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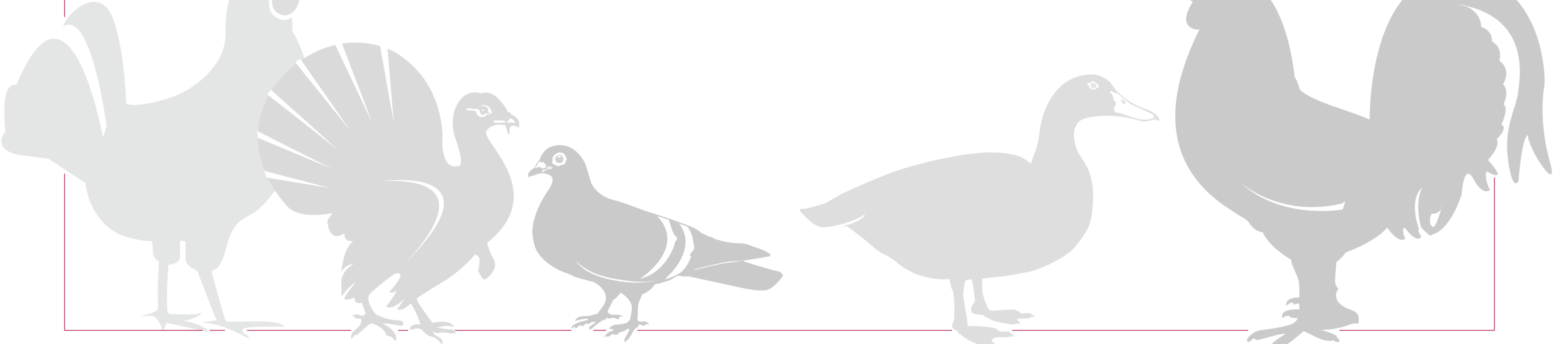

Poultry feed availability and nutrition in developing countries

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Worldwide, production of poultry meat and eggs has increased consistently over the years, and this trend is expected to continue. It is predicted that most increases in poultry production during the next two decades will occur in developing countries, where rapid economic growth, urbanization and higher household incomes will increase the demand for animal proteins. Several factors have contributed to the consistent growth in world poultry production, including: i) genetic progress in poultry strains for meat and egg production; ii) better understanding of the fundamentals of nutrition; and iii) disease control. For example, the age for a meat chicken to reach the market weight of 2 kg has steadily decreased from 63 days in 1976 to 35 days in 2009, and the efficiency of converting feed into poultry products also continues to improve. This growth in poultry production is having a profound effect on the demand for feed and raw materials. Feed is the most important input for poultry production in terms of cost, and the availability of low-priced, high-quality feeds is critical if poultry production is to remain competitive and continue to grow to meet the demand for animal protein.

PRODUCTION SYSTEMS AND FEEDING

Historically, the poultry sector has evolved through three phases: i) traditional systems, which include family poultry consisting of scavenging birds and backyard raising; ii) small-scale semi-commercial systems; and iii) large-scale commercial systems. Each of these systems is based on a unique set of technologies. They differ markedly in investment, type of birds used, husbandry level and inputs such as feeds. The feed resources, feeding and feed requirements required to raise poultry also vary widely, depending on the system used.

The traditional system is the most common type of poultry production in most developing countries. Possible feed resources for the local birds raised in this system include: i) household wastes; ii) materials from the environment (insects, worms, snails, greens, seeds, etc.); iii) crop residues, fodders and water plants; and iv) by-products from local small industrial units (cereal by-products, etc.). The survival and growth of extensive poultry systems are determined by the competition for feed resources in villages. This system works well where biomass is abundant, but in areas with scarce natural resources and low rainfall, the competition for natural resources with other animals can be extreme.

Between the two extremes of traditional and commercial production systems is the semi-commercial system, which is characterized by small to medium-sized flocks (50 to 500 birds) of local, crossbred or "improved" genotype stock, and the purchase of at least part of their feed from commercial compounders. Several feeding strategies may be used in this system: i) on-farm mixing of complete rations, using purchased and locally available feed ingredients; ii) dilution of purchased commercial feeds with local ingredients; and iii) blending of a purchased concentrate mixture with local ingredients or whole grains.

The large-scale commercial system is the dominant production system in developed countries, and this sector has also recently expanded in many developing countries. Commercial systems are characterized by large vertically integrated production units and use high-producing modern strains of birds. In these systems, feed is the most important variable cost component, accounting for 65 to 70 percent of production costs. High productivity and efficiency depend on feeding nutritionally balanced feeds that are formulated to meet the birds' nutritional requirements.

POULTRY NEED TO BE FED WELL-BALANCED DIETS

Most poultry species are omnivores, which in nutritional terms means that they have a simple digestive system with non-functional caeca. Exceptions to this general rule include geese and ostriches, which have well-developed functional caeca. The digestive tract of poultry has more organs but is shorter than that of other domestic animals. The unique features of this digestive tract include the crop, which is a storage organ, and the gizzard, which is a grinding organ. In fast-growing meat chickens, it takes less than three hours for feed to pass from mouth to cloaca and for nutrients to be digested and absorbed. To compensate for the relatively short digestive tract and rapid digesta transit time, high-performing birds need easily digested, nutrient-dense diets. Nutrient balance is critical.

The rates of genetic change in growth and feed efficiency over the years have also changed the physiology of the birds. Nutrient requirements and nutritional management have therefore changed to satisfy the genetic potential of the new strains. The high genetic potential of current poultry strains can only be achieved with properly formulated feeds that are protein- and energy-dense. Poultry, especially growing birds, are unique among domestic animals in that any change in nutrition is reflected in bird performance almost immediately. This phenomenon has been successfully exploited by the commercial poultry industry to improve growth, carcass yield and egg production.

The term "poultry" encompasses a range of domesticated species, including chickens, turkeys, ducks, geese, game birds (such as quails and pheasants) and ratites (emus and ostriches). This overview does not discuss the nutrition of all these species, but focuses on chickens, which constitute more than 90 percent of the poultry market. However, the principles of nutritional management for chickens are generally applicable to other poultry species grown for meat and eggs.

NUTRIENT REQUIREMENTS

For maximum growth and good health, intensively reared poultry need a balanced array of nutrients in their diet. The nutrients required by birds vary according to species, age and the purpose of production – whether the birds are kept for meat or egg production. Table 1 provides a summary of recommended minimum levels of selected nutrients for meat chickens of different ages and for layers. To meet these specific needs, different classes of poultry have to be fed different types of diets. These recommendations should only be considered as guidelines and used as the basis for setting dietary nutrient concentrations in practical diets. Historically, recommendations on nutrient requirements have been based on available literature and data from expert groups. Currently, however, because each specific genotype has its own requirements, most commercial feed formulations use minimum requirements recommended by the breeding companies that supply the chicks.

Poultry require nutrients to maintain their current state (maintenance) and to enable body growth (weight gain) or egg production. Birds need a steady supply of energy, protein, essential amino acids, essential fatty acids, minerals, vitamins and, most important, water. Poultry obtain energy and required nutrients through the digestion of natural feedstuffs, but minerals, vitamins and some key essential amino acids (lysine, methionine, threonine and tryptophan) are often offered as synthetic supplements.

Energy

Poultry can derive energy from simple carbohydrates, fat and protein. They cannot digest and utilize some complex carbohydrates, such as fibre, so feed formulation should use a system based on available energy. Metabolizable energy (ME) is the conventional measure of the available energy content of feed ingredients and the requirements of poultry. This takes account of energy losses in the faeces and urine.

TABLE 1

Recommended minimum nutrient requirements of meat chickens and laying hens, as percentages or units per kilogram of diet (90 percent dry matter)

		Meat chickens			Laying hens
Nutrient	**Unit**	**0–3 weeks**	**3–6 weeks**	**6–8 weeks**	
Metabolizable energy	kcal/kg	3 200	3 200	3 200	2 900
	MJ/kg	13.38	13.38	13.38	12.13
Crude protein	%	23	20	18	15
Amino acids					
Arginine	%	1.25	1.10	1.00	0.70
Glycine + Serine	%	1.25	1.14	0.97	-
Histidine	%	0.35	0.32	0.27	0.17
Isoleucine	%	0.80	0.73	0.62	0.65
Leucine	%	1.20	1.09	0.93	0.82
Lysine	%	1.10	1.00	0.85	0.69
Methionine	%	0.50	0.38	0.32	0.30
Methionine + Cysteine	%	0.90	0.72	0.60	0.58
Phenylalanine	%	0.72	0.65	0.56	0.47
Phenylalanine + Tyrosine	%	1.34	1.22	1.04	0.83
Threonine	%	0.80	0.74	0.68	0.47
Tryptophan	%	0.20	0.18	0.16	0.16
Valine	%	0.90	0.82	0.70	0.70
Fatty acid					
Linoleic acid	%	1.00	1.00	1.00	1.00
Major minerals					
Calcium	%	1.00	0.90	0.80	3.25
Chlorine	%	0.20	0.15	0.12	0.13
Non-phytate phosphorus	%	0.45	0.35	0.30	0.25
Potassium	%	0.30	0.30	0.30	0.15
Sodium	%	0.20	0.15	0.12	0.15
Trace minerals					
Copper	mg	8	8	8	-
Iodine	mg	0.35	0.35	0.35	0.04
Iron	mg	80	80	80	45
Manganese	mg	60	60	60	20
Selenium	mg	0.15	0.15	0.15	0.06
Zinc	mg	40	40	40	35

Source: Adapted from National Research Council, 1994.

Birds eat primarily to satisfy their energy needs, provided that the diet is adequate in all other essential nutrients. The energy level in the diet is therefore a major determinant of poultry's feed intake. When the dietary energy level changes, the feed intake will change, and the specifications for other nutrients must be modified to maintain the required intake. For this reason, the dietary energy level is often used as the starting point in the formulation of practical diets for poultry.

Different classes of poultry need different amounts of energy for metabolic purposes, and a deficiency will affect productive performance. To sustain high productivity, modern poultry strains are typically fed relatively high-energy diets. The dietary energy levels used in a given situation are largely dictated by the availability and cost of energy-rich feedstuffs. Because of the high cost of cereals, particularly maize, the use of low-energy diets for poultry feeding is not uncommon in many developing countries.

Protein and amino acids

The function of dietary protein is to supply amino acids for maintenance, muscle growth and synthesis of egg protein. The synthesis of muscle and egg proteins requires a supply of 20 amino acids, all of which are physiological requirements. Ten of these are either not synthesized at all or are synthesized too slowly to meet the metabolic requirements, and are designated as *essential* elements of the diet. These need to be supplied in the diet. The balance can be synthesised from other amino acids; these are referred to as *dietary non-essential* elements and need not be considered in feed formulations. From a physiological point of view, however, all 20 amino acids are essential for the synthesis of various proteins in the body. The essential amino acids for poultry are lysine, methionine, threonine, tryptophan, isoleucine, leucine, histidine, valine, phenylalanine and arginine. In addition, some consider glycine to be essential for young birds. Cysteine and tyrosine are considered semi-essential amino acids, because they can be synthesized from methionine and phenylalanine, respectively. Of the ten essential amino acids, lysine, methionine and threonine are the most limiting in most practical poultry diets.

Poultry do not have a requirement for protein *per se*. However, an adequate dietary supply of nitrogen from protein is essential to synthesize non-essential amino acids. This ensures that the essential amino acids are not used to supply the nitrogen for the synthesis of non-essential amino acids. Satisfying the recommended requirements for both protein and essential amino acids therefore ensures the provision of all amino acids to meet the birds' physiological needs. The amino acid requirements of poultry are influenced by several factors, including production level, genotype, sex, physiological status, environment and health status. For example, high levels of lean meat deposition require relatively high levels of lysine. High levels of egg output or feather growth require relatively high levels of methionine. However, most changes in amino acid requirements do not lead to changes in the relative proportions of the different amino acids. There is therefore an ideal balance of dietary amino acids for poultry, and changes in amino acid requirements are normally expressed in relation to a balanced protein or ideal protein.

Fats and fatty acids

Because of the greater energy density of fat compared with carbohydrates and protein, poultry diets usually include fats to achieve the needed dietary energy concentration. Fat accounts for about 3 to no more than 5 percent of most practical diets. Other benefits of using fats include better dust control in feed mills and poultry houses, and improved palatability of diets. Poultry do not have a specific requirement for fats as a source of energy, but a requirement for linoleic acid has been demonstrated. Linoleic acid is the only essential fatty acid needed by poultry, and its deficiency has rarely been observed in birds fed practical diets. Linoleic acid's main effect in laying birds is on egg size.

Minerals

Minerals are needed for formation of the skeletal system, for general health, as components of general metabolic activity, and for maintenance of the body's acid-base balance. Calcium and phosphorus are the most abundant mineral elements in the body, and are classified as macro-minerals, along with sodium, potassium, chloride, sulphur and magnesium. Macro-minerals are elements required in the diet at concentrations of more than 100 mg/kg.

Calcium and phosphorus are necessary for the formation and maintenance of the skeletal structure and for good egg-shell quality. In general, 60 to 80 percent of total phosphorus present in plant-derived ingredients is in the form of phytate-phosphorus. Under normal dietary conditions, phytate phosphorus is poorly utilized by poultry owing to the lack of endogenous phytase in their digestive enzymes. It is generally assumed that about one-third of the phosphorus in plant feedstuffs is non-phytate and is biologically available to poultry, so the phosphorus requirement for poultry is expressed as non-phytate phosphorus, rather than total phosphorus. A ratio of 2:1 must be maintained between calcium and non-phytate phosphorus in growing birds' diets, to optimize the absorption of these two minerals. The ratio in laying birds' diets is 13:1, because of the very high requirement for calcium for good shell quality.

Dietary proportions of sodium (Na), potassium (K) and chloride (Cl) largely determine the acid-base balance in the body for maintaining the physiological pH. If a shift occurs towards acid or base conditions, the metabolic processes are altered to maintain the pH, with the likely result of depressed performance. The dietary electrolyte balance is described by the simple formula ($Na^+ + K^+ - Cl^-$) and expressed as mEq/kg diet. Prevention of electrolyte imbalance needs careful consideration, especially in hot climates. Under most conditions, a balance of about 250 mEq/kg of diet appears satisfactory for optimum growth. The overall balance among these three minerals, and their individual concentrations are important. To be effective, their dietary levels must each be within acceptable ranges, not deficient and not excessive. Birds exposed to heat stress consume more water, and are better able to withstand heat when the water contains electrolytes. The replacement of part of the supplemental dietary sodium chloride with sodium bicarbonate has proved useful under these conditions.

Trace elements, including copper, iodine, iron, manganese, selenium, zinc and cobalt, function as components of larger molecules and as co-factors of enzymes in various metabolic reactions. These are required in the diet in only very small amounts (Table 1). Practical poultry diets should be supplemented with these major and trace minerals, because typical cereal-based diets are deficient in them. Organic forms of some trace minerals are currently available, and are generally considered to have higher biological availability than inorganic forms.

Vitamins

Vitamins are classified as fat-soluble (vitamins A, D, E and K) and water-soluble (vitamin B complex and vitamin C). All vitamins, except for vitamin C, must be provided in the diet. Vitamin C is not generally classified as a dietary essential as it can be synthesized by the bird. However, under adverse circumstances such as heat stress, dietary supplementation of vitamin C may be beneficial. The metabolic roles of the vitamins are more complex than those of other nutrients. Vitamins are not simple body building units or energy sources, but are mediators of or participants in all biochemical pathways in the body.

Water

Water is the most important, but most neglected nutrient in poultry nutrition. Water has an impact on virtually every physiological function of the bird. A constant supply of water is important to: i) the digestion of feed; ii) the absorption of nutrients; iii) the excretion of waste products; and iv) the regulation of body temperature. Water constitutes about 80 percent of the body. Unlike other animals, poultry eat and drink all the time. If they are deprived of water for even a short time, production and growth are irreversibly affected. Water must therefore be made available at all times. Both feed intake and growth rate are highly correlated with water intake. Precise requirements for water are difficult to state, and are influenced by several factors, including ambient conditions, and the age and physiological status of the birds. Under most conditions, water intake is assumed to be twice the amount of feed intake. Drinking-water temperatures should be between 10 and 25 °C. Temperatures over 30 °C will reduce consumption.

The quality of water is equally important. Quality is often taken for granted, but poor water quality can lead to poor productivity and extensive economic losses. Water is an ideal medium for the distribution of contaminants, such as chemicals and minerals, and the proliferation of harmful microorganisms. Water quality for poultry can be a major issue in arid and semi-arid regions where water is scarce. In particular, underground water in these areas can have high levels of salt. Saline drinking-water containing less than 0.25 percent salt is tolerated by birds, but can cause sodium toxicity if water intake is restricted.

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Advances in poultry nutrition

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Feed represents the greatest single expenditure associated with poultry production. Nutritional research in poultry has therefore centred on issues related to identifying barriers to effective digestion and utilization of nutrients, and on approaches for improving feed utilization. Poultry nutritionists have increasingly combined their expertise with that of specialists in other biological sciences, including immunology, microbiology, histology and molecular biology.

Although broilers and layers are highly efficient in converting feed to food products, they still excrete significant amounts of unutilized nutrients. For example, in their manure, broilers lose almost 30 percent of ingested dry matter, 25 percent of gross energy, 50 percent of nitrogen, and 55 percent of phosphorus intake. There is therefore considerable room for improving the efficiency of feed conversion to animal products. Much of the inefficiency results from the presence of undesirable components and the indigestibility of nutrients in the feed.

Recent advances in poultry nutrition have focussed on three main aspects: i) developing an understanding of nutrient metabolism and nutrient requirements; ii) determining the supply and availability of nutrients in feed ingredients; and iii) formulating least-cost diets that bring nutrient requirements and nutrient supply together effectively. The overall aim is *precision feeding* to lower costs and maximize economic efficiency. In the past, there was a tendency to overformulate diets when there was doubt about the availability of critical nutrients (especially amino acids and phosphorus) or when nutrient requirements were uncertain. This practice is no longer acceptable, not only because it is wasteful, but also because excess nutrients excreted in the manure are ultimately a source of pollution. Fine-tuning diets so that they more closely match the requirements of the birds, helps to optimize the efficiency of nutrient utilization. The major developments towards achieving the goal of precision feeding are discussed in the following sections.

DEFINING NUTRIENT REQUIREMENTS

Defining nutrient needs is challenging because they are influenced by several factors and are subject to constant change. The factors influencing nutrient requirements are of two main types: bird-related ones, such as genetics, sex, and type and stage of production; and external ones, such as thermal environment, stress and husbandry conditions. Precision in defining requirements requires accuracy in both areas. Great advances in the definition of nutrient requirements for various classes of poultry have been made possible largely by the increasing uniformity of genotypes, housing and husbandry practices throughout the poultry industry.

Defining requirements for the ten essential amino acids has been made easier by acceptance of the *ideal protein* concept. As for other nutrients, the requirements for amino acids are influenced by various factors, including genetics, sex, physiological status, environment and health status. However, most changes in amino acid requirements do not lead to changes in the relative proportion of the different amino acids. Thus actual changes in amino acid requirements can be expressed in relation to a balanced protein or ideal protein. The ideal protein concept uses lysine as the reference amino acid, and the requirements for other essential amino acids are set as percentages (or ratios) of the lysine requirement. Table 1 shows the ideal protein balances for meat chickens at different growth phases. The advantage of this system is that once the lysine requirements for a variety of conditions are determined, the needs for all other essential amino acids can be calculated. This approach has now become accepted practice for setting the amino acid specifications of feed formulations in the poultry industry.

DEFINING NUTRIENT COMPOSITION AND INGREDIENT QUALITY

Poultry producers are continually looking for opportunities that allow more flexibility in both the types and the levels of feed ingredients for use in feed formulations. Such opportunities are becoming increasingly frequent because of advances in nutrient analysis and feed evaluation techniques.

TABLE 1

Ideal amino acid ratios of meat chickens for three growth periods

Amino acid	1–21 days	22–42 days	43–56 days
Lysine[1]	100	100	100
Arginine	105	108	108
Histidine	35	35	35
Isoleucine	67	69	69
Leucine	109	109	109
Methionine + cysteine	72	72	72
Phenylalanine + tyrosine	105	105	105
Threonine	67	68.5	68.5
Tryptophan	16	17	17
Valine	77	80	80

[1] Recommended digestible lysine requirements for meat chickens of 1 to 21, 22 to 42 and 43 to 56 days are 1.070, 0.865 and 0.745 percent, respectively.

The principal role of feed ingredients is to provide the nutrients that the bird digests and utilizes for productive functions. Currently, considerable data are available on the ability of raw materials to supply these nutrients. However, a degree of variability is inherent to each raw material, and this places pressure on precise feed formulations. Data on variation (or matrices) are available for the main feed ingredients and are applied in feed formulation programmes to achieve better precision. A related development is the availability of *rapid tests*, such as near-infrared reflectance analysis, to predict gross nutrient composition and assess the variability in ingredient supplies on an ongoing basis.

It is recognized that not all the nutrients in ingredients are available for production purposes, and a portion of nutrients is excreted undigested or not utilized. As feed evaluation techniques develop, data have been accumulating on the availability of nutrients for poultry, especially of amino acids and phosphorus. For example, a recent development has been the wider use of *digestible amino acid* concentrations, rather than total amino acid concentrations, in feed formulations. The use of digestible amino acid content is particularly relevant in developing countries, where highly digestible conventional ingredients are not available and diet formulations may include ingredients of low digestibility. Formulating diets based on digestible amino acids makes it possible to increase the range of ingredients that can be used and the inclusion levels of alternative ingredients in poultry diets. This improves the precision of formulation, may lower feed costs, and ensures more predictable bird performance.

BETTER FEED FORMULATION

Once the nutritional needs are defined, the next step is to match these needs with combinations of ingredients and supplements. The object of formulation is to derive a balanced diet that provides appropriate quantities of biologically available nutrients. For commercial producers, a further object is to formulate a balanced diet at least cost. Given the range of possible feedstuffs and nutrients needed, a large number of arithmetical calculations are required to produce a least-cost diet. Over the years, feed formulation has evolved from a simple balancing of a few feedstuffs for a limited number of nutrients to a linear programming system that operates with the aid of computers. Systems using *stochastic non-linear programming* are now becoming popular, with commercially available formulation software. Variability in ingredient composition is non-linear, so stochastic programmes address this issue in the most cost-effective manner possible.

A related development is the use of *growth models* to simulate feed intake and production parameters under given husbandry conditions. Such models are effective tools for: i) comparing actual versus potential performance, which can indicate the extent of management or health problems in a flock; and ii) providing economic analysis of alternative feeding regimens. Several commercial growth models are available for predicting the production performance of both meat chickens and laying hens. However, because of the extreme complexity of biological responses, the models are only as good as the data used to establish them. There is a need for accurate and detailed information and data from a variety of production systems to enable the development of robust models that can provide accurate prediction of performance.

TABLE 2

Examples of biotechnological applications that are widely used in animal nutrition

Application	Aim(s) of the technology
1. New ingredients	To produce microbial proteins as new feed sources for animal feeding (e.g., single-cell protein, yeast protein)
2. Designer ingredients	To enhance nutrition (e.g., high-oil maize, high-methionine lupins) or reduce the level of anti-nutritive components in common feed ingredients (e.g., low-phytate maize)
3. Feed additives:	
a) Antimicrobials	To suppress the growth of harmful bacteria and promote the establishment of a desirable gut flora balance (e.g., antibiotics)
b) Crystalline amino acids	To increase the dietary supply of specific amino acids and improve the protein balance in diet formulations
c) Feed enzymes	To improve the availability of nutrients (energy, amino acids, phosphorus, etc.) in feed ingredients by reducing the negative effects of anti-nutritive components (e.g., microbial phytases acting on phytate, xylanases acting on arabinoxylans in wheat)
4. Gut ecosystem enhancers:	
a) Probiotics	To promote the establishment of a desirable gut ecosystem through the proliferation of beneficial species (e.g., direct-fed microbials)
b) Prebiotics	To exclude harmful organisms competitively, to promote the establishment of a desirable gut ecosystem (e.g., mannan oligosaccharides)

PRODUCTS OF BIOTECHNOLOGY IN POULTRY FEEDING

Progress in biotechnology during the past two decades has provided new opportunities for enhancing the productivity and efficiency of animals through improved nutrition. Biotechnologies have a vast range of applications in animal nutrition. Some of these are already in use (Table 2), while others are known to have potential but are not yet commercially applied because of technical limitations and public concerns (Table 3).

FEED PROCESSING

Today, after their ingredients have been mixed, most poultry feeds undergo some form of processing, which involves a wide range of thermal treatments including extrusion, expansion, conditioning and pelleting. Most of the feed used in the production of meat chickens is fed in pelleted or crumbled form, which enhances the economics of production by improving feed efficiency and growth performance. These improvements are attributed to decreased feed wastage, higher nutrient density, reduced selective feeding, decreased time and energy spent on eating, destruction of pathogenic organisms, and thermal modification of starch and protein. Introduction of pellet feeds is a notable feature in countries seeking to improve the production efficiency of the poultry sector.

PHASE FEEDING

The current recommendations for poultry list the nutrient requirements for only selected growth periods; the three periods of up to three weeks, three to six weeks, and six to eight weeks are con-

TABLE 3

Examples of biotechnological applications with future potential in animal nutrition

Application	Aim(s) of the technology
1. Modification of gut microbes	To modify genetically the microorganisms naturally present in the gut, to enhance their capacity for defined functions or to add new functions (e.g., rumen microbes to improve cellulose digestion)
2. Introduction of new gut microbes	To introduce new species or strains of micro-organisms into the gut
3. Bioactive peptides	Improved growth and efficiency (e.g., growth hormone-releasing peptides), improved gut function, immunomodulation, antibacterial properties
4. Antimicrobial replacers	Antimicrobial enzymes (e.g., lysozyme), to deliver specific antibodies via spray-dried plasma and egg products
5. Transgenesis	To modify nutrient metabolism and improve growth efficiency by transfer of genes

sidered for meat chickens. In practice, however, grow-out periods can range from four to ten weeks of age, depending on local market needs. Recognizing that changes in nutrient needs are more dynamic than these general recommendations, the commercial poultry industry is increasingly using phase-feeding systems to maximize performance and increase profit margins. Dietary protein and amino acid specifications are usually decreased in a progression of different feeds that satisfy changing requirements and economics. Typical feeding programmes over a five- to seven-week production cycle now include four to five feeds, such as pre-starter, starter, grower and finisher; or pre-starter, starter, grower, finisher and withdrawal. The withdrawal diets often fed during the last seven to ten days of growth involve removal of certain pharmaceutical additives and reduction of protein/amino acids. In recent years, they have also involved the reduction of certain vitamins and trace minerals, and energy.

WHOLE GRAIN FEEDING

Another recent development has been the feeding of whole grains (wheat or barley) along with a balanced concentrate feed. The benefits of whole grain feeding include better performance, reduced feed processing costs and improved flock health. These benefits appear to arise from a combination of two physiological actions: physical benefits of gizzard development and increased proventriculus secretions; and better matching of daily requirements through self-selection by the bird. The usual method of whole grain feeding is to blend 10 to 25 percent of the weight of the feed on top of the feed in delivery trucks or at the poultry house.

SUSTAINABLE POULTRY FEEDING

Not long ago, the main objective of formulating feeds was to supply nutrients (nutrient input). Today there is much public concern about what comes out of the bird (nutrient output). Animal agriculture, including the commercial poultry sector, is clearly releasing excess nutrients into the environment, and must assume responsibility for its impact on the environment, especially on water quality. Without question, the poultry industry must achieve the goal of sustainability, as environmental concerns have a major influence on its future growth and expansion. From a nutrition point of view, the most obvious strategy is to feed birds to match their requirements (precision feeding) and to improve the efficiency of birds' nutrient utilization, which will reduce the nutrient load in manure.

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Main ingredients used in poultry feed formulations

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Feed represents the major cost of poultry production, constituting up to 70 percent of the total. Of total feed cost, about 95 percent is used to meet energy and protein requirements, about 3 to 4 percent for major mineral, trace mineral and vitamin requirements, and 1 to 2 percent for various feed additives. Poultry diets are formulated from a mixture of ingredients, including cereal grains, cereal by-products, fats, plant protein sources, animal by-products, vitamin and mineral supplements, crystalline amino acids and feed additives. These are assembled on a least-cost basis, taking into consideration their nutrient contents as well as their unit prices. Table 1 shows common ingredients used in poultry feed formulations in most parts of the world.

MAIN INGREDIENTS: AVAILABILITY ISSUES

Energy sources constitute the largest component of poultry diets, followed by plant protein sources and animal protein sources. Globally, maize (corn) is the most commonly used energy source, and soybean meal is a common plant protein source. However, other grains such as wheat and sorghum, and plant protein meals such as canola meal, peas and sunflower meal are also widely used in some countries. The main animal protein ingredients are fishmeal and meat meal. Almost all developing countries are net importers of these ingredients; the poultry feed industries in Africa and Asia depend on imports, which are a drain on their foreign exchange reserves. Quite often, the semi-commercial and commercial sectors in these countries are forced to limit their output of compounded feeds.

TABLE 1
Common ingredients used in typical poultry feed formulations

1. Energy sources:
- cereals (mainly maize),[1] cereal by-products
- animal fats and vegetable oils
2. Plant protein sources:[2] soybean meal
3. Animal protein sources: fishmeal, meat and bone meal
4. Mineral supplements:
- calcium supplements: limestone, shell grit
- calcium and phosphorus supplements: dicalcium phosphate, defluorinated rock phosphate, bone meal
- trace minerals: trace mineral premixes
- sodium sources: salt, sodium bicarbonate
5. Miscellaneous:
- vitamin supplements: vitamin premixes
- crystalline amino acids: methionine, lysine, threonine
- non-nutritive feed additives: enzymes, antibiotics, etc.

[1] Wheat and sorghum are widely used in some parts of the world.
[2] Canola meal, peas and sunflower meal are also used in some parts of the world.

The diversion of grains, particularly maize, from the animal feed market to ethanol production is a major recent development that has caused severe grain supply problems in the world market, with dramatic price increases. With government policies to promote the use of biofuels, the global production of ethanol has rapidly increased in recent years, and further large increases are expected in the future. Despite record prices, the import demand for main ingredients in developing countries continues to increase to meet the feed demands of an expanding poultry sector, putting further pressure on prices. Paradoxically, the solution for the rocketing price of maize could come from the biofuel industry, through its major co-product – distillers' dried grains with solubles (DDGS) – which has been shown to be a good source of available amino acids and energy. Worldwide, feed millers are showing keen interest in DDGS because of its cost-effectiveness and ready availability. Good-quality DDGS is a potentially useful feed ingredient, containing about 25 percent protein and 10 percent fat, and rich mineral and vitamin resources. The amino acid availability in DDGS is similar to that in soybean meal. This may be the only raw material whose supply is assured and will increase in the future.

MAIN ENERGY SOURCE

The predominant feedgrain used in poultry feeds worldwide is maize. This is mainly because its energy source is starch, which is highly digestible for poultry. In addition, it is highly palatable, is a high-density source of readily available energy, and is free of anti-nutritional factors. The metabolizable energy value of maize is generally considered the standard with which other energy sources are compared.

In North America and Brazil, the feed industry has benefited from surplus maize, resulting from increased mechanization and the application of genetic and agronomic techniques to raise productivity. In the Asian and African regions, however, maize yield per hectare is low, and in most countries, production has never been sufficient to meet the needs of the growing human population. The net result is a continuing shortage of maize for feed use in these regions.

The other energy source that meets most of the same criteria as maize is low-tannin sorghum. Sorghum can be grown in low-rainfall areas and is a popular crop in hot, drought-prone regions. The high tannin content of many older sorghum varieties limits their use in poultry diets, but low-tannin varieties are now available and can be used in poultry diets without any limitation. The energy value of low-tannin sorghum is 90 to 95 percent that of maize.

MAIN PLANT PROTEIN SOURCE

After energy-yielding raw materials, protein supplements constitute the largest component of poultry diets. Plant protein sources supply the major portion of dietary protein (or nitrogen) requirements. The plant protein source traditionally used for feed manufacture is soybean meal, which is the preferred source for poultry feed.

Soybean meal contains 40 to 48 percent crude protein, depending on the amount of hulls removed and the oil extraction procedure. Relative to other oilseed meals, soybean protein has a good balance of essential amino acids, which can complement most cereal-based diets. The amino acid availability in soybean meal is higher than those for other oilseed meals. The metabolizable energy content is also substantially higher than in other oilseed meals.

Raw soybeans contain several anti-nutritional factors, including protease inhibitors, which can negatively affect protein digestion and bird performance. However, these inhibitors are destroyed by heat during the processing of soybean meal. Properly processed soybean meal is an excellent protein source for all classes of poultry, with no restrictions on its use.

Soybean production has increased substantially over the past two decades to meet the rising demands for oil for the human food market and meal for the animal feed market. The major producers of soybeans are the United States, Brazil and Argentina, which are also the major exporters. More than 50 percent of the current crop is now genetically modified (GM), mainly for herbicide tolerance, and there is an ongoing debate and campaign to reject GM ingredients from animal diets. If GM sources are not accepted in the market place, the potential for further nutritional quality enhancement and increased productivity will be limited.

MAIN ANIMAL PROTEIN SOURCES

With the notable exception of soybean meal, plant protein sources are generally nutritionally imbalanced in terms of essential amino acids, particularly lysine, the first limiting amino acid in cereals. Unless supplemented with animal protein sources and crystalline amino acids, plant-based diets may not meet the requirements for critical amino acids for egg and meat production. Owing to their high prices, animal protein ingredients are normally used to balance the amino acid contents of diets rather than as major sources of protein. In many countries, feed manufacturers ensure that animal protein ingredients do not fall below minimum levels in poultry diets, especially for young birds whose amino acid requirements are high. The requirements for essential amino acids are progressively reduced as the birds grow older, and it is possible to meet the needs of older birds with diets containing lower levels of animal protein and relatively higher levels of plant protein. Fishmeal and meat meal are the animal protein sources most widely used in poultry diets

FISHMEAL

Fishmeal is an exceptionally good source of high-quality protein, and its price usually reflects this. It also provides abundant amounts of minerals (calcium, phosphorus and trace minerals), B vitamins and essential fatty acids. The presence of unidentified growth factors is another feature of fishmeal. Feed formulations therefore seek to ensure minimum levels of fishmeal in diets.

Fishmeal consists essentially of dried, ground carcasses of fish. Good-quality fishmeal is brown, but the colour varies according to the type of fish used and the processing conditions. A very dark colour is indicative of overheating, which can destroy amino acids, reduce amino acid availability and substantially lower the protein quality.

Fishmeal is an important – sometimes the only – source of animal protein ingredients in most developing countries. It is either imported or locally produced. Local fishmeals typically contain between 40 and 50 percent crude protein, compared with more than 60 percent protein in imported fishmeals. Local fishmeals are generally of low quality owing to lack of control over raw fish quality, processing and storage conditions. They are often adulterated with cheap diluents, including poor-quality protein sources (dried poultry manure, oilseed meals), urea and non-nutritive diluents such as sand. Some fishmeals may be objectionable because of putrefaction, impurities or excessive salt content. Samples containing as much as 15 percent salt are not uncommon. This situation underlines the lack of quality control measures in most developing countries. As salt has laxative and growth depressing effects, the salt content of fishmeals should be carefully monitored; it should be less than 3 percent for best results, but legally may be up to 7 percent.

The correct quantity of fishmeal to include depends on the types of cereal and oilseed meals in the feed formulation. The cost of fishmeal is another important determinant. In general, average inclusion levels may be up to 8 percent for young birds, and less than 4 percent for older meat birds and layers. Higher levels must be avoided in finishing and laying diets, as they may lend a fishy taint to meat and eggs. Use of fishmeal can compensate, to an extent, where husbandry conditions are less than ideal.

Future expansion possibilities in fishmeal production are limited. Production does not seem to have increased over the past 20 years, and is unlikely to do so in the future, given the pressures on world fisheries. Fishmeal is included in the overall animal protein ban in Europe, and there is also an underlying concern about possible pollutant (e.g., dioxin) levels in fishmeal.

MEAT MEAL

Meat meal contains relatively high levels of protein, calcium and available phosphorus. Meat meal is the dry-rendered product from mammalian tissues, excluding hair, hooves, horns, hide trimmings, blood and stomach contents, except in such amounts as occur in good slaughterhouse practice. Meat meals are derived mainly from bones and associated tissues such as tendons, ligaments, some skeletal muscle, gastrointestinal tract, lungs and condemned livers. Variation in the proportions of these raw materials contributes to the large variations in meat meal quality. Depending on the proportion of bone to soft tissue used in the manufacture, the finished product is designated as meat meal (containing more than 55 percent crude protein and less than 4.4 percent phosphorus) or meat and bone meal (containing less than 55 percent crude protein and more than 4.4 percent phosphorus).

Collagen is the major protein in bone, connective tissue, cartilage and tendon, and contains no tryptophan. In poor-quality meat meals, 50 to 65 percent of total protein may be collagen. Increasing the level of bone in meat meal lowers the nutritive value, and the quality of its protein may vary greatly in terms of amino acid composition and digestibility. Protein quality is also affected by the temperature used to process the meat meal.

As a supplement to cereal-based diets, meat meal is of lower quality than fishmeal or soybean meal. Tryptophan is the first limiting amino acid in meat meal for poultry fed maize-based diets; lysine and methionine are also limiting. Normally, no more than 10 percent meat and bone meal is recommended for use in poultry diets, largely because phosphorus requirements are met at that level.

In recent years, feed manufacturers have to cope with increasing safety concerns, exemplified by the bovine spongiform encephalopathy (BSE) crisis, associated with the feeding of meat meal to ruminant animals. The use of meat meal in animal feed manufacture is now banned in some parts of the world, and the long-term future of this raw material seems uncertain.

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Feed supplements and additives

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The objective of feed formulation is to derive a balanced diet that will provide appropriate quantities of biologically available nutrients required by the bird. In addition to energy and protein, formulations contain supplements to provide minerals, vitamins and specific amino acids. These supplements must be added to all diets as they provide essential nutrients necessary for health and performance. Modern feed formulations also contain a diverse range of non-nutritive additives, which may not be essential but have an important bearing on performance and health. In many cases, the need for their inclusion is well understood: A major factor to be considered in selecting these additives is their efficacy. Feed supplements and additives are used in only small quantities, and it is particularly important that they are mixed carefully with the main ingredients so that they are evenly distributed.

NUTRITIONAL SUPPLEMENTS USED IN POULTRY FEED FORMULATIONS

Mineral supplements

Only part of birds' mineral requirements is provided by the natural feedstuffs in their diets. Mineral supplements must therefore be included in feed formulations.

Major minerals: Poultry require relatively large amounts of some minerals, such as calcium, phosphorus and sodium. Calcium and phosphorus are needed for normal growth and skeletal development, and poultry have unusually high requirements for calcium during the period of egg production, for the formation of strong egg shells. The calcium supplements commonly used in poultry feeding are limestone, crushed sea shells or sea-shell flour. Limestone powder can be included at no more than 3 percent, because higher levels will lower feed intake. It is therefore necessary to provide the extra calcium needed by high-producing layers as shell grit or limestone grit.

To meet the phosphorus needs of poultry, formulations must be supplemented with inorganic phosphorus sources. In diets containing fishmeal and meat and bone meal, supplementation with inorganic sources may not be necessary. The inorganic phosphates used in poultry diets are dicalcium phosphate, bone meal, rock phosphate, defluorinated phosphate and tricalcium phosphate, all of which supply both calcium and phosphorus. It is important that the inorganic phosphates are obtained from reliable sources, as contamination with fluorine can be a problem in some regions. Excess levels of fluorine in the phosphate source can adversely affect bird performance.

A recent development in phosphorus nutrition has been the availability of commercial phytase enzymes, which assist the bird's digestion and utilization of the phosphorus bound in phytic acid. This enzyme improves the availability of phosphorus from plant materials and reduces the need for inorganic phosphates in feed formulations. This enzyme is a non-nutritive additive.

Common salt is included in all diets as a source of sodium and an appetite stimulant. Salt is added in poultry diets at levels of 0.2 to 0.4 percent. Excessive salt increases water consumption and leads to wet excreta. The use of salt can be lowered or even omitted if more than 5 percent fishmeal is used in the diet.

Most formulations also contain 0.2 to 0.3 percent sodium bicarbonate (common baking soda); inclusion of this substance is particularly important in hot climates. When environmental temperatures are high, birds increase their respiration rate to increase the rate of evaporative cooling, thereby losing excessive amounts of carbon dioxide. This may be reflected in reduced growth rate and a decline in egg-shell quality, often seen in high-producing layers. Under these conditions, the replacement of part of the supplemental salt with sodium bicarbonate is recommended.

Trace minerals: These elements are required in the diet at concentrations in trace amounts, usually about 0.01 percent. Trace minerals (zinc, copper, iron, manganese, cobalt, selenium) are therefore usually added in the form of propriety premixes.

Vitamin supplements

All vitamins, except vitamin C, must be provided in the diet. Vitamins are required in only small amounts, and are usually provided in propriety vitamin premixes, which can be purchased from commercial suppliers. Although vitamin premixes represent only 0.05 percent of the diet, they can have a large effect on bird performance.

Crystalline amino acids

Pure forms of individual amino acids are now commercially available. Currently the limiting amino acids in poultry diets – methionine, lysine, threonine and tryptophan (in that order) – can be purchased at reasonable cost and included in poultry diets to balance dietary amino acid levels. Amino acid supplements now play a very important role in improving protein utilization in animal feeding.

TABLE 1

Non-nutritive feed additives commonly used in poultry feed formulations.

Additive	Examples	Reasons for use
Enzymes	Xylanases, ß-glucanases, phytase	To overcome the anti-nutritional effects of arabinoxylans (in wheat and triticale), ß-glucans (in barley) or phytate (in all plant feedstuffs); to improve the overall nutrient availability and feed value
Antibiotics[1]	Avilamycin,virginiamycin, zinc bacitracin, avoparcin, tylosin, spiramycin	To control gram-positive, harmful bacterial species in the gut; to improve production efficiency; as a prophylactic measure against necrotic enteritis
Coccidiostats	Monensin, salinomycin, narasin	To prevent and control the clinical symptoms of coccidiosis
Pigments	Xanthophyll (natural and synthetic)	To increase yolk colour in eggs and to improve the skin colour and appearance of carcasses
Antioxidants	Butylated hydroxy toluene (BHT), butylated hydroxy anisole (BHA), ethoxyquin	To prevent auto-oxidation of fats and oils in the diet
Antifungals		To control mould growth in feed; to bind and mitigate the negative effects of mycotoxins
Antibiotic replacers[2]		
i. Direct-fed microbials	Probiotics	To provide beneficial species such as *lactobacilli* and *streptococci*
ii. Prebiotics	Fructo oligosaccharides (FOS), mannan oligosaccharides (MOS)	To bind harmful bacteria
iii. Organic acids	Propionic acid, diformate	To lower gut pH and prevent the growth of harmful bacteria
iv. Botanicals	Herbs, spices, plant extracts, essential oils	To prevent the growth of harmful bacteria
v. Antimicrobial proteins/ peptides	Lysozyme, lactacin F, lactoferrin, α-lactalbumin	To prevent the growth of harmful bacteria

[1] The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin and tylosin phosphate as animal feed additives was banned in the European Union in 1998.

[2] Envisaging a total ban on in-feed antibiotic use, a multitude of compounds (individually and in combination) are currently being tested.

NON-NUTRITIVE ADDITIVES USED IN POULTRY FEED FORMULATIONS

Poultry formulations also contain an array of substances known as "feed additives". These are non-nutritive substances usually added in amounts of less than 0.05 percent to maintain health status, uniformity and production efficiency in intensive production systems. These additives have now become vital components of practical diets. Table 1 presents a list of commonly used feed additives.

Two recent developments relating to feed additives deserve special mention. First, there is increased interest in the use of feed enzymes to improve the utilization of nutrients in raw materials and to reduce feed cost. Improvements in nutrient availability are achieved by one or more of the following mechanisms: i) degradation of specific bonds in ingredients not usually degraded by endogenous digestive enzymes; ii) degradation of anti-nutritive factors that lower the availability of nutrients; iii) increased accessibility of nutrients to endogenous digestive enzymes; and iv) supplementation of the enzyme capacity of young animals. Enzymes widely used in the poultry industry are the carbohydrases that cleave the viscous fibre components in cereals (Table 1) and phytases that target the phytic acid-complexes in plant ingredients. More recently, technically successful enzyme preparations for use in maize-soybean diets have become available. Future advances in feed enzyme technology will involve the development of enzymes that can be used to target the anti-nutritive factors in non-traditional feedstuffs and improve their feeding value.

The second development is the recent ban on the use of in-feed antibiotics in animal feeds in some countries. In other countries, the number of in-feed antibiotics available for use in poultry diets has been restricted. Antibiotics have been used in poultry diets for many years as protection against pathogens and sub-clinical diseases, and for the resulting improved growth. The withdrawal of this preventive measure has serious implications for the productivity of birds, encouraging considerable research effort into finding potential alternatives for antibiotics, some of which are listed in Table 1.

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Alternative feedstuffs for use in poultry feed formulations

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Global consumption of poultry products, especially poultry meat, has consistently increased over the years, and this trend is expected to continue. Much of the increase in global demand for poultry products will be in developing countries. Such growth in the poultry industry is having a profound effect on the demand for feed and raw materials. However, it is also becoming clear that the requirements for the four traditional feed ingredients – maize, soybean meal, fishmeal and meat meal – cannot be met, even according to optimistic forecasts. The gap between local supply and demand for these traditional ingredients is expected to widen over the coming decades, providing a compelling reason for exploring the usefulness of locally available, alternative feedstuffs in feed formulations.

A wide range of alternative feedstuffs are available for feeding in all three poultry production systems. The greatest potential for efficiently utilizing these feedstuffs will be in traditional family poultry systems (scavenging and backyard) and the semi-commercial system. In the semi-commercial system, only part of the feed requirement is purchased from commercial compounders, so there is opportunity for on-farm mixing or dilution of purchased feeds with locally available, alternative feedstuffs. In low-input family poultry systems, locally available, alternative feedstuffs can be used to supplement the scavenging feed base.

NON-TRADITIONAL FEEDSTUFFS – THE ISSUES

Alternative feedstuffs are often referred as "non-traditional feedstuffs" because they have not traditionally been used in animal feeding or are not normally used in commercial animal diets. However, it is difficult to draw a clear distinction between traditional and non-traditional feeds. Feedstuffs that may be classified as non-traditional in some regions, may actually be traditional and based on many years of usage in others. Some feedstuffs may have started as non-traditional, but are now being used increasingly in commercial diets. A good example is palm kernel meal, which is a non-traditional feedstuff in Western Africa, but an increasingly normal feedstuff for feed millers in Southeast Asia, especially in pullet and layer diets.

It is widely recognized that in developing African and Asian countries, existing feed resources in many circumstances are either unutilized and wasted or used inefficiently. Most of these alternative feedstuffs have obvious potential, but their use has been negligible owing to constraints imposed by nutritional, technical and socio-economic factors (Table 1). Three major criteria determine the regular use of a feedstuff in commercial diets: i) it must be available in economic quantities, even if its availability is seasonal; ii) the price must be competitive against the main feedstuffs; and iii) its nutritive value must be understood, including its nutrient content, existing variation and nutrient digestibility. In many developing countries, in may be difficult to assess the nutritive value of any feedstuff, owing to the lack or scarcity of appropriate research or analytical facilities. This is a major factor discouraging commercial feed mills from considering the use of alternative ingredients.

There has been keen interest in evaluating alternative feed resources over the years, and a proliferation of published data, especially from developing countries. Lists of alternative feedstuffs that seem to have the greatest potential as substitutes for maize, soybean meal and animal proteins are presented in Tables 2, 3 and 4, respectively. These lists are by no means exhaustive; this information note does not aim to review all the available literature on each individual ingredient, but rather to identify the general issues limiting their use and maximum inclusion levels in commercial poultry diets.

FUTURE PROSPECTS FOR ALTERNATIVE FEEDSTUFFS

The immediate prospects for the use of alternative feedstuffs listed in Tables 2, 3 and 4 will be in semi-commercial poultry units that employ some degree of on-farm feed mixing, and family poultry units. In these sectors, where the objective is economic

TABLE 1

Factors limiting the use of alternative feed ingredients in poultry feed formulations

Nutritional aspects
- Variability (or lack of consistency) in nutrient quality
- Limited information on the availability of nutrients
- High fibre content
- Presence of anti-nutritional factor(s)
- Need for nutrient supplementation (added cost)
Technical aspects
- Seasonal and unreliable supply
- Bulkiness, physical characteristics
- Need for de-hulling and/or processing (drying, detoxification)
- Limited research and development facilities for determining nutrient composition and inclusion levels in poultry diets
Socio-economic aspects
- Competition with use as human food
- Poor prices relative to other arable crops (farmer)
- Cost per unit of energy or limiting amino acids, relative to traditional feedstuffs (feed manufacturer)
- Cost of processing

TABLE 2

Alternative energy sources that can replace maize in poultry diets

Feedstuff	Comments
Cereals	
Wheat	Can be used when cost-competitive Limitation: high non-starch polysaccharide contents result in intestinal digesta viscosity problems; can be used without restriction when exogenous carbohydrases are added
Sorghum	Limitation: tannins lower protein and energy digestibility; low-tannin sorghum can completely replace maize
Millets	Can replace 50–65% of maize, depending on millet type Limitations: high fibre contents, presence of tannins
Cereal milling co-products	
Rice bran/polishing	Limitations: high fibre, phytic acid, rancidity; good-quality material can be used at levels of 5–10% in broiler diets and up to 40% in layer diets
Wheat bran/pollard	Limitation: high fibre; can be used at levels less than 5% in broiler diets and up to 15% in layer diets
Roots and tubers	
Cassava root meal	High in starch, excellent energy source Limitations: low protein, powdery texture, needs detoxification to remove the cyanogenic glucosides; can be used at levels of 30–40% in nutritionally balanced, pelleted diets
Cassava peel meal	Limitations: high fibre, very high levels of cyanogenic glucosides, needs processing; carefully prepared meal may be used at 5% level
Sweet potato tuber meal	High in starch, good energy source Limitation: powdery texture; can be used at levels up to 50% in nutritionally balanced, pelleted diets
Taro	Limitations: poor palatability caused by calcium oxalate, needs processing; processed meal can be used at up to 10%
Fruits and fruit co-products	
Banana and plantain meal	Limitation: low palatability due to tannins in the peel; removal of peels improves nutritive value; inclusion must be limited to 10–20%
Breadfruit meal	Good energy source; can be included at up to 30%
Jack seed meal	Limitations: lectins in raw seeds, needs processing; processed meal can be included at up to 30%
Mango seed kernel meal	Limitation: high levels of tannins; processed meal can be used at levels of 5–10%
Date waste	Limitation: high sugar content; use must be restricted to 30% of the diet
Miscellaneous	
Sago meal	Limitation: powdery texture; can be included at up to 25%
Cane molasses	Limitations: high sugar content, wet litter problems; use must be limited to 15% of the diet
Animal fat	Tallow, lard and poultry fat; high-density energy sources that enable the use of low-energy feedstuffs in formulations; can be used at up to 5–8%
Distillers dried grains with solubles (DDGS)	High fat content (10%), good energy source; can be used at up to 25%

TABLE 3

Alternative protein sources that can replace soybean meal in poultry diets

Feedstuff	Comments
Oilseed meals[1]	
Cottonseed meal	Limitations: high fibre, presence of gossypol; low-gossypol meal can be used at levels of 10–15% in broiler diets; limit use in layer diets because of effects on internal quality of eggs
Canola meal	Limitation: glucosinolates; low-glucosinolate meals can be used at up to 30%
Groundnut meal	Limitations: tannins, aflatoxin; good-quality meal can be used at up to 15%
Sunflower meal	Limitation: high fibre Rich in methionine; can be used at up to 15%
Sesame meal	Limitation: high phytate content Good source of methionine; can be used at up to 15%
Palm kernel meal	Limitations: high fibre, poor texture, low palatability; good-quality meal can be used at levels of 5–10% in broiler diets and up to 30% in layer diets
Copra (coconut) meal	Limitations: low protein, mycotoxins; can be used at up to 20%
Rubber seed meal	Limitations: low protein, presence of cyanogenic glucosides, requires processing; can be used at up to 10%
Grain legumes[2]	
Lupins, field peas, chick peas, cowpeas, pigeon peas, faba beans, etc.	Limitations: presence of anti-nutrients, low in methionine; can be used at up to 20–30% when processed and supplemented with methionine; current cultivars contain low levels of anti-nutrients
Green meals	
Leaf meals, aquatic plant meals	Rich in minerals, moderate levels of protein Limitations: high fibre, high moisture content and requires drying; most green meals can be used at levels less than 5%; some, such as duckweed, can be included at higher levels
Distillery co-products	
DGGS	Good source of protein, amino acids and available energy Limitation: variable amino acid availability; good-quality meals can be used at up to 25%

[1] Compared with soybean meal, other oilseed meals have lower contents of available energy, protein and essential amino acids, and require supplementation with synthetic amino acids and energy sources. Suggested inclusion levels are for nutritionally balanced diets.

[2] A range of grain legumes are grown in developing countries. Only selected species are identified here. It must be noted that all raw legumes contain a number of anti-nutritive factors, but most of these can be eliminated by processing.

productivity rather than maximum biological productivity, alternative feedstuffs can make a useful contribution to poultry feeding.

Before the use of these feedstuffs can be considered in the modern commercial poultry sector, most – if not all – of the limitations identified in Tables 2, 3 and 4 must be resolved. A number of other possibilities are available for improving the feeding value and increasing the inclusion levels of many of these alternative feedstuffs: i) formulation of diets based on digestible amino acids, rather than total amino acids; ii) use of crystalline amino acids to balance amino acid specifications; and iii) supplementation with commercial exogenous enzymes to improve nutrient and energy

TABLE 4

Alternative animal protein sources for use in poultry diets

Feedstuff	Comments
Dried fish silage	A way of turning waste fish into quality animal protein supplement; can completely replace fishmeal Limitation: requires drying
Blood meal	High protein content Limitations: extremely deficient in isoleucine, poor palatability; can be included at no more than 5%
Hydrolysed feather meal	High protein content Limitations: deficient in several essential amino acids, low availability of amino acids; can be included at no more than 5%
Poultry by-product meal	Feeding value similar to that of meat meal; recommended inclusion level of 5%
Skimmed milk powder	Reject milk powder; good-quality protein; can be included at up to 5%
Novel sources: insects, fly larvae, earthworms, termites, bees, snails, etc.	Good protein sources; can replace 50% of fishmeal in formulations; useful supplements for family poultry Limitation: no commercial production and harvesting systems

availability. The effect of supplemental enzymes on alternative feedstuffs is twofold: first, they eliminate or reduce the action of anti-nutritive factors; and second, they increase digestibility and improve nutritive value

The greatest potential for using alternative feedstuffs is in the feeding of layers, irrespective of the production system. Owing to physiological differences, pullets and layers are more tolerant to high fibre, poor-quality feedstuffs and nutritional challenges than fast-growing meat birds are. Some of these feedstuffs can be included at high levels, but have negative effects on egg production. Rice bran and palm kernel meal are good examples of this tolerance; both can be used at maximum levels of only 10 percent in broiler diets, but may be safely incorporated into pullet and layer diets at levels of up to 30 percent.

SUPPLEMENTARY FEEDING STRATEGIES FOR FAMILY POULTRY

The scavenging area for family poultry is usually limited and often over-scavenged. The quantity and quality of the feed base for family poultry are also very variable, depending particularly on the season, but also on rainfall and agricultural activities. The supply of protein, minerals and vitamins is often high during the rainy season, owing to the abundance of insects and green materials, but becomes critical during the dry season. On the other hand, most of the materials available are deficient in energy throughout most of the year, because the feed base is generally high in fibre. Overall, feed consumed by family poultry can be considered deficient in all major nutrients – energy, protein, calcium and phosphorus. It is therefore recognized that scavenging alone will not provide enough feed to support the needs for growth or egg production, and that body weights and egg numbers can be markedly improved by the provision of supplementary feed. Small amounts of strategically administered supplements are likely to increase production and minimize mortality. Several of the alternative feedstuffs identified in this information note can play an important role as supplementary feeds.

Unlike the intensive poultry production system, the family poultry system lends itself well to the inclusion of locally available, alternative feedstuffs. Most of these feedstuffs are available only seasonally, in limited quantities and in specific locations, but can easily be accommodated within the family poultry system. Many of these materials are dusty in nature, and could be wasted if offered in dry form. To avoid wastage, these materials are therefore best offered as wet mash.

Energy supplements

The main feature of the traditional poultry system is that it does not directly compete with humans for the same food. However, where possible, it is advisable to offer small amounts of grains such as millets, maize and sorghum as energy supplements. Attention must therefore be paid to available cereal by-products. In most households and locations, several by-products from cereal milling are available for animal feeding, including bran, hulls and screenings. Despite their high fibre contents, these can be valuable sources of energy.

Small and damaged tubers and roots of cassava, sweet potatoes and yams, which are unfit for human consumption, are available in many areas and could be processed into a high-energy animal feed. The most practical method is to slice, sun-dry and pound or grind them into a meal. Cassava peels (which constitute 10 percent of the tuber weight) are not used for human consumption, and represent an economical feed for family poultry. However, they contain high levels of cyanide and must be processed to eliminate this toxic factor prior to feeding; simple sun-drying is adequate for this. Residues from the production of fermented cassava products can also be useful energy supplements.

A number of locally available fruit by-products can be used to provide energy. A good example is banana peels, which can be collected from local markets, sun-dried and milled into a meal. Proper drying is important to avoid spoilage and bacterial growth. A similar meal can be prepared from mango seed kernel, which has to be boiled prior to drying. On their own, both these meals have poor palatability and have to be offered in a mixture with other feedstuffs.

In areas where breweries or fruit processing operations are located, by-products may be collected and offered to poultry in wet form. These materials are good sources of supplemental energy.

Protein supplements

Green materials

Green materials are the cheapest sources of protein available to family poultry. A wide range of materials are available, including herbs, fodder leaves (e.g., leucaena, calliandra, sesbania), leaves from cultivated plants (e.g., cassava) and aquatic plants (e.g., azolla, water hyacinth, duckweed). These can be grown in small plots around the household. Where lagoons are available, the cultivation of aquatic plants should be promoted. The advantage of green materials is their high dry matter yields, which can be harvested and fed directly to poultry in fresh form. Not only are these materials good sources of protein, but they are also rich in pigments, vitamins and minerals.

Industrial by-products

By-products from local industries such as oil mills (palm kernel meal, sesame meal, coconut meal, rubber seed meal) and fibres (cotton, kapok) represent good sources of protein. Some of these materials are already used to supplement the feeding of family poultry.

Animal and fish by-products

In areas where there are fishing and meat processing operations, there is good potential for using offal for poultry feeding, in either fresh form or after processing. For example, the edible flesh of most types of fish represents only 40 percent of their total weight, leaving 60 percent for use as a protein feed resource. Scrap fish and fish wastes or residues (heads and offal) can be dried and processed into a meal, or be preserved as silage. The technique for making fish silage is simple, but the producer requires training.

Meals from insects

Insects can be used to produce cheaper proteins from non-food animals. Insects are part of the natural diet of poultry, and scavenging poultry consume a wide variety, including grasshoppers, crickets, termites, aphids, scale insects, beetles, caterpillars, pupa, flies, fleas, bees, wasps and ants. Insects are rich in protein, with reported protein contents ranging from 40 to 75 percent. These novel protein sources can be collected from surrounding areas. There is also opportunity for the production of insects using waste materials.

Insect larva: The biological digestion of animal wastes by the larval stage of flies (especially house and soldier flies), and the harvest and use of larvae and pupae is a cheap way of supplying high-protein materials to family poultry. Insect larva can be produced from kitchen and animal wastes. The materials are left to decompose in a protected area, where insects come and lay their eggs. Guidelines on the medium- to large-scale production of fly pupae using animal wastes describe how light is used to induce the migration of larvae out of the waste, through a screen and into a lower compartment, where they pupate and are harvested.

Termites: Termites are not only collected from nature, but can also be grown near the family unit and harvested. Termites have a unique ability to digest fibre, and the production of termites should be linked to the recycling of wood and paper wastes. A simple method of rearing termites on crop residues for family poultry supplementation is practised in some African countries. This involves the use of inverted clay pots containing termites and filled with moistened fibrous material. The pots must be protected against excessive heat and desiccation, and the termite larvae can be harvested after three to four weeks.

Meals from small animals

Earthworms: Earthworms are a natural food source for poultry kept under free-range systems and, live or dried, are highly palatable to poultry. Worm cultivation for fishing is common in many countries. Earthworms can also easily be produced and harvested for feeding family poultry, based on the biodegradation of animal manure. Techniques for the culture of earthworms (referred to as vermiculture) are well established and can be modified to suit small-scale production systems. Successful culture of earthworms requires: i) a food source; ii) adequate moisture (more than 50 percent water content); iii) adequate aeration; and iv) protection from excessive heat. A kilogram of earthworms consumes and digests 0.5 to 1.0 kg of waste a day. Because worms are top feeders, most of them will be found in the top 10 to 20 cm of the manure and can easily be harvested. Alternatively, the chickens can be let into the area to harvest the worms themselves. Under suitable growing conditions, up to 30 000 worms per square metre of surface area may be harvested.

Snails: The African giant snail is a major garden pest, which is particularly abundant during the wet season. The collection and use of snails as animal feed is therefore also of interest in the context of pest control. The bodies of snails contain hydrocyanic acid, presumably accumulated from the ingestion of cyanide-containing materials, but this toxic factor can be completely eliminated by cooking.

Mineral and vitamin supplements

Scavenging birds have far greater opportunity to balance their own micronutrient requirements. In the scavenging situation, minerals and vitamins are often provided from organic and non-organic materials pecked from the environment by the birds. Important sources of minerals and vitamins include snail shells, insects, fruits and fresh green materials.

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Animal feed safety

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POTENTIAL HAZARDS ASSOCIATED WITH FEED

Feed safety and its regulation are of major international concern. Animal feeds are routinely subject to contamination from diverse sources, which may have serious consequences on the safety of foods of animal origin. Public concerns over food safety have heightened in recent years, because of problems such as bovine spongiform encephalopathy (BSE), melamine and dioxin contaminations, outbreaks of food-borne bacterial infections, and potential microbial resistance to antibiotics. Given the direct links between feed safety and the safety of foods of animal origin, it is essential that feed production and manufacture procedures meet stringent safety requirements.

Some sources of feed contamination are high priorities in all production systems and countries: i) mycotoxins (or fungal toxins); ii) pathogenic biological agents; and iii) various chemicals. These agents may contaminate feed at any stage of production up to the point of feeding, and can result in hazards in food of animal origin. Biological agents and chemicals normally enter the feed supply under specific conditions. Mycotoxins are more widespread, however, particularly in developing countries, because of improper agricultural, storage and processing practices. Not only do mycotoxins represent a food safety issue, but they can also have serious consequences on poultry performance, and so are discussed in some detail in this information note.

DISEASE-CAUSING BIOLOGICAL AGENTS

Poultry feed may be the source of human illness resulting from the consumption of poultry products. The agent of major concern in poultry feeds is salmonella, which is associated with food poisoning in humans. The principal manifestation of human salmonellosis is gastroenteritis. Salmonella is widely distributed in nature, and animal feed is only one of many sources for farm animals. Feedstuffs of animal origin are particularly frequently contaminated with salmonella.

Salmonella contamination can be avoided by sourcing and using salmonella-negative feedstuffs in diet formulation. Heat treatments of varying severity are commonly used to ensure the microbiological quality of animal feed.

CHEMICAL CONTAMINATION

A wide range of chemicals can enter the feed production system, intentionally or unintentionally. Potential hazards include veterinary drugs, agricultural chemicals (e.g., pesticides, fungicides), industrial chemicals (e.g., dioxin), heavy metals (e.g., mercury, lead, cadmium) and adulterants (e.g., melamine). These chemicals can accumulate in animal tissues, or are excreted in milk or incorporated in eggs, and cause health problems in humans.

Some veterinary drugs, such as antibiotics and coccidiostats, are routinely included in poultry feeds as additives. In meat-producing birds, the problem of drug residues in meat are overcome by providing a withdrawal diet containing no drugs for seven to ten days prior to slaughter. However, the possible development of microbial resistance due to the use of antimicrobials in animal diets has become a major public concern in recent years. As a result, the use of in-feed antibiotics is either banned or restricted in the poultry industries of developed countries.

Most other chemical contaminants enter feeds through plant materials, especially cereals and treated seeds. The levels of chemicals in plant materials are closely related to the levels of soil contaminants where they are grown. Similarly, animal fats used in formulations may contain high levels of lipid-soluble contaminants if they are produced from feed grown in polluted areas

MYCOTOXINS

The term “mycotoxin” refers to all toxins produced by various types of fungus when they grow on agricultural products before or after harvest or during transportation or storage. The most commonly affected feedstuffs are cereals, oilseeds and oilseed meals. These toxins have the capacity not only to impair bird performance, but also to affect humans through toxin residues that can be deposited in animal tissues. Many mycotoxins with different chemical structures and biological activities have been identified. Table 1 presents a list of major mycotoxins of economic importance in poultry feeds.

When environmental conditions are conducive to fungal growth, mycotoxin contamination of grains may start in the field, and can also take place during processing and storage of har-

TABLE 1
Origins of major mycotoxins found in common feedstuffs

Mycotoxin	Fungal species
Aflatoxins	*Aspergillus flavus; A. parasiticus*
Ochratoxins	*A. ochraceus; Penicillium viridicatum; P. cyclopium*
Trichothecenes	
- Deoxynivalenol	*Fusarium culmorum; F. graminearum*
- T-2 toxin	*F. sporotrichioides; F. poae*
Zearalenone	*F. culmorum; F. graminearum; F.pPoae*
Fumonisins	*F. moniliforme*

vested products. The moisture content of the harvested product and the ambient temperature are principal determinants of fungal contamination and mycotoxin production. Some fungi, such as *Fusarium* spp., normally infest grains before harvest; others, such as *Penicillium* spp., invade after harvest, while *Aspergillus* spp. can grow both before and after harvest. However, the presence of fungi does not necessarily indicate contamination with mycotoxins.

Different mycotoxins affect animals in different ways. Some are cancer-causing toxins (e.g., aflatoxin B_1, ochratoxin A, fumonisin B_1) and some are oestrogenic (zearalenones). Some affect the nervous system (fumonisin B_1), while others affect the kidneys (ochratoxins) or suppress the immune system (aflatoxin B_1, ochratoxin A, and T-2 toxin). Depending on the degree of contamination, these effects will eventually have negative impacts on performance. It is often difficult to diagnose the effects of a mycotoxin because they are not necessarily unique to a given mycotoxin, but may be shared by others or magnified by interactions with others. Many fungal species are also capable of producing several mycotoxins. Recent evidence has highlighted the co-contamination of feed samples with multiple mycotoxins, which has serious consequences for both feed safety and animal performance. The hazards induced by the simultaneous presence of several mycotoxins are not clearly understood.

In addition, depending on the degree of contamination, mycotoxins or their metabolites can be deposited in meat, visceral organs and eggs. Their concentration in animal products is considerably lower than the levels present in the feed consumed by the animals, and will not cause acute toxicity in humans, but residues of carcinogenic mycotoxins, such as aflatoxins and ochratoxin A, can affect human health. In most cases, however, the principal source of mycotoxins for humans is contaminated cereals and legumes rather than animal products.

Alfatoxins

Aspergilli, the fungi producing aflatoxins, proliferate under conditions of relatively high humidity and temperature, and are generally regarded as storage fungi. Aflatoxin contamination is therefore almost exclusively confined to hot climates. Aflatoxin levels in certain types of feeds (cereals and oilseed meals) are a major problem in tropical countries, and require careful monitoring and appropriate treatment. All poultry species are susceptible to aflatoxin, especially young ducks.

Ochratoxins

Ochratoxins are produced by one *Aspergillus* species and two *Penicillium* species. Both are storage species, but *Aspergillus* thrives in hot, humid conditions, whereas *Penicillium* fungi are essentially temperate. Ochratoxins are therefore problems in both tropical and temperate regions. Ochratoxin A and B are two forms that occur naturally as contaminants, with A being more ubiquitous and occurring predominantly in cereal grains and the tissues of animals fed with contaminated feedstuffs.

Fusarium mycotoxins

Fusarium fungi are "field moulds", as arable conditions (high moisture) favour their survival and growth. *Fusarium* fungi are ubiquitous, and cereal grains and animal feed are contaminated with *Fusarium* mycotoxins all over the world. The majority of *Fusarium* fungi have the ability to produce toxins. Of particular importance are the trichothecenes, zearalenone (ZEN) and the fumonisins. The trichothecenes include T-2 toxin and deoxynivalenol (DON; also known as vomitoxin). In addition, a given species can produce several different toxins, and grain crops are often contaminated by several *Fusarium* species at the same time. Thus, several toxins may be present simultaneously in contaminated feeds.

METHODS OF CONTROLLING OR DECONTAMINATING MYCOTOXINS

Mycotoxins are regularly found in feed ingredients such as maize, sorghum, barley, wheat, rice meal, cottonseed meal, groundnuts and other legumes. In general, mycotoxins are relatively stable compounds that are not destroyed by processing of feed, and may even be concentrated by screening. Feeds contaminated with mycotoxins in excess of established levels should not be fed to animals producing eggs or meat for human consumption.

It is not easy to prevent mycotoxins in the environment. Prevention of the contamination of agricultural commodities by fungi and their mycotoxins can be divided into the following three levels.

Primary prevention

The best pre- or post-harvest strategy to use in a particular year depends on the climatic conditions of that year. Unfortunately, avoiding weather that favours fungal infection is beyond human control. Nonetheless, understanding the environmental factors that promote infection, growth and toxin production is the first step in minimizing mycotoxins in feeds. Several practices may help to maintain conditions that are unfavourable for fungal growth: i) development of fungal-resistant crop varieties; ii) control of on-field infection with fungicides; iii) scheduling of harvests in the period suitable for the region; and iv) lowering the moisture content of the feedstuff after harvest and during storage.

Secondary prevention

This level of prevention is required when the fungi are already in the feedstuff. The fungi should be eliminated or their growth stopped to prevent further deterioration and mycotoxin contamination. The following measures may be useful: i) protecting stored products from conditions that favour continuing fungal growth; ii) using mould inhibitors (such as organic acids) against fungal growth; iii) storing commodity at low temperatures, where economically possible; iv) stopping the growth of infested fungi by re-drying the products; and v) removing contaminated material.

Tertiary prevention

When the product is heavily infested by toxic fungi, primary and secondary prevention are no longer feasible. If the mycotoxin levels are known, it may be possible to dilute the contaminated material and produce a final blended feed that contains less than the critical level of the specific mycotoxin. Such blending of feeds to reduce mycotoxin concentrations is officially permitted, with restrictions in several countries.

A number of additives are available for use in practical diets to remove or detoxify mycotoxins and reduce their negative effects on animals. These additives fall into two categories: mycotoxin binders, which bind and adsorb the mycotoxins and prevent their absorption in the gut; and mycotoxin deactivators, which deactivate specific mycotoxins. The effects of some mycotoxins (aflatoxin, ochratoxin and fumonisin) can be effectively reduced by the inclusion of appropriate adsorbent-type binders, while others (trichothecenes and zearaleone) can be removed only by deactivation. Common mycotoxin binders include hydrated sodium calcium aluminosilicate, esterified yeast-wall polysaccharides, and clays such as zeolites and bentonites. Different sorbents have differing affinities for specific mycotoxins. However, there is a risk that non-specific adsorbing agents may prevent the uptake of micronutrients in the gut. Some effective mycotoxin deactivators that are now available act by enzymatic degradation or biotransformation of mycotoxins.

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