Indian Journal of Animal Sciences **91** (8): 616–622, August 2021/Review Article
https://doi.org/10.56093/ijans.v91i8.115917

Advances in poultry nutrition

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Received: 15 August 2021; Accepted: 24 August 2021

ABSTRACT

In the fast-developing poultry sectors of Asia, particularly in India, it is thought that the elevated levels of poultry feed will be required for fast development of the poultry sector, in particular, to meet the highest consumer demand for poultry products. The significant increase in feed demand will be associated with increased outputs of formulated compound feeds. Globally, few protein and energy ingredients are being used in the manufacture of poultry feed for landless and large-scale commercial operations, with a significant reliance on soybean and traditional cereal grains to achieve nutrient supply and balance. The feed versus fuel debate over cereal usage is continued, which will have impact on feed and livestock production levels, and also on feed-industry dynamics. New and refined technologies are now being used by using ethanol by-products with good amounts of nutritional characteristics—for example, dried distillers' grains with solubles (DDGS) in the future, parallel to the economic evaluation and justification of such products with respect to competitor feed ingredients. This review article discusses the importance and growth of the poultry sector along with nutritional research efforts in the 21st century.

Keywords: Advanced techniques, Poultry production, Nutrition

Poultry is a term used for any kind of domesticated bird, captive-raised for its utility, and traditionally the word has been used to refer to wildfowl (Galliformes) and waterfowl (Anseriformes) but not to cagebirds such as songbirds and parrots. Poultry can be defined as domestic fowls, including chickens, turkeys, guinea fowl, geese and ducks, raised for the production of meat or eggs and the word is also used for the flesh of these birds used as food (Crawford 1990). For proper growth and production, individuals including animals and poultry have to eat food to generate energy. Animals use this energy to perform their normal body functions such as breathing, walking, eating, digesting, and maintaining body temperature. Nutrients also provide the energy and different materials needed for proper development of bone, flesh, feathers, and eggs in poultry also. Each of these compounds is important in providing poultry the nutrients they need, and a deficit of even one can have serious health consequences for poultry.

Poultry nutrition is one of the most important criteria for a successful poultry production system with proper scale and sophistication. It requires a continuous enterprise cycle, which can be achieved by embracing the important elements of sustainability in terms of physical and financial status. Systems which are in use for poultry nutrition, will need complete focus on 'resource sufficiency' not scarcity, along with evaluation of alternative protein and other nutrient input sources, with reduced reliance on the traditional proteins like fishmeal and soybean in poultry diets. They contribute great supply of high-quality protein (meat and egg) for humans. The intensification and commercialization of the poultry sector is dependent on research discoveries in the field of breeding, nutrition, housing management and disease control. However, the explosion in poultry nutrition research, in particular, has significant impact on the success of the poultry sector. The progress in nutritional research is made possible by several advanced techniques used in both academia and industry.

Nutritional research is mainly geared towards improving knowledge on feed ingredients good for the growth and health of the bird catering the nutritional requirements for various types of birds, and also able to match the nutritional requirements of birds with various environmental and managemental conditions. Sustainable diets and feed systems, therefore, have a potential for maintaining profitability of feed systems while reducing their negative environmental and social impacts (Bocquier and González-García 2010). Everything that an animal or plant does to take in and use its food is what we term nutrition. For any animal to carry on its necessary life functions, as well as to grow and be able to produce food for humans, there are specific chemical compounds that must be in their diet in the right amounts. This is because no animal is capable of producing every necessary components on its own. The study of nutrition is about understanding that there is no 'perfect' food, or no one ingredient that contains in the exact concentrations every nutrient an animal needs. Providing

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the right nutrition for your chickens means ensuring that what they eat supplies all of the essential amino acids, fatty acids, carbohydrates, vitamins, minerals, and water that they will need to produce the meat or eggs (Fowler 2015). This review discusses the importance and growth of the poultry sector along with nutritional research efforts in the 21st Century.

Basic poultry nutrition

For proper growth, development and generation of energy, animal and poultry need certain basic ingredients or components that can have serious health consequences for poultry (Jacob 2018). These components are water, carbohydrates, fats, proteins, minerals and vitamins.

Water: Water is one of the most important nutrients, but often overlooked. It plays an important role in the body of an animal. An animal can live without food longer than it can live without water. A shortage of water for just a few hours can result in reduced egg production in a laying flock, so clean water should be provided to birds all the times. The water requirement is mainly dependent on age, functional status, environmental temperature and other factors (ICAR 2013).Water softens feed and carries it through the digestive tract. It is a component of blood (90% of blood content) which carries nutrients and waste products from the digestive tract to cells and vice versa. Water also helps in cooling through evaporation as birds do not have sweat glands, so the heat loss occurs in the air sacs and lungs through rapid respiration.

A baby chick is composed of about 80% water. Even though this percentage decreases as a bird gets older, the need for water always remains. There is no precise quantity requirement for water because there are several factors that affect the amount of water a bird needs, viz. age, body condition, diet, temperature, water quality, and humidity. As a rule of thumb, poultry consume twice as much water as feed.

Carbohydrates: Carbohydrates (compounds with carbon, hydrogen, and oxygen) are the main energy source for animals and they make the largest portion of a poultry diet. Carbohydrates are eaten in the form of starch, sugar, cellulose, and other non-starch compounds. Poultry do not digest cellulose and the non-starch compounds (crude fibre) properly. Important sources of carbohydrates in poultry feed ingredients include energy concentrates such as corn, oats, wheat, barley, sorghum, and milling by-products. The intake

Table 1. Nutrient requirement for layers

Nutrient	Laying pullets			Cockrels	
	0–8 wk	8–16 wk	16–18 wk	0–4 wk	4–10 wk
CP %	18.50	15.50	15.00	19.00	17.50
ME (Kcal/kg diet)	2600.00	2600.00	2700.00	2600.00	2600.00
Ly %	0.85	0.65	0.50	0.98	0.90
Meth %	0.32	0.29	0.27	0.35	0.33
Meth+Cysteine %	0.65	0.59	0.54	0.70	0.67
Threonine %	0.68	0.58	0.50	0.78	0.70
Linoleic acid %	1.00	0.8	0.80	1.00	0.80
Ca %	1.00	0.8	2.00	1.00	0.85
Av. P %	0.40	0.35	0.32	0.41	0.38
Na %	0.15	0.15	0.15	0.15	0.15
Cl %	0.15	0.12	0.12	0.15	0.15
Cu (mg/kg)	8.00	5.0	5.00	8.00	8.00
I (mg/kg)	0.35	0.35	0.35	0.35	0.35
Fe (mg/kg)	60.00	60.00	60.00	60.00	60.00
Mn (mg/kg)	50.00	40.00	40.00	50.00	45.00
Se (mg/kg)	0.15	0.10	0.10	0.15	0.15
Zn (mg/kg)	40.00	35.00	35.00	40.00	40.00
Vit. A (IU/kg)	3000.00	2500.00	3000.00	3000.00	2500.00
Vit. D_3 (IU/kg)	300.00	250.00	300.00	300.00	250.00
Vit. E (IU/kg)	10.00	10.00	10.00	10.00	10.00
Vit. K (mg/kg)	0.50	0.50	0.50	0.50	0.50
Thiamine (mg/kg)	1.00	1.00	1.00	1.00	1.00
Riboflavin (mg/kg)	3.60	1.80	1.80	3.60	3.00
Pyradoxin (mg/kg)	3.00	3.00	3.00	3.00	3.00
Vit. B_{12} (mg/kg)	0.009	0.003	0.003	0.009	0.005
Biotin (mg/kg)	0.15	0.10	0.10	0.15	0.15
Folic acid (mg/kg)	0.55	0.25	0.25	0.55	0.55
Niacin (mg/kg)	25.00	11.00	11.00	25.00	25.00
Pantothenic acid (mg/kg)	10.00	10.00	10.00	10.00	10.00
Choline (mg)	1300.00	900.00	500.00	1300.00	1300.00

Source: ICAR (2013).

Table 2. Nutrient requirement for Leghorn type layers and breeder males

Parameter	Laying pullets			Cockrels	
	18–30 wk	18–30 wk	>30 wk	>30 wk	>20 wk
Live weight (g)	1300.00	1400.00	1400.00	1500.00	
Egg mass (g)	42.50	45.00	45.00	50.00	
Shed temp. (°C)	25.00	25.00	25.00	25.00	
Feed intake (g)	90.00	100.00	100.00	100.00	
Nutrient					
CP %	20.00	18.00	16.50	15.00	16.50
ME (Kcal/kg Diet)	2700.00	2600.00	2600.00	2550.00	2600.00
Ly %	0.90	0.82	0.76	0.98	0.90
Meth %	0.40	0.36	0.34	0.32	0.34
Meth+Cysteine %	0.78	0.70	0.65	0.60	0.77
Threonine %	0.63	0.56	0.52	0.47	0.52
Arginine %	0.93	0.84	0.77	0.70	.077
Tryptophan %	0.21	0.19	0.18	0.16	0.18
Linoleic acid %	1.10	1.00	1.00	0.85	1.00
Ca %	3.80	3.61	3.60	3.40	1.00
Av. P %	0.36	0.28	0.32	0.30	0.32
Na %	0.17	0.15	0.15	0.14	0.15
I (mg/kg)	0.040	0.035	0.035	0.032	0.035
Fe (mg/kg)	55.00	50.00	50.00	45.00	50.00
Mn (mg/kg)	50.00	45.00	45.00	40.00	45.00
Se (mg/kg)	0.08	0.06	0.06	0.05	0.06
Zn (mg/kg)	50.00	45.00	45.00	40.00	45.00

Source: ICAR (2013).

of energy by a chicken (Tables 1, 2) is governed by energy content of the diet, productive state and.nutritional adequacy (ICAR 2013).

Fats: Fat provides nine calories of energy per gram, as compared to carbohydrates which provide only four. Common sources of supplemental fat in commercially produced poultry feeds may be animal fat, poultry fat, and yellow grease. The high cost of vegetable oils makes inclusion of these fats in poultry diets uneconomical. Poultry have a specific requirement for linoleic acid, an essential fatty acid, so it must be included in the diet.

Fats are composed of smaller compounds called fatty acids. Fatty acids are responsible for cell membrane integrity and hormone synthesis. Fat must be present in the diet for poultry to absorb the fat-soluble vitamins A, D, E, and K. In addition to its role in nutrition, fat is added to feed to reduce grain dust. Fat addition also improves the palatability of feed (that is, makes the feed more appetizing). Fats, incorporated in feed, have a tendency to become rancid, so antioxidants are added to poultry diets containing added fat. A common antioxidant listed on feed labels is ethoxyquin.

Proteins: Proteins are complex compounds made up of smaller units called amino acids formed after break down the protein into amino acids by digestion. The amino acids are converted into the specific proteins required by the animal. Proteins are used in the construction of body tissues such as muscles, nerves, cartilage, skin, feathers, beak, and so on. Egg white is also high in protein. Amino acids are typically divided into two categories, viz. essential and non-essential (Table 3). Essential amino acids are those that cannot be made in adequate amounts to meet the needs of the animal. The nonessential amino acids are those that the

Table 3. Requirement of amino acids

Non-essential amino acids	Essential amino acids		
	Critical and limiting	Critical	Limiting
Alanine	Lysine	Lysine	Lysine
Aspartic acid	Methionine	Methionine	Methionine
Glutamic acid	Methionine + Cystine	Methionine + Cystine	Threonine
Hydroxyproline	Tryptophan	Tryptophan	
Proline	Threonine	Threonine	
Glycine	Arginine	Arginine	
Serine	Isoleucine Leucine Valine Histidine Phenylalanine Phenylalanine + Tyrosine	Isoleucine	

The need of cystine can be met by cystine or methionine. The need of tyrosine can be met by tyrosine or phenylalanine. *Source:* http://www.ndvsu.org/images/StudyMaterials/Nutrition/Poultry-nutrition.pdf

body can generate in sufficient quantities as long as the appropriate starting material is available. There are 20 amino acids commonly found in feed ingredients. Of these, 12 are essential and must be supplied in the feed. Poultry diets typically contain a variety of feedstuffs because no single ingredient is able to supply all the necessary amino acids in the right levels. For poultry, methionine and lysine are the two most critical amino acids. Deficiencies of either of these will lead to a significant drop in productivity and the health of the flock. Commercial poultry diets must contain methionine and lysine supplements.

The main sources of protein in poultry diets are plant proteins such as soybean meal, canola meal, corn gluten meal, and so on. Animal proteins used include fishmeal meat and bone meal. Fishmeal can be used only in limited quantities (less than 5% of the total composition of the diet) or it will give poultry meat and eggs a fishy flavour.

Minerals: Minerals play a role in bone formation and also required for number of important functions like formation of blood cells, blood clotting, enzyme activation, energy metabolism and muscle function. Minerals are typically classified as macro- or microminerals. Poultry require higher levels of macrominerals and lower levels of microminerals in their diets. The microminerals (Table 4) include copper, iodine, iron, manganese, selenium, and zinc, which play essential role in the body's metabolism. Iodine is required to produce thyroid hormones that regulate energy metabolism. Similarly, zinc is necessary in many enzyme-based reactions in the body, and iron required for blood formation and oxygen transportation within the body.

The macrominerals include calcium, phosphorus, chlorine, magnesium, potassium, and sodium. Calcium plays an important role in blood clotting, bone formation, muscle contraction and eggshell quality (Tables 5, 6). Phosphorus is important for bone development, a part of cell membranes and is used for many metabolic functions. Chlorine required for the formation of hydrochloric acid in the stomach and thus plays a role in digestion. Sodium and potassium are electrolytes important for metabolic, muscle, and nerve functions. Magnesium also assists with metabolic and muscle functions. Grains are low in minerals, so mineral supplements are added to commercial poultry feeds. Limestone or oyster shell is common source of calcium. Dicalcium phosphate is a common source of phosphorus and calcium. The microminerals are supplied in a mineral premix.

Table 4. Nutrient requirement for broilers

Nutrient	Pre starter (0–3 W)	Starter (3–6 W)	Finisher (6–8 W)
CP %	23.00	20.00	18.00
ME (Kcal/kg diet)	3200.00	3200.00	3200.00
Ly %	1.10	1.00	1.85
Meth %	0.50	0.38	0.32
Ca %	1.00	0.90	0.80
NPP %	0.45	0.35	0.30
Cu (mg/kg)	8.00	8.00	8.00
I (mg/kg)	0.35	0.35	0.35
Fe (mg/kg)	80.00	80.00	80.00
Mn (mg/kg)	60.00	60.00	60.00
Zn (mg/kg)	40.00	40.00	40.00
Se (mg/kg)	0.15	0.15	0.15
Vit. A (IU/Kg)	5000.00	5000.00	5000.00
Vit. D_3 (IU/kg)	2400.00	2400.00	2400.00

Source: NRC (1994).

Table 5. Nutrient requirement for broilers

Nutrient	Pre starter (0–14 d)	Starter (14–21 d)	Finisher (21–42 d)
CP %	22.00	21.50	19.50
ME (Kcal/kg diet)	3000.00	3050.00	3100.00
Ly %	1.20	1.07	0.94
Meth %	0.52	0.48	0.41
Ca %	1.00	0.95	0.85
Av. P %	0.45	0.40	0.38

Source: ICAR (2013).

Table 6. Nutrient requirement for broilers

Nutrient	Pre starter (0–7 d)	Starter (8–21 d)	Finisher (21 d to market)
CP %	23.00	22.00	20.00
ME (Kcal/kg diet)	3000.00	3100.00	3200.00
Ly %	1.30	1.20	1.00
Meth %	0.50	0.50	0.45
Ca %	1.00	1.00	1.00
Average P %	0.45	0.45	0.45

Source: BIS (2007).

Several factors influence the requirements of minerals viz. breed of the chicken, age of the chicken, animal adaptation, level of production, chemical form and interrelation with other elements.

Vitamins: Vitamins are organic compounds, required in small quantities by poultry. Vitamins are essential for normal body functions, growth, and reproduction (Table 4). A deficiency of these vitamins can lead to a number of diseases or syndromes. Vitamins are divided into two categories, viz. fat-soluble and water-soluble. The fat-soluble vitamins are A, D, E, and K. Vitamin A is required for normal growth and development of epithelial tissue (skin and the linings of the digestive, reproductive, and respiratory tracts) and reproduction. Vitamin D_3 is required for normal growth, bone development, and eggshell formation. Vitamin K is essential for blood clotting.

The water-soluble vitamins include vitamin C and the B vitamins. The B vitamins include vitamin B_{12}, biotin, folacin, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin. The B vitamins are involved in metabolic functions. Poultry can synthesize vitamin C, so there is no dietary requirement established for this vitamin. Vitamin C supplementation, however, has been shown to be useful when birds are stressed.

Some vitamins are produced by microorganisms in the digestive tract. Vitamin D can be produced when sunlight hits the bird's skin. Other vitamins must be supplied because they are not synthesized by the birds. Many essential vitamins are partially supplied by feed ingredients. Vitamin pre-mix, vitamin-rich plant sources such as alfalfa and other plants leaves, hulls, and brans also provide vitamins. Fish oil may provide vitamins A and D. Yeast provides some of the B vitamins. Sunlight is a good source of vitamin D for ranging chickens. Sprouting grains, are also a very good source of vitamins like vitamin A precursor and certain digestive enzymes such as phytase, β glucanase, etc. Sprouting can be a source of year-round forage, and beneficial for poultry production because it reduces the amount of synthetic vitamins required in their diet. Eating plants may provide a yellow colour to the skin of slaughtered chickens and a deeper yellow colour to egg yolks (Fanatico 2003).

Advanced poultry nutrition

Number of feed additives are now being used for improvement in the production performance of poultry in terms of body weight for meat, and egg production in terms of egg weight, egg quality and number of eggs. The feed additives are discussed below.

Antibiotics: Antibiotics which are commonly used as feed additives are mycin and cycline drugs such as Aureomycin (chlortetracycline), Terramycin (oxytetracycline), Gallimycin (erythromycin), and Duravet. Injectable drugs include Tylan (tylosin) and others. Most oral antibiotics should be used as the only product in the water as growth promoters.

Prebiotics and probiotics: Prebiotics are the products which are non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and activity of one or a limited number of bacteria in the colon (Gibson and Roberfroid 1995). The most common prebiotics are oligosaccharides, which are non-digestible carbohydrates.

Prebiotics can be included together with probiotics or alone in order to promote beneficial bacteria survivability (Dunislawska *et al.* 2017). They also help to strengthen your immune system (Al-Khalaifah 2018).

Poultry probiotics are defined as live microorganisms causing no pathological disorders and promoting enteric microbiota balance (Ohimain and Ofongo 2012), optimizing function of enteric epithelia and mucosal immunity, which is an important first line of defense against the intrusion of enteric pathogens (Fagarasan 2006). Commercial rations often contain antibiotics and arsenicals to promote health and improve growth, coccidiostats for combating coccidiosis, and sometimes mold inhibitors (Krysiak 2021). There are mainly two major categories of probiotics namely, Sporulated *Bacillus* spp. and Lactic acid producing bacteria.

Synbiotics: They are the compounds, composed of both probiotics and prebiotics which work synergistically, for the benefit of poultry to enhance their biological activity (Dunislawska *et al.* 2017). Synbiotics can be a useful scientific development to diminish the impact of common gastric issues that impair birds' performance. Synbiotics promote microbiota balance between pathogenic and beneficial bacteria (Ohimain and Ofongo 2013) reinforcing gut integrity (Ritzi *et al.* 2014) by enhancing mucus production, sustaining gut epithelial protection as this is the first physical barrier found by pathogens (Kogut 2013, Dal Pont *et al.* 2020).

Sprouting: Sprouting grains can increase the amounts of carotene (vitamin A precursor) in the grain and as a source of year-round forage, could be an advantage for certified organic poultry production to reduce the amount of synthetic vitamins required in the diet. Eating sprouts may provide a yellow colour to the skin of slaughtered chickens and a deeper yellow colour to egg yolks. Through sprouting, many number of enzymes like phytase, beta glucanase, etc. may be released from the grain allowing 40% to 80% of the grain to become digestible to poultry. The nutrients within sprouted grains also become more bio-available. That means that a significant amount of protein, minerals, omega-3s, amino acids, and vitamins are found in sprout grains (Mandal *et al.* 2013, Karoriya *et al.* 2020a and b).

Antioxidants: These are the compounds which prevent body from the ill effects of free radicals and stabilize free radicals. They are present naturally in canola, corn, oat and wheat germ oils. Zinc and some vitamins work as antioxidants. The protective effects of three polyphenolics like resveratrol, curcumin (a yellow polyphenol extracted from the zingiber plant), and epigallocatechin gallate (EGCG), the primary component of green tea extract (Surai *et al.* 2020). Though they don't have direct antioxidants effect in biological systems but rather indirectly affect antioxidant defense mechanisms in poultry, human and farm animals.

Organic acids: Organic acids are organic compounds that contain a carboxyl group (-COOH), which dissociates in solution releasing a proton, thus giving the compound acidic properties (Voet and Voet 1995). The acidifiers may be used to favorably manipulate the intestinal microbial populations and improve the immune response, hence perform an activity similar to antibiotics in food animals in countering pathogenic bacteria (Table 7). Acidifiers also improve the digestibility of nutrients and increase the absorption of minerals (Jadhao 2019). Acidification with various weak organic acids to diets such as formic, fumaric, propionic, lactic and sorbic acid have been reported to decrease colonization of pathogen and production of toxic metabolites, improve digestibility of protein, Ca, P, Mg and Zn, and serve as substrates in the intermediary metabolism. Organic acids, such as lactic, acetic, tannic, fumaric, propionic, caprylic acids, etc. have been shown to exhibit beneficial effects on the intestinal health and performance of birds (Hazati 2018).

Phytobiotics: Due to the hazardous use of antimicrobials in poultry production sector, development of drug resistance have become a worldwide problem. Therefore, using biotic

Table 7. Concentration and effects of supplementing organic acid in poultry nutrition

Acid	Conc.	Effect
Fumaric acid	0.5–1.0	Improvement in weight gain on broilers. Improved feed efficiency in both broilers and layers
Bufferred propionic acid	0.15–0.20	Increase in dressing percentage and reduction in abdominal fat
Malic acid	05–2.0	Increase in weight gain
Sorbic acid	1.12	Improved feed efficiency
Tarteric acid	0.33	Increase in weight gain
Lactic acid	2.0	Increase in body weight gain, feed to gain ratio improved
Formic acid	0.5–1.0	Bactericidal effect
Benzoic acid	0.2	Increment in growth
Butyric acid	0.15	Maintain beneficial micro flora

or natural products, such as phytobiotics (phytogenics or botanicals) have received a great attention as antibiotic substitutes (El-Ghany 2020). These are the natural bioactive compounds derived from the plants such as herbs and spices, and can be added to poultry feed for the improvement of the performance and well-being of the animals and birds (Gheisar and Kim 2018). The active ingredients are carotenoids which acts as antioxidants, phytosterols decreases cholesterol, iso-flavanoids present in soyabean are anti-treating in nature, toco-trienols and toco-triphenols, fibres are used against colorectal diseases.

Nutraceuticals: These may be defined as substances, which have physiological benefit or provide protection against chronic, infectious and non-infectious diseases. Nutraceuticals may be used to improve health, delay the aging process, prevent chronic diseases, increase life expectancy, or support the structure or function of the body. A variety of nutraceuticals are used as isolated nutrients (vitamin, mineral, amino acids, fatty acids, etc.), herbal products (polyphenols, herbs, spices, etc.), and dietary supplements (probiotics, prebiotics, synbiotic, organic acids, antioxidants, enzyme, etc.) to genetically modified foods (Alagawany *et al.* 2021). Nutraceuticals antioxidants such as curcumin, cutein, lycopene, turmeric and β-carotene exert positive effects on specific diseases by combating oxidative stress. They have the potential to modulate the gut microbial populations and immune systems of the host (Sugiharto 2016). Nutraceuticals may also be used for prevention and/or treatment of enteric infections in the chicken.

The poultry nutrition is very important along with the addition of feed additives for the proper production and growth. If the growth is faster, the poultry rearing by the poultry farmer is profitable.

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