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Nutritional perspectives and innovations in alternative feed resources for sustainable poultry production: A review

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Abstract
The rising global demand for poultry products, coupled with the high cost and ecological burden of conventional feed ingredients like maize and soybean meal, has intensified interest in alternative feed sources. This chapter provides a critical evaluation of diverse sustainable options such as plant-based by-products, insect meals, agro-industrial residues, and food waste. These alternatives present valuable nutritional attributes, economic feasibility, and environmental advantages, aligning with circular economy principles while promoting poultry health and productivity. The discussion focuses on innovative feeding approaches, the nutrient composition and functional properties of non-traditional ingredients, and their influence on growth performance and product quality. Key challenges including variability in nutrient content, anti-nutritional compounds, digestibility issues, and palatability are explored, along with the importance of suitable processing methods and regulatory measures. Additionally, the chapter outlines the economic and environmental benefits of sustainable feeding systems and offers recommendations for future research, policy development, and industry uptake to ensure their practical implementation and scalability in poultry production.

Keywords: Nutritional perspectives, innovations, alternative, poultry production, policy development

1. Introduction
Poultry production remains one of the most rapidly expanding segments of global livestock farming, driven by rising consumer demand for affordable, high-quality animal protein. However, feed expenses account for roughly 60-70% of total production costs, with maize and soybean meal serving as the primary energy and protein sources. Heavy dependence on these conventional ingredients creates economic pressures and raises sustainability concerns due to land-use competition, volatile market prices, and environmental impacts.

The poultry sector plays a vital role in global food systems, supplying meat and eggs as key sources of animal protein (Henchion, 2021) [7]. Yet, reliance on corn and soybean meal is associated with challenges such as deforestation, biodiversity loss, and increased greenhouse gas emissions from their cultivation, processing, and transport (Siddiqui, 2024) [21]. This scenario underscores the urgent need for alternative feeding strategies that are cost-effective, nutritionally balanced, and environmentally responsible.

In recent years, research has increasingly focused on the potential of unconventional feed ingredients to complement or replace traditional poultry diets. Such alternatives not only have the potential to reduce the ecological footprint of poultry farming but may also enhance the nutritional profile of poultry products and improve production performance. Promising examples include legume processing residues (Martens, 2012) [12], oilseed meals (Vlaicu, 2021) [24], fruit and vegetable wastes, foliage from specific plants, and other agricultural by-products (Seidavi, 2021) [20]. Despite their potential, adopting alternative feed resources requires careful consideration of nutritional adequacy, palatability, cost-efficiency, and supply chain feasibility. Formulating balanced diets demands a thorough understanding of poultry nutrient requirements alongside detailed compositional data for each ingredient.

Additionally, variability in nutrient levels and the presence of anti-nutritional factors necessitate appropriate processing and laboratory evaluation to ensure safe and effective utilization (Samtiya, 2020) [19]. Advances in feed technology and poultry nutrition science have made it increasingly possible to incorporate such ingredients into practical feed formulations, maintaining or even improving poultry performance and product quality, as discussed in this chapter.

2. Objectives behind developing alternative poultry feeding practices

Modern poultry feeding combines both traditional and innovative approaches to meet birds' nutritional requirements while maximizing productivity. Conventional feeding practices rely on well-established ingredients, particularly grains such as corn and wheat as primary energy sources, and soybean meal as the main protein source. These are typically supplemented with animal by-products, fats, vitamins, and minerals to create balanced diets that cater to specific growth stages and production goals. Proper formulation ensures optimal macronutrient (protein, carbohydrate, and fat) ratios and an adequate supply of essential micronutrients, which are crucial for maintaining poultry health, preventing nutrient deficiencies, and enhancing production performance.

Despite their proven effectiveness, traditional diets face notable limitations. The high and often volatile prices of key ingredients like corn and soybean meal can constrain profitability, especially for smallholder farmers (Van der, 2020) [23]. Moreover, reliance on these crops raises sustainability concerns, including deforestation, excessive water use, and greenhouse gas emissions linked to their production and transportation. These challenges have driven growing interest in alternative feed ingredients that can partially or fully replace conventional components, offering comparable nutritional value while lowering costs and environmental impact (Vlaicu *et al*., 2023) [25].

Innovative strategies in poultry nutrition also involve incorporating feed additives and supplements that improve feed efficiency and bird health. Medicinal and herbal plants (Pliego *et al*., 2022) [16], legumes (Harouna, 2018) [6], fruit pomace, and other plant co-products (Untea, 2023) [25] have shown potential in enhancing digestion, nutrient absorption, and gut health. Such additives are particularly valuable in diets containing alternative ingredients, as they can help correct nutrient imbalances, improve bioavailability, and enhance the nutritional quality of poultry products, contributing to healthier and more affordable food for consumers.

Sustainable feeding practices are increasingly prioritized to reduce the environmental footprint of poultry farming (Ponnampalam, 2023) [17]. This includes optimizing formulations to improve nutrient utilization, reduce waste, and increase resource efficiency. Using locally sourced ingredients that meet birds' dietary needs not only supports sustainability by lowering transportation emissions and pollution but also strengthens local agricultural systems.

3. Novel feeding approaches for sustainable poultry production

Sustainable poultry feeding strategies prioritize the incorporation of alternative feed sources to address the economic, resource, and environmental limitations of conventional diets. Such alternatives can partially or fully replace traditional staples like corn and soybean meal, drawing on plant-derived materials such as legume residues, oilseed by-products, leafy plants, and various agricultural co-products. Recent reviews have also highlighted unconventional feed options including insects, algae, and food waste as promising candidates for sustainable poultry nutrition (Brunetti, 2022) [2].

The advantages of using plant-based and by-product feeds are multifaceted. Economically, these innovations can substantially lower feed costs, improving profitability, particularly for smallholder farmers with limited resources. Many of these ingredients are agricultural by-products, which are inexpensive to source and contribute to waste reduction within the food system. Moreover, supplementing poultry diets with such materials can ease competition between feed and human food crops, fostering more balanced and sustainable agricultural practices (Babatunde, 2021) [1].

From a nutritional perspective, alternative feed ingredients often provide a broad spectrum of essential nutrients to meet poultry dietary requirements. Legumes and oilseeds offer high-quality proteins and amino acids, while agricultural by-products supply energy, fiber, and bioactive compounds with potential health benefits. Importantly, integrating diverse feed resources can enhance the resilience of poultry production systems by reducing dependence on volatile markets and vulnerable supply chains. As Davis (2021) [3] notes, such resilience is critical for global food security, ensuring consistent poultry product availability even under economic or environmental pressures.

4. Categories of alternative feed resources

4.1 Plant-Derived Alternative Feed Ingredients

Plant-based feeds have traditionally formed the backbone of poultry nutrition due to their availability, affordability, and high nutritional value. Common staples such as corn, barley, wheat, and soybean meal serve as primary sources of energy and protein, supporting rapid growth and productivity in poultry (Brunetti, 2022) [2]. However, increasing global demand for these crops for both human consumption and animal feed has intensified competition for resources, raising sustainability concerns.

To address these challenges, researchers and industry stakeholders are identifying alternative plant-derived ingredients that are both nutritionally adequate and environmentally sustainable. Many of these alternatives are by-products of other agricultural processes, requiring fewer resources to produce. Examples include protein-rich legumes such as lupins, faba beans, chickpeas, and peas, which have a lower environmental impact compared to soybeans. Oilseed meals from canola, flax, and rapeseed produced as by-products of oil extraction also provide substantial protein and fat, making them suitable partial replacements for soybean meal.

Agricultural residues and cereal by-products such as rice bran, wheat bran, and other milling by-products present another promising category. Repurposing these low-value materials into poultry feed supports circular economy principles, reduces waste, and contributes to food system efficiency. Nevertheless, their variable nutrient composition and potential presence of anti-nutritional compounds (Purohit, 2023) [18] necessitate careful formulation and processing to safeguard poultry health and performance.

Advancements in feed technology including fermentation, enzyme supplementation, and genetic improvement are being explored to enhance digestibility and nutrient availability in plant-based alternatives. These feeds typically have a smaller carbon footprint, require less land and water than animal-

derived feeds (Kustar, 2021) [10], and align with environmental sustainability goals. Despite this, challenges such as cost variability, regional availability, and nutrient consistency continue to limit widespread adoption, underscoring the need for ongoing research and development.

4.2 Insect-derived alternative feed ingredients

Over the past decade, insect-based feeds have gained significant attention as a sustainable and high-quality protein source for poultry (Figure 1). Species such as black soldier fly larvae, mealworms, and crickets efficiently convert organic waste into nutrient-dense biomass, offering a protein content ranging from 30% to 80% depending on species and growth stage. These insects supply essential amino acids, beneficial fatty acids (n-3 and n-6), and minerals, making them competitive with traditional protein sources like fish meal and soybean meal. Black soldier fly larvae, for instance, possess a balanced amino acid profile (Khalifa *et al*., 2023) [9].

Insect farming offers distinct environmental benefits, as insects can be reared on agricultural residues, food waste, and other organic by-products, thus reducing landfill use and supporting circular economy principles (Jagtap, 2021) [8]. This dual role waste management and protein production helps minimize the carbon footprint of poultry farming while reducing reliance on resource-intensive crops.

However, several challenges hinder large-scale adoption. Regulatory frameworks in many regions remain restrictive, particularly regarding the substrates allowed for insect rearing. Scaling production requires investment in infrastructure and technology, and insect protein remains more expensive than conventional feed ingredients, though costs are expected to decline as production efficiency improves.

Current research focuses on optimizing rearing conditions, enhancing the nutritional profile of insect meals, and evaluating their long-term impacts on poultry performance and health. Findings indicate that insect protein can replace a substantial proportion of conventional protein sources without impairing growth or feed efficiency, and in some cases, may improve gut health and immune function, suggesting benefits beyond basic nutrition.

Fig 1: Use of by products for sustainable poultry farming

4.3 By-products and waste-derived alternative feed ingredients: Nutritional composition and bioactive compounds

The nutritional profile of alternative poultry feed ingredients is a key factor in determining their effectiveness in meeting birds' dietary needs (Table 1). Poultry require balanced amounts of protein (16-18% for layers; 20-23% for broilers), essential amino acids such as lysine (0.9-1.1% for layers; 1.1-1.3% for broilers), methionine (0.4-0.5% for layers; 0.5-0.6% for broilers), threonine (0.6-0.8% for layers; 0.8-1.0% for broilers), and tryptophan (0.2% for both), as well as carbohydrates (50-60% of the diet), fats (3-6%), vitamins A (7,500-12,000 IU/kg), D_3 (2,000-3,000 IU/kg), and E (10-20 mg/kg), plus minerals like calcium (3.5-4.5% for layers; 1% for broilers) and phosphorus (0.45-0.5%). These values are detailed in breed-specific management guidelines. While the composition of alternative feed ingredients varies widely by source, they can supply the essential nutrients required for poultry health, growth, and productivity. Understanding these values is essential for formulating balanced diets. Several plant families provide nutrient-rich by-products and wastes with potential for poultry feeding.

Table 1: Nutrient requirements for layers and broilers based on breed-specific guidelines

Nutrient	Layers Requirement	Broilers Requirement
Protein	16-18%	20-23%
Lysine	0.9-1.1%	1.1-1.3%
Methionine	0.4-0.5%	0.5-0.6%
Threonine	0.6-0.8%	0.8-1.0%
Tryptophan	0.2%	0.2%
Carbohydrates	50-60%	50-60%
Fats	3-6%	3-6%
Vitamin A	7,500-12,000 IU/kg	7,500-12,000 IU/kg
Vitamin D_3	2,000-3,000 IU/kg	2,000-3,000 IU/kg
Vitamin E	10-20 mg/kg	10-20 mg/kg
Calcium	3.5-4.5%	1.0%
Phosphorus	0.45-0.5%	0.45-0.5%

Source: Vlaicu, 2023 [25]

4.4 Utilization of Azolla as a Fodder Source in Poultry Nutrition

Azolla, a fast-growing aquatic fern, has emerged as a cost-effective, nutrient-dense feed supplement for poultry (Figure 2). Containing 20-30% crude protein (dry matter basis), along with essential amino acids, beta-carotene, calcium, and iron, it enhances growth, feed efficiency, and egg production. Research indicates that including Azolla at 10-15% of the diet can boost body weight, improve feed conversion ratio, and increase yolk pigmentation without harming bird health. Its cultivation requires minimal land and water, making it ideal for smallholder and backyard systems pursuing low-input, sustainable production. Incorporating Azolla helps reduce feed costs while supporting circular farming and environmentally friendly poultry management.

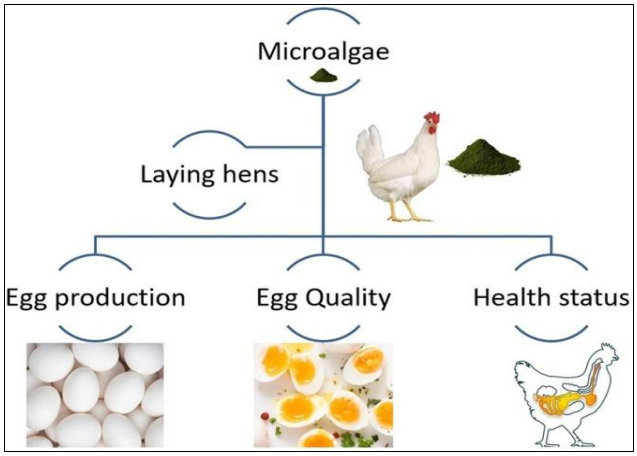

Fig 2: Azolla as an alternative source of protein in poultry diets for sustainable production and disease resistance: present status and future considerations

5. Impact on Poultry Performance

Alternative plant-based feed ingredients can enhance poultry health, productivity, and product quality when used at optimal dosages and preparations. Apiaceae family: Carrot waste and leaves improved egg quality, nutrient digestibility, and production; anise seeds boosted immune function and meat quality; coriander seeds (1.5%) improved dressing percentage; parsley leaves aided heat-stressed hens and enhanced broiler carcass traits; dill leaves improved performance and lipid metabolism. Asteraceae family: Chicory reduced abdominal fat, improved production and egg lipid profiles; calendula flowers increased carcass yield (≤ 1% inclusion); dandelion leaves/meal enhanced meat and egg quality; echinacea supported broiler health. Brassicaceae family: Rapeseed tolerated up to 30% in broilers and < 20% in layers without performance loss; hemp seed by-products improved fatty acid profile and health markers (Panaite, 2022) [14]. Fabaceae family: Alfalfa (5-10%) improved antioxidant content, reduced FCR, mortality, fat yield, and yolk cholesterol; peas (4-48%) replaced soybean meal/corn without affecting meat quality. Allium species: Garlic improved health status, with raw garlic powder enhancing broiler performance but altering meat aroma; onion had similar effects. Zingiberaceae family: Ginger powder reduced gizzard weight, suggesting gut health benefits, without affecting performance.

Overall, well-selected plant ingredients can support poultry growth, health, and product quality while reducing reliance on conventional feeds (Hammod, 2020) [23].

6. Environmental and Economic Benefits

The move toward alternative and sustainable feeding strategies in poultry production is motivated not only by nutritional and animal welfare considerations but also by the urgent need to reduce the environmental and economic impacts of conventional feed systems. As global poultry demand rises, it is increasingly important to adopt practices that lower carbon emissions, conserve resources, and reduce production costs (Marmelstein, 2024) [11].

Research by Osorio *et al*. (2021) [13] shows that using agricultural by-products in poultry feed supports a circular economy by recycling waste materials and reducing the environmental burden of disposal. This practice also decreases the overall carbon footprint of poultry farming.

While the environmental benefits of sustainable feeding are clear, economic feasibility remains crucial for widespread adoption. Costs for alternative feed ingredients are expected to decline as the sustainable feed market grows, production technologies improve, and economies of scale take effect. Increased competition and innovation in processing will further drive accessibility for producers. Additionally, alternative feeds can open new market opportunities and revenue streams (Gómez, 2021) [5].

Consumer trends also play a role: surveys indicate that growing awareness of environmental issues and interest in ethical food are increasing demand for sustainably produced poultry. Farmers adopting green feeding strategies may benefit from premium pricing and expanded market share.

Although shifting away from conventional feeds presents challenges, it offers significant potential to reduce environmental burdens and strengthen economic resilience in the poultry sector. Continued investment in research, technological innovation, and supportive policy frameworks will be essential to unlock these opportunities and promote environmentally friendly poultry production at scale.

6.1 Limitations of Alternative Sustainable Poultry Feeding

Quality control is essential when incorporating unconventional ingredients such as fruit waste or other by-products into poultry diets. While these materials can supply valuable nutrients, their composition is highly variable and may contain anti-nutritional factors.

Nutrient profiles (proteins, fats, fiber, amino acids, fatty acids, and vitamins A, C, E) should be analyzed, as values can fluctuate with growing conditions, harvest stage, and processing (Patra, 2024) [15]. Anti-nutritional compounds like tannins, saponins, phytic acid, and oxalates can impair digestion, reduce mineral absorption, and lower protein utilization.

Digestibility is another concern high-fiber ingredients such as fruit peels can decrease feed efficiency and hinder nutrient absorption if unprocessed. Palatability issues, caused by strong or unfamiliar flavors, odors, or textures, may also reduce intake.

Inclusion rates must be carefully balanced to avoid diluting energy density or overloading diets with indigestible material. While many plant-derived wastes provide antioxidants and fiber, excess amounts can disrupt nutrient balance.

Formulation software and nutritional modeling are recommended to optimize inclusion levels based on detailed nutrient analyses, ensuring sustainable feed ingredients are incorporated safely and effectively.

7. Challenges and Future Directions

Maximizing the benefits of alternative poultry feeds requires supportive policies, research investment, and industry engagement. Key priorities include:

- **Nutritional Optimization:** Improve digestibility, palatability, and nutrient bioavailability of novel ingredients to meet poultry needs cost-effectively.
- **Environmental Assessment:** Use life-cycle analyses to measure carbon footprint, water use, and ecological impacts versus conventional feeds.
- **Economic Viability:** Conduct cost-benefit studies across production scales and assess consumer perceptions to enhance market acceptance.
- **Long-term Health & Productivity:** Evaluate effects on bird health, growth, reproduction, and product quality through extended trials.
- **Policy & Incentives:** Offer grants, tax benefits, or subsidies for infrastructure supporting insect- and plant-based protein production.
- **Research & Collaboration:** Fund feed formulation improvements, scalable production, and long-term studies through academia-industry-government partnerships.
- **Awareness & Training:** Educate farmers, stakeholders, and consumers to overcome resistance and boost demand for sustainably raised poultry.
- **Regulatory Frameworks:** Establish safety, quality, and environmental standards, especially for emerging insect-based feeds.

8. Conclusion

The rapid global growth of poultry production demands innovative and sustainable feeding approaches to overcome the economic, environmental, and supply limitations of conventional feeds such as maize and soybean meal. This review has examined the potential of diverse alternatives including plant-based by-products, insect meals, agro-industrial waste, and food residues as viable substitutes or supplements in poultry nutrition.

When optimally processed and included at appropriate levels, these resources can reduce costs, diversify nutrient supply, and lower the sector's environmental footprint, contributing to a circular economy and enhanced resilience against market volatility. They also have the potential to lessen competition between human food and animal feed while supporting local feed self-sufficiency.

Nevertheless, the successful integration of these feed sources into mainstream poultry production depends on addressing key challenges: variability in nutrient composition, anti-nutritional factors, digestibility, palatability, and the establishment of robust regulatory frameworks. Advanced feed formulation technologies, combined with targeted processing methods, will be essential to overcome these constraints.

Looking ahead, a coordinated effort combining sustained research investment, supportive policy measures, industry engagement, and consumer education will be critical to scaling up sustainable feeding solutions. Achieving a balance between productivity, environmental stewardship, and economic viability will determine the future success of alternative feed systems in global poultry production.

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