ALTERNATIVE PROTEIN SOURCES IN BROILER NUTRITION: NATIONAL OPPORTUNITIES AND GLOBAL CHALLENGES FOR SUSTAINABLE PRODUCTION

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Abstract
Chicken meat is, globally, one of the most efficient sources of animal protein, due to superior feed conversion and the rapid growth rate of poultry species. However, it relies heavily on soybean meal a largely imported resource with significant economic and environmental impact. In the current context, marked by international market volatility and the growing pressure for sustainability, diversifying protein sources has become a strategic priority. This paper analyzes the nutritional composition, economic feasibility, and practical potential of alternative protein sources in broiler nutrition, with a focus on locally available ingredients: sunflower meal, rapeseed meal, and grain legumes (peas, chickpeas, lentils). The advantages and limitations of each source are discussed in the national context, alongside international trends (insect meal and algae-based proteins), and their implications for zootechnical performance, meat quality, and sustainability. The conclusions support the combined use of local ingredients, balanced with synthetic amino acids, as a viable alternative to conventional soybean-based formulations, aiming to reduce feed costs and carbon footprint.

Key words: *broiler nutrition, alternative protein sources, soybean meal replacement, local feed ingredients, sustainability*

INTRODUCTION

Poultry meat has become one of the most widely consumed sources of animal protein worldwide due to its affordability, high nutritional value, and efficient feed conversion [1]. Among poultry species, broiler chickens stand out for their rapid growth rate and superior feed conversion, reaching slaughter weight within just a few weeks [2]. These characteristics have positioned broiler farming as a central pillar of global food security and a key response to the increasing demand for high-quality protein [3]. Protein is an essential nutrient for broilers, playing a decisive role in muscle development, metabolic processes, and overall performance. In commercial diets, soybean meal is used as the reference protein source, due to its high crude protein content and balanced amino acid profile [4]. However, the growing dependency on soybean meal raises economic, ecological, and logistical concerns. A large share of the soybean meal used in Europe is imported often from genetically modified crops in South America an origin associated with deforestation, significant carbon emissions, and price instability [5].

Against this backdrop, the identification and integration of alternative protein sources in broiler nutrition have become a priority for both research and practice [6]. Several locally available ingredients such as sunflower meal, rapeseed meal, and grain legumes (peas, chickpeas, lentils) offer promising nutritional potential and important

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economic viability [7]. In parallel, innovative sources such as insect meal or algae-derived proteins are being tested internationally, although their use remains limited due to high production costs and existing regulatory frameworks [8].

This paper aims to provide a comparative analysis of conventional and alternative protein sources used in broiler nutrition, focusing on nutritional composition, economic impact, and ecological footprint. Special attention is given to the Romanian context, where opportunities exist to enhance feed sustainability and reduce dependence on imported soybean meal through the intelligent use of local agricultural by-products.

MATERIAL AND METHOD

This paper is a narrative review based on a critical analysis of national and international scientific literature concerning the use of alternative protein sources in broiler nutrition. Information was gathered from academic databases such as ScienceDirect, Scopus, Web of Science, PubMed, and Google Scholar, as well as from specialized articles, FAO reports, and technical sources from feed manufacturers and commercial hybrid providers.

The reviewed sources include both conventional protein ingredients (soybean meal) and alternative ones: sunflower meal, rapeseed meal, grain legumes (peas, chickpeas, lentils), insect meal, and algae-based proteins. The information was compared based on nutritional parameters (crude protein content, digestibility, and essential amino acid profile), economic criteria (cost per ton, local availability), and environmental aspects (carbon footprint, land use).

The analysis included both experimental data and theoretical syntheses, with the aim of formulating conclusions applicable to the context of poultry production in Romania.

RESULTS AND DISCUSSIONS

Soybean Meal (SBM) and Its Role in Broiler Nutrition

Soybean meal (SBM) remains the gold-standard protein source in poultry nutrition, serving as the benchmark against which other protein ingredients are evaluated. High-protein soybean meal (dehulled) contains approximately 47–48% crude protein, while standard SBM provides around 44% [4, 9]. Its amino acid profile is excellent rich in lysine (about 2.8–3.0% of dry matter), [10] and well-balanced overall, with methionine being the only limiting amino acid typically supplemented synthetically [11]. Soy protein is highly digestible, with true ileal amino acid digestibility values of around 88–90%, and it is highly palatable to poultry, resulting in superior growth performance [12, 13]. Broiler diets based on conventional corn–soy formulations consistently support rapid growth and efficient feed utilization, achieving final body weights of 2.5–3.0 kg by 6–7 weeks and feed conversion ratios (FCR) of 1.6-1.8-figures that define the performance baseline for modern broiler production [14, 15].

In commercial practice, SBM is included at approximately 25–30% of the diet in starter feeds and 20–25% in grower or finisher feeds [16], depending on the genetic potential of the broiler strain and dietary crude protein requirements. Its inclusion is mainly limited by formulation constraints such as calorie-to-protein balance, cost, and the presence of anti-nutritional factors (ANFs) [17]. However, modern processing methods, including toasting and solvent extraction, effectively inactivate trypsin inhibitors, lectins, and other ANFs [18]. Consequently, residual anti-nutritional factors in commercial SBM are minimal and rarely impair broiler performance [19]. Because of these advantages, soybean meal constitutes the predominant protein source in broiler feeds whenever economically feasible.

From a nutritional standpoint, SBM offers an unparalleled concentration of digestible protein and essential amino acids. [12].

It also provides moderate metabolizable energy (approximately 2.3–2.5 Mcal/kg) and has a relatively low fiber content, which improves nutrient utilization [4, 13]. Its consistent nutrient composition facilitates precise feed formulation, and the presence of minor bioactive compounds such as isoflavones generally has no adverse effects at typical inclusion rates [20].

Despite these advantages, the major limitations of SBM are economic and environmental. It is among the most expensive plant protein sources, and in Romania, a large share of soybean meal is imported, primarily from South and North America [5]. This dependency increases exposure to price volatility, exchange rate fluctuations, and potential supply disruptions [21].

Moreover, global soy cultivation has raised sustainability concerns due to deforestation and intensive land use in major producing regions [22]. Nutritionally, the low methionine content remains the main limiting factor, necessitating supplementation with synthetic amino acids [23]. Additionally, while genetically modified (GM) soybeans are nutritionally equivalent to non-GM varieties, their widespread use may pose marketing challenges for certain production systems emphasizing "non-GMO" or organic standards [24].

Romania's domestic soybean production remains insufficient to meet feed industry demand, despite favorable agro-climatic conditions [25]. The majority of SBM used in broiler diets is imported, which underscores the country's dependence on external protein sources [26]. This situation has spurred research into alternative protein ingredients capable of partially or fully replacing soybean meal without impairing broiler performance. Initiatives such as the European Union's Protein Plan (2018) and Romania's national subsidies for local protein crops aim to enhance self-sufficiency and sustainability in feed protein supply [27, 28].

Broilers raised on alternative protein sources have been widely compared to those fed conventional soybean meal (SBM) diets [29]. Research consistently shows that many of these alternatives can partially replace SBM without compromising body weight, daily gain, or feed conversion ratio (FCR), provided that the diets are properly balanced in amino acids [30, 31]. These findings underline the potential of alternative plant and animal-derived proteins to support efficient broiler production while reducing reliance on imported soybean meal.

Sunflower Meal (SFM)

Given the increasing emphasis on reducing dependence on imported soybean meal, sunflower meal (SFM) has gained growing attention as a locally produced, cost-effective protein source for poultry. Its nutrient composition and complementary amino acid profile make it a promising ingredient for partial replacement of soybean meal in broiler diets, particularly in sunflower-producing regions such as Romania [25, 32]. Sunflower meal, a by-product of sunflower oil extraction, represents a major potential protein ingredient for poultry nutrition [33]. Its crude protein content typically ranges from 28% up to 36%, depending on processing and dehulling; decorticated sunflower meal can reach about 40% crude protein (CP), while underholed meal contains more hull material, leading to higher crude fiber (18–30%) and lower protein [34, 35]. Sunflower protein is relatively rich in sulfur-containing amino acids (methionine + cystine) but deficient in lysine essentially the opposite amino acid profile of soybean meal. This complementary profile allows SFM to be used alongside SBM to improve the methionine balance of the diet [36]. However, because of its lower lysine content and higher fiber, sunflower meal cannot fully replace soybean meal unless supplemented with synthetic lysine [31].

Broiler diets typically include sunflower meal at 5–10% of the ration. At these inclusion levels, growth performance is usually maintained, especially when enzymes are added to improve fiber digestion [33]. New processing technologies such as dehulling to reduce fiber and enzyme supplementation (xylanases, phytase) can enable higher inclusion rates without performance loss. Studies have shown that substituting up to 10% of soybean protein with sunflower protein (equivalent to about 8–12% of the diet) had no adverse effects on final weight or FCR and could even lower feed cost per kilogram of gain [35]. In other experiments, broilers fed diets with 15% sunflower meal supplemented with multi-enzymes performed comparably to those on soy-based diets [37]. Thus, in practice, SFM inclusion can exceed 10% in grower and finisher feeds when the meal is of good quality (low hull content) and diets are properly balanced for lysine and energy [38].

Romania, as one of Europe's leading sunflower seed producers, has abundant access to this by-product, which reduces reliance on imported soy and enhances feed self-sufficiency [39]. Unlike raw soy, sunflower meal contains no trypsin inhibitors and does not require special heat treatment; it is also free from phytoestrogens. SFM has a relatively high methionine content, which can reduce the need for synthetic methionine supplementation when used alongside low-methionine ingredients [40]. Additionally, it contributes valuable minerals such as phosphorus (although much of it is bound in phytate form) and B-vitamins to the diet. The inclusion of sunflower meal combined with phytase can also reduce phosphorus excretion due to improved phytate degradation [41].

The main nutritional limitation of sunflower meal (SFM) is its high fiber content, which lowers dietary energy density and may reduce nutrient digestibility when used at high levels [42, 43] Broilers are particularly sensitive to excessive fiber due to their short digestive tracts, which can increase gut fill and depress growth [12]. In addition, SFM has a relatively low lysine content (typically <1% vs. ~3% in soybean meal), requiring synthetic lysine supplementation [44]. Phenolic compounds such as chlorogenic acid and the presence of phytate may further reduce nutrient utilization, while the nutrient composition of SFM varies with dehulling efficiency and oil extraction method [45,46]. For these reasons, SFM is recommended mainly for grower and finisher phases rather than for starter diets [47]. Sunflower meal (SFM) is a major by-product of Romania's oilseed industry and a readily available local protein source. Although it plays a secondary role to soybean meal in broiler diets, it is incorporated by poultry integrators to reduce feed costs when formulation and market conditions allow [48,49]. Economic evaluations indicate that partial replacement of soybean meal (5–10%) with SFM can lower feed cost per kilogram of gain without impairing feed conversion [50]. Recent Romanian studies report that low-fiber, dehulled SFM combined with phytase improves growth performance and blood parameters in broilers [51,52]. Consequently, SFM represents the most important indigenous plant-protein alternative to soybean meal in Romania, with growing potential as processing efficiency and feed technologies advance [53].

Rapeseed Meal (Canola Meal)

Rapeseed meal (RSM), also known as canola meal from low-glucosinolate "double-zero" rapeseed, is a key vegetable protein source in Europe and Canada [54, 55]. It contains about 34–38% crude protein lower than soybean meal (SBM) but higher than most pulses and provides a balanced amino acid profile, being richer in tryptophan and sulfur amino acids though still limited in lysine [56]. Standard RSM has relatively high fiber (~11–12%), which reduces metabolizable energy and nutrient digestibility for broilers [57].

In broiler diets, RSM is typically used at 10–15% inclusion, maintaining growth and feed efficiency comparable to all-soy diets when amino acid balance is adequate [58]. Inclusion beyond 15–20% can depress performance or affect thyroid metabolism due to residual glucosinolates [59]. Heat treatment and enzyme supplementation improve its nutritional value and safety [60].

Economically, RSM is less expensive than SBM and widely produced in Romania's oilseed sector, reducing dependence on imported soy [61]. It provides valuable minerals (notably phosphorus, much of it in phytate form) and high tryptophan, choline, and selenium contents [62]. Modern low-glucosinolate varieties make it safe for poultry feeding, though excessive inclusion may still reduce palatability or energy density [63]. For these reasons, RSM is recommended at ≤7% in starter and up to 15–20% in grower–finisher phases, balancing local availability and feed cost efficiency [64].

Rapeseed meal (RSM) is readily available from Romania's oil processing sector and is used by feed mills as a complementary protein source [61,65]. It is commonly included in Romanian broiler feed formulas at moderate levels (5–15%), partially replacing soybean meal to reduce feed cost [61]. Experimental data from Romanian and European studies indicate that moderate inclusion levels of rapeseed meal (up to about 15%) can reduce feed costs while maintaining normal growth performance and carcass quality in broilers [64].

The use of rapeseed meal has increased in recent years due to higher national rapeseed production and the European Union's focus on protein diversification [66]. Although some poultry producers in Romania remain cautious particularly when formulating "premium" feeds recent studies indicate that moderate inclusion of low-glucosinolate rapeseed meal does not negatively affect growth performance or meat quality when diets are properly balanced [**Eroare! Marcaj în document nedefinit.**,67]. With the adoption of modern double-zero (low-erucic, low-glucosinolate) rapeseed cultivars widely grown in Europe, the nutritional quality and safety of RSM have improved substantially [68,69]. Overall, rapeseed meal represents a cost-effective local protein alternative to soybean meal in Romania, provided inclusion levels are optimized to avoid anti-nutritional effects [61].

Peas (Field Peas)

Field peas (Pisum sativum) are among the most widely used grain legumes in European poultry feeding and have potential as a local protein source in Romania [70]. Dried peas contain approximately 22–25% crude protein, 40–50% starch, and 6–8% fibre, offering both protein and energy to broiler diets [71]. Pea protein is rich in lysine (>1.6% of DM), complementing cereal-based feeds that are typically lysine-deficient, though peas remain limiting in methionine and cystine. In addition, peas contain B-vitamins and minerals, moderate levels of anti-nutritional factors (ANFs) such as tannins and trypsin inhibitors, and low levels of oligosaccharides compared to raw soybeans or faba beans, especially in newer low-tannin cultivars [72].

Broiler feeding trials have demonstrated that peas can replace up to 20% of the diet without affecting growth performance or feed conversion, provided that diets are balanced for methionine [73]. When used at 10–15%, peas are generally well tolerated and can maintain carcass yield and meat quality [74]. Research conducted under Romanian conditions using Pisum sativum cv. Tudor reported that inclusion up to 15–20% did not adversely affect growth, blood parameters, or intestinal morphology, when amino acid balance was maintained [75]. Higher inclusions (20–30%) may be feasible but require methionine supplementation and proper energy balance to avoid digestive issues [73]. In starter diets, peas at 5–10% are recommended, while 10–20% is suitable for grower and finisher phases if economically justifies [76].

Peas have several advantages for sustainable broiler feeding. Their high lysine content allows partial replacement of soybean meal and may reduce the need for synthetic lysine supplementation [1-6]. Recent comparative studies have also shown that substituting soybean meal with peas can maintain growth performance while reducing the environmental footprint of broiler production [77]. Economically, when soy prices rise or local pea yields are high, they can become a cost-competitive alternative [78].

The main limitations are related to amino acid balance and ANFs [79]. Peas are deficient in methionine and cystine, thus requiring supplementation. The presence of tannins and oligosaccharides can impair nutrient digestibility and cause mild digestive disturbances at high inclusion levels. Pea composition is variable depending on cultivar and environmental conditions, and feeding very high levels (>20%) can sometimes lead to wetter litter or softer pellets, due to higher soluble fiber and starch content [80].

In Romania, pea cultivation has expanded since 2013 due to EU protein crop support programs. Peas are grown both for human consumption and as rotational crops, with feed-grade peas being available for livestock nutrition [5]. Although peas are used more commonly in pig and ruminant diets, several Romanian studies confirm their feasibility in broiler feeding [81]. However, competition with human food markets and year-to-year price variation can limit their inclusion in feed. When available at competitive prices, peas can be included at 10–15% in broiler diets to reduce soybean meal dependency and support sustainable, locally sourced feed production [82].

Chickpeas, Lentils and Lupins

Grain legumes such as chickpeas (Cicer arietinum), lentils (Lens culinaris), and lupins (Lupinus spp.) are gaining interest as local protein sources for sustainable poultry feeding in Mediterranean and Eastern European regions, including Romania [83]. These crops provide valuable plant protein (typically 20–40% CP) and lysine-rich amino acid profiles that complement cereal-based diets [84].

Chickpeas contain about 20–24% crude protein and are rich in lysine and arginine but low in methionine [85]. Lentils have slightly higher protein (24–26%) and similar lysine content, while white and narrow-leaf lupins contain 30–40% crude protein and up to 10% oil [84,86]. In feeding trials, chickpeas can replace up to 50% of soybean protein (~15–20% of diet) without affecting growth or FCR when diets are balanced for methionine [87]. Lentils are safely included up to 10–15% and up to 20% in grower–finisher phases, while sweet lupins are tolerated up to 7–10% and occasionally 15–20% when dehulled or enzyme-supplemented [88,89].

These legumes supply high-quality, non-GM protein and energy from starch or oil, improving feed autonomy and diversification. They are palatable, support nitrogen fixation in cropping systems, and can lower feed costs or carbon footprint when locally sourced [86,88]. Chickpeas and lentils improve dietary lysine levels and may enhance meat lipid profile, while lupins contribute additional energy via unsaturated fats [90].

All three are deficient in methionine and cystine and contain some anti-nutritional factors (trypsin inhibitors, tannins, oligosaccharides, alkaloids in lupin). Heat treatment, dehulling, or enzyme supplementation can mitigate these issues [87, 88].

Chickpea and lentil cultivation is increasing in southern and western Romania, though still limited [91]. Romanian studies confirm the feasibility of incorporating up to 15–20% chickpeas or 20% lentils in broiler diets without adverse effects [92]. White lupin trials at 7.5% inclusion produced performance comparable to soy-fed controls while improving feed efficiency [89]. These crops thus represent viable local protein alternatives that could reduce reliance on imported soybean meal, particularly in sustainable and non-GM poultry systems [90].

Insect and Algae-Based Proteins in Broiler Nutrition

Insect-derived and microalgal meals have gained increasing attention as alternative, sustainable protein sources in poultry feeding. Insects such as black soldier fly (BSF, Hermetia illucens) and mealworms (Tenebrio molitor) provide nutrient-dense protein (40–60% CP) with a balanced amino acid profile, including relatively high methionine and lysine contents (1–3) [93,94]. Defatted BSF meal can reach over 60% crude protein and contains bioactive compounds like lauric acid and chitin, which may support gut health and immunity [95]. Inclusion levels of 5–15% BSF meal in broiler diets typically sustain growth and feed conversion comparable to soybean-based controls, and moderate supplementation (5–10%) may even enhance gut morphology and reduce pathogenic load [96,97].

Insect meal's main advantages are its high digestibility, favorable amino acid balance, and natural compatibility with poultry diets. Environmentally, insect farming requires minimal land and water, and can upcycle organic byproducts, offering potential for local circular-feed systems in countries such as Romania [98]. However, high production costs and limited availability currently restrict commercial use to experimental or niche feeds. EU regulations now permit seven insect species in poultry feed, paving the way for gradual adoption as production scales up [99,100].

Similarly, spirulina (Arthrospira platensis) has emerged as a high-protein (60–70% CP) and functional ingredient for broilers. When included at 1–2% of diet, spirulina enhances antioxidant capacity, immune response, and skin pigmentation, owing to its content of phycocyanin, carotenoids, and γ-linolenic acid [101]. Higher inclusion (up to 5%) can still sustain performance but may affect palatability or cause carcass discoloration if excessive pigments accumulate [102]. Spirulina is thus better suited as a feed additive rather than a bulk protein source [103].

In Romania, both insect and microalgal proteins remain at the experimental stage; small-scale projects exist, but large-scale inclusion in broiler feeds is limited by production costs [104].

Considering these aspects, it is important to emphasize that the nutritional value of protein sources depends primarily on the content and proportion of essential amino acids. Although animal-derived proteins are recognized for their superior quality and high supply of essential amino acids, similar performance can also be achieved when alternative proteins including those from insects and microalgae are used in combination with other protein sources, so that limiting amino acids are compensated for. Through a balanced diet formulation, the mixture of proteins can ensure the optimal requirements for the biosynthesis of body proteins, regardless of the individual origin of the ingredients [105].

Omnivores consider animal products the only true source of vitamin B12, since plant foods contain only B12 analogues that differ in structure and are poorly absorbed. Vitamin B12 from food exists as a B12 protein complex that must be hydrolyzed in the stomach and then bind to intrinsic factor for absorption. Because intrinsic factor is not produced in the colon, any B12 synthesized by the microbiota is excreted.

Thus, vegans are at risk of B12 deficiency, which can cause megaloblastic anemia and neurological symptoms such as numbness, tingling, disorientation, hallucinations, and muscle weakness. To prevent deficiency, vegans need B12 supplements; folic acid supplements may mask the deficiency until body stores are severely depleted [106].

CONCLUSIONS

Diversifying protein sources in broiler nutrition is no longer optional it's both a national priority and a global challenge. Heavy dependence on soybean meal has created structural risks that go beyond animal nutrition. Global price volatility, environmental damage from deforestation in major soy-producing regions, and geopolitical tensions all threaten the stability and sustainability of poultry production worldwide.

Romania faces these same pressures, but it also has clear opportunities. The country's well-established oilseed sector provides consistent access to sunflower and rapeseed meals cost-effective alternatives that can replace a significant portion of soybean meal without sacrificing broiler performance. In addition, the cultivation of grain legumes like peas, chickpeas, lentils, and lupins supports greater feed autonomy, improves soil fertility through nitrogen fixation, and aligns with European sustainability goals. When incorporated into well-balanced diets, these crops can maintain growth rates and feed efficiency comparable to soy-based feeds, especially when amino acid profiles are carefully adjusted.

Looking ahead, novel protein sources like insect meal and microalgae offer promising options for long-term sustainability. Insects such as Hermetia illucens (black soldier fly) and Tenebrio Molitor (mealworm) deliver high-quality protein with a favorable amino acid balance and a minimal environmental footprint. Meanwhile, microalgae like Arthrospira platensis (spirulina) contribute not just protein, but functional compounds with antioxidant and immune-boosting effects. While high production costs and technological barriers limit large-scale adoption for now, these options align closely with the EU Green Deal and circular bioeconomy principles. They represent an important step toward future protein self-sufficiency.

Still, no single ingredient can replace soybean meal entirely. Success will depend on a strategic mix of conventional and alternative proteins, backed by sound nutritional planning, enzyme use, and targeted amino acid supplementation. Equally important is the need to link feed innovation with agricultural policy and local production capabilities. Coordinated action across sectors will be key to building a more resilient poultry industry.

In short, sustainable broiler nutrition depends on matching Romania's local strengths with broader environmental and food security goals. Oilseed meals and legumes already offer practical, scalable alternatives to soy. At the same time, emerging sources like insect meal and microalgae point to what's possible in a more circular, climate-smart feed system. By investing in a balanced and locally grounded approach, Romania's poultry sector can reduce soy dependence, lower environmental impact, and help shape a more secure and sustainable food future.

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