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## Recent trends in poultry nutrition: A review

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**Abstract**

The poultry industry is one of the fastest-growing sectors of livestock production, driven by the increasing global demand for affordable and high-quality protein sources. This rapid expansion necessitates the adoption of efficient, sustainable, and economically viable nutritional strategies. The present review highlights recent trends and advancements in poultry nutrition aimed at improving feed efficiency, enhancing nutrient utilization, and promoting overall bird health while minimizing environmental impact. Key developments discussed include biotechnological interventions, precision feeding approaches such as phase and split feeding, and the application of nanotechnology and organic trace minerals to improve nutrient bioavailability. The review also emphasizes the importance of amino acid-based feed formulation in reducing crude protein levels and nitrogen excretion. Furthermore, alternative strategies for antibiotic-free production, including probiotics, prebiotics, enzymes, organic acids, and phytochemical additives, are examined for their roles in maintaining gut health and productivity. Emerging innovations such as *in ovo*-nutrition are also explored for their potential to enhance embryonic development and post-hatch performance. Collectively, these advancements represent a shift toward precision, sustainability, and innovation in poultry nutrition, offering promising solutions to meet the growing demands of the global poultry industry.

**Keywords:** Feed efficiency, gut health, nanotechnology, antibiotic-free nutrition

**1. Introduction**

The poultry sector plays a crucial role in ensuring food security and nutritional availability worldwide. According to the 20th Livestock Census (2019) [1], India's poultry population reached approximately 851.81 million, reflecting rapid growth in the sector. The industry has shown consistent expansion, with annual growth rates of approximately 8.51% in egg production and 7.52% in broiler production (Belim *et al.*, 2021) [2]. Furthermore, per capita egg consumption in India has increased significantly from 30 to 68 eggs per annum, alongside a 15-20% annual rise in demand for processed poultry meat. Globally, India ranks third in egg production and eighth in broiler meat production (FAOSTAT, 2020) [3]. This rapid expansion necessitates advancements in nutritional strategies to improve productivity, feed efficiency, and sustainability.

Poultry production has emerged as one of the fastest-growing sectors of animal agriculture, driven by increasing global demand for affordable and high-quality protein sources (Ravindran, 2013) [4]. Within this sector, nutrition plays a pivotal role in determining productivity, efficiency, and overall flock health. Traditionally, poultry feeding strategies focused on meeting basic nutrient requirements; however, modern production systems demand more precise, efficient, and sustainable approaches. As a result, advancements in nutritional science and technology have significantly transformed the way poultry diets are formulated and utilized (Asmare, 2014) [5].

In recent years, innovations in biotechnology, feed formulation techniques, and health management strategies have revolutionized poultry nutrition. These developments aim not only to enhance growth performance and feed efficiency but also to reduce production costs and minimize environmental impact (Harn *et al.*, 2020) [6]. The shift toward antibiotic-free production systems has further accelerated the adoption of alternative feed additives and gut health-promoting strategies (Das *et al.*, 2012) [7]. Emerging concepts such as precision feeding, nanotechnology, organic trace mineral supplementation, and amino acid-based diet formulation are reshaping conventional feeding practices. Additionally, novel approaches like *in ovo* nutrition and the use of bioactive compounds are opening new avenues for

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improving early development and long-term productivity in poultry (Mijena and Getiso, 2024) <sup>[8, 11]</sup>. Collectively, these advancements reflect a transition toward more sustainable, efficient, and science-driven poultry production systems. This article explores the key innovations and strategies in modern poultry nutrition, highlighting their roles in improving feed utilization, supporting animal health, and addressing environmental concerns while meeting the growing global demand for poultry products (Cowieson *et al.*, 2010) <sup>[9]</sup>.

## 2. Biotechnological Interventions in Poultry Nutrition

Biotechnology has profoundly transformed poultry nutrition by enhancing feed quality and improving nutrient availability, with the overarching goal of increasing feed efficiency while minimizing nutrient losses and environmental pollution (Asmare, 2014) <sup>[5]</sup>. These advancements have enabled the development of more sustainable and nutritionally optimized feeding strategies. One of the key contributions of biotechnology is the production of novel feed ingredients, including single-cell proteins and yeast-derived proteins, which serve as viable alternative protein sources to conventional feedstuffs (Ravindran, 2013) <sup>[4]</sup>. In addition, the development of designer feed ingredients—such as high-oil maize, low-phytate maize, and high-methionine lupin—has significantly improved nutrient density and digestibility, thereby enhancing overall feed utilization efficiency.

Biotechnological innovations have also facilitated the incorporation of advanced feed additives, including crystalline amino acids, probiotics, prebiotics, and exogenous enzymes. These additives play a critical role in improving digestive efficiency and nutrient absorption, leading to enhanced growth performance and productivity (Das *et al.*, 2012; Cowieson *et al.*, 2010) <sup>[7, 9]</sup>. For example, enzymes such as phytase are widely used to hydrolyze phytate-bound phosphorus, thereby increasing phosphorus availability, reducing its excretion, and mitigating environmental contamination.

Furthermore, emerging areas in biotechnology include the application of bioactive peptides and growth hormone-releasing peptides, which have shown potential in improving metabolic efficiency and physiological performance. Advances in transgenic technologies also offer promising prospects by enabling targeted modifications in nutrient metabolism at the genetic level, which may contribute to improved growth rates and feed conversion efficiency (Harn *et al.*, 2020) <sup>[6]</sup>.

## 3. Precision Feeding Strategies

Precision feeding strategies have gained considerable attention in modern poultry production as a means of optimizing nutrient utilization, improving production efficiency, and reducing environmental impact. These strategies are designed to align nutrient supply more closely with the bird's physiological requirements at different stages of growth and production, thereby minimizing nutrient wastage and enhancing economic returns.

### 3.1 Phase Feeding

Phase feeding is a systematic nutritional approach that involves adjusting the dietary composition in accordance with the bird's age, physiological status, and production stage. In commercial layer operations, feeding programs are

commonly divided into distinct phases, such as 21-45 weeks (peak production phase) and 46-72 weeks (late production phase), to reflect changes in nutrient requirements over time (Kuney DR, *et al.*, 1980) <sup>[10]</sup>. During the early or peak production phase, hens exhibit high metabolic activity due to rapid growth, increased egg production, and elevated nutrient demands. Consequently, diets during this stage are formulated with higher levels of protein, essential amino acids, energy, and minerals to support optimal performance. As birds progress into the later stages of production, their growth rate stabilizes and egg production gradually declines, leading to reduced requirements for protein and certain amino acids. Therefore, diet formulations must be adjusted accordingly to prevent oversupply of nutrients. This targeted adjustment of nutrient intake offers several advantages, including reduced feed costs, improved feed efficiency, and decreased nitrogen excretion into the environment. Excess dietary protein, if not utilized, is excreted as nitrogenous waste, contributing to environmental pollution. By aligning nutrient supply with actual requirements, phase feeding enhances both economic and environmental sustainability (Mijena and Getiso, 2024; Ravindran, 2013) <sup>[8, 11, 4]</sup>.

Among essential amino acids, methionine is of particular importance in layer nutrition, as it plays a critical role in determining egg size and overall production performance. Adequate methionine supplementation is therefore essential, especially during peak production, to maintain egg quality and optimize output. Overall, phase feeding represents a practical and effective strategy for improving nutrient efficiency and sustainability in poultry systems. Meremikwu and Obikaonu (2020) <sup>[12]</sup>

### 3.2 Split Feeding

Split feeding is another advanced precision feeding technique that involves offering different diets to birds at specific times of the day, typically in the morning and afternoon. This approach is based on the understanding that nutrient requirements fluctuate throughout the day, particularly in laying hens, due to the physiological processes associated with egg formation. In the morning, birds primarily require nutrients such as protein and energy to support metabolic activities and albumen synthesis. In contrast, during the afternoon and evening, calcium demand increases significantly due to eggshell formation. Split feeding addresses these temporal variations by providing diets with differing nutrient compositions at appropriate times, thereby ensuring more efficient nutrient utilization.

Research has demonstrated that split feeding can significantly improve feed conversion ratio (FCR), reduce overall feed intake, and enhance egg production, egg mass, and shell quality. Additionally, by improving the synchronization between nutrient supply and physiological demand, this strategy minimizes nutrient wastage and enhances economic efficiency. Furthermore, split feeding contributes to environmental sustainability by reducing excess nutrient excretion, particularly nitrogen and minerals, which are major contributors to environmental pollution. As a result, it is increasingly being recognized as a promising approach for sustainable poultry production systems.

Overall, precision feeding strategies such as phase feeding and split feeding play a crucial role in modern poultry nutrition by improving production efficiency, reducing feed costs, and supporting environmentally sustainable practices

#### 4. Nano-Technology in Poultry Nutrition

Nanotechnology has introduced a new dimension to poultry nutrition through the use of nano-sized minerals and particles (1-100 nm). These nano-minerals exhibit higher surface area and bioavailability compared to conventional mineral sources. Nanotechnology has shown considerable potential in poultry nutrition, particularly through the application of nano-minerals to enhance productivity and health outcomes. For instance, supplementation with zinc oxide nanoparticles in broiler diets has been reported to improve antioxidant capacity and promote growth performance (Zhao *et al.*, 2014) <sup>[13]</sup>. Similarly, the inclusion of nano zinc in layer diets has been associated with improvements in average body weight and feed conversion ratio (FCR), indicating enhanced feed efficiency (Mishra *et al.*, 2014) <sup>[14]</sup>. In laying hens, the use of nano calcium carbonate has demonstrated beneficial effects on eggshell quality, notably by increasing shell strength, while also promoting water intake to help birds better cope with heat stress (Wang *et al.*, 2017) <sup>[15]</sup>. Furthermore, zinc oxide nanoparticles have been shown to improve egg quality parameters, bone characteristics, and antioxidant status in laying hens, highlighting their multifaceted role in enhancing both productivity and physiological health (Abedini *et al.*, 2018) <sup>[16]</sup>. Overall, these findings suggest that nano-minerals can serve as effective nutritional interventions in poultry diets by improving performance, product quality, and stress resilience.

#### 5. Organic Trace Minerals

Organic trace minerals are formed by binding inorganic minerals with amino acids or peptides, resulting in higher bioavailability. Compared to inorganic sources, organic minerals are absorbed more efficiently, reducing the need for higher inclusion levels. Supplementation with organic minerals such as chromium has been shown to improve growth performance in broilers. For instance, birds receiving organic chromium (0.5 ppm) exhibited higher body weight gain compared to those receiving inorganic sources (Mohammed *et al.*, 2014) <sup>[17]</sup>. Moreover, the reduced excretion of minerals minimizes environmental contamination, making organic minerals an eco-friendly alternative (Bao *et al.*, 2007; Bao and Choct, 2009) <sup>[18, 19]</sup>.

#### 6. Amino Acid-Based Feed Formulation

Traditional poultry diets rely heavily on crude protein levels, which can lead to excessive nitrogen excretion and environmental pollution. Modern approaches focus on digestible amino acid-based formulations, allowing precise nutrient supply. Supplementation with synthetic amino acids enables reduction in crude protein levels by approximately 2.2-2.3% without compromising growth performance (Harn *et al.*, 2020) <sup>[6]</sup>. This not only lowers feed costs but also reduces nitrogen excretion, improving environmental sustainability. Formulating diets based on digestible amino acids enhances precision, ensures predictable performance, and optimizes nutrient utilization (Ravindran, 2013) <sup>[4]</sup>.

#### 7. Antibiotic-Free Nutrition and Gut Health

The global shift away from antibiotic growth promoters has led to increased emphasis on alternative strategies for maintaining gut health and productivity.

#### 7.1 Probiotics and Prebiotics

Probiotics are beneficial microorganisms that improve gut microbial balance, enhance immune response, and inhibit pathogenic bacteria. They can be defined as single or mixed cultures of live microorganisms which, when administered in adequate amounts, confer health benefits to the host. These benefits are primarily achieved through the improvement of intestinal microbial balance, enhancement of colonization resistance against pathogenic organisms, and stimulation of the host immune response (Das *et al.*, 2012) <sup>[7]</sup>. A wide range of microorganisms are utilized in probiotic formulations, with lactic acid bacteria (LAB) being the most commonly employed. These include species such as *Lactobacillus bulgaricus*, *Lactobacillus acidophilus*, *Lactobacillus casei*, *Lactobacillus lactis*, *Lactobacillus salivarius*, and *Lactobacillus plantarum*, as well as *Streptococcus thermophilus*, *Enterococcus faecium*, *Enterococcus faecalis*, and various *Bifidobacterium* species. Collectively, these probiotic microorganisms play a crucial role in maintaining gut health and enhancing overall physiological performance in poultry.

Prebiotics are defined as non-digestible feed ingredients that beneficially influence the host by selectively modulating the composition and metabolic activity of the gut microbiota. They serve as substrates for beneficial endogenous microorganisms, particularly *Bifidobacterium* and *Lactobacillus* species, thereby promoting a balanced intestinal microbial ecosystem and improving overall gut health (Das *et al.*, 2012) <sup>[7]</sup>. Commonly used prebiotics include fructooligosaccharides (FOS), inulin, galactooligosaccharides (GOS), xylo-oligosaccharides (XOS), pyrodextrins, and lactulose (Alloui *et al.*, 2013). These compounds enhance the proliferation and activity of beneficial gut bacteria, contributing to improved nutrient utilization and host health.

The combined use of probiotics and prebiotics results in the formation of synbiotics, which exert synergistic effects on the host (Huyghebaert *et al.*, 2011) <sup>[21]</sup>. Synbiotics are designed to improve the survival and colonization of beneficial microorganisms in the gastrointestinal tract. Their functional benefits include enhanced resistance to gastrointestinal infections, antimicrobial activity against pathogenic bacteria, and improved immune response, making them a promising strategy in poultry nutrition (Saminathan *et al.*, 2011) <sup>[22]</sup>.

#### 7.2 Enzymes and Organic Acids

The incorporation of exogenous enzymes in poultry diets has become a well-established strategy to enhance nutrient digestibility and overall feed efficiency. Enzymes such as xylanase and  $\beta$ -glucanase target non-starch polysaccharides (NSPs) present in cereal-based diets, reducing intestinal viscosity and improving the availability of encapsulated nutrients. Phytase, one of the most widely used feed enzymes, hydrolyzes phytate-bound phosphorus, thereby increasing phosphorus bioavailability and reducing the need for inorganic phosphorus supplementation. This not only improves nutrient utilization but also minimizes phosphorus excretion and environmental pollution (Cowieson *et al.*, 2010; Ravindran, 2013) <sup>[9, 4]</sup>. Furthermore, the use of multi-enzyme complexes has been shown to produce synergistic effects, enhancing the digestibility of proteins, carbohydrates, and lipids more effectively than single-enzyme supplementation. These improvements contribute to

better growth performance, enhanced feed conversion ratio (FCR), and reduced feed costs in poultry production systems (Bedford and Partridge, 2010) [22].

In addition to enzymes, organic acids are widely utilized as feed additives to promote gut health and improve performance, particularly in antibiotic-free production systems. Commonly used organic acids include butyric acid, lactic acid, formic acid, propionic acid, and citric acid. These acids exert their beneficial effects primarily by lowering the pH of the gastrointestinal tract, thereby creating an unfavorable environment for pathogenic bacteria such as *Salmonella* and *Escherichia coli*, while promoting the growth of beneficial microbiota (Dibner and Buttin, 2002) [24]. Organic acids also enhance nutrient digestibility by stimulating the secretion of digestive enzymes and improving intestinal morphology, including increased villus height and surface area for nutrient absorption. Butyric acid, in particular, serves as an important energy source for intestinal epithelial cells and plays a key role in maintaining gut integrity and immune function (Adil *et al.*, 2010) [25]. Moreover, organic acids have been shown to improve mineral absorption, especially calcium and phosphorus, by increasing their solubility in the digestive tract. The combined use of enzymes and organic acids can have complementary effects, further enhancing nutrient utilization, improving growth performance, and supporting gut health in poultry (Partanen and Mroz, 1999) [26]. Overall, the strategic inclusion of exogenous enzymes and organic acids represents an effective and sustainable approach to improving feed efficiency, maintaining gut health, and reducing reliance on antibiotic growth promoters in modern poultry production systems.

### 7.3 Phytogenic Additives

Phytogenic additives, also referred to as phytobiotics or botanicals, are plant-derived feed additives that have gained considerable attention as natural alternatives to antibiotic growth promoters in poultry nutrition. These additives include a wide range of bioactive compounds such as essential oils, herbs, spices, and plant extracts, which exert beneficial effects on digestion, metabolism, and overall bird health. Their primary functions include stimulation of digestive secretions, enhancement of nutrient absorption, and modulation of gut microbiota, ultimately leading to improved growth performance and feed efficiency (Karangiya *et al.*, 2016; Windisch *et al.*, 2008) [27, 28]. One of the key mechanisms of action of phytogenics is their ability to stimulate the secretion of digestive enzymes, such as amylase, protease, and lipase, thereby improving the digestibility of nutrients. In addition, many phytogenic compounds possess antioxidant properties that help mitigate oxidative stress and support cellular health. Their antimicrobial activity against pathogenic microorganisms, including *Salmonella* and *Escherichia coli*, further contributes to maintaining a balanced intestinal microflora and reducing disease incidence (Hashemi and Davoodi, 2011) [29].

Phytogenic additives also play a role in modulating the immune system by enhancing both humoral and cellular immune responses. This immunomodulatory effect is particularly important in antibiotic-free production systems, where maintaining gut health and disease resistance is critical. Studies have demonstrated that phytogenics can reduce inflammatory responses and improve resilience to

environmental and physiological stressors, thereby supporting overall productivity (Ebeid *et al.*, 2021) [30]. Moreover, recent research indicates that the combined use of phytogenic additives with exogenous enzymes produces synergistic effects, further enhancing nutrient digestibility and feed utilization efficiency. Such combinations have been shown to effectively replace antibiotic growth promoters without compromising performance, making them a sustainable and economically viable option for modern poultry production (Singh *et al.*, 2020) [31].

In addition to improving performance, phytogenic additives contribute to product quality by enhancing meat flavor, oxidative stability, and shelf life. Their natural origin and eco-friendly characteristics align well with consumer preferences for antibiotic-free and sustainable poultry products.

### 8. In ovo Nutrition

*In ovo* nutrition is an advanced and innovative feeding strategy that involves the administration of nutrients directly into the egg during embryonic development, typically between days 12 and 18 of incubation. This technique is designed to supplement the developing embryo with essential nutrients that may become limiting during late embryogenesis, thereby improving hatchability, early growth, and post-hatch performance (Uni and Ferket, 2004) [32]. Nutrient delivery can occur through intra-embryonic or extra-embryonic routes, including the amniotic fluid, yolk sac, and air cell, depending on the timing and intended physiological outcome. During the final stages of incubation, the embryo undergoes rapid growth and increased metabolic activity, often exceeding the nutrient supply available from the yolk. *In ovo* feeding addresses this limitation by providing readily available nutrients that support intestinal development, enzyme activity, and energy metabolism. Consequently, chicks exhibit improved gut morphology, including increased villus height and absorptive surface area, leading to enhanced nutrient utilization immediately after hatching (Uni *et al.*, 2005) [33].

A wide range of nutrients has been utilized in *in ovo* feeding, including carbohydrates (e.g., glucose and maltose), amino acids (such as arginine, methionine, and threonine), fatty acids, vitamins (A, D, E, and C), minerals, and immunomodulatory compounds. Carbohydrates provide an immediate source of energy, reducing the need for muscle protein catabolism during hatching, while amino acids support protein synthesis and tissue development. Additionally, immunostimulants enhance early immune competence and disease resistance (Foye *et al.*, 2006) [34].

Recent studies (2020-2024) have further expanded the scope and effectiveness of *in ovo* nutrition. Modern poultry production systems often involve a delay in post-hatch feeding, which can negatively impact gut development and immune function. *In ovo* feeding helps mitigate these challenges by stimulating early gastrointestinal development, promoting beneficial microbial colonization, and enhancing immune responses prior to hatch (Das *et al.*, 2021) [35].

Contemporary research has also explored the inclusion of novel bioactive compounds. For example, *in ovo* supplementation of vitamins has been shown to improve hatchability, growth performance, and physiological status in broilers (Ncho *et al.*, 2024) [36]. Similarly, the administration of creatine monohydrate has demonstrated

positive effects on embryonic energy reserves, muscle development, and post-hatch growth (Dayan *et al.*, 2023) [37].

In addition, emerging studies have investigated the use of probiotics, prebiotics, synbiotics, and nanoparticles in *in ovo* applications. These interventions have been shown to enhance hatchability, improve gut microbial balance, strengthen immune function, and reduce pathogenic bacterial load, thereby improving overall chick quality and performance (Ahmed *et al.*, 2023) [38]. From both economic and environmental perspectives, *in ovo* nutrition contributes to improved feed efficiency, reduced mortality, and enhanced flock uniformity. By promoting early development and reducing post-hatch stress, this approach supports sustainable poultry production with lower nutrient wastage and environmental impact.

Overall, *in ovo* nutrition represents a cutting-edge strategy that integrates early nutritional intervention with modern poultry management practices. It plays a crucial role in enhancing embryonic development, improving post-hatch performance, strengthening immune competence, and advancing sustainable and antibiotic-free poultry production systems.

## 8. Future Directions in Poultry Nutrition

The future of poultry nutrition is increasingly centered on the integration of advanced technologies with sustainable production practices. Precision nutrition, supported by emerging tools such as data analytics, machine learning, and artificial intelligence, is expected to significantly enhance feed formulation by enabling real-time adjustments based on bird performance, environmental conditions, and nutrient availability. These technologies allow for more accurate prediction of nutrient requirements, thereby improving feed efficiency, reducing costs, and minimizing nutrient wastage (Ravindran, 2013; Siegford *et al.*, 2021) [4, 39]. Advancements in genetics and molecular biology are also expected to play a transformative role in poultry nutrition. The use of genomic and metabolomic tools may enable the development of customized feeding strategies tailored to specific breeds, production systems, and environmental conditions. Such approaches can optimize nutrient utilization at the individual or flock level, improving growth performance, health, and resilience to stress (Aggrey, 2018) [40].

Sustainability will remain a key driving force in shaping future nutritional strategies. Increasing concerns about environmental pollution, particularly nitrogen and phosphorus excretion, are encouraging the adoption of low-protein diets supplemented with synthetic amino acids. These approaches help maintain performance while significantly reducing environmental impact. In addition, the use of alternative feed ingredients such as insect meal, algae, and agro-industrial by-products is gaining attention as a means to reduce dependence on conventional feed resources and enhance sustainability (Makkar *et al.*, 2014) [41]. Furthermore, the growing demand for antibiotic-free poultry production is accelerating the development and application of eco-friendly feed additives, including probiotics, prebiotics, phytogenics, organic acids, and enzymes. These alternatives support gut health, improve immune function, and maintain productivity without the risks associated with antibiotic resistance (Huyghebaert *et al.*, 2011) [21].

Emerging innovations such as nanotechnology and *in ovo* nutrition are also expected to play a pivotal role in the future of poultry production. Nanotechnology offers improved nutrient delivery systems with enhanced bioavailability, while *in ovo* feeding enables early nutritional intervention to improve embryonic development, hatchability, and post-hatch performance (Das *et al.*, 2021) [35].

## 10. Conclusion

Modern poultry nutrition has undergone significant transformation, driven by the need to improve productivity, efficiency, and sustainability in response to the rapidly growing global demand for poultry products. Advances in biotechnology, precision feeding strategies, nanotechnology, and amino acid-based formulations have enabled more efficient utilization of nutrients while reducing feed costs and environmental impact. The shift toward antibiotic-free production has further accelerated the adoption of alternative feed additives such as probiotics, prebiotics, enzymes, organic acids, and phytogenics, all of which contribute to improved gut health, immunity, and overall performance. Additionally, innovative approaches such as *in ovo* nutrition and the use of nano-minerals have demonstrated substantial potential in enhancing early development, feed efficiency, and product quality. Looking ahead, the integration of precision nutrition tools, genetic advancements, and sustainable feed resources will play a critical role in shaping the future of poultry production. Overall, the adoption of these advanced nutritional strategies will be essential for achieving economically viable, environmentally sustainable, and high-performing poultry production systems.

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