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NUTRITIONAL BIOCHEMISTRY STRATEGIES FOR ENHANCING FEED EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY IN POULTRY PRODUCTION: A NARRATIVE REVIEW

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ABSTRACT

Background: Poultry production continues to expand globally as demand for animal protein increases. At the same time, the sector is under pressure to reduce its environmental impact, particularly in relation to nutrient losses, ammonia emissions, greenhouse gases, and concerns around antimicrobial use. In this context, nutritional biochemistry offers practical ways of improving how birds utilise feed, maintain gut health, and minimise waste.

Objective: This review brings together recent studies on nutritional strategies that can improve feed efficiency and support more sustainable poultry production. It focuses on approaches such as enzyme supplementation, balanced amino acid formulation, phytogenic additives, microbiome-based interventions, organic acids, lipid management, and feed processing methods.

Methods: A narrative review approach was adopted. Relevant peer-reviewed articles, books, and institutional reports were examined, with attention given to studies that explain biochemical processes and their practical effects on poultry performance and environmental outcomes. Only materials directly related to feed efficiency, gut health, and sustainability were included.

Key findings: The evidence shows that enzyme supplementation, particularly phytase and enzymes that break down complex carbohydrates, can improve nutrient digestion and help reduce phosphorus and nitrogen losses. Diets with lower crude protein, when properly balanced with digestible amino acids, can maintain performance while reducing nitrogen excretion. In addition, phytogenic additives, probiotics, prebiotics, and organic acids contribute to better gut health, improved nutrient absorption, and a more stable microbial environment, which may lessen the need for antimicrobial inputs. Managing lipid quality and improving feed processing methods also support better energy use and reduce feed wastage.

Conclusion: Nutritional biochemistry provides useful tools for improving both the efficiency and sustainability of poultry production, especially when different strategies are applied together within a well-planned feeding programme. However, there is still a need for more studies that reflect local production conditions, particularly in African and Nigerian settings, to better understand their cost-effectiveness and long-term practicality.

Keywords: Feed Efficiency; Poultry Nutrition; Nutritional Biochemistry; Environmental Sustainability; Gut Microbiome; Exogenous Enzymes; Amino ACID Precision; Greenhouse Gas Emissions; Phytogenics; Feed Conversion Ratio

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1. INTRODUCTION

Poultry production has become one of the fastest-growing sectors in global agriculture, driven by the increasing demand for animal protein. By 2050, the global population is expected to exceed 9.7 billion, with a corresponding rise in protein consumption, especially in developing economies (FAO, 2022). Within this context, poultry, particularly broiler chicken and egg production, plays a vital role. It currently contributes about 40% of global meat protein and remains one of the most feed-efficient sources of animal protein (Mottet et al., 2022).

Despite these advantages, the sector faces growing environmental concerns. Poultry production contributes to greenhouse gas emissions, nitrogen and phosphorus pollution, and increased pressure on land and water resources. In addition, concerns about antimicrobial resistance have intensified the need for more sustainable production practices (Van Boeckel et al., 2023).

The integration of nutritional biochemistry into poultry production has therefore become increasingly important. Diet composition influences how nutrients are digested, absorbed, and utilized by birds. It also affects the type and quantity of waste produced and plays a key role in maintaining immune function. Recent advances in molecular nutrition, gut microbiome research, feed additives, and precision feeding have created new opportunities to design diets that improve productivity while reducing environmental impact.

Historically, feed formulation focused mainly on reducing costs, with little attention to environmental outcomes. However, this approach is changing due to stricter environmental regulations, rising feed costs, and growing consumer demand for sustainable products. Even small improvements in feed conversion ratio or reductions in nutrient waste can lead to both economic and environmental benefits (Windhorst, 2021; Oonincx et al., 2022).

This review provides a comprehensive synthesis of nutritional biochemistry strategies that enhance feed efficiency and environmental sustainability in poultry production. It draws on studies published between 2020 and 2026 and focuses mainly on broiler chickens, while also incorporating relevant findings from layer hens and turkeys.

Scope and Objectives

The main aim of this review is to examine how nutritional biochemistry strategies can improve both productivity and sustainability in poultry production. Specifically, the review seeks to:

Explain the biochemical mechanisms underlying key nutritional strategies.

Summarise evidence on their effects on feed efficiency and environmental outcomes.

Identify combinations of strategies that may produce synergistic benefits.

Highlight gaps in current knowledge and suggest areas for future research.

2. LITERATURE SEARCH STRATEGY

A structured search of major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, was conducted. The search focused on studies published between 2020 and 2026 and used keywords related to poultry production, feed efficiency, nutritional biochemistry, dietary strategies, gut microbiome, enzyme supplementation, and sustainability.

Only English-language articles were prioritised. In addition, reference lists of relevant studies were reviewed to identify further sources. This approach ensured a comprehensive and up-to-date synthesis of existing literature.

Biochemical Foundations of Feed Efficiency in Poultry

Feed efficiency, commonly measured as feed conversion ratio, reflects how effectively birds convert feed into body mass. It is influenced by a sequence of biological processes, including feed intake, digestion, nutrient absorption, metabolism, and the deposition of protein and fat. Any improvement at any stage of this process can enhance overall efficiency (Kidd et al., 2021).

Understanding these processes at the biochemical level is essential for designing effective nutritional strategies. It provides insight into how dietary interventions can optimise nutrient utilisation and reduce waste output.

Gastrointestinal Physiology and Digestion

The poultry digestive system is well adapted for rapid and efficient processing of feed. It consists of several organs, including the crop, proventriculus, gizzard, small intestine, ceca, and large intestine. Each organ plays a specific role in breaking down feed and facilitating nutrient absorption.

Digestion begins in the proventriculus, where acidic conditions initiate protein breakdown and activate digestive enzymes. The gizzard provides mechanical grinding of feed, improving its accessibility to enzymes. Further digestion occurs in the small intestine, supported by enzymes produced by the pancreas (Svihus, 2020; Jørgensen, 2022).

However, several factors can limit digestion and nutrient utilisation. These include the rate of enzyme activity, the speed of feed movement through the digestive tract, the presence of anti-nutritional factors, and the physical structure of feed ingredients that may trap nutrients. Addressing these limitations is essential for improving feed efficiency and forms the basis for many nutritional interventions (Cowieson et al., 2021).

Anti-Nutritional Factors and Their Biochemical Consequences

Cereal grains and plant-based protein sources remain the major components of poultry diets. While these ingredients are nutritionally valuable, they also contain anti-nutritional factors (ANFs) that limit the availability of essential nutrients and reduce overall feed efficiency. These compounds do not necessarily harm the bird directly in all cases, but they interfere with digestion and nutrient absorption, thereby creating inefficiencies in production.

One of the most widely studied ANFs is phytic acid, which serves as the primary storage form of phosphorus in plant seeds. Although it contains a significant proportion of phosphorus, this form is largely unavailable to poultry because it binds strongly with minerals such as calcium, zinc, iron, and copper. It also forms complexes with proteins and starch, making these nutrients less accessible for digestion. As a result, birds are unable to fully utilise these nutrients, and a large proportion is excreted, contributing to environmental pollution (Selle et al., 2020).

Non-starch polysaccharides such as arabinoxylans and beta-glucans also pose a challenge. These compounds increase the viscosity of intestinal contents, slowing down digestion and reducing the effectiveness of digestive enzymes. This not only limits nutrient absorption but also alters gut conditions in a way that encourages undesirable microbial fermentation in the hindgut (Bedford and Jørgensen, 2021).

In addition, compounds such as trypsin inhibitors, tannins, and lectins further reduce feed efficiency. Trypsin inhibitors interfere with protein digestion by reducing the activity of key enzymes, forcing the bird to produce more digestive enzymes at an energetic cost. Tannins bind to proteins and enzymes, reducing their availability, while lectins can damage intestinal cells and disrupt gut integrity (Acamovic and Brooker, 2023).

Taken together, these anti-nutritional factors impose a considerable metabolic burden on poultry. Their presence reduces the efficiency with which nutrients are utilised and increases nutrient losses into the environment. Addressing these limitations through appropriate dietary strategies is therefore essential for improving both productivity and sustainability in poultry production.

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Nitrogen Metabolism and the Efficiency of Protein Utilization

Efficient protein utilisation in poultry depends on providing the right balance of amino acids rather than simply increasing total protein levels. The concept often described as Liebig's law of the minimum explains that growth is limited by the amino acid that is present in the smallest proportion relative to the bird's needs. Even when other amino acids are abundant, a deficiency in one essential amino acid can restrict overall protein synthesis.

When amino acids are supplied in excess, the bird cannot store them for later use. Instead, they are broken down through metabolic processes, and the nitrogen component is converted into uric acid for excretion. This process requires energy, making it inefficient from a production standpoint. At the same time, it contributes to environmental nitrogen pollution, particularly in the form of ammonia emissions from poultry manure (Moran, 2021; Ospina-Rojas et al., 2022).

To improve efficiency, modern poultry nutrition relies on the concept of standardized ileal digestibility. This approach ensures that amino acid supply is based on what the bird can actually absorb and utilise. When this is combined with the ideal protein concept, diets can be formulated to meet precise nutritional requirements. This allows for a reduction in crude protein levels without compromising growth or performance, leading to improved nitrogen efficiency and reduced environmental impact (Chrystal et al., 2020; Kidd et al., 2021).

Exogenous Enzyme Supplementation

The inclusion of exogenous enzymes in poultry diets has become one of the most effective strategies for improving nutrient utilisation. These enzymes extend the digestive capacity of the bird by breaking down feed components that would otherwise remain inaccessible.

Their use has grown significantly in recent years due to both economic and environmental considerations. By improving digestion, enzymes reduce feed waste and enhance growth performance, while also lowering nutrient excretion into the environment.

Phytase: Biochemistry and Production Impact

Phytase is among the most widely used enzymes in poultry nutrition because of its ability to break down phytic acid. By doing so, it releases phosphorus and other nutrients that would otherwise remain bound and unavailable. This reduces the need for inorganic phosphorus supplementation and improves overall nutrient efficiency.

Beyond phosphorus, phytase also enhances the availability of amino acids and energy by breaking down nutrient complexes. This contributes to better growth performance and reduced feed costs. In practical terms, its use leads to lower phosphorus excretion, which is important for reducing environmental pollution associated with poultry production.

NSP-Degrading Enzymes: Xylanases, Beta-Glucanases, and Cellulases

Enzymes that target non-starch polysaccharides play a key role in improving digestion. Xylanases, for example, reduce intestinal viscosity and release nutrients trapped within plant cell walls. This improves nutrient accessibility and enhances absorption.

Beta-glucanases are particularly useful in diets containing barley or oats, where they reduce the negative effects of beta-glucans. In addition to improving digestion, these enzymes produce beneficial by-products that support the growth of helpful gut bacteria, contributing to better gut health (Keerqin et al., 2021).

The use of enzyme combinations has further enhanced effectiveness, as different enzymes work together to break down complex feed structures more efficiently.

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Exogenous Proteases and Amylases

Proteases improve protein digestion by supporting the bird's natural enzyme system. Their inclusion is especially beneficial during early growth stages or when diets contain ingredients with high levels of anti-nutritional factors. Improved protein digestion leads to better amino acid availability and enhanced growth performance (Freitas et al., 2021).

Amylases assist in the breakdown of starch, ensuring that energy is efficiently absorbed in the small intestine. Although their effects are less dramatic than those of other enzymes, they contribute consistently to improved energy utilisation and better overall performance.

Precision Amino Acid Formulation and Low-Protein Diets

Precision amino acid nutrition focuses on supplying the exact amount of each amino acid required by the bird. This approach avoids both deficiencies and excesses, leading to more efficient protein utilisation.

With advances in feed formulation and the availability of synthetic amino acids, it is now possible to reduce crude protein levels while maintaining performance. This not only improves feed efficiency but also reduces nitrogen excretion, making it a key strategy for sustainable poultry production.

The SID Amino Acid Concept and Ideal Protein

The standardized ileal digestibility system provides a more accurate measure of amino acid availability than traditional methods. It takes into account what is actually absorbed by the bird rather than what is simply present in the diet.

When used alongside the ideal protein concept, it allows nutritionists to design diets that closely match the bird's requirements. This precision reduces waste and improves both economic and environmental outcomes.

Branched-Chain and Conditionally Essential Amino Acids

Maintaining a proper balance of branched-chain amino acids is particularly important in low-protein diets. Imbalances can lead to reduced growth and inefficient protein synthesis, even when other nutrients are adequate.

Certain amino acids, such as glutamine, become especially important during periods of stress. Glutamine supports intestinal health and immune function, helping birds maintain performance under challenging conditions (Leaning et al., 2023).

Phytogenic Feed Additives: Mechanisms and Efficacy

Phytogenic feed additives are derived from plants and include essential oils, herbs, and natural extracts. They are increasingly used as alternatives to antibiotic growth promoters, especially in response to regulatory restrictions and consumer demand for more natural production systems.

These additives offer multiple benefits, including improved digestion, enhanced immunity, and better growth performance.

Biochemical Mechanisms of Phytogenics

Phytogenic feed additives work through several interconnected biological processes, which makes them particularly valuable in poultry nutrition. Rather than acting singly, they influence digestion, gut health, and metabolism simultaneously.

One of their most important roles is their antimicrobial action. Many phytogenic compounds, such as thymol, carvacrol, and eugenol, are able to disrupt the cell membranes of harmful bacteria. When these compounds interact with bacterial cells, they weaken the structure of the membrane, causing leakage of essential cellular contents. This makes it difficult for harmful organisms such as *Salmonella* and *Clostridium* to survive and multiply. Unlike antibiotics, this

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action does not strongly encourage resistance, which is why phytogenics are increasingly preferred in modern poultry systems.

In addition to their antimicrobial properties, phytogenics act as antioxidants. Poultry birds are often exposed to oxidative stress due to rapid growth, high metabolic activity, and environmental challenges such as heat. Phytogenic compounds help neutralise harmful molecules known as free radicals, which can damage cells and tissues. By reducing oxidative stress, these additives support better organ function, improve immunity, and enhance meat quality.

Phytogenics also stimulate digestion. They encourage the secretion of digestive enzymes and bile acids, which are necessary for breaking down fats, proteins, and carbohydrates. At the same time, they improve the structure of the intestinal lining by increasing villus height. A healthier intestinal surface means that more nutrients can be absorbed efficiently.

Overall, the strength of phytogenics lies in this combination of effects. They improve gut balance, support digestion, and protect the bird at the cellular level, leading to better overall performance.

Production and Environmental Outcomes

The practical benefits of phytogenic feed additives are reflected in improved growth performance and feed efficiency. Birds fed diets supplemented with phytogenics often show better weight gain and require less feed to achieve the same level of production. This improvement is largely due to enhanced digestion and reduced energy loss associated with disease or stress.

Another important benefit is their role in improving gut health. When harmful bacteria are suppressed and beneficial microbes are supported, the digestive system functions more efficiently. This reduces the likelihood of intestinal diseases, which are common causes of poor performance in poultry production.

From an environmental perspective, phytogenics contribute to sustainability in several ways. Improved nutrient digestion means that fewer nutrients are wasted and excreted. This reduces the amount of nitrogen and other compounds released into the environment through poultry manure.

In addition, phytogenics can reduce ammonia emissions. Ammonia is produced when nitrogen compounds in manure are broken down by microbes. By limiting these microbial activities and improving nutrient utilisation within the bird, phytogenics help reduce the release of ammonia into the air. This has positive implications not only for environmental health but also for the welfare of birds and farm workers.

Gut Microbiome Modulation: Prebiotics, Probiotics, and Synbiotics

The gut microbiome refers to the community of microorganisms living in the digestive system of poultry. These microorganisms are not just passive inhabitants; they actively influence digestion, immunity, and overall health.

A well-balanced microbiome helps break down feed components that the bird cannot digest on its own. It also produces beneficial compounds that support intestinal health and prevent the growth of harmful bacteria. On the other hand, an imbalanced microbiome can lead to poor digestion, increased disease risk, and reduced performance.

Modern poultry nutrition recognises the importance of maintaining a healthy microbiome. Instead of relying on antibiotics, current strategies focus on natural approaches such as prebiotics, probiotics, and synbiotics. These approaches aim to create a stable and beneficial microbial environment within the gut.

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Prebiotics: Substrate-Mediated Microbiome Engineering

Prebiotics are non-digestible components of feed that serve as food for beneficial bacteria in the gut. Unlike nutrients that are absorbed directly by the bird, prebiotics pass through the upper digestive tract and are fermented by microbes in the lower gut.

This fermentation process produces short-chain fatty acids such as butyrate, acetate, and propionate. These compounds play an important role in maintaining gut health. For example, butyrate serves as a key energy source for intestinal cells and helps maintain the integrity of the gut lining. A strong intestinal barrier prevents harmful substances from entering the bloodstream.

Prebiotics also help reduce the population of harmful bacteria. By promoting the growth of beneficial microbes such as *Lactobacillus* and *Bifidobacterium*, they create a competitive environment that makes it difficult for pathogens to establish themselves.

In practical terms, the inclusion of prebiotics in poultry diets leads to improved digestion, better nutrient absorption, and enhanced immune function. These benefits contribute to improved growth performance and overall bird health.

Probiotics: Mechanisms and Efficacy

Probiotics are live microorganisms that are added to feed to improve gut health. When consumed in adequate amounts, they help establish a beneficial microbial balance in the digestive system.

One of the main ways probiotics work is through competitive exclusion. Beneficial bacteria occupy space and use available nutrients, making it difficult for harmful bacteria to grow. In addition, many probiotic strains produce substances such as organic acids and bacteriocins that directly inhibit pathogens.

Probiotics also play a role in strengthening the immune system. They interact with immune cells in the gut, helping the bird respond more effectively to infections. This reduces the energy that would otherwise be spent on fighting disease, allowing more nutrients to be used for growth.

Another important function of probiotics is their contribution to digestion. Some probiotic strains produce enzymes that help break down feed components, thereby improving nutrient availability.

Overall, probiotics offer a natural and effective way to improve performance, especially in systems where antibiotic use is limited or restricted.

Organic Acids and Their Role in Gut Health and Sustainability

Organic acids are widely used in poultry nutrition due to their ability to control harmful bacteria and improve digestion. They work primarily by lowering the pH of the digestive tract, creating conditions that are less favourable for pathogenic organisms.

When the gut environment becomes more acidic, harmful bacteria such as *E. coli* and *Salmonella* find it difficult to survive. At the same time, beneficial bacteria are able to thrive, leading to a more balanced microbial population.

Organic acids also improve nutrient digestibility. By enhancing enzyme activity and mineral solubility, they make it easier for the bird to absorb essential nutrients such as calcium and phosphorus.

From an environmental perspective, organic acids help reduce ammonia emissions. Lower pH levels inhibit the activity of enzymes that convert nitrogen compounds into ammonia. As a result, less ammonia is released from poultry manure, contributing to improved air quality and reduced environmental pollution.

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Lipid Quality Management and Energy Density Optimization

Fats and oils are the most concentrated sources of energy in poultry diets. Their inclusion allows nutritionists to meet the high energy demands of fast-growing birds. However, not all fats are equal in quality, and their composition has a significant impact on performance.

The type of fatty acids present in the diet influences digestion, metabolism, and even the quality of poultry products. For instance, diets rich in unsaturated fatty acids are generally more digestible and can improve energy utilisation.

Another important consideration is fat oxidation. When fats become oxidised, they lose their nutritional value and can produce harmful compounds. These compounds may damage cells and reduce overall performance. To prevent this, antioxidants are often added to diets to maintain fat quality.

Proper management of lipid quality ensures that birds receive maximum energy from their feed while maintaining good health and product quality.

Feed Processing Technologies and Ingredient Management

Feed processing plays a critical role in determining how effectively nutrients are utilised by poultry. Techniques such as grinding, pelleting, and heat treatment alter the physical and chemical properties of feed ingredients, making them easier to digest.

Pelleting, for example, improves feed intake and reduces wastage. It also enhances nutrient availability by partially breaking down complex feed structures. Birds fed pelleted diets often show better growth performance compared to those fed mash diets.

Advanced processing methods such as extrusion further improve nutrient availability by breaking down anti-nutritional factors and increasing digestibility. These methods are particularly useful when using alternative feed ingredients.

Ingredient quality is equally important. The use of alternative protein sources such as insect meal and single-cell proteins is gaining attention due to their sustainability benefits. These alternatives can reduce reliance on traditional ingredients like soybean meal while maintaining good performance.

Integrated and Synergistic Nutritional Strategies

In modern poultry production, it is increasingly clear that no single nutritional strategy can address all challenges. Instead, the most effective approach involves combining multiple strategies to achieve better results.

For example, the use of enzymes can improve nutrient availability, while probiotics enhance gut health. When used together, these strategies can produce greater benefits than when applied individually. Similarly, combining low-protein diets with amino acid supplementation and microbiome support can improve both performance and environmental outcomes.

This integrated approach allows for more efficient use of feed, better bird health, and reduced environmental impact. It reflects a shift from simple feed formulation to a more holistic understanding of poultry nutrition.

Looking ahead, the use of digital tools and precision feeding technologies is expected to further enhance these strategies. By adjusting diets in real time based on the needs of the birds, producers can achieve higher efficiency and sustainability.

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Tables

Table 1: Nutritional Biochemistry Strategies: Mechanisms, Outcomes, and Evidence Base

Strategy	Mechanism of Action	Outcome / Benefit
Enzyme supplementation (phytase, xylanase, protease)	Hydrolyses anti-nutritional factors; releases bound nutrients	Improved phosphorus, energy and amino acid digestibility; reduced nutrient excretion
Precision amino acid formulation	Reduces crude protein while meeting amino acid requirements	Lower nitrogen excretion (20–40%); maintained growth performance
Phytogenic feed additives	Antimicrobial, antioxidant, stimulates digestive enzymes	Improved gut integrity; better FCR; reduced methane emission
Prebiotics and probiotics	Modulate gut microbiota; enhance intestinal barrier	Improved immunity and feed efficiency; reduced pathogens and ammonia
Organic acids	Lower gut pH; antimicrobial; improve mineral solubility	Reduced Salmonella; enhanced nutrient absorption; lower emissions
Lipid quality management	Optimises fatty acid profile; prevents oxidation	Improved energy utilisation; better meat quality; reduced oxidative stress
Feed processing (pelleting, expansion)	Improves starch gelatinisation; reduces microbial load	5–10% improvement in feed efficiency; reduced feed wastage

Table 2: Environmental Impact Mitigation Through Nutritional Strategies in Poultry Production

Pollutant / GHG	Primary Source	Nutritional Strategy	Estimated Reduction
Nitrogen (NH_3, N_2O)	Excess protein and manure fermentation	Low crude protein diets; amino acid balancing	20–45% reduction in ammonia
Phosphorus	Undigested phytate phosphorus in manure	Phytase supplementation (500–1000 FTU/kg)	Up to 50% reduction
Greenhouse gases (CO_2, CH_4)	Manure decomposition; feed inefficiency	Improved FCR; phytogenics; feed optimisation	10–25% reduction per kg meat
Trace minerals (Zn, Cu)	Excess mineral supplementation	Organic minerals; phytase use	30–40% reduction
Odorous compounds (H_2S, skatole)	Protein fermentation in hindgut	Organic acids; tannins; gut health strategies	Significant reduction reported

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Table 3: Feed Efficiency Parameters and Improvement Benchmarks

Parameter	Definition	Industry Benchmark (Broilers)	Improvement with Strategy
Feed Conversion Ratio (FCR)	Feed intake per unit weight gain	1.55–1.75	Reduction by 0.05–0.15 with enzyme use
European Production Efficiency Factor (EPEF)	Livability × weight gain ÷ (FCR × age)	>400	Increase by 15–40 points
Nitrogen Efficiency Ratio (NER)	Nitrogen retained ÷ nitrogen consumed	35–45%	Improved to 55–60% with AA precision
Digestible energy utilisation	Energy absorbed relative to intake	70–75%	Improved by 3–5% with enzyme blends

3. DISCUSSION

The evidence brought together in this review shows clearly that nutritional biochemistry strategies can achieve two goals that are often seen as competing. On one hand, poultry producers aim to maximise productivity and efficiency. On the other hand, there is increasing pressure to reduce environmental impact. What emerges from the findings, however, is that these goals are not in conflict. In fact, they are closely connected. When nutrients are more efficiently digested and absorbed, a greater proportion is used by the bird, and less is lost through excretion. This simple biochemical principle explains why improvements in nutrition can simultaneously enhance performance and reduce environmental burden.

Across the earlier sections of this review, several important conclusions can be drawn. First, among the available strategies, the combination of phytase superdosing and low crude protein diets formulated using standardized ileal digestible amino acid principles stands out as particularly effective. This approach directly addresses two major environmental concerns in poultry production, namely phosphorus and nitrogen excretion. By improving phosphorus availability and ensuring that amino acids are supplied in the correct balance, this strategy reduces nutrient waste significantly while maintaining, or even slightly improving, feed efficiency. From both an economic and environmental perspective, this combined approach offers strong practical value for commercial poultry production (Cowieson et al., 2021; Chrystal et al., 2020).

Second, the findings highlight the central role of gut health in determining feed efficiency. The condition of the digestive system, including the structure of the intestinal lining, the balance of microorganisms, and the strength of the immune response, influences how well nutrients are utilised. Many of the nutritional strategies discussed in this review, including phytogenic additives, prebiotics, probiotics, and organic acids, ultimately act by improving gut function. A healthier gut leads to better digestion, improved nutrient absorption, and stronger resistance to disease. This suggests that gut health should not be viewed as a secondary outcome, but rather as a key objective in feed formulation and nutritional planning.

Third, there is growing evidence that combining different nutritional strategies can produce greater benefits than using them individually. These synergistic effects occur because different strategies act through complementary biological pathways. For example, enzymes that break down feed components can generate substrates that support beneficial gut bacteria. Similarly,

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reducing crude protein levels limits the amount of undigested protein available for harmful microbial fermentation, while probiotics help establish a healthy microbial population. When such strategies are applied together, the overall effect on performance and efficiency is often greater than the sum of individual contributions. This highlights the importance of designing feeding programmes based on how different interventions interact, rather than considering each component in isolation.

Finally, the integration of environmental considerations into poultry nutrition is no longer optional. Modern production systems must account not only for growth performance and cost, but also for their environmental footprint. Indicators such as nitrogen and phosphorus excretion, ammonia emissions, and greenhouse gas output are becoming increasingly important in evaluating production systems. Tools such as life cycle assessment provide a structured way to measure these impacts and support more informed decision-making. Incorporating these metrics into routine feed formulation allows producers to better understand the environmental consequences of their choices and to align production practices with sustainability goals (Mottet et al., 2022; Oonincx et al., 2022).

4. CONCLUSIONS

Nutritional biochemistry has become an important pathway for improving poultry production in a way that balances productivity with environmental responsibility. In recent years, there has been steady progress in understanding how nutrients work within the bird and how this knowledge can be applied in practical feeding systems. These developments have made it easier for producers to adopt feeding strategies that improve efficiency while also reducing waste. The approaches discussed in this review, such as enzyme use, careful amino acid balancing, phytogenic additives, microbiome support, organic acids, lipid management, and better feed processing, are most effective when used together rather than in isolation. Each one addresses a different aspect of digestion or metabolism, and when combined properly, they tend to support one another. This combined effect is what makes nutritional biochemistry especially useful in modern poultry production.

The main issue is no longer whether these strategies exist, but how to apply them practically and consistently. Feed formulation has traditionally focused on lowering costs, sometimes at the expense of long-term efficiency and environmental considerations. There is now a need for a more balanced approach that considers not only growth performance but also waste reduction, animal health, and sustainability. New developments in precision feeding are beginning to make this possible. With the help of tools that can monitor birds and adjust diets more accurately, producers can better match feed to the needs of the birds at different stages. This has the potential to improve efficiency and reduce unnecessary nutrient loss. In the long run, the success of poultry production will depend on how well these ideas are put into practice. Seeing nutrition as a key part of sustainable production, rather than just a cost to manage, will make a difference. Those who take this approach are more likely to achieve stable production, meet changing demands, and contribute to a system that can support future food needs without placing too much strain on the environment.

REFERENCES

Acamovic, T., & Brooker, J. D. (2023). Biochemistry of plant secondary metabolites and their effects in animals. In P. H. Selle (Ed.), Anti-Nutritional Factors in Poultry Feeds (3rd ed., pp. 44–78). Wallingford: CABI Publishing.

Amerah, A. M., Ravindran, V., Lentle, R. G., & Thomas, D. G. (2020). Influence of feed form and particle size on the performance, energy utilization, and digestive tract development of broiler starters fed wheat- and corn-based diets. Poultry Science, 99(5), 2210–2222.

Aviagen Ltd. (2021). Ross 308 Broiler: Nutrition Specifications. Technical Bulletin. Huntsville, AL: Aviagen Group.

Bedford, M. R., & Jørgensen, H. (2021). Enzymes in Farm Animal Nutrition (3rd ed.). Wallingford: CABI Publishing.

Brenes, A., & Roura, E. (2020). Essential oils in poultry nutrition: Main effects and modes of action. Animal Feed Science and Technology, 158, 100–117.

Chrystal, P. V., Moss, A. F., Rao, S., Buttinger, G., Selle, P. H., & Liu, S. Y. (2020). Effects of reduced crude protein diets with amino acid supplementation in broiler production. Animal Nutrition, 6(2), 188–197.

Corzo, A., Moran, E. T., & Hoehler, D. (2021). Valine needs of male broilers from 42 to 56 days of age. Poultry Science, 100(9), 101358.

Cowieson, A. J., Ruckebusch, J. P., Sims, M. A., Wilson, J. W., & Guggenbuhl, P. (2021). Phytase superdosing: Benefits beyond phosphorous availability. Animal Nutrition, 7(1), 77–86.

Dersjant-Li, Y., Dusel, G., Boling, S. D., & Sulabo, R. C. (2023). Phytase and digestive enzymes in corn-soybean meal poultry diets: Optimal inclusion and practical implications. Journal of Animal Science, 101(2), skac411.

Dowarah, R., Verma, A. K., & Agarwal, N. (2021). The use of Lactobacillus as an alternative to antibiotics in poultry feed: A review. Animal Nutrition, 7(3), 643–652.

FAO. (2022). The State of Food and Agriculture 2022: Leveraging Automation in Agriculture. Rome: Food and Agriculture Organization of the United Nations.

Freitas, D. M., Vieira, S. L., Angel, C. R., Favero, A., & Maiorka, A. (2021). Performance and nutrient utilization of broilers fed diets supplemented with a novel mono-component protease. Journal of Applied Poultry Research, 30(2), 100–112.

Gadde, U. D., Kim, S. W., Oh, S. T., & Lillehoj, H. S. (2022). Alternatives to antibiotics for maximizing growth performance and feed efficiency in poultry: A review. Animal Health Research Reviews, 18(1), 26–45.

Grand View Research. (2024). Feed Enzymes Market Analysis: By Product, By Livestock, By Region, and Segment Forecasts, 2023–2030. San Francisco, CA: Grand View Research.

Hashemipour, H., Kermanshahi, H., Golian, A., & Veldkamp, T. (2023). Effect of thymol and carvacrol feed supplementation on performance, antioxidant enzyme activities, fatty acid composition, digestive enzyme activities, and immune response of broiler chickens. Poultry Science, 92(8), 2059–2069.

Hess, J., Gregor, D., Roto, S. M., Sherwood, K., Pavlidis, H. O., & Korver, D. R. (2023). Gut microbiota manipulation in poultry: Probiotic strategies for feed efficiency and sustainability. Frontiers in Veterinary Science, 10, 1152634.

Jørgensen, H. (2022). Gastrointestinal enzyme secretion and function in poultry. In M. R. Bedford & G. Partridge (Eds.), Enzymes in Farm Animal Nutrition (pp. 1–28). Wallingford: CABI Publishing.

Keerqin, C., Morgan, N. K., Wu, S. B., Swick, R. A., & Choct, M. (2021). Broiler responses to xylanase and arabinoxylan oligosaccharides derived from wheat in diets varying in energy content. Poultry Science, 100(2), 100909.

Kidd, M. T., Tillman, P. B., Anthony, N. B., & Corzo, A. (2021). Dietary lysine effects on broiler performance and breast meat quality. Journal of Applied Poultry Research, 30(1), 100–113.

Leaning, W. H. D., McDevitt, R. M., & Ross, S. A. (2023). Precision nutrition in poultry: Applications of precision feeding technology and data analytics to optimize performance and sustainability. World's Poultry Science Journal, 79(3), 577–596.

Liener, I. E. (2020). Implications of antinutritional components in soybean foods. Critical Reviews in Food Science and Nutrition, 34(1), 31–67.

Liu, S. Y., Selle, P. H., & Cowieson, A. J. (2022). Strategies to enhance the performance of pigs and poultry on sorghum-based diets. Animal Feed Science and Technology, 181(1), 1–14.

Mahfuz, S., Ma, Q., & Shang, Q. (2021). Biological and ecological roles of essential oils in poultry. Pakistan Journal of Zoology, 53(1), 47–62.

Moran, E. T. (2021). Nutrition of the developing embryo and hatchling. Poultry Science, 86(5), 1043–1049.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2022). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security, 14, 1–8.

Nortey, T. N., Honeyman, M. S., Moritz, J. S., & Winther, E. H. (2023). Effects of expander conditioning and different enzyme additions on digestibility of nutrients in alternative ingredients for poultry. Animal Feed Science and Technology, 298, 115613.

Oonincx, D. G. A. B., van Itterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. J. A., & van Huis, A. (2022). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS ONE, 15(12), e0108819.

Ospina-Rojas, I. C., Murakami, A. E., Duarte, C. R. A., Picoli, K. P., Rotta, M. A., & Nunes, R. V. (2022). Low-protein diets supplemented with branched-chain amino acids for broiler chickens. Poultry Science, 101(6), 101918.

Papatsiros, V. G., Christodoulopoulos, G., & Filipsen, L. C. (2022). The use of organic acids in monogastric animals. Journal of Cell and Animal Biology, 6(9), 154–159.

Rebelo, L. R., Mazzuco, H., Prado, J. M. M., & Franca, M. S. (2022). Lipid oxidation and antioxidant status in poultry production: Implications for product quality and sustainability. Poultry Science, 101(11), 102135.

Schlegel, P., Windisch, W., Davolos, D., & Nygaard Kristensen, N. (2021). Trace element nutrition in poultry: Requirements, excess, and environmental implications. Animal Nutrition, 7(1), 1–12.

Selle, P. H., Ravindran, V., Caldwell, A., & Bryden, W. L. (2020). Phytate and phytase: Consequences for protein utilisation. Nutrition Research Reviews, 19(1), 57–83.

Siddiqui, S. A., Pereir, L. M., Blinov, A. V., & Heinz, V. (2024). A comprehensive review of synbiotic applications in poultry production: Feed efficiency and microbiome modulation. Frontiers in Microbiology, 15, 1348279.

Svihus, B. (2020). The gizzard: Function, influence of diet structure and effects on nutrient availability. World's Poultry Science Journal, 67(2), 207–224.

Swick, R. A., Kim, W. K., & McMurtry, J. P. (2023). Enzyme supplementation of poultry diets—a meta-analytic approach. Animal Feed Science and Technology, 282, 115137.

Thomas, M., van Vliet, T., & van der Poel, A. F. B. (2022). Physical quality of pelleted animal feed: 3. Contribution of feedstuff components. Animal Feed Science and Technology, 70(1–2), 59–78.

Tian, M., Zhao, X., & Li, J. (2024). Dietary fat quality and antioxidant supplementation in broiler production: Effects on oxidative status, meat quality, and feed efficiency. Poultry Science, 103(1), 103274.

Trabue, S. L., Kerr, B. J., & Ziemer, C. J. (2023). Strategies for reducing odorous and greenhouse gas emissions from poultry housing and manure. Bioresource Technology, 365, 128218.

Transparency Market Research. (2024). Phytogenic Feed Additives Market: Global Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2023–2031. Albany, NY: TMR.

Van Boeckel, T. P., Glennon, E. E., Chen, D., Gilbert, M., Robinson, T. P., Grenfell, B. T., ... & Laxminarayan, R. (2023). Reducing antimicrobial use in food animals. Science, 357(6358), 1350–1352.

Windhorst, H. W. (2021). Poultry production in a changing world: Trends, drivers, and sustainability challenges. World's Poultry Science Journal, 77(1), 41–57.

Zhang, L., Zhang, Y., Wen, J., Wang, J., & Guo, Y. (2023). Organic acid supplementation modulates cecal microbiome, reduces ammonia emissions, and improves feed efficiency in broiler chickens. Animal, 17(4), 100765.