (TE)/g dried weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.
¥ indicates significantly different at p ← 0.05 within the same column.

Table 9. Ferric reducing ability of dabai fruits from different growing areas.

FRAP	Kanowit¥	Purple dabai fruits Kapit¥	Song¥	Red dabai fruits Sarikei¥
Cooked fruit	0.93±0.30b (0.65–1.35)	1.74±0.32a (1.31–2.05)	1.08±0.31b (0.79–1.64)	0.27±0.02c (0.26–0.29)
Uncooked fruit	0.03±0.01b (0.01–0.04)	0.50±0.15a (0.35–0.74)	0.08±0.09b (0.00–0.25)	0.02±0.01b (0.01–0.02)

FRAP, ferric reducing ability expressed as mmol of Fe2+/g dried weight. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.
¥ indicates significantly different at p ← 0.05 within the same column.

7. Antioxidant capacities

Trolox equivalents antioxidant capacities were found different among fruits from different growing areas; and between the red and purple dabai fruits. Dabai fruits collected from Kapit exhibited the highest TEAC ($p < 0.01$). The significantly lowest TEAC ($p < 0.01$) was found in red dabai fruits. The TEAC of fruits increased after fruits were cooked at 60°C for 3–5 minutes (Table 8). The FRAP values of dabai fruits indicated differences among fruits from different divisions; and differed between the red and purple varieties. While the significantly highest FRAP value ($p < 0.01$) was found in purple dabai fruits from Kapit, the significantly lowest ($p < 0.01$) was of red dabai fruits. Similarly, cooking of the fruits at 60°C for 3–5 minutes resulted in increases of FRAP values (Table 9).

Table 10. DPPH radicals scavenging activity of dabai fruits from different growing areas.

DPPH	Kanowit¥	Purple dabai fruits Kapit¥	Song¥	Red dabai fruits Sarikei
Cooked fruit	89.45±0.50a,b (88.85–90.08)	88.14±1.21b (85.84–89.57)	88.12±1.09b (85.80–88.94)	90.96±0.22a (90.80–91.21)
Uncooked fruit	71.22±3.34b (66.74–74.84)	58.96±7.89c (51.44–70.91)	64.59±8.30b,c (49.27–72.35)	91.03±0.03a (91.01–91.0

DPPH, DPPH radicals scavenging activity expressed as percentage of inhibition. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at $p \leftarrow 0.05$ within the same row.
¥ indicates significantly different at $p \leftarrow 0.05$ within the same column.

All dabai fruits exhibited high DPPH free radicals scavenging activities of more than 88 percent, indicating good potential as free radicals scavengers. The hierarchy of dabai fruits with respect to their abilities to scavenge DPPH free radicals was red dabai fruits > purple dabai fruits from Kanowit > purple dabai fruits from Kapit > purple dabai fruits from Song. Cooking of fruits at 60°C for 3–5 minutes also resulted in increases of DPPH free radicals scavenging activity (Table 10). Interestingly, red dabai fruits from Sarikei with lowest TEAC and FRAP value demonstrated the greatest DPPH free radicals scavenging activity.

Purple dabai fruits from Kapit that were found to possess significantly the highest TPC, TFC and TAC exhibited significantly the greatest TEAC and FRAP. Similarly, significantly the lowest TEAC and FRAP were observed in red dabai fruits from Sarikei which had significantly the least TPC, TFC and TAC. These data suggest that phenolic compounds (including flavonoids and anthocyanins) in dabai fruits provide substantial antioxidant activities. It is strongly believed that the antioxidant properties of purple dabai fruits from Kapit are intimately related to the geographical location of Kapit. It is a remote division of Sarawak, with less exposure to pollutants which could have a positive effect on the phytochemical properties of dabai fruits cultivated in Kapit.

Further data analysis indicated very strong linear correlations between TPC and TEAC (r = 0.958), and between TPC and FRAP (r = 0.999). Similarly, very strong linear correlations between TFC and TEAC (r = 0.991), and between TFC and FRAP (r = 0.983) were noted. Strong linear correlations between TAC and TEAC (r = 0.870), and between TAC and FRAP (r = 0.906) were also observed. Due to the lower correlations of TAC with TEAC and FRAP values, we could say that anthocyanins did not play a major role in antioxidant mechanisms with these tests. Moderate to strong negative correlations were found between TPC and DPPH (r = -0.898), between TFC and DPPH (r = -0.794) and between TAC and DPPH (r = -0.912).

8. Phenolic compounds

In the present study, the chromatographic profiles of phenolic acids and flavonoids in dabai fruits were qualitatively similar for the two varieties (purple and red dabai fruits). However, they differed in the amount of phenolic compounds identified. The chromatographic profile of anthocyanidins and anthocyanins in dabai fruits revealed marked differences between varieties, with more phenolics in purple dabai fruits. Anthocyanidins and anthocyanins were relatively more abundant in purple dabai fruits.

Catechin was the major phenolic compound in dabai fruits. Catechin in red dabai fruits (0.33 mg/g DW)

Table 11. Contents of phenolic acids and flavonoids in dabai fruits from different growing areas.

Phenolic compound	Kanowit	Purple dabai fruits Kapit	Song	Red dabai fruits Sarikei
Catechin	3.01±0.06b (2.93–3.08)	4.00±0.58a (3.31–4.69)	3.22±0.29a,b (2.84–3.64)	0.33±0.02c (0.31–0.34)
Epigalocatechin gallate	0.28±0.01a (0.27–0.29)	0.25±0.06a (0.16–0.30)	0.24±0.04a,b (0.21–0.29)	0.16±0.01b (0.15–0.16)
Epicatechin	0.09±0.01a (0.08–0.10)	0.10±0.04a (0.05–0.14)	0.08±0.01a (0.06–0.10)	0.07±0.00a (0.07–0.07)
Epicatechin gallate	0.04±0.01a,b (0.04–0.05)	0.05±0.01a (0.03–0.06)	0.03±0.01a,b (0.02–0.04)	0.03±0.00b (0.03–0.03)
Apigenin	0.09±0.01a,b (0.08–0.10)	0.12±0.02a (0.11–0.14)	0.08±0.02b (0.05–0.10)	0.08±0.00b (0.08–0.08)
Ellagic acid	0.09±0.02a (0.07–0.11)	0.21±0.11a (0.08–0.34)	0.16±0.07a (0.10–0.27)	0.10±0.01a (0.09–0.10)
Vanilic acid	0.01±0.00a,b (0.01–0.01)	0.02±0.01a (0.01–0.02)	0.01±0.00a,b (0.01–0.02)	0.01±0.00b (0.01–0.01)
Ethyl gallate	0.02±0.00b (0.01–0.02)	0.03±0.01a (0.02–0.03)	0.01±0.00b (0.01–0.02)	0.01±0.00b (0.01–0.01)

mg/g DW. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.

was significantly lower than purple dabai fruits (3.01 to 4.00 mg/g DW) ($p < 0.01$); while the content of other identified phenolic compounds was comparable in both varieties. Epigalocatechin gallate, epicatechin, epicatechin gallate, apigenin and ellagic acid were all present in appreciable amounts, while vanilic acid and ethyl gallate were relatively lower (Table 11). Cyanidin-3-O-rutinoside was the major anthocyanin with its content been 16 and 26 times higher in purple variety than red variety. Cyanidin and its glycosides (cyanidin-3-O-glucoside and cyanidin-3-O-rutinoside) were the main anthocyanidins and anthocyanins detected in both varieties; with trace amount of pelargonidin. In addition, delphinidin, malvidin-3,5-di-O-glucoside at appreciable amount and trace of peonidin-3-O-glucoside were also detected in purple dabai fruits (Table 12). Within the same variety, in purple dabai fruits, considerable variability in the content of all identified phenolic compounds from one division to another was noted. Tura *et al*. (2007) reported a similar observation that the phenolic compounds content of olive fruits was influenced by site of cultivation/growing environment. Dabai fruits collected from Kapit clearly exhibited the highest content of almost all the identified phenolic acids and flavonoids. Similarly, dabai fruits possessed the highest content of all identified anthocyanidins and anthocyanins were collected from Kapit. It is noted that the total flavanols content of purple dabai fruits was much higher than apple, blackberry, blueberry, black grape, raspberry and strawberry (Arts *et al.*,

Table 12. Contents of anthocyanidins and anthocyanins in dabai fruits from different growing areas.

Phenolic compound	Kanowit	Purple dabai fruits Kapit	Song	Red dabai fruits Sarikei
Cyanidin	0.06±0.01a (0.06–0.07)	0.07±0.01a (0.05–0.08)	0.06±0.01a (0.05–0.08)	0.03±0.00b (0.03–0.03)
Cyanidin-3-O-glucoside	0.34±0.02a (0.31–0.37)	0.39±0.07a (0.29–0.46)	0.32±0.07a (0.25–0.41)	0.03±0.00b (0.03–0.03)
Cyanidin-3-O-rutinoside	1.16±0.03b (1.13–1.19)	1.85±0.34a (1.49–2.27)	1.41±0.13b (1.31–1.63)	0.07±0.00c (0.07–0.07)
Delphinidin	0.02±0.00b (0.01–0.02)	0.11±0.03a (0.08–0.16)	0.04±0.03b (0.01–0.08)	ND
Malvidin-3,5-di-O-glucoside (0.03-0.15)	0.07±0.02b (0.05–0.10)	0.20±0.07a (0.12–0.28)	0.09±0.04b	ND
Pelargonidin	Tr	Tr	Tr	Tr
Peonidin-3-O-glucoside	Tr	Tr	Tr	ND

Tr, trace; ND, not detected (← 10 ng/injection (20μl)).
mg/g DW. Results are expressed in mean±SD and (range).
Values with different letters are significantly different at p ← 0.05 within the same row.

2000; de Pascual-Teresa and Sanchez-Ballesta, 2008; Tsanova-Savova *et al.*, 2005) while the total anthocyanins content was comparable among them.

9. Conclusions

All data obtained revealed that dabai fruit was a very nutritious fruit. While the proximate, amino acids and fatty acids compositions of dabai fruits varied to a lesser extent among fruits from different growing areas as well as between the red and purple varieties; total phenolics (TPC), flavonoids (TFC) and anthocyanins (TAC) contents of fruits were found varied greatly among growing areas and especially between the two varieties. Dabai fruit had high nutritional values and great antioxidant properties; exhibiting huge potential of extrapolation. It is postulated that, in addition to the beneficial effects conferred by its unsaturated fatty acids on blood lipids profile by lowering blood cholesterol and triglyceride levels, phenolic compounds of dabai fruit give positive effects against oxidative stress.

The numerous potential biological capabilities of dabai fruits based on the specific phenolic compounds identified, such as the cardioprotective effects of anthocyanins and antidiabetic effects of flavanols deserve more precise and specific further investigations. Considering that little or no information is available about the four divisions under investigation including their soils, rainfall and other important variables, further studies to achieve this purpose need to be conducted especially in Kapit, a division where dabai fruits collected distinguishably having great antioxidant properties. Moreover, based on the knowledge obtained in this study on the variability between the purple and red varieties, further investigation is needed to make the best use of the two varieties.

Acknowledgements

The authors would like to thank the Agriculture Research Centre (ARC), Semongok, Sarawak for providing funding and the dabai fruits from Sarikei and Kanowit; and the laboratory facilities of Universiti Putra Malaysia.

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IMPROVED MANAGEMENT, INCREASED CULTURE AND CONSUMPTION OF SMALL FISH SPECIES CAN IMPROVE DIETS OF THE RURAL POOR

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Abstract
In many low-income countries with water resources, small fish species are important for the livelihoods, nutrition and income of the rural poor. The small size of fish favours frequent consumption by and nutrition of the rural poor, as these fish are captured, sold and bought in small quantities; used both raw and processed in traditional dishes; and are nutrient-rich. All small fish species are a rich source of animal protein, and – as they are eaten whole – have a very high content of bioavailable calcium. Some are rich in vitamin A, iron, zinc and essential fats. Measures to improve management and increase culture and consumption of small fish include community-based management of common water bodies; culture of small fish in ponds and rice fields; use of small marine fish for direct human consumption, especially in vulnerable population groups; and improved handling, transportation, processing – especially drying – and market chains to reduce loss and increase accessibility, especially in hard to reach population groups. Recent integrated initiatives such as Scaling Up Nutrition (SUN) Framework and Roadmap: 1,000 Days Global Effort, focusing on the linkages between agriculture and nutrition give good opportunities for promoting improved management, and increased culture and consumption of small fish species.

1. Introduction
In many low-income countries, with water resources, fish and fisheries are an integral part of the livelihoods, nutrition and income of the rural poor. In these population groups, a large proportion of the fish caught, bought and consumed is from capture fisheries, and made up of small fish species. However, as national statistics on fish production and consumption fail to capture data on these small fish species, their importance in diets is neglected (Roos *et al.*, 2006). Very few consumption surveys have reported on fish intake at species level. In Bangladesh, data from some rural surveys show that small freshwater fish species make up a large part of total household fish consumption; fish is a traditional and common food; the frequency of fish intake is high; and the amounts consumed are small. These surveys also show that fish is an irreplaceable animal source food for the rural poor; adding diversity to a diet dominated by one grain staple, rice. In addition, survey data show that the total fish consumption among the rural poor has decreased, as well as the proportion of small fish species of total fish consumption (Thompson *et al.*, 2002). In Bangladesh, small indigenous fish species are characterized as species growing to a maximum of 25 cm or less. In some African countries, for example, Malawi, Kenya, Tanzania and Zambia, the importance of small fish species, for example kapenta (*Limnothrissa* spp.) as a major animal source food in the diets of rural populations, living close to lakes is recognized (Haug *et al.*, 2010). In coastal communities, small marine fish species are also important in the diets of the poor.

2. Factors related to the small size of fish which benefit consumption
There are many factors related to the small size of fish species, which make them especially favourable for inclusion in the diets of the rural poor. In Bangladesh, the diversity of small fish species is large; and a large proportion of the over 267 freshwater and 400 species from the mangrove waters in the Sundarbans is of small size (Islam and Haque, 2004; Rahman, 1989). Capture fisheries continue to be an important source of fish. In the monsoon and post-monsoon periods (June–November), the floodplains are inundated, providing an ideal habitat for the many fish species, and people have access to these for consumption as well as local sale. Much of the small fish is sold in small rural markets, and this is the major source of fish for consumption by the rural population. Small fish are sold in small heaps of mixed species, can be bought in quantities which are affordable, and can be cooked for one meal or for daily consumption, favouring a high frequency of consumption (Roos, 2001). This is important, taking

into consideration that fish is highly perishable and the rural population does not have the possibility to keep foods cold or frozen. In northern Zambia, heaps of around 20 g raw chisense (many small fish species, dominated by *Poecilothrissa moeruensis*) are sold and bought. Fish capture and production are highly seasonal with peak and lean seasons, and processing of fish, especially sun-drying gives the possibility to make good use of small fish species which are plentiful and affordable in the peak season, reduce weight which eases transportation and storage, as well as extend the length of storage time and duration of intake. Traditional products such as dried, smoked, salted and fermented small fish, as well as fish paste and fish sauce are made at household level and bought in small quantities from local markets. Raw and processed small fish are normally cooked as a mixed curry or stew dish, with little oil, vegetables and spices. It is reported that these dishes are well-liked, easy to prepare, add taste and flavour to meals made up of large quantities of one staple, for example rice or maize, as well as contribute to dietary diversity. A dish with small fish and vegetables can be shared more equitably among household members, including women and young children (Roos et al., 2007b). Surveys of perceptions of small fish species in rural Bangladesh show that many are considered beneficial for well-being, nutrition and health, and women ranked small fish as the second most preferred food to buy – after fruits – if they had more income to spend on food (Deb and Haque, 2011; Nielsen *et al.*, 2003; Thilsted and Roos, 1999).

3. Intake and nutritional contribution of small fish species

Some rural surveys have shown the effect of location, seasonality, year and household socio-economic status on fish consumption. In a survey conducted in 1997–98, in an area in northern Bangladesh with rich fisheries resources; the average fish intake in the peak fish production season (October), 82 g raw, edible parts/person/d was more than double that in the lean season (July); and five common small species made up 57 percent of the total intake (Roos *et al.*, 2003). The nutritional contribution of small fish species is high. It is well recognized that fish are a rich source of animal protein, and some marine fish have a high content of total fat and essential fats. Recently, some small freshwater fish species have been reported as being rich sources of fat and essential fats. Trey sloeuk russey (*Paralaubuca typus*) from Cambodia has a high fat content (12 g/100 g dried fish) (Roos *et al.*, 2010). Dried usipe (*Engraulicypris sardella*) from an area around Lake Malawi contains 1 700 mg docosahexaenoic acid (DHA) per 100 g dried fish, comparable to salmon. The DHA concentration in the breast milk of women from this area was found to be about 0.7 percent of fatty acids; about twice the global average (K. Dewey, personal communication, 7 April 2011).

However, the contribution of small fish species as a rich source of vitamins and minerals has not been widely documented and is overlooked. In the above-mentioned study from Bangladesh, small fish contributed 40 percent and 31 percent of the total recommended intakes of vitamin A and calcium, respectively, at household level, in the peak fish production season (Roos *et al.*, 2006). Some common small species, mola (*Amblypharyngodon mola*), chanda (*Parambassis* spp), dhela (*Ostreobrama cotio cotio*) and darkina (*Esomus danricus*) have high content of vitamin A. As most small fish species are eaten whole, with bones, they are also a very rich source of highly bioavailable calcium. Darkina, as well as trey changwa plieng (*Esomus longimanus*) from Cambodia have a high iron and zinc content (Roos *et al.*, 2007a). A traditional daily meal of rice and sour soup made with trey changwa plieng can meet 45 percent of the daily iron requirement of a Cambodian woman. In addition, fish enhances the bioavailability of iron and zinc from the other foods in a meal (Aung-Than-Batu *et al.*, 1976).

4. Measures to increase the availability and consumption of small fish species

With fast-growing populations in low-income countries, changing trends in use of land and water, overfishing, degradation of fish habitats and lack of management of water and fisheries resources, the availability of freshwater fish, especially small species has decreased. In some Asian countries, aquaculture of large, fast-growing fish species has been vigorously promoted in response to declining fish availability. In Bangladesh, pond polyculture of carps, and recently, monoculture of the introduced species, Nile tilapia (*Oreochromis niloticus*) and pangas (*Pangasius sutchi*), mainly for urban markets, have been very successful. The intake of silver carp (*Hypophthalmichthys molitrix*) – a large fish which is not well liked and makes up a large proportion of aquaculture production – has increased among the poor, as total fish intake has decreased. Due to species differences in nutrient content, as well as large fish not eaten whole as small fish – for example, the bones are plate waste – this production technology of large fish does not favour increased fish consumption by the poor or contribution to micronutrient intake (Roos *et al.*, 2007b).

Recognizing the decline in biodiversity of indigenous freshwater fish species in Bangladesh, as well as growing attention to the nutritional importance of small species, some measures have been taken to conserve, manage and culture indigenous fish.

Conservation and management of common fisheries resources and fish migration routes through community-based and community-managed fisheries approaches have proved successful in increasing total fish production many times, the diversity of fish species, as well as the proportion of small fish species captured and consumed by landless and small farming households (Center for Natural Resource Studies, 1996). Similar positive results have been achieved in the Management of Aquatic Ecosystems through Community Husbandry (MACH) projects (1998–2003) which included interventions to restore three major wetlands habitats, ensure sustainable productivity and improve the livelihoods of the poor who depend on these wetlands, through community based co-management (Anonymous, 2003).

Pond polyculture of carps with the vitamin A rich small fish, mola was introduced in Bangladesh in the late 1990s. No significant difference in total fish production was seen between ponds stocked with carps and mola, and those with carps alone. However, the nutritional quality of the total fish production improved considerably in the ponds with mola. In this production system, the eradication of indigenous fish, the majority being small species, by repeated netting, dewatering, and the use of a piscicide, rotenone; prestocking of carp fingerlings – based on the rationale that competition exists between native and stocked fish – was stopped. As small fish species breed in ponds, frequent partial harvesting must be practised, and this favours home consumption. In addition to the production of carps, a small mola production of 10 kg/pond/y, in the estimated four million small, seasonal ponds in Bangladesh can meet the annual recommended vitamin A intake of six million children (Roos *et al.*, 2007b). This production technology of carp-small fish pond polyculture has gained wide acceptance by the Government of Bangladesh and development partners, and is also being practised in Sundarbans, West Bengal and Terai, Nepal. Carp production and management of indigenous fish species in beels (floodplain depressions and lakes) have also resulted in large increases in total fish production (over 0.6 tonnes/ha, in 6 months, of which 45 percent were non-stocked fish, mainly small species) (Rahman *et al.*, 2008). Depending on geographical location and season, different culture practices with fish and rice have shown to increase fish diversity, as well as the nutritional quality of the combined rice and fish production (Dewan *et al.*, 2003; Kunda *et al.*, 2009).

A central issue regarding the availability of small fish species for direct human consumption is the vast amounts of small marine fish (about 23.8 million tonnes in 2006) used to produce fish meal and fish oil, primarily for aquaculture (Tacon and Metian, 2009). There is growing concern of the dwindling supplies and population collapse of small marine fish species (Pinsky *et al.*, 2011). More focused advocacy and awareness, as well as development and implementation of policies, regulations and interventions are needed in order to significantly reduce this trend. Fish powder made from small marine fish can be used as an excellent source of essential nutrients in feeding programmes for pregnant and lactating women, young children, school children, the sick and elderly. In the WINFOOD project presently being conducted in Cambodia and Kenya, complementary foods for young children with powdered, nutrient-rich small fish species have been developed, and efficacy studies are being carried out (Roos *et al.*, 2010).

Improving handling and transportation, processing and market chains to reduce the large amounts of fish lost due to spoilage and waste can greatly increase the accessibility of small fish and fish products to the poor and population groups which are hard to reach. Recognizing that improvements in transportation and storage systems for raw fish can be difficult to achieve in low-income countries, much more efforts should be made to improve traditional sun-drying methods. In Mali, a simple, robust mobile fish dryer has been developed which eliminates contamination caused by spreading the fish on soil, and the use of insecticides to keep away flies during sun-drying. In addition, the time needed for drying is short, and the temperature used is controlled and lower than that reached from direct exposure to the sun, resulting in a product of high nutritional and food safety quality (Heilporn *et al.*, 2010).

5. Conclusion

Recent attention to linkages between agriculture, human nutrition and health gives new possibilities to focus on management and culture of small fish species for improved diets. There are initiatives such as the CGIAR Research Programmes; USAID funded Feed the Future; Scaling Up Nutrition (SUN) Framework and Roadmap: 1,000 Days Global Effort; Bill and Melinda Gates Foundation, Grand Challenges Explorations Rounds 7 and 8: Explore Nutrition for Healthy Growth of Infants and Young Children; and CIDA funded Grand Challenges Canada: Saving Brains focus on integrated approaches to improve nutrition. For implementing SUN: 1,000 Days Global Effort, recommendations for the increased availability, accessibility and intake of fish as a rich source of essential fats, crucial for cognitive development have been highlighted.

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TRADITIONAL FOOD SYSTEMS IN ASSURING FOOD SECURITY IN NIGERIA

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Introduction

Traditional food systems refer to the human managed biophysical systems that are involved in the production, distribution and consumption of food in a particular environment. Food systems are a natural locus for improving nutrition security in societies because agriculture is the primary employment sector for the extremely poor and because food consumes a very large share of the expenditures of this group of people. The causal mechanisms underpinning the poverty trap in which the poor, unhealthy and undernourished rural Africans too often find themselves remain only partially understood, but are clearly rooted in the food system that guides their production, exchange, consumption and investment behaviours.

The most basic thing we know is that ill health, malnutrition and extreme poverty are mutually reinforcing states. The links are multidirectional. Low real incomes are the primary cause of chronic and acute hunger, as a vast literature spawned by Sen (1981) emphasizes. Even when food availability is adequate – which is not the case in large portions of SSA today – low incomes impede access to sufficient and appropriate food to maintain a healthy lifestyle. But causality runs the other way as well. The WHO (2002) reports that undernutrition, including micronutrient deficiencies, is the leading risk factor for disease and death worldwide, accounting for over half the disease burden in low-income countries. Undernutrition also impedes cognitive and physical development, thereby depressing educational attainment and adult earnings.

Disease, in turn, impedes the uptake of scarce nutrients, aggravating hunger and micronutrient malnutrition problems and hurting labour productivity and earnings. Indeed, recent research suggests that major health shocks are perhaps the leading cause of collapse into long-term poverty (Gertler and Gruber, 2002; Barrett and Swallow, 2006). And a large literature amply demonstrates the corollary that improved nutrition and health status increase the current and lifetime productivity of individuals, thereby increasing incomes and assets and contributing to poverty reduction (Dasgupta, 1997). Food systems are the natural locus for developing an integrated strategy for addressing hunger, ill health and poverty jointly and thus assuring nutrition security.

Nutrition security is the access to adequate diet by every member of the household. Access to food is tied to production of enough food by the agricultural system, importation of food, income, cooking methods and household food-sharing formula. Each of these factors is multifaceted such that an attempt to individually discuss them will be impossible within the scope of this write-up.

What are these traditional food systems

These involve the methods and types of foods produced within the given community or state or country. In Nigeria the traditional foods available are many and varied depending on climate/agro-ecological zone. Traditional foods are foods produced locally which form part of the food culture inherent in the locality. The local climate enables the cultivation of such crops either for subsistence or for cash or both.

Food plants are traditional in the sense that they are accepted by rural communities by custom, habit and tradition as appropriate and desirable food. People are used to them; they know how to cultivate and prepare them and enjoy the dishes made from them. They are grown for food within the farming systems operating in any particular locality or gathered as wild or semi-wild products. There are two groups of foods: those consumed in the areas where they are grown as traditional dietary staples, for example, cassava, yam, cocoyam, sweet potatoes (*Ipomoea batatas*), plantains (*Musa paradisiaca*) and maize. The second group is made up of those consumed as a component of accompanying relishes

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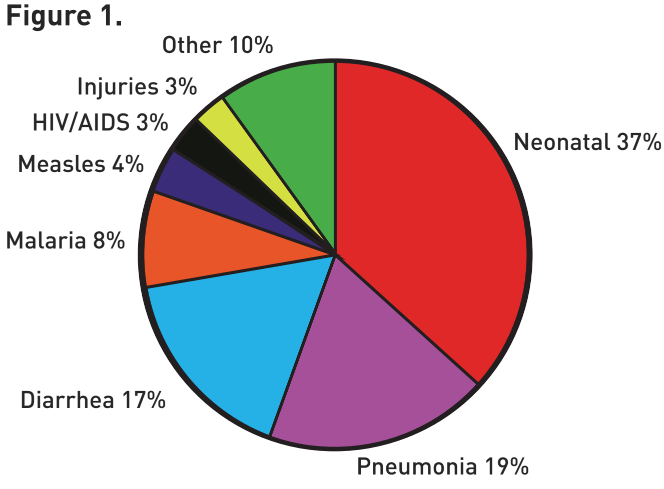
and sauces. These include oilseeds, fruits and vegetables. There is no universally accepted shortlist of such plants. Communities have evolved their own preferences and food habits (Okeke *et al.*, 2008).

Improvement in the food systems have been found to greatly reduce hunger, improve income and reduce malnutrition and the related disease conditions in so many countries.

Child mortality is 88 deaths per 1 000 live births, overall under-five mortality rate is 138 deaths per 1 000 live births and there is a drop in exclusive breastfeeding (EBF) from 17 percent to 13 percent (NDHS, 2008).

Food security is closely linked to nutrition security. In Nigeria malnutrition contributes to unacceptably high maternal, newborn and child mortality rates. A woman's chance of dying from pregnancy and childbirth is 1 in 13. Other data show that infant mortality rate (IMR) is 75 deaths per 1,000 live births. Over 50 percent of the underlying causes of these deaths is undernutrition.

Figure 1.



A few questions naturally arise at this point

1. What is the nature of the Nigerian traditional food system?
2. What are the methods of food production in Nigeria?
3. What are the traditional foods in Nigeria?
4. What are the nutrient compositions of traditional Nigerian foods?
5. Can the traditional food systems and the nutrient compositions assure nutrition security?

The Nigerian traditional food system is characterized by low return on investments, crude and ineffective farm implements, low irrigation, expensive inputs such as fertilizers, improved planting materials, low yielding plants and livestock etc.

Classification of traditional foods

Traditional foods in Nigeria can be classified into the following:

a. Roots and tubers
b. Cereals and legumes
c. Vegetables and fruits
d. Herbs and spices
e. Livestock and game

a. Roots and tubers

Examples of roots and tubers include cassava, yams, coco yams – these are mainly produced and consumed in the humid savannah and rainforest agro-ecological zones. These stretch from the middle belt to the southern part of Nigeria.

b. Cereals and legumes

Examples include maize, sorghum, millet, acha, rice, beni seed (cereals), and cowpeas, pigeon pea, African yam bean, bambara nuts.

Food products from cereals include boiled rice, jollof and rice pudding, e.g. tuwo shinkafa, cornfood, pap, eko/agidi, "maize–rice", African bread fruit jollof, toasted bread fruit seeds, beni seed soup, acha, tuwo masara, boiled or roasted corn. Legume products include boiled beans, mashed beans, rice and beans, jollof beans, moin, akara, gbegiri soup, bean pottage, roasted groundnut, groundnut soup. Products from roots and tubers include the following: pounded yam, amala (yam flour paste), garri, boiled yam, akpu, tapioca, abacha flakes.

A woman and two children peeling cassava and tubers of yam on display for sale

Tubers of yam

Yellow maize

Unshelled groundnuts

Millet

Different types of legumes

c. Fruits and vegetables

Fruits are described as the ripened seeds of plants and the adjoining tissues which house them (Onimawo and Egbekun, 1998). They are commonly used as desserts.

Vegetables are the leafy outgrowth of plants or part of plants that are used in making soups or eaten with the principal part of a meal. In southern Nigeria, leafy vegetables are grouped into:

i cultivated leafy vegetables such as pumpkin, green (spinach), bitter leaf, ewedu, water leaf;

ii semi-wild vegetables which grow wild in the bush but are now protected to grow in the home garden, e.g. utazi, uziza, atama (Ibos) okpai (Edo);

iii wild vegetables – okazi, edikan (Ibibio and Efik).

Many useful fruit trees which are exploited from semi-wild conditions include breadfruit (*Treculia* sp.), African pear (*Dacroydes* sp.), *Irvingia* sp. and *Pentaclethra macrophylla* (oil bean seed), *Dialium* sp., *Parkia vitex* and *Chrysophyllum* sp. Wild and semiwild leaf vegetables of importance include *Pterocarpus* sp., *Pergularia* sp. and *Gnetum* sp.

Several fruits exist in Nigeria. These fruits are distributed across the agro-ecological zones. In the humid savannah several of the fruits include pawpaw (*Carica papaya*), oranges, guava, lime, grapes, African star apple (udara), mangoes, velvet tamarin (*Vitex doniana*), bananas, tangerine, cashew, garden eggs. In the northern part of Nigeria, particularly in the Plateau State axis there are different types of vegetables such as carrots, cabbage, water melon, garden eggs. About 294 species and over 400 varieties of foods were documented in the south-

A bunch of bananas

Mango

Pawpaw

Tomatoes

eastern part of Nigeria alone (Okeke *et al.*, 2008). Twenty-one species of starchy roots and tubers, 20 legumes, 21 nuts/seeds, 116 vegetables, 12 mushrooms and 36 fruits have been documented in southern Nigeria. Cereals, starchy roots and tubers are important food groups for the majority of Nigerians. The foreign rice syndrome has in the recent past overtaken many households, especially in the urban areas.

Generally, plant foods are available all year round but are more abundant during the harvest season. The most commonly consumed legume in Nigeria is the cowpea (*Vigna unguiculata*). Local varieties of cowpea and other species of legumes are also available but not produced in very large quantities including bambara nut, African yam bean, groundnut. Mushrooms are also consumed though in relatively small quantities. Fruits are not main parts of the diet but are eaten outside regular meals. Two types of oil (red palm oil and vegetable oil – mainly ground nut oil) are commonly used. A total of 21 condiments and spices were identified. Some of these condiments are soup thickeners and are high in dietary fibre.

Animal foods were about 27 species for meat/poultry/eggs, 12 species of fish and 3 species of insect/larvae were documented (Okeke *et al.*, 2008). The most popular game meats are grasscutter, rabbit and antelope. Milk and milk products are not common food items except in the northern part of Nigeria but rare in the usual diets of most households in the southern part of Nigeria. In most communities, foods are eaten not only for their nutritional values but also for their medicinal and sociocultural significance.

Green amaranthus

Okra

Table 1. Some Nigerian traditional foods.

	Scientific name Fruits	English/ common name	Local name	Preparation
1	Abelmoschus esculenta	Lady's finger	okwulu npiene	Used for soups
2	Anacardium occidentalis	Cashew	mkpuru cashew	Roasted and eaten as a snack
3	Anonas comosus	Pineapple	Akwuolu	Fruit eaten when ripe
4	Anonas muricarta	Soursop		Fruit eaten when ripe
5	Artocarpus communis	Breadfruit	ukwa bekee	-
6	Azadirachta indica	Neem	Dogoyaro	Used for malaria
7	Canarium schweinfurthii	Pear	ube okpoko	Soften in hot water and pulp eaten
8	Carica papaya	Pawpaw	okwuru ezi	Fruit eaten when ripe
9	Chrysophyllum albiduim	Bush apple (African star apple)	udala nkiti	Fruit eaten when ripe
10	Citrus aurantifolia	Orange	Oromankiti	-
11	Citrus aurantium	Orange	Oroma	Fruit eaten when ripe
12	Cocos nucifera	Coconut	Akuoyibe	Eaten raw with corn/maize
13	Cola spp.	`kola	oji ogodo	Chewed raw, medicinal
14	Curcurbita pepo (2 var.)	Pumpkin	anyu, ugboguru	Used to cook yam or cocoyam. Soften on cooling, boiled and eaten as snack
15	Curcurbita pepo (1 var.)	Pumpkin	nkpuru anyu	Boiled, milled and used for soup
16	Dacryodes edulis (2 var.)	Pear	ube Igbo	Soften in boiled water or roasted and used to eat maize,corn or alone
17	Dennettia tripetala	Pepper fruit	Mmimi	Hot pepper eaten alone or with garden eggs
18	Dialium guineense	Velvet tamarind	Icheku	Eaten raw
19	Elaeis guineensis	Palm fruit	Aku	Major source of cooking oil
20	Garcinia kola	Bitter cola	aki ilu	-
21	Grewia spp.	Jute plant	Ayauma	-
22	Husolandia opprosita	Mint	Aluluisinmo	Used for upset stomach
23	Icacemia spp.	-	Urumbia	Eaten as a fruit
24	Irvingia spp.	Bush mango	Ugiri	Fruit eaten when ripe
25	Landolphia owariensis	Rubber plant	utu npiwa	Fruit eaten when ripe
26	Landolphia spp. (4 var.)	Rubber plant	akwari, ubune utu mmaeso, utu mmaenyi,	Fruit eaten when ripe
27	Lycopersicum esculentum (4 var)	Tomatoes	tomatoes	Used for stews and other preparations
28	Magnifera indica (4 var.)	Mabgo	mangoro	Fruit eaten when ripe
29	Myrianthus arboreus	Ujuju fruit	ujuju	Fruit eaten when ripe
30	Pachystela breviceps	Monkey apple	udala nwaenwe	F ruit eaten when ripe
31	Persia Americana	Avocado pear	ube oyibo	English pear is ripened and eaten alone
32	Piper umbellate	Sand pepper	njanja	Dry leaves used for soup during the dry season
33	Psidium guajava	Guava	gova	Eaten when ripe
34	Senna occidentalis	Nigero plant	sigbunmuo	Used for cooking yam pottage
35	Solanum macrocarpum	Garden egg fruit	anyara	A fruit eaten with peanut butter or alone
36	Sterculia spp.	Kola (wild) wa ebunne	nkpuruamun	Wild fruit
37	Uraria chamae	-	okpaokuku	Used for soup, tuber used for insect bite
38		-	utabe efi	Wild fruit

Okeke *et al.* (2008), Onimawo and Egbekun (1988).

Nutrient content of some Nigerian traditional foods

Every community in Nigeria has its own food preferences and over the years has developed the taste for such foods. The communities also have their peculiar ways of preparing their traditional foods. These cultural practices contribute to the nutrient content and nutrient retention in traditional foods. Nutrient content of some of these Nigerian foods are shown in Tables 2–8 below.

Table 2. Chemical composition of some tropical roots and tubers (100 g).

Commodity	Dry matter (g)	Crude protein (g)	Crude fat (g)	Total ash (g)	Energy (kcal)	Ascorbic acid (mg)	Calcium (mg)	Phosphorus (mg)	Iron (mg)
Cassava (Manihot utilissima)	31.94	2.71	0.53	2.66	390.0	35.0	10.0	35.0	0.50
Yam (Dioscorea rotundata)	26.17	5.87	0.46	4.30	385.9	17.0	18.9	40.7	0.48
Cocoyam (Taro) (colocasia esculenta)	26.52	8.66	0.71	4.83	376.4	14.0	24.0	53.6	0.72
Cocoyam 2 (Tannia) (Xanthosoma Sagittifolium)	24.89	7.85	0.70	5.22	382.6	10.0	6.0	360.0	0.70
Sweet Potato (Ipomoea batatas)	28.08	5.36	0.33	3.15	391.0	26.2	16.6	31.0	0.83

FAO (1968); Onimawo and Egbekun (1988).

Table 3. Nutrient composition of selected Nigerian traditional foods (per 100 g fresh edible portion).

Food	Moisture	Energy		Protein	Fat	CHO	Fibre	Ash	Vit A (RE)	Thiamin	Riboflavin	Niacin	Folate	Vit C	Calcium	Phosphorus	Iron	Zinc
	g	kcal	kj	g	g	g	g	g	µg	mg	mg	mg	µg	mg	mg	mg	mg	mg
Legumes nuts and seeds																		
Black pepper seed	10.5	324	1 354	3.4	0.2	77.1	4.2	4.6	38.6	0.08	2.3	1.0	3	14.4	254.6	533.2	5.7	3.7
Castor oil seed	39.7	337	1 409	27.4	18.9	14.3	0.3	1.2	54.1	0.14	1.83	1.7	5	25	517.5	450.1	15.3	4.2
Ehulu seed	15.6	321	1 342	3.8	0.2	76.0	1.3	3.1	-	-	-	-	-	-	55.8	549	13.3	2.8
Olima seed	29.2	272	1 137	14.7	0.1	53.1	1.1	1.8	-	-	-	-	-	-	5.4	21.6	12.0	1.8
Pumpkin seed	60.3	121	506	4.8	2.6	19.6	2.1	0.6	29.9	0.37	1.94	1.7	12	1.6	170.5	626.1	3.7	1.4
Seeded herb	56.7	140	585	3.9	0.1	30.8	4.4	4.1	44	0.24	0	3.8	7	4.7	166.8	125.3	3.4	2.4
Uda seed	42.7	247	1 032	3.6	12.4	30.2	6.8	4.3	53.8	0.27	0.34	0.9	10	1.8	-	-	-	-
Vegetable and mushroom																		
Black pepper leaf	67.6	114	477	16.9	1.3	8.7	3.1	2.4	19.4	0.14	0.91	0.7	5	11.7	245.8	13.7	6.4	1.2
Bitter leaf	62.1	154	644	14.6	2.1	19.2	0.4	1.6	31.2	0.13	0.56	0.6	4	8.6	278.3	228.4	3.4	2.2
Cam wood	56.3	144	602	3.5	0.8	30.8	4.8	3.8	29.9	0.37	1.94	1.7	12	1.6	5.3	126.2	9.0	0.9
Ero awaga	67.4	130	543	4.6	1.6	24.2	1.6	0.6	4.1	0.22	0.42	4.5	7	2.3	2.5	240.9	11.2	1.7
Water leaf (wild)	56.7	163	681	22.7	0.1	17.9	1.2	1.4	31.2	0.39	0.28	2.0	13	38.4	114.4	152.9	1.6	114
Water leaf	70.2	74	309	2.4	0.8	14.2	1.0	1.8	-	-	-	-	-	-	89	128.2	1.6	114
Uncommon vegetables																		
Agbolukwu	71.1	107	447	7.9	0.4	18.0	1.7	0.9	18.9	0.28	0.36	3.0	0	4.48	529.0	188	2.0	1.3
Agili ezi	57.9	160	669	6.4	0.3	33.0	0.7	1.6	-	-	-	-	-	-	4.1	15.7	5.4	1.1
Alice mose	65.7	121	506	14.8	0.7	13.9	2.1	2.9	-	-	-	-	-	-	380.9	127.8	11.1	1.6
Aluluisi	36.0	319	1333	4.6	1.2	72.4	1.6	3.4	55.5	0.09	0.93	1.2	3.0	18.0	657.6	338.3	9.5	3.3
Anya-azu	66.4	131	548	12.8	1.3	17.1	0.6	1.8	25.7	0.18	1.1	1.5	6	22.9	166.2	134.6	14.6	1.0
Awolowo weed	47.3	192	803	9.6	0.4	37.4	2.1	3.2	69.5	0.17	0.52	2.4	6	30.8	582.1	326.2	5.8	2.5
Azei	60.8	117	489	4.2	0.4	24.1	6.3	4.2	6.9	0.18	0.36	1.1	6	2.9	43.4	85.0	11.9	1.0
Bush marigold	52.9	181	757	6.8	0.6	37.0	0.9	1.8	-	-	-	-	-	-	473.4	235.6	5.4	2.4
Flame tree	44.0	212	886	8.6	0.3	43.7	0.8	2.6	28.3	1.3	0.54	2.0	44	31.5	76.1	33.8	5.4	2.4
Hog weed	65.9	121	506	8.6	0.2	21.3	1.6	2.4	19.4	0.69	0.86	1.1	23	16.4	65.7	233.8	2.1	1.8
Ifulu nkpisi	46.0	192	803	6.8	0.2	40.7	2.1	4.2	69.5	0.32	0.54	3.7	11	54.4	260.4	131.5	9.4	1.1
Illenagbelede	32.9	210	878	16.4	1.4	32.9	4.6	1.4	32.7	0.36	0.94	1.2	12	16.1	367.4	405.2	9.9	3.3

Table 3 contd.
Nutrient composition of selected Nigerian traditional foods (per 100 g fresh edible portion).

Food	Moisture	Energy		Protein	Fat	CHO	Fibre	Ash	Vit A (RE)	Thia min	Ribofl avin	Niacin	Folate	Vit C	Calcium	Phos phorus	Iron	Zinc
	g	kcal	kj	g	g	g	g	g	µg	mg	mg	mg	µg	mg	mg	mg	mg	mg
Uncommon vegetables (continued)																		
Ikpo kpo	61.6	130	543	2.8	0.4	28.7	2.8	3.7	28.3	0.29	0.43	2.6	1	3.6	263.3	84.0	2.7	2.3
Inine	77.8	109	456	15.4	1.2	9.1	1.5	1.2	64.5	0.15	0.04	13	20	1.2	91.1	137.7	2.0	0.8
Isii osisii	59.3	135	564	3.4	0.9	28.3	4.3	3.8	33.5	0.22	0.13	0.8	7	1.7	32.7	252.8	1.9	0.8
Isi-udele	44.6	211	882	4.8	0.2	47.6	2.1	1.3	4.1	0.22	0.42	4.5	7	2.3	330.9	267.1	10.3	1.8
Lemon grass	47.7	204	853	4.3	0.4	45.8	0.4	1.4	18.2	0.21	0.9	1.2	7	16.1	118.5	154.1	2.7	2.7
Local onion	56.4	142	594	3.8	0.6	30.4	5.2	3.6	41.8	0.57	0.3	2.0	20	2.9	56.9	145.6	6.5	1.2
Mgbidi mgbi	69.7	113	472	2.9	0.1	25.2	1.2	0.9	-	-	-	-	-	-	584	127.3	2.3	3.7
Mint	56.7	147	614	7.3	0.7	27.8	3.9	3.6	-	-	-	-	-	-	488.7	18.8	1.0	1.5
Nghotoncha	49.9	166	694	4.7	0.8	35.1	3.6	5.9	-	-	-	-	-	-	471.6	171.6	7.3	1.2
Nigero plant	56.7	146	610	8.9	0.5	26.4	3.9	3.6	-	-	-	-	-	-	42.7	143.5	5.0	0.8
Obi ogbene	69.5	106	443	4.8	1.2	18.9	1.0	4.6	44.0	0.28	1.10	2.0	9	30.3	326.5	122.0	3.2	1.4
Obu aka enwe	38.4	230	961	6.9	0.3	50.0	1.6	2.6	18.9	0.28	0.36	3.0	0	4.48	42.3	431.1	4.9	1.8
Ogbunkwu	18.6	249	1041	2.1	0.1	60.0	12.3	6.9	0.0	0.12	0.0	1.0	0	0.00	110.6	198.1	3.5	2.0
Ogume okpe	41.2	230	961	6.8	0.8	49.0	1.1	2.1	20.5	0.35	1.7	3.8	16	58.0	162.3	332.9	7.7	2.7
Onunu gaover	35.4	248	1037	3.3	0.1	58.5	0.9	1.8	6.8	0.42	0.32	1.6	0	10.6	152.4	389.8	8.6	3.1
Onunu iluoygbo	69.3	102	426	2.4	0.6	21.8	1.4	4.5	30.9	0.62	0.11	1.6	0	3.6	117.5	88.2	2.4	1.7
Otulu ogwai	42.5	206	861	6.9	0.4	43.7	3.1	3.4	35.9	1.62	0.58	1.8	0	22.8	198.4	417.1	5.75	2.6
Pumpkin	69.0	125	523	22.8	2.8	2.2	1.8	1.4	-	-	-	-	7	-	147.4	130.2	0.3	0.8
Senna plant	58.4	159	665	6.8	0.6	31.5	0.9	1.8	51.7	0.45	1.4	1.3	15	18.6	314.3	307.3	6.2	1.5
Ugbfoncha	57.2	140	858	8.6	1.1	23.8	2.4	6.9	30.4	0.24	0.6	1.4	0	26.4	295.5	231.5	4.5	1.9
Ujuju	58.1	148	619	8.3	1.2	25.9	2.1	4.4	16.0	0.23	0.87	1.3	8	18.4	3.3	176.0	1.6	0.8
Utazi	56.7	172	719	18.0	4.8	14.2	3.6	2.7	20.4	0.3	0.82	0.2	0.0	0.3	258.6	204.9	8.1	1.4
Meat																		
Canda (skin)	38.4	320	1338	28.3	16.8	13.9	0.0	2.6	30.9	0.62	0.11	1.6	0	3.6	8.15	160.0	5.4	2.0
Snail	65.7	126	527	10.6	1.2	18.2	0.0	4.3	-	-	-	-	-	-	204.8	161.6	5.8	1.0

Table 4. Key micronutrient-rich traditional foods by food groups/species.

Food group/species	Local name	Scientific name	Major micronutrient(s)
Cereals			
Yellow maize	Oka	Zea mays	β-carotene
Starchy roots/tubers			
Sweet potatoes	Ji nwannu	Ipomaea batatas	Iron, β-carotene
Three leaf yam	Ona	Dioscorea dumentorum	Iodine,
Yellow yam	Ji Oku/Okwu	Dioscorea cayenensis	β-carotene, iodine, iron
Starchy fruits			
Banana	Unele, Ogede	Musa sapientum	Zinc, folate, iron, β-carotene
Plantain	Nba/jiono Obughunu	Musa paradisiacal	Zinc, folate, iron
African bread fruit	Ukwa	Treculia Africana	Iron, zinc
Legumes/nuts and seeds	All legumes/nuts	All legumes/nuts	Iron, zinc, copper
Cashew	Mkpuru/ Mkpulu cashew	Anacardium occidentalis	Iron, zinc
All fruits	Mkpulu osisi	All fruits	Iron, zinc, carotenoids, copper, selenium, vitamin C, vitamin E
Palm fruit	Aku	Elaeis guineensis	β-carotene
All vegetables	Akwukwo nni	All vegetables	Iron, zinc, carotenes
Mushroom	Ero/elo	Not yet properly identified	Iron, copper, zinc
All animal foods	See Table 3	See Table 3	Iron, zinc, vitamin A

Adapted from Okeke *et al.* (2008); Oguntona and Akinyele (1995).

Table 5. Recommended curing and storage conditions for roots and tubers.

Commodity	Temperature °C	Relative humidity %				
	Curing	Storage	Duration of curing (days)	Curing	Storage	Duration of storage (weeks)
Cassava	25–40	32.38	4–9	80–85	58–90	8
Yam	25–40	13–16	5–10	55–62	70	21–28
Cocoyam (Taro)	11–13	30–35	18–21	85–90	70–80	4
Cocoyam (Tannia)	11–13	30–35	18–21	85–90	70–80	4
Sweet Potato	30–32	13–16	13–20	90	85–90	21–28

Okaka (1997).

Table 6. Some fruits and vegetables.

Fruits	Vegetables
Avocado	Beans
Banana	Peas
Breadfruit	Carrot
Pineapple	Cucumber
Mango	Eggplant
Guava	Onions
Pawpaw	Garlic
Oranges	Pepper
Grapefruit	Melon
Lemon fruit	Tomatoes
Tangerine	Pumpkin leaf
Plantain	Lettuce
Cashew apple	Spinach
Passion fruit	Cabbage
Pears	Amaranths
Sour sop	Bitter leaf

Table 7. Typical composition of some fruits and vegetables per 100 g edible portion.

Commodity	Water(%)	Energy (cal)	Protein (%)	Fat(%)	Carbo hydrate (%)	Ascorbic acid (%)	Calcium (mg)	Phospho rus(mg)	Vit. A (I.U.)
Fruits									
Banana	75	86	1.1	0.2	24	10	8	26	190
Pineapple	85	65	0.4	0.4	15	110	20	11	30
Mango	83	63	0.6	0.1	15	30	10	10	180
Guava	80	58	1.0	0.4	13	200	15	33	200
Orange	86	49	1.0	0.2	12	50	41	20	200
Lemon	85	58	1.0	0.9	11	43	40	22	
Cashew apple	85		0.7		13	250	10		150
Pawpaw ripe	81	40	0.5	0.6	10	110	16	8	2 200
Vegetables									
Onions	89	38	1.5	0.1	9	10	27	56	40
Carrot	88	42	1.1	0.2	10	51	37	36	11 000
Spinach	91	26	3.2	0.3	5	51	93	51	8 100
Cabbage	92	24	1.3	0.2	4	47	49	29	130
Pepper	92	22	1.2	0.2	4	125	9	22	420
Tomato	93	22	1.1	0.2	5	30	13	27	190

Table 8. Nutrient composition of some protein foods per 100 g.

Food	Moisture (g)	Protein (g)	Fat (g)	Ash (g)	Dietary fibre (g)	CHO (g)	Calcium (mg)	Iron (mg)
Legumes								
Cowpea (black eye pea)	0	27	2.0	4.1	17.1	50	83	7.4
Pigeon pea	0	22	1.8	3.9	23.8	48	110	5.0
African yam bean	0	22	2.1	3.1	19.1	54	46	4.7
Bambara nut	10	19	6.0	3.4		61	62	12.0
Lima bean	12.7	21	1.4	3.4		61	11	4.9
Soya bean	9.5	34	18.0	5.0		34	183	6.1
Groundnut (dried)	6.5	23	45	2.5		23	49	3.8
Groundnut (roasted)	1.8	23	51	2.4		22	42	
Groundnut (boiled)	44.6	17	8.5	4.0		26	45	5.1
Oil bean seed	8	26	40			20	190	16.0
Pumpkin	5	28	52	3.6		8	53	7.3
Animal foods (meat)								
Beef (moderate fat)	63	18	17.7	1.0			11	3.6
Egg	79	11.8	9.6	1.0		1	45	2.6
Goat Meat (moderate fat)	68	18.0	11.0	1.1			11	2.3
Intestine (cattle)	76	14.5	9.3	0.8		1	10	3.4
Liver (cattle)	70	19.0	4.7	1.3		5	8	10.0
Pork (moderate fat)	46	12.4	40.5	1.0			11	1.8
Chicken	72	20.5	6.5	1.0			10	1.1
Fish and other sea foods								
Crayfish	26	69.5	4.5	13.6			660	155
Mackerel (raw)	64	19.0	16.3				24	1.0
Smoked fish (whole)	5	70.4	10.2	14.2			1 696	25
Crab (meat cooked)	12	31.2	77.0	39.5		10	1 280	
Periwinkle (dried)	14	55	1.4	11.8			733	38.8
Prawn (dried)	16	70.8	6.0	2.5		4	1 740	8.0
Stockfish (raw)	70	21.8	5.4	3.0			1 696	25
Snail	78	12.0	2.0			4	1 500	8.0

Okeke *et al.* (2008); Onimawo (1995); Oguntona and Akinyele (1995).

Contribution of traditional foods to assuring nutrition security

The detailed work carried out by Okeke *et al.* (2008) showed that traditional Nigerian foods fed to children 3–5 years supplied adequate energy (101.24%), protein (149.8%), iron (228.43%), vitamin A (307.9%), thiamin (275.71%), niacin (141.59%) and ascorbic acid (440.05%), which were higher than FAO/WHO requirement intakes. Their intake was adequate for calcium (88.5%) and riboflavin (81.0%) only. Traditional foods contributed over 90% of the energy, protein, thiamin, niacin and ascorbic acid and over 70% of vitamin A and iron intakes of these children.

Among the traditional foods, cereals made the most significant contribution to energy (31.1%) and niacin (39.9%). Legumes made the highest contribution to protein (49.1%). The calcium intake came mainly from vegetables (16.8%) and legumes (16.0%). About 26.5% of the iron came from cereals. This was followed by legumes (26.3%). Only 6.8% of the vitamin A came from vegetables. The rest (71.8%) came from red palm oil. Thiamin and riboflavin came mainly from nuts and seeds (33.9% and 29.9%). The bulk of the ascorbic acid came from starchy roots and tubers (58.1%).

Studies involving school age children 6–12yr (Onimawo *et al.,* 2008) indicated low protein and micronutreints intake particularly iron and zinc. However when meals were prepared from traditionally available foods with appropriate combinations for children 3–5yr, the results showed adequate intake of energy, protein and most of the micronutrients in some cases.

The results from these studies carried out in the southern geopolitical zone in Nigeria show clearly that when properly prepared and combined, Nigerian traditional foods can assure nutrition security even in all segments of the society including the under-fives and school age children.

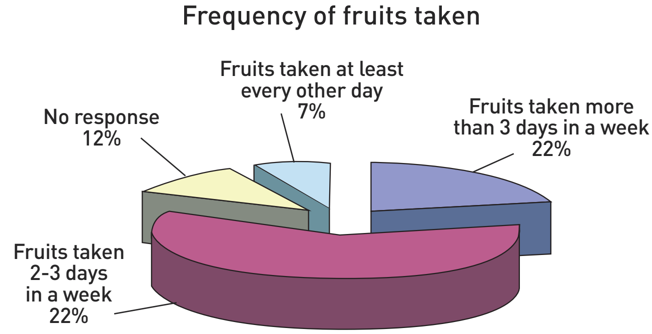


Figure 2. Vegetable consumption pattern of school age children prior to nutrition education.

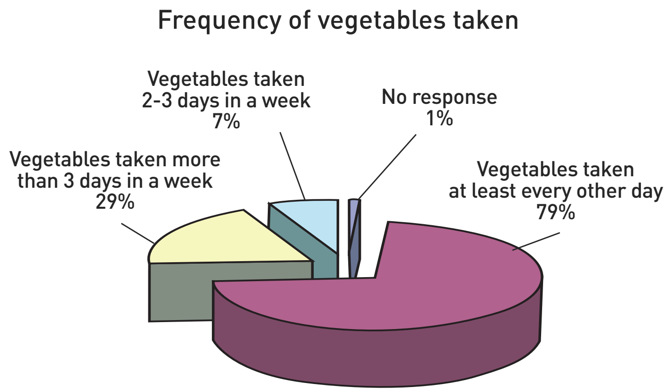


Figure 3.
Improvement in vegetable consumption pattern of school age children after nutrition education.

Following nutrition education, school age children gradually increased vegetable intakes leading to improvement in micronutrient intake of the children. This study further proved that Nigerian traditional foods can support nutrition security if nutrition education is properly carried out.

Summary of the findings on Nigerian traditional foods

Several other studies indicated the following:

- Traditional foods are rich in all the required nutrients.
- Poor combination of the various foods is the bane of adequate nutrient intake.
- Poor processing and culinary methods contribute significantly to nutrient losses.
- Underexploitation of traditional foods undermine their rich nutritional value.
- Lack of nutrition education contributes to the inappropriate uses of traditional foods.

- Low consumption levels of traditional fresh fruits and vegetables contribute significantly to micronutrient deficiency.
- Wrong choice of food and age-long food/dietary habits affected adequate nutrient intake.

There are community variations in the contribution of specific food groups.

- In the southern states in Nigeria, starchy roots and tubers, legumes, nuts and seeds made substantial contributions to energy intake.
- In northern Nigeria, legumes and cereals significantly contribute to the intake of energy.

Conclusion

- Malnutrition characterized by undernutrition is prevalent in Nigeria.
- Undernutrition can be reduced significantly when the traditional Nigerian food system is improved using a combination of strategies including nutrition education.
- One of the main areas that need attention if our traditional food system will assure food security is encouragement of vegetable and fruit consumption. Figures 2 and 3 above show that vegetable and fruit consumption improved significantly after nutrition education of the school children.
- Poverty causes and aggravates malnutrition.
- Need to draw attention to traditional foods that are almost forgotten in preference to westernized diets that invaded our food system.

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EDIBLE INSECTS IN EASTERN AND SOUTHERN AFRICA: CHALLENGES AND OPPORTUNITIES

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Abstract
Insects have for a long time been known only as pests and pollinators, recent studies show they actually offer more ecological, economic and social benefits to man. On the contrary, entomophagy, the eating of insects has been part of African indigenous diets for as long as the African race has existed. Therefore, edible insects are culturally accepted in many African societies as food. They are a good source of proteins, minerals and essential fats. Edible insects are not used to cope with food scarcity, but are rather an integral part of cultural diets planned for throughout the year. As entomophagy gains popularity in the western world; it is important to closely look at the practice. The potential of insects as food remains poorly understood and taped in Africa with some insects threatened with extinction from unsustainable harvesting, ecosystems destruction and effects of climate change. Insects are one group of foods from the wild that would ensure dietary diversity among many poor people and communities. Incorporating biodiversity in nutrition will go a long way to ensuring food security and sustainable development. This paper explores the challenges and opportunities for wider use of edible insects in traditional diets of the people of eastern and southern Africa.

1. Introduction

Edible insects continue to play a great and significant role in nourishing Africa's indigenous communities. The practice of entomophagy is an age-old one in many African cultures, with many communities paying attention to this aspect in their indigenous knowledge. However, little attention has been paid to this aspect of traditional African diets in western literature until recently. In the past western literature played a great role in labelling them pests creating an apparent contradiction on whether to conserve them for dietary purposes or destroy them as pests.

Studies in entomophagy indicate that consumption of insects is gaining ground not only in Africa but in many parts of western societies (Ayeiko *et al.*, 2010). It has now been realized that entomophagy can make significant contributions to diets as an alternative protein source and to insect conservation through sustainable harvesting in conjunction with appropriate habitat management hence reducing adverse environmental impacts of livestock production (Yen, 2008). The world today is confronted with a larger problem; supplying adequate nutrients in a sustainable way to its growing population as well as protecting the environment. As the world's population continues to grow, great pressure is exerted on land; some edible insects are feared to become endangered or extinct.

According to FAO, more than one billion of the world's population was hungry in 2010, the highest ever registered since 1970. Two hundred and sixty-five million of the world's hungry lived in sub-Saharan Africa and the numbers were likely to increase. Sub-Saharan Africa however, also has the largest prevalence of undernourishment (32%) in the world relative to its population size. Such numbers are unacceptable given that Africa is rich in natural resources among which are forests that contribute about 40% of the world's natural resources and 80% of resources for the world's poor (FAO, 2010), among these resources are highly nutritious foods.

There is a current increase in demand for food production as a result of Africa's rapidly growing population; hence Africa is marred with constant food shortages alongside poverty, these two factors aggravate the nutrition status of many poor families and communities. With the realization of pending food shortage particularly in developing countries, the consumption of edible insects is sure to increase (Meyer-Rochow *et al.*, 2007). Agriculturalists and nutritionists the world over are calling for diversification of diets. Dietary diversification is a priority for improving nutrition and health of the rural and urban poor. Entomophagy contributes to dietary diversification to household diets.

Entomophagy is well accepted in Africa and is a major component in many traditional cultures. As the world becomes a global village, entomophagy is faced with several challenges like land degradation, climate change, globalization and commercialization of agriculture. This paper explores the challenges and opportunities for wider use of edible insects in traditional diets of the people of eastern and southern Africa.

1.1 Edible insects of eastern and southern Africa

Insects possess enormous biodiversity and form great biomass in nature. Insects have played an important role in the history of human nutrition in Africa, Asia and Latin America (Bodenheimer, 1951). They also offer ecological benefits (in pollination, biomass recycling), economic (apiculture, sericulture) and social benefits (in medicine, human and animal nutrition religion, art and handicrafts) (Jharna Chakravorty, 2009). Detailed information regarding the diversity, mode of consumption and economic values of the edible insects in many tropical and subtropical regions of the world is compiled by De Foliart (2002). In eastern and southern Africa, insects are not only pests like it is thought in many parts of the world, they are food items too. In places where animal protein sources are rare or expensive, insects have filled the gap as a major source of protein and animal fat. Insects have been used as livestock feed, human feed and medicine in many African cultures. Huis (2003) reported that there are approximately 250 known edible insect species in sub-Saharan Africa that are high in nutritive value. Preference for which species are utilized depends on their taste, nutritional value, and ethnic customs, preferences or prohibitions. Common edible insect orders in eastern and southern Africa include; Lepidoptera (moths and butterflies), Hymenoptera (bees), Isoptera (termites, queen and reproductives), Coleoptera (beetles), Hemiptera (true bugs), Orthoptera (locusts and grasshoppers), and Odonata (dragon fly). Insects are eaten at different stages of their life cycles; eaten as either larvae or nymphs or adults depending on the insect of interest.

Studies show that arthropods of class insecta are rich in protein especially in the dry form in which they are frequently stored or sold in village markets of developing countries. Some insects are high in fat, and hence energy and many are rich sources of minerals and vitamins (Deforliart, 1995). Illgner and Nel (2000), argue that the importance of entomophagy in Africa is more due to "necessity than choice", because of the climate and small-scale nature of animal husbandry which reduces the amount of meat consumed; the diets have been broadened to include insects. Though, worth noting is, entomophagy is not a coping strategy in the times of crisis as was earlier thought (Bodenheimer, 1951), but rather an integral part of cultural diets in many societies depending on seasonal availability. Entomophagy has been practised for as long as man has lived on the African continent and for that it is incorporated in the indigenous knowledge systems of societies that practise entomophagy. There is a wide base of knowledge that remains undocumented in communities on culinary practices, special traditional harvesting technologies and conservation methods for different and various species of edible insects.

Insect collection and gathering practices are vestiges of the gathering trait seen in our forefathers and therefore it is common to find that many edible insects are collected in the wild. Major gathering spots are woodlands, grasslands and forests. Insects form part of the biodiversity in these ecosystems. It is on this premise, the role of non-wood forest products in food security and development should not be underestimated. Non-wood food products are important in the provision of important community needs that are known to improve rural livelihoods, household food security and nutrition. They help generate additional employment and income, offer opportunities for processing enterprises and more so support biodiversity conservation. Studies show that African diets though lacking in meat proteins, natives still remain healthy and fit. This observation is attributed to edible insects filling in the gaps. Attaining such benefits however comes with various challenges.

2. Challenges

2.1 Climate change

Climate change affects ecosystems and their components with its effects aggravated by unchecked human activities. There is increasing evidence that the earth's climate is undergoing change largely due to human activities. It is estimated that global climate change will have a profound impact on all ecosystems and hence biodiversity (Ayeiko *et al.*, 2010). It is also feared that climate change will lead to loss of biodiversity in many places around the world. The importance of biodiversity in food security, nutrition and sustainable livelihoods cannot be neglected. According to FAO (2010), biodiversity contributes directly to food security, nutrition and human well-being by providing a variety of plant and animal foods from domesticated and wild sources. Environmental integrity is therefore critical for maintaining and building positive options for human well-being.

Insects are an integral part of all ecosystems and will therefore not be spared by the change in a number of ways not yet determined by scientists. Studies point out that insect populations are likely to increase with changing climate (Saunders, 2008). Increased temperature and moisture that are products of climate change are known to affect insect populations. High temperatures stimulate high fecundity in female insects and hence large numbers of individuals at emergency (Rattle, 1985). Ayeiko *et al.* (2010) reported large quantity harvests of termites on the shores of Lake Victoria in western Kenya. They also noted moisture variability and availability in the recent past kept insect mounds moist much longer in certain areas than in other years. Insects respond to change in thermal environment through migration, adaptation or evolution (Dunn and Crutchfield, 2006). This enables them to adapt faster to other areas to survive the climate changes and thereby increase their availability to human consumption and predators. However, confronted with both low quantity and large quantity harvests for some insects is Africa ready to take on the challenge. Insects are highly perishable, if supply is to be maintained there is need to look at processing methods and storage to cut down on post-harvest losses.

2.2 Globalization

As Africa positions itself for globalization many undesired outcomes are observed. Globalization has seen adoption of a universal cultural system largely based on western values, customs and habits including changes in food customs. It has resulted in the use of more fast foods and pre-prepared foods and the loss of traditional ways of life (Illgner and Nel, 2000). People opt for simple diets as they become busier abandoning dietary practices that are perceived as time-wasting and archaic. Entomophagy is one such practice requiring a lot of time, women and children spend a lot of time in the wild looking for insect delicacies. Diet simplification negatively impacts on human food security, nutritional balance and health.

2.3 Population growth and commercialization of agriculture

A rapidly growing human population commands increased demand for food production along with changing food production and consumption patterns. Africa's population is growing at a rate of 3 percent and the population is expected to be 2 billion by 2050 (FAO, 2010). Population pressures in the recent past have led to the evolution of agriculture from traditional to modern intensive systems. Increased globalization and urbanization has led to more arable land being lost for food production (Yen, 2009). As the human population grows and environmental degradation continues, the world faces a major problem in providing adequate animal-based protein. Consequently forests are cleared to create land for agriculture and infrastructural development. Such systems have a big bearing on biodiversity loss. Many edible insects are becoming scarce, for example, in Uganda termites are not common in urban areas. The reason behind the low occurrences is the perception about termites, the worker termite is known to destroy furniture and crops, and hence is a pest. It is therefore regarded as a menace and termataria are destroyed as soon as they show up. In large-scale agriculture they are destroyed as the land is prepared for cultivation. This compromises the quantities produced and sustainable harvest of the insects. Grasshoppers and palm weevil breed in forests and thick vegetation like forests whereas termites will breed in both dense and sparse vegetation areas. Consequently, these insects are lost and biodiversity damaged.

2.4 Pollution and use of insecticides

Populations continue to soar and industrialization becomes a viable option. As a result more greenhouse gases are produced. There is more carbon dioxide in the atmosphere and consequently in the water bodies. This means that the waters are more acid than ever before, consequently affecting the flora and fauna in water bodies. Ayeiko *et al.* (2010) also noted that the harvests of lake flies in western Kenya was lower than in the previous years. This was as a result of increased acidity of the water. Lake flies breed at the bottom of the lake, and therefore the change in PH of the water grossly affects the breeding cycle. Coupled with increased temperature, oxygen availability is compromised leading to death of the larvae. In the quest to control diseases and increase yields insecticides, pesticides and herbicides are used extensively in cities and farms. Pesticide, herbicide and fungicide use can make insects unsuitable for human consumption as pesticides accumulate in insect bodies.

3. Opportunities

Faced with several challenges, Africa can convert these challenges to opportunities. Insects in the diet clearly show the meeting point of nutrition and biodiversity in food security and sustainable development. For Africa to meet her food security and environment protection targets of the MDGs, then it is important to look at opportunities that entomophagy avails us with; however, the achievement of food security should not be at the expense of the environment. Insects present a link; they are eco- friendly as food. They consume relatively little and do not require grazing land and antibiotics like our conventional livestock (Yen *et al.*, 2008). Today livestock is one of the major contributors to greenhouse gases. As demand for animal protein increases the world over, it is probable that levels of pollution will reach their highest limits.

3.1 Cultivation of insects

The mass production of insects has great potential to provide animal proteins for human consumption, either directly, or indirectly as livestock feed. The latter could reduce energy requirements in livestock production. The use of insects as an additional source of protein could result in increased conversion efficiencies and a smaller environmental footprint in our livestock production, especially if closed systems can be developed at the village or farm level (Steinfeld *et al.,* 2006).

Insects are easy to raise and to harvest, and they are highly nutritious to eat. They have higher food conversion efficiency than more traditional meats. When reared at 30°C or more, and fed a diet of equal quality to the diet used to rear conventional livestock, house crickets show a food conversion twice as efficient as pigs and broiler chicks, four times that of sheep, and six times higher than steers when losses in carcass trim and dressing percentage are counted (Jharna Chakravorty, 2009). Protein production for human consumption would be more effective and cost fewer resources than animal protein. It is therefore important to rear or cultivate the most preferred edible insects, especially those with high nutrition value in home gardens with application of modern tools and techniques. Success stories of insect rearing are seen in the Lao People's Democratic Republic and Japan, where crickets, bugs and many other insects are harvested in home gardens (FAO, 2010; Toms and Nonaka, 2005). For this to be possible it is important to understand different cultures and indigenous knowledge.

3.2 Promote indigenous knowledge systems (IKS)

Communities that practise entomophagy have ingrained traditional knowledge and practices on how to harvest and use food insects. With changing food habits communities lose valuable traditional knowledge as such knowledge and practices are considered outdated and primitive by the younger generations. Incorporated in this knowledge system are elements that promote and favour responsible and respectful use of nature. Transmitting traditional values and wisdom to children and teenagers is important; experience shows that across many fields a combination of customary knowledge and approaches has tremendous benefits and values towards understanding science and modern trends. South Africa has taken on promoting indigenous knowledge of diets and harvesting insects into the classrooms. In their outcome-based education system, children are taught at an early stage the importance of consuming insects and sustainable harvesting for food security. They are taught about complex life cycles of the common edible insects like the mopane worms and the stink bugs (Toms and Nonaka, 2005). It is important for the harvesters to understand the complex life cycles as many insects are consumed at different stages of the life cycle. Understanding that if a particular stage is overly consumed it will lead to loss of a particular insect from the ecosystem is very important. Understanding that destruction of termataria or palm trees (forests) will lead to no harvest of white ants or palm weevil respectively is grossly important in sustainable use of resources. In northern Uganda, termataria are owned by families in grazing grounds and are jealously guarded from intruders who are considered thieves. Therefore promotion of sustainable harvesting for food security and complex life cycles of insects through the use of IKS should be adopted.

In east Africa for example, natives will tell the type of edible white ants by the type of termatarium and therefore different species of edible white ants are harvested in different ways. Great care is taken to ensure that the termataria are not destroyed. Such knowledge is not documented but is passed on by word of mouth from generation to generation. However some methods involve destroying the vegetation around the termataria and in the case of palm weevil, palm trees are destroyed. Promoting sustainable use and harvesting methods is key in IKS as well as enabling the harvesters to harvest large quantities. Traditional knowledge along with nutrition education are therefore essential foundations for advancing entomophagy, but it also has to address food security and food safety issues (Yen *et al.*, 2009).

3.3 Trade and value addition

Collection of food insects is a good source of income especially for the women as they require little capital input if gathered by hand. Insects are widely offered in local village markets, while some preferred species like grasshoppers in east Africa, mopane worms in southern Africa reach urban markets across borders. Agea *et al.* (2008) noted that grasshoppers in Kampala and Masaka, were a major source of income to the harvesters who were mainly women. Many of the harvesters noted that trade in insects had actually improved their livelihoods. However, the harvesters target is always to sell the day's catch, sometimes at lower prices because edible insects are highly perishable. It is important to add value and improve preservation methods in order to fetch more revenue and also cater for all year availability.

Elsewhere in the world, as the popularity of entomophagy grows, restaurants have opened that cater specifically to those who enjoy entomophagy. Restaurants in Singapore serve larvae and scorpions and seat sell-out crowds nightly. In some countries insects are canned, exported and sold in foreign supermarkets all year round. Therefore there should be an effort to increase the insects' commercial value as food and feed for livestock especially chicken and availability on demand in a sustainable manner. This will in the long run serve a twin purpose of insect (natural resource) use as food (food products and feed) and conservation (Jharna Chakravorty, 2009).

4. Conclusion

Insects form a large form of biodiversity in diets. It is therefore important to note that nutrition biodiversity also serves as a safety net to vulnerable households during times of crisis, presents income opportunities to the rural poor and sustains productive agricultural systems. Therefore maintenance of biodiversity is essential for the sustainable production of food and other agricultural products and provides benefits to humanity like food security, nutrition and livelihoods.

Acknowledgements

The author acknowledges Bioversity International for sponsoring her to attend the International Scientific Symposium on Biodiversity and Sustainable Diets; United Against Hunger in Rome, Italy in 2010. Thanks to Prof. Thomas Omara-Alwala (Lincoln University, Missouri) for his assistance, friendship and helpful comments on the manuscript.

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BIOACTIVE NON-NUTRIENT COMPONENTS IN INDIGENOUS AFRICAN VEGETABLES

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Abstract
In many African cultures, vegetables form an important part of a healthy traditional diet because of their nutritional and health benefits. Vegetables have been reported to have many health protecting properties, thus illustrating the relationship between nutrition and medicine which has long been recognized in African cultures. This study evaluated the phytochemical composition of selected indigenous vegetables in Uganda. The crude extracts of diethyl ether, 96 percent ethanol and distilled water indicated that *Amaranthus hybridus* L., *Amaranthus cruentus* L., *Solanum aethiopicum* L., *Cleome gynandra* L. and *Vigna unguiculata* L. contain alkaloids, tannins, flavonoids, saponins, carotenoids, coumarin derivatives and glucides phytochemicals. Another phytochemical, steroid glycoside, was detected in the distilled water extract of *A. cruentus*, *S. aethiopicum* and *V. unguiculata*. The quantitative analysis of the total flavonoid content in *A. hybridus*, *A. cruentus*, *S. aethiopicum*, *C. gynandra* and *V. unguiculata* showed 8.7, 12.0, 15.2, 26.4 and 10.6 g per 100 g dry weight, respectively, while the total alkaloid content showed 2.7, 3.3, 4.0, 3.8 and 1.7 g per 100 g dry weight, respectively. The phytochemical composition in the respective indigenous African vegetables justifies their therapeutic activity against a wide range of diseases. These phytochemicals have anti-oxidant, antihypertensive, antidiabetic and anti-ulcer properties that can prevent a number of diseases. With these health benefits, there is need to emphasize a diet rich in indigenous green leafy vegetables to promote health and prevent diseases in the population. There is also need for further research and value addition to indigenous African vegetables as a potential source of drugs or medicines.

1. Introduction

In many African cultures, vegetables are widely consumed together with starchy staple foods such as bananas, millet, sorghum, maize, cassava and sweet potatoes. Vegetables form an important part of a traditional African diet, since they have enormous nutritional and health benefits, besides adding taste and palatability to food (Akubugwo *et al.*, 2008; Rubaihayo, 1997). Consumption of vegetables is believed to play a significant protective role against degenerative diseases such as cancer, chronic cardiovascular diseases and high cholesterol levels (Adefegha and Oboh, 2011; Agudo *et al.*, 2002).

In fact, it is reported that consumption of fruits and vegetables lowers total cholesterol (Dragsted *et al.*, 2006), while consumption of 400 g of fruits and vegetables per day is recommended by WHO/FAO for prevention of chronic cardiovascular diseases (Kanungsukkasem *et al.*, 2009). However, consumption of vegetables in sub-Saharan Africa still lags behind other regions, yet it is endowed with a high diversity of edible vegetables (Habwe and Walingo, 2008). Of the 1 000 edible green vegetables species in sub-Saharan Africa, Uganda has about 600 local vegetable species (Ssekabembe *et al.*, 2003).

A study carried out by Bukenya-Ziraba *et al.* (1999) reported 38 different types of vegetables sold in different major markets of Kampala, Uganda. Of the reported vegetable species, *Amaranthus* sp., *Solanum* sp., *Capsicum* sp. and *Cleome gynandra* are identified as the most commonly consumed vegetable species (Ssekabembe *et al.*, 2003). Although vegetables are consumed widely, they are prepared differently, depending on preferences and indigenous knowledge of the local communities.

In Uganda, vegetables are prepared by steaming, mashing or boiling with staple food to make a local dish (*Katogo*), frying with edible oil and pasting with groundnuts or sesame (Musinguzi *et al.*, 2006). Frying is the most popular method of vegetable preparation for eating in urban centres of Uganda and has been adopted in rural areas as well. Vegetables are eaten as food in form of sauce, raw as snack and salads or even side dishes of the main meal (Musinguzi *et al.*, 2006). The nutrition and bioactive composition of vegetables make them very important in the household, especially during times of food shortage.

Vegetables have been found to improve nutrition, boost food security, foster rural development, support sustainable land care and offer health protecting properties (Agea *et al.*, 2010). This illustrates the relationship between nutrition and medicine that is recognized in African cultures. Epidemiological studies indicate a relationship between consumption of vegetables and prevention of chronic diseases such as cancer, hypertension and heart diseases (Katt, 2005; Pierini *et al.*, 2008). Phytochemicals found in vegetables such as flavanoids exert a protective effect against these chronic diseases (Franke *et al.*, 2004)

Although many of the indigenous vegetables are available and consumed in Africa, little is known about their phytochemical composition that contributes to their therapeutic effects. Recent trends show that public health experts are interested to know the composition of vegetables to provide proof of their health benefits. This study evaluated the phytochemical composition of selected indigenous vegetables in Uganda.

2. Materials and methods

2.1 Sample collection

About 5 kg of fresh, sorted and disease-free vegetable leaf samples that included: *Amaranthus hybridus*, *Amaranthus cruentus*, *Cleome gynandra*, *Solanun aethiopicum* and *Vigna unguiculata*, were purchased from a market vendor in Kampala, Uganda in June 2009. These vegetable species are among the most grown and consumed vegetables in Uganda (Bukenya-Ziraba *et al.*, 1999; Ssekabembe *et al.*, 2003). The vegetable species were scientifically identified by a taxonomist. Voucher specimens were prepared and deposited at the herbarium of the Natural Chemotherapeutics Research Institute, Ministry of Health, Kampala, Uganda for future reference.

2.2 Sample preparation

The vegetable samples were cleaned with distilled water and dried to a constant weight in vacuum oven (40–50°C). The dry leaves were pulverized into powder and kept in a cool dry place until extraction was completed.

2.3 Extraction and analysis

The leaf powder of each vegetable sample was divided into two portions. One portion was used for qualitative phytochemical screening and another portion for quantitative determination of total flavanoids and total alkaloids. The sample portion for phytochemical qualitative screening (200 g) was analysed using standard methods reported by Culei (1982) and Idu *et al.* (2006). In brief, diethyl ether and 96 percent ethanol solvents were used in soxhlet apparatus extraction of the samples in a successive manner. The residue of soxhlet extraction was then boiled in distilled water to extract with water. The extracts of diethyl ether and ethanol were then concentrated under reduced pressure with rotary evaporator, while the water extract was filtered. All the extracts of diethyl ether, ethanol and water were then subjected to qualitative phytochemical screening.

The other vegetable sample portion was used for determination of total flavanoids and total alkaloids using standard method reported by Edeoga *et al.* (2005). For determination of total flavanoids, 10 g of vegetable leaf powder was put into a round bottom flask and repeatedly extracted with 80% aqueous methanol (100 ml) at room temperature for 4 hours with regular shaking. The solution was then filtered using whatman filter paper no. 1 and the filtrate concentrated under reduced pressure with rotary evapourator at 50°C. The concentrate was then evaporated to dryness in a vacuum oven at 50°C and total flavanoids were determined gravimetrically.

All analyses were done in triplicate.

In determination of total alkaloids, 5 g of dry vegetable leaf powder was weighed, carefully transferred into a beaker and 10 percent acetic acid (200 ml) in ethanol added. The mixture was covered and allowed to stand for 4 hours and filtered. The filtrate was concentrated on a hot water bath to one-quarter of the original volume. The concentrate was allowed to cool at room temperature and concentrated ammonia added dropwise until precipitation was complete. The solution was allowed to settle and the precipitates collected by filtering using whatman filter paper no 1. The precipitate on the filter paper was washed with dilute ammonia and a residue dried in a vacuum oven at 50°C and weighed. The total alkaloids were determined gravimetrically. All analyses were also done in triplicate.

3. Results and discussion

The results of the phytochemical composition of selected indigenous African vegetables are presented in Table 1. The phytochemical components in the dry vegetable leaf crude extracts included alkaloids, tannins, flavonoids, saponins, carotenoids, coumarin derivatives and glucides. Phytochemicals have therapeutic properties such as anti-allergic, anti-inflammatory, antihypertensive, antidiabetic, anti-oxidant, anti-ulcer, anti-cancer activity which are beneficial to human health (Dembinska-Kiec *et al.,* 2008; Issa *et al.*, 2006). Specifically, tannins, flavanoids and coumarins are known anti oxidants which are essential in the prevention of complicated degenerative diseases such as cancer, cardiovascular, alzheimers and parkinson (Ahmad *et al.*, 2006; Tungjai *et al.*, 2008).

Dietary anti-oxidants prevent production of free radicals by chelating reactive species produced in the body that are responsible for causing degenerative diseases (Adedayo *et al.*, 2010; Adefegha and Oboh 2011; Okigbo *et al.*, 2009). It is also known that alkaloids, flavanoids, tannins, reducing compound, sterols and triterpenes have good antimicrobial properties that are essential in the management of diseases such as malaria, fever, diarrhea and respiratory tract infection (Adebayo-Tayo and Adegoke, 2008; Kubmarawa *et al.*, 2007).

Therefore, consumption of *A. hybridus*, *A. cruentus*, *S. aethiopicum*, *C. gynandra* and *V. unguiculata* provides a diet with health benefits. It is necessary for policy-makers to consider indigenous African vegetables as important resources for human nutrition and improved health of the population. This emphasizes the need to sensitize the population on benefits of a vegetable diet in disease prevention, thus reduce morbidity.

Table 1. Phytochemical composition of selected African edible vegetables.

Species of vegetable	*A. hybridus*	*A. cruentus*	*S. aethiopicum*	*C. gynandra*	*V. unguiculata*
Diethyl ether extract					
Sterols and triterpenes	(–)	(–)	(–)	(–)	(–)
Carotenoids	(+)	(+)	(+)	(+)	(+)
Basic alkaloids	(+)	(+)	(+)	(+)	(+)
Flavanoid aglycones	(+)	(+)	(+)	(+)	(+)
Emodols	(+)	(–)	(–)	(–)	(–)
Coumarins	(–)	(–)	(+)	(+)	(+)
96% ethanol extract					
Tannins	(+)	(+)	(+)	(+)	(+)
Reducing compounds	(–)	(–)	(–)	(–)	(–)
Alkaloids	(+)	(+)	(+)	(+)	(+)
Coumarin derivatives	(+)	(+)	(+)	(+)	(+)
Anthracenosides	(–)	(–)	(–)	(–)	(–)
Steroid glycosides	(–)	(+)	(+)	(–)	(+)
Flavonosides	(+)	(+)	(+)	(+)	(+)
Saponins	(+)	(+)	(+)	(+)	(+)
Water extract					
Polyuronides	(–)	(–)	(–)	(–)	(–)
Reducing compounds	(–)	(–)	(–)	(–)	(–)
Glucides	(+)	(+)	(+)	(+)	(+)
Starch	(–)	(–)	(–)	(–)	(–)
Saponins	(+)	(+)	(+)	(+)	(+)
Tannins	(+)	(+)	(+)	(+)	(+)
Alkaloid salts	(–)	(–)	(–)	(–)	(–)

Key: (+) present or detected (–) not present or not detected

Apart from preventing diseases, vegetables can be a source of drugs for treatment. Several drugs have been developed from plant extract. An alkaloid (quinine) and a sesquiterpene (artemesinin) that is used in the treatment of complicated malaria have been developed from the bark of Cichona tree and *Artemisia annua* plants, respectively. This therefore means that vegetables can also be a potential source of phytochemicals that can be developed into drugs for prevention or treatment of diseases (Table 2). There is also need to understand the chemical compounds in indigenous African vegetables that can be scientifically investigated and developed into potential drugs. Further research is needed to isolate and determine specific chemical compounds in the identified alkaloids and flavanoids that can be developed into drugs.

Table 2. Total flavanoids and alkaloids in selected African edible vegetables.

Vegetable species	Total flavanoids (%)	Total alkaloids (%)
A. hybridus	8.7±0.1	2.7±0.3
A. cruentus	12.0±0.3	3.3±0.0
V. unguiculata	10.6±0.1	1.7±0.1
C. gynandra	15.2±0.2	4.0±0.3
S. aethiopicum	26.4±0.6	3.8±0.2

4. Conclusion and recommendations

Based on the findings of this study, it can be concluded that a diet rich in some indigenous African vegetables can be of therapeutic use for prevention and treatment of diseases as well as a potential source of drugs. Therefore, policy-makers need to promote vegetable consumption and conduct further scientific research on indigenous African vegetables to isolate chemical compounds that can be developed into drugs.

Acknowledgements

We thank the Government of Uganda through the Natural Chemotherapeutics Research Institute, Ministry of Health for funding this research and the vegetable market vendor in Kampala for providing vegetable samples.

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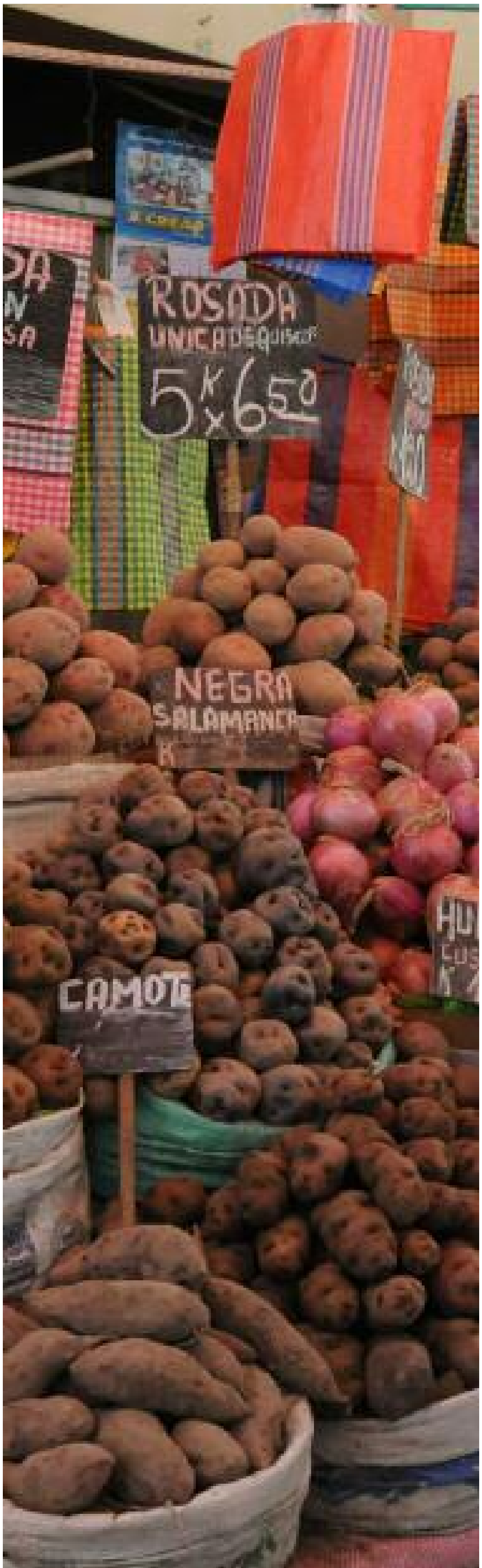

ACHIEVEMENTS IN BIODIVERSITY IN REGARD TO FOOD COMPOSITION IN LATIN AMERICA

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Abstract
Biodiversity in food composition supplies human beings with both macro-and micronutrients as well as the bioactive compounds they require to maintain optimum physiological conditions throughout life. Latin America has a high level of natural food biodiversity, but at the same time obesity and malnutrition in children are present. The foods a community consumes is an excellent tool to be used for learning about its history and culture. Before Christopher Columbus's trip in 1492, there were many different cultural groups in Latin America, including three great empires from the north to the extreme south: the Mayas, the Aztecs and the Incas. A retrospective view of the native foods cultivated by these ancient cultures will be presented considering their biodiversity and composition. Three foods, which maintain their importance until today, were basic in these three empires: corn (*Zea mays*), yuca (*Manihot esculenta, Manihot utilissima*) and potatoes (*Solanum tuberosum*). These were wisely complemented with other native foods with high protein content, such as beans (*Phaseolus vulgaris*), other seeds, vegetables and many fruits. After 1492, Spanish and Portuguese navigators carried at least 22 foods back to Europe, Africa, Asia and Oceania, transforming previously colourless and monotone diets, and contributing to better health while saving many lives with their nutrients and bioactive compounds. Other traditional foods have been forgotten or underutilized, and it is time to rediscover them. These foods can help restore a healthy life to "developed society", which is suffering from inadequate management of its daily diet, leaving many children in the world still lacking the minimum levels of nutrients needed for survival. Latin American governments and Latin American branches of LATINFOODS through FAO TCP projects have made important efforts towards generating new food composition data focused on the twin priorities of biodiversity and nutrition.

1. Introduction

Biodiversity in food composition supplies human beings with both macro- and micronutrients and the bioactive compounds they require to maintain optimum physiological conditions throughout life. Distortions in diets in some Latin American and Caribbean countries lead to obesity and malnutrition in children, indicating that opportunities open to different sectors of the population are not equal, even as statistics say that food production in each individual country is sufficient (FAOSTAT, 2010; FAO, 2010a).

According to the FAO Declaration (2010b), efforts must be made by government agencies, international institutions, the food industry and academia towards generating food composition data for native components and sustainable diets. INNFOODS through LATINFOODS Net and their Latin American branches are the best technical platforms available for the development of programmes and policies that individual governments can use in this regard.

2. Culture and foods and their social impact

The foods a community consumes is an excellent tool to be used for learning about its history and culture. One or two basic foods should be rich in carbohydrates to guarantee primary energy requirements, with these complemented by other foods belonging to the country's local ecology. These basic foods represent emblematic meals, always present at all social activities, and they must be maintained and protected as they are part of the culture and in some cases of the religious traditions of these societies. This harmonious link between man and food reflects a people's actions, culture and life. In Latin America, there are many examples of the strong relationship between man and his environment, foods and divinities. Before Christopher Columbus's arrival in 1492, many different cultural groups were settled in this large land mass, including from the north to the south the three powerful empires of the Mayas, Aztecs and Incas, representing cultures that were more than 3 000 years old. They had well-structured civil organizations, advanced knowledge in science, arts, architecture, astronomy, agriculture and irrigation, active commerce, and natural laws directing daily life according to their divinities. Total population was estimated to be at about 60 000 000 inhabitants, with the Aztec Empire the largest at close to 20 000 000; Tenochtitlan, where Mexico City now stands, had more than 500 000 inhabitants. More than 200 languages were spoken, and native people had deep contact with and knowledge of nature. They "domesticated" the best lines they could obtain from their wild plants, taking care of their own natural biodiversity (Lucena, 2005).

Three foods, which maintain their importance and wide biodiversity until today, were basic for feeding the large populations in these three empires: corn (*Zea mays*), yuca (*Manihot esculenta*, *Manihot utilissima*) and potatoes (*Solanum tuberosum*). Corn (*Zea mays*), the "sacred" food, was basic for the Mayan, Aztec and Incan populations, and its importance is maintained until today as it continues to be the basic food for many typical meals in Latin America. The oldest evidence of its cultivation is found in the Tehuacán valley, Mexico, from about 7 000 years ago. Corn means "support of the life", and it had great importance in religious ceremonies, celebrations and nutrition.

The Aztecs said that "corn is our body, our blood and bones". Corn was the first Latin America species introduced to Europe at the end of the fifteenth Century. It maintains its great biodiversity in grain colour: white, yellow, deep yellow, brownish, deep violet (FAO, 1993; Tapia, 1997), and is a good source of Zeaxantina and Luteina (Kimura *et al.*, 2007). "Nixtamalization" is an ancient procedure still used in Mexico to improve the availability of minerals, vitamin B and protein in corn flour, giving the Aztecs a sustainable diet based mainly on nixtamal, plus beans, pumpkin, hot chili, tomato, prickly pears etc., and it is considered nutritionally satisfactory (FAO, 1993). Corn germ oil is a good source of linoleic acid (close to 60%), tocopherols, and phytosterols (Moreau *et al.*, 2009).

Yuca root, cassava or manioc was the basic food in the middle tropical region. One variety was sweet (*Manihot utilissima*), and one bitter (*Manihot esculenta*). The latter variety is detoxified for human consumption, and is the base for preparing "tapioca" flour. Its history starts in around the year 2700 BC. The sweet variety is found from the Pacific to Mexico and Central America, and the bitter one from Paraguay to northeast Brazil. Portuguese navigators introduced yuca to Africa in the seventeenth century, after corn, and yuca then expanded to the Indian Ocean Islands, India, Asia and the Pacific Islands. Yuca is one of the more widely cultivated plants in the world. With its low costs for production and processing, high yield, and low commercial importance, it is a food dedicated mainly to private consumption in the local communities in developing countries. In Paraguay and in Brazil, one of the largest producers of yuca, this native root is still a food consumed daily in different forms. In Brazil, it is the principal ingredient in two symbolic foods, "farofa" and "pirão". In Colombia and Venezuela, yuca also has great importance (Ospina and Ceballos, 2002; Cartay, 2004). Yuca is a high source of carbohydrates, some minerals, and vitamins (TACO, 2006).

Potatoes (*Solanum tuberosum*) are the third basic food. Originating in South America, high in the Lake Titicaca region of the Andes Mountains at an altitude of 3 800 m, the potato has been consumed in the Andes for about 8 000 years. Maintaining its leadership position in the Andes valleys together with corn (Tapia, 1997), Andean potatoes have great biodiversity, with different shapes, sizes and skin colours: green, yellow, pink, red and violet. Potatoes are an important source of energy, vitamin C, minerals, carotenoids, anthocyanins in the peel and flesh (Schmidt-Hebbel *et al.*, 1992; Andre *et al.*, 2007a; Andre *et al.*, 2007b; Moenne-Locoz, 2008; Burmeister *et al.*, 2011). There are more than 5 000 varieties in the Andes region and more than 200 Andean potato varieties in Jujuy northwest of Argentine 26–28° parallel latitude south. Seven varieties have been analysed, (Jimenez *et al.*, 2009a, b), with the best in regard to carbohydrates and protein being the "Imilla Colorada" variety (Figure 1).

Figure 1. Native potatoes from Andean northwest Jujuy, Argentine, parallel 26 – 28º latitude south, cultivated at 3000 m altitude.

Another old native source of potatoes is located in the extreme south of Chile, in the Chiloe Island at the 41– 43° parallel latitude south. These also present great biodiversity in shape, peel colour, and flesh, and are a good source of vitamin C, flavonoids, and anthocyanin pigments (Moenne-Locoz, 2008) (Figure 2).

The two varieties analysed, "Bruja" and "Michuñe negro", have dark skins and violet flesh, and they provide more protein, ash, vitamin C, total flavonoids and anthocyanin, and fewer carbohydrates than the normal Chilean commercial variety potato (Schmidt-Hebbel *et al.*, 1992). Sixteenth century Spanish navigators picked large amounts of potatoes in the Chiloe Island for food for their long voyages, and while they did not know it, the potatoes' vitamin C content saved the lives of many mariners by preventing scorbutic disease.

Chiloe potatoes are now in the Chilean market as "Rainbow potatoes" from the South of the World (Figure 3).

Figure 3. Commercial native potatoes "Arco Iris" (Rainbow) from the "South of the World", Chiloe Island, Chile, raw and boiled.

Figure 2. Native potatoes from Chiloe Island, Chile, parallel 41 – 43° latitude south, cultivated at sea level, raw, halved and potato chips home made.

The book "International Year of the Potato" is dedicated to this old and nutritious food which today can solve hunger problems in the world and contains quite extensive information. History tells us that the Spanish carried it to Europe in the sixteenth century, and it quickly spread across the globe from China's Yunnan plateau to the steppes of the Ukraine, changing the history of food in the Old World. It is the world's number one non-grain food commodity, production reached a record 325 million tonnes in 2007, China is the world's principal producer (FAO, 2008). Our native potato is unique in the world, and represents a real treasure that needs to be appreciated in Latin America and taken care of.

These three basic native foods that are rich in carbohydrates were wisely complemented with other native foods with a high content in protein, such as beans (*Phaseolus vulgaris*). With evidence of cultivation from 500–8 000 years ago, beans are still present in daily diets from North to South America. They also present a high level of biodiversity in peel colour, shape and composition, and are a source of bioactive components, their oil 2 percent, a good source of linolenic acid, about 40 percent (TACO, 2006).

In the Andes Region, other native seeds complemented the Incan diet, such as quinoa (*Chenopodium quinoa*), with more protein and fat than cereals. The four limiting amino acids in a mixed human diet, lysine, sulphurs (methionine and cystine), threonine and tryptophan, are present in higher amounts than in wheat, confirming the high quality of its biological protein (Bascur and Ramelli, 1959; Tapia, 1997; Schmidt-Hebbel *et al.,* 1992), the 7.4% oilseed content is 7.8% linolenic, 50% linoleic, 23% oleic, and 11% palmitic, good n-6:n-3 ratio of 6.4:1 according to current recommendations (FAO, 2010c; Masson and Mella, 1985). "High Plateau" quinoa, a whole plant food, is a good source of vitamins and minerals and needs more research. Its plants and seeds present great biodiversity, and they grow at a high altitude, 3 000–4 000 m above sea level, in very aggressive conditions, including low temperatures, strong winds, high sun irradiation, salty soil.

They develop bioactive compounds, such as flavonoids and anthocyanin, as defence mechanisms. Quinoa leaves and seeds are pink, green, yellow, brownish, deep black colour, and they are highly valued in external markets (Tapia, 1997). Tarwi or lupine seeds (*Lupinus mutabilis*), the bitter variety, have their alkaloids taken out for human consumption (Tapia, 1997). The composition of tarwi seeds is close to that of soybeans. Their fatty acids are a good source of linolenic acid 9%, and linoleic acid 21%, with a n-6:n-3 ratio of 2.2:1. Between 200 m and 4 000 m in altitude, other tubers were also grown, such as oca (*Oxalis tuberose*) (Tapia, 1997). Six varieties, with different shapes and peel colours of pink, yellow, deep violet and white, were analysed (Jimenez and Sammán, 2009).

The pink peel variety has the best composition. Some roots other than yuca have also been important in Andean and Central American diets, such as sweet potato (*Hipomea batata*). With its rustic cultivation and high productivity, it saved the lives of many people in catastrophic situations in Europe and Asia. It is a good source of carbohydrates, fibre, and β-carotene (Schmidt-Hebbel *et al.*, 1992; Kimura *et al.,* 2007).

Amaranto or kiwicha (*Amaranthus caudatus*) also complemented the protein in the Andean diet (Tapia, 1997). Fourteen samples of genetic material from four amaranto seed varieties (*A. mantegazzianus, A. caudatus, A. cruentus , A. hipochondriacus*) were analysed, including the fatty acid composition of the seed oil, before reintroducing them in Jujuy, Argentina. The best variety was *A. caudatus* CT 10, which is highly resistant to extreme drought (Acuña *et al.*, 2007). The fatty acid groups were 24% saturated, 29% monounsaturated and 44% polyunsaturated. Squash or pumpkin (*Cucurbita maxima*), a good source of β-carotene (Kimura *et al.,* 2007; Azebedo-Melero and Rodriguez-Amaya, 2007), together with corn and beans continues to be a part of the basic diet in Latin American cultures. Incan, Mayan and Aztec diets were balanced in quantity and quality in carbohydrates, protein, fibre, fats and good n-6:n-3 ratios, which is now difficult to attain, as well as in terms of micronutrients such as minerals, vitamins, and bioactive compounds. It was a more vegetarian diet, animal protein was not so important, in the north it came from native Mexican turkey (*Gallopavo meleagis*) or Guajalote, in the Andean Region from lama (*Lama glama*) and cuy (*Cavia porcellus*) and in general, from rivers, lakes and the sea (Tapia, 1997; Bengoa, 2001).

3. Latin American food biodiversity related to food composition and health

From ancient times, Latin America has been a good example of food biodiversity. PACHAMAMA, the Mother Earth to the Incan culture, opens up each year offering all kinds of fruits, roots, tubers, leaves, flowers, seeds and species, each one maintaining its biodiversity unchanged over the centuries. Now it is our turn to do research and to discover the secrets of their healthy components. A brief comment on 22 native foods cultivated by these ancient cultures and introduced to the whole globe by Spanish and Portuguese navigators after 1492 now follows, all of which have high biodiversity, and have changed the colourless and monotone diet of the Old World. Like a rainbow that settled overseas forever, they are present on the tables of millions of families around the world on a daily basis, brightening them with their attractive colours: deep reds, oranges, yellows, pinks, deep greens, deep violets, black, white and browns.

They not only enhance taste and flavour, but offer health and life to consumers through their contributions of vegetable proteins, carbohydrates, fats, vitamins, minerals and natural antioxidants (Hoffmann-Ribani *et al.,* 2009; Rodriguez-Amaya *et al.,* 2008). Corn (*Zea mays*), beans (*Phaseolus vulgaris*), yuca (*Manihot esculenta, Manihot utilissima*), potatoes (*Solanum tuberosum*), sweet potato (*Hipomea batata*) and squash or pumpkin (*Cucurbita maxima*) have been commented on. Tomato (*Lycopersicum esculentum* Mill.), the best source of lycopene, conquered Italy, and became a daily ingredient of Italian meals. Ají or hot chili and sweet chili (*Capsicum annuum*), changed gastronomy in Asian countries, capsaisina is responsible for hot taste. Exotics fruits from the tropical zone, include avocado (*Persea americana* Mill.), cherimola (*Annona cherimola* Mill.), papaw (*Carica papaya*), pineapple (*Ananas sativus* (Lindl) *Schult.*), guayaba (*Psidium guajava*), maracuyá, (*Passiflora edulis*, *Pasiflora edulis flavicarpa*).

From the Chilean forest come white strawberries (*Fragaria chiloensis*), and from Mexico, prickly pear (*Opuntia ficus-indica*) representing many options for different attractive and good tasting formats. From Brazil, two seeds, the peanut (*Araquis hypogaea*) and the cashew nut (*Anacardium occidentale* L.), can be found in the pockets of people of all ages around the world, and are high in protein and fat content. From Mexico, sunflower seeds (*Heliantus annus*) are a source of one of the most important vegetable oils produced in the world. Also from Mexico, come two spices: vanilla (*Vanilla planifolia*), a delicate natural flavouring and source of the powerful antioxidant vanillin, and rocu seeds (*Bixa orellana*) with natural red-orange bixina carotenoid food dye. From Ecuador, cocoa seeds (*Theobroma cacao*) "Food for Gods", from the Mayan word "Ka'kaw", an important beverage for the Mayans and the Aztecs, was domesticated more than 2 000 years ago and introduced to Africa and Oceania. Its seeds contain the most delicious fat in the world, impossible to duplicate, and a source of natural antioxidants (Visioli *et al.*, 2009). The composition of most of these foods is in the cited literature.

New data has been generated and published in recent years in Food Composition Tables: Centro America (2006), Costa Rica: Alfaro *et al.* (2006), Blanco-Metzler *et al.* (2006), Monge-Rojas and Campos (2006), Brazil: TACO (2006), Rodriguez-Amaya *et al.* (2008), México: Villalpando *et al.* (2007), other updated Lajolo *et al.* (2000), Tablas de Composición de América Latina (2009 rev.), Schmidt.-Hebbel *et al*. (1992). Data of seeds from native Latin America fruits cultivated in Chile and their extracted fatty acid oil composition, tocopherols and phytosterols has been published: cherimola (*Annona cherimola*), papaw (*Carica pubescens*), prickly pear (*Carica ficus-indica*) (Masson *et al.*, 2008a) and native Chilean palm seeds (*Jubaea chilensis* Molina, Baillon) (Masson *et al.*, 2008b). These special oils have their own fatty acid composition and bioactive compounds, offering new raw material for food and cosmetic purposes, and they represent a real possibility to extract more value from agro waste materials that are currently not utilized.

4. Final remarks

Some traditional Latin American foods have been "forgotten" or "underutilized", it is time to rediscover them. Their great biodiversity represents an excellent source of bioactive components which can contribute to the restoration of the poor health of "developed society", which is suffering from the inadequate management of its daily diet, while also offering healthy foods to many children, who today still do not have the minimum levels of nutrients for survival.

Latin American countries must strengthen efforts to establish government policies for the generation of food composition data, including those "forgotten" or "underutilized" ancient foods high in natural biodiversity.

Project TCP/RLA/3107 (D) (2008–09), has contributed to strengthening food composition activities in Argentina, Chile and Paraguay, together with their respective governments' support, in Chile, food composition is now a part of government policy.

Efforts in this direction must be supported through agreements between the international agencies involved in food resources, nutrition, health and biodiversity, together with INNFOODS through LATINFOODS NET and their national branches, the governments involved and the private industrial sector.

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