lipidology

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Review

Lipid Sources in Poultry Diets: Metabolic Effects, Physiological Implications, and Modulation of Egg Yolk Fatty Acid Composition

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Abstract

Lipids play a central role in poultry nutrition by modulating energy utilization, nutrient digestibility, and metabolic processes related to lipid absorption and deposition. This review synthesizes current knowledge on the main dietary lipid sources used in poultry nutrition and their effects on performance, lipid metabolism, and egg yolk fatty acid composition. Conventional lipid sources, including vegetable oils and animal fats, differ in fatty acid profile, degree of saturation, and digestibility, which directly influence metabolic efficiency and productive responses. In addition, the strategic use of lipid sources enables the modulation of fatty acid profiles in poultry products, particularly through the enrichment of polyunsaturated fatty acids such as omega-3. These effects are associated with mechanisms involving lipid digestion, absorption, and hepatic lipoprotein synthesis, which regulate fatty acid deposition in tissues and egg yolks. However, responses to dietary lipids are influenced by factors such as inclusion level, oxidative stability, and lipid composition. Overall, dietary lipid manipulation represents an effective strategy to optimize production efficiency and enhance the nutritional quality of poultry-derived foods.

Keywords: fatty acid digestibility; feed efficiency; lipoprotein metabolism; nutritional modulation; polyunsaturated fatty acids (PUFAs)

1. Introduction

Poultry production, particularly egg production, continues to expand globally as a result of the increasing demand for affordable nutritional enhancement. Eggs are widely consumed in both their whole form and as ingredients in processed foods, which makes them an excellent vehicle for nutritional improvement. Because the fatty acid profile of egg yolk responds rapidly and consistently to dietary lipid composition, eggs represent an effective platform for enriching human diets with polyunsaturated fatty acids (PUFAs), including omega-3 fatty acids [1–3].

Dietary lipids serve multiple functions in poultry nutrition. Beyond supplying essential fatty acids, they contribute substantially to dietary energy density, improve feed palatability, facilitate the absorption of fat-soluble vitamins, and support physiological processes related to membrane integrity, oxidative balance, and immune function [4,5]. Because lipids generate less metabolic heat during digestion compared with carbohydrates, their inclusion in poultry diets can also support thermal comfort and performance under heat-stress conditions [6].

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Academic Editor: Dirk Dannenberger

Received: 27 March 2026
Revised: 19 May 2026
Accepted: 5 June 2026
Published: 7 June 2026

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The nutritional and functional value of dietary lipids depend on their fatty acid composition, degree of saturation, positional distribution on the glycerol backbone, and digestibility characteristics. These biochemical attributes directly influence how efficiently lipids are emulsified, hydrolyzed, absorbed, and metabolically utilized by birds, ultimately affecting growth performance, metabolic responses, and the deposition of fatty acids in egg yolks [7]. Differences in lipid digestibility and metabolizable energy among oils and fats highlight the importance of evaluating lipid sources not only by chemical composition but also by their nutritional availability to the animal.

Given the diversity of lipid sources used in poultry diets, a comprehensive understanding of their metabolic roles and physiological effects is essential for optimizing both animal performance and the nutritional quality of animal-derived products intended for human consumption.

Therefore, this review aims to discuss lipid sources used in poultry nutrition, their metabolic roles, and their effects on productive performance and egg fatty acid composition, with primary emphasis on chickens, particularly broilers and laying hens, due to the greater availability of scientific literature in these production systems.

Studies included in this review were identified through searches in scientific databases such as Scopus, Web of Science, PubMed, and Google Scholar, prioritizing peer-reviewed studies related to lipid sources, fatty acid metabolism, poultry performance, and egg yolk fatty acid modulation in poultry production systems.

2. Role of Dietary Lipids in Poultry Nutrition

The available literature highlights the growing scientific interest in the use of lipid sources in poultry nutrition. Dietary lipids are not only important energy sources but also play a key role in improving nutrient utilization, modulating lipid metabolism, and enhancing the fatty acid composition of poultry products. In recent years, research has increasingly focused on strategies to manipulate the fatty acid profiles of eggs and poultry meat through dietary interventions, particularly by including lipid sources rich in polyunsaturated fatty acids (PUFAs) [8,9].

In addition to their well-established roles in energy supply and nutrient utilization, dietary lipids also play important roles in neural function and oxidative balance. Polyunsaturated fatty acids, particularly long-chain n-3 fatty acids such as docosahexaenoic acid (DHA), are essential structural components of neuronal membranes and are involved in synaptic function, neurodevelopment, and signal transduction. Furthermore, lipids are closely associated with antioxidant processes, as they influence membrane stability and susceptibility to lipid peroxidation. The presence of lipid-soluble antioxidants, such as tocopherols, contributes to protecting cellular structures against oxidative damage, reinforcing the importance of lipid quality in poultry diets [10,11].

In addition to their energetic contribution, lipids influence key metabolic processes, including β-oxidation of fatty acids, hepatic lipogenesis, lipoprotein synthesis and transport, and cellular signaling pathways associated with energy homeostasis [9]. The inclusion of lipid sources in poultry diets can affect feed efficiency, nutrient digestibility, and the metabolic utilization of fatty acids, ultimately influencing animal performance. Consequently, dietary lipid supplementation has been widely investigated as a nutritional strategy to optimize poultry production while improving the fatty acid profile of poultry products.

Lipids perform essential functions in animal nutrition, primarily acting as concentrated sources of energy and playing an important role in metabolic regulation. In poultry diets, lipids contribute not only to energy availability but also participate in the synthesis of prostaglandins and steroid hormones, which are involved in several physiological processes [12]. Despite their chemical diversity, lipids share the common characteristic of

being insoluble in water, allowing them to function as carriers of fat-soluble vitamins and other bioactive compounds, including fat-soluble vitamins (A, D, E, and K), phospholipids, sterols, and antioxidant molecules such as tocopherols [13]. Due to their high energy density, lipid sources are widely used in poultry diets to improve the energetic balance and overall efficiency of feed formulations [14].

However, the magnitude and nature of these responses are highly dependent on the biochemical characteristics and digestibility of the lipid sources, which directly influence their metabolic utilization and subsequent deposition in animal products.

Therefore, the selection of lipid sources in poultry diets should also consider cost-effectiveness, balancing nutritional benefits, inclusion levels, and market price variability to ensure economically sustainable production. In practical poultry diets, lipid inclusion levels commonly vary according to bird category, age, production phase, dietary energy targets, and ingredient costs. In broiler diets, fats and oils are frequently included to increase dietary energy density and improve feed efficiency, whereas in laying hens, lipid supplementation is also used to support egg production, yolk formation, and fatty acid modulation. Therefore, defining the appropriate lipid level requires balancing energy supply, digestibility, oxidative stability, pellet quality, and economic viability.

3. Biochemical Characteristics of Lipid Sources

In practical feeding systems, lipid ingredients are generally categorized into two main groups: vegetable oils and animal fats [15]. Although lipids offer several nutritional advantages, their stability and quality must be carefully considered in feed formulations. Unsaturated fatty acids present in lipid sources are particularly susceptible to oxidative processes during storage and feed processing [16]. Lipid oxidation can negatively affect feed quality by altering sensory characteristics such as color, taste, and texture, as well as by producing potentially harmful compounds that reduce the nutritional value of diet [17]. Therefore, maintaining the stability and quality of lipid sources is essential to ensure the effectiveness of their inclusion in poultry diets.

To mitigate lipid oxidation in poultry diets, the inclusion of antioxidants is a common and effective strategy. Lipid-soluble antioxidants, particularly tocopherols (vitamin E), play a central role in protecting unsaturated fatty acids from peroxidation during feed storage and digestion [11,13]. In addition, synthetic antioxidants such as butylated hydroxytoluene (BHT) and ethoxyquin are widely used in feed formulations to improve oxidative stability [11]. The effectiveness of antioxidant supplementation depends on factors such as lipid source, degree of unsaturation, storage conditions, and processing methods, highlighting the importance of combining high-quality lipid sources with appropriate antioxidant strategies to maintain feed quality and animal performance.

Lipid sources used in animal nutrition vary considerably in their chemical composition and nutritional value depending on their origin, raw material quality, extraction methods, and storage conditions [18]. These factors directly influence lipid stability, oxidative susceptibility, and nutritional availability, reinforcing the importance of properly evaluating lipid sources in feed formulation [17].

Among the lipid sources commonly used in non-ruminant animal nutrition are soybean oil, sunflower oil, canola oil, corn oil, poultry fat, cottonseed oil, flaxseed oil, fish oil, pork fat, and beef tallow [19] (Figure 1). These lipid sources differ in fatty acid composition and nutritional characteristics, which influence lipid metabolism, nutrient digestibility, and fatty acid deposition in poultry products such as eggs and meat.

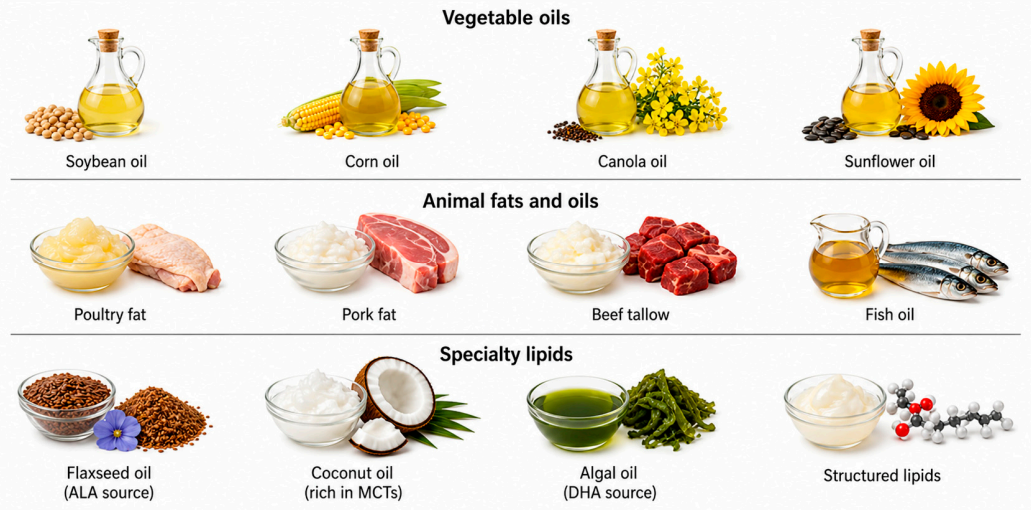


Figure 1. Representative lipid sources commonly used in poultry diets, including vegetable oils (soybean, corn, canola, and sunflower oils), animal fats (poultry fat, pork fat, beef tallow, and fish oil), and selected specialty lipids (e.g., flaxseed oil, coconut oil, and algal oil). Although some specialty lipids are of plant origin, they are categorized based on their functional and metabolic properties. *This figure was generated using artificial intelligence tools and refined by the authors to ensure scientific accuracy.*

In poultry nutrition, vegetable oils and animal fats present distinct fatty acid profiles, digestibility characteristics, and metabolic effects in birds. In general, vegetable oils are richer in unsaturated fatty acids, whereas animal fats tend to contain higher proportions of saturated fatty acids. These differences are critical for energy utilization, lipid metabolism, and the modulation of egg yolk fatty acid composition, and will be discussed in detail in the following sections.

3.1. Vegetable Oils

Soybean oil is one of the primary lipid sources used in poultry production due to its high energy value and favorable fatty acid composition. It consists predominantly of triglycerides and provides approximately 8790 kcal/kg of apparent metabolizable energy for poultry [19], making it an efficient dietary energy source. From a nutritional perspective, soybean oil is highly digestible due to its high proportion of unsaturated fatty acids, which typically account for approximately 85% of its total lipid content, with linoleic acid as the predominant fatty acid, followed by oleic and linolenic acids [20]. In addition, soybean oil contains tocopherols (vitamin E), which contribute to its antioxidant properties [16].

Corn oil is another lipid source used in poultry nutrition, characterized by a high proportion of unsaturated fatty acids and considerable energy value. Its fatty acid profile is predominantly composed of linoleic acid (48.02%) and oleic acid (34.68%), with smaller amounts of saturated fatty acids such as palmitic (12.5%) and stearic acids (2.11%) [21]. This composition contributes to its nutritional value and suitability as a dietary energy source. In addition, corn oil presents relatively good oxidative stability compared with other lipid sources, which may contribute to improved storage and feed quality [22].

Canola oil is widely used in animal nutrition and is characterized by a favorable fatty acid profile, with a low proportion of saturated fatty acids (approximately 7%) and a high content of monounsaturated fatty acids, particularly oleic acid, which accounts for around 61% of its total fatty acid composition [23,24]. Additionally, canola oil contains moderate levels of omega-3 fatty acids, generally ranging from 6 to 14%, contributing to its nutritional value. Due to this balanced fatty acid composition, canola oil represents an important dietary source of essential fatty acids, including α-linolenic acid (C18:3).

Sunflower oil is another commonly used vegetable oil in poultry diets and is characterized by a high proportion of unsaturated fatty acids, particularly oleic and linoleic acids [25]. However, it contains relatively low levels of α-linolenic acid, resulting in a high omega-6/omega-3 ratio [26]. This characteristic may influence the fatty acid balance of poultry diets, particularly when sunflower oil is used as the primary lipid source. In addition, sunflower oil contains considerable amounts of vitamin E, which contributes to its antioxidant capacity and oxidative stability.

In contrast to the previously mentioned vegetable oils, which are predominantly rich in long-chain unsaturated fatty acids, coconut oil presents a distinct lipid profile characterized by a high proportion of saturated medium-chain fatty acids, particularly lauric acid. These medium-chain fatty acids are rapidly hydrolyzed and absorbed, as they do not require micelle formation for intestinal uptake, which may enhance energy utilization under certain dietary conditions. Studies have shown that coconut oil supplementation can influence growth performance, feed efficiency, and antioxidant status in poultry, although responses may vary depending on inclusion level and dietary composition. Due to its unique metabolic characteristics, coconut oil represents a functional lipid source rather than a conventional energy ingredient, and its use in poultry diets is often associated with specific physiological and metabolic responses [27,28].

In contrast to vegetable oils, which are predominantly characterized by high levels of unsaturated fatty acids, animal fats generally present a greater proportion of saturated fatty acids and more variable physicochemical properties. These differences directly influence lipid digestibility, metabolic utilization, and energy availability in poultry diets. Therefore, understanding the specific characteristics of animal-derived lipid sources is essential for optimizing their use in feed formulations and evaluating their effects on poultry metabolism and product quality.

3.2. Animal Fats

Poultry fat is obtained from the separation of abdominal and gizzard fat during poultry processing and represents a potential alternative lipid source in feed formulations, particularly as a partial substitute for vegetable oils. As a byproduct of the poultry industry, its use also contributes to the efficient utilization of processing residues, supporting more sustainable production systems [29]. In general, poultry fat accounts for approximately 1.3% to 1.6% of the bird's body weight, with slightly higher proportions observed in females [30].

From a nutritional perspective, poultry fat presents a distinct fatty acid profile compared with vegetable oils, with a relatively higher proportion of saturated fatty acids, which may reduce lipid digestibility under certain dietary conditions [31]. However, compared with other animal fats, such as pork fat and beef tallow, poultry fat generally contains higher levels of unsaturated fatty acids. Its composition is mainly characterized by oleic, palmitic, and linoleic acids, with polyunsaturated fatty acids representing approximately 40% of the total lipid fraction [32].

These compositional characteristics influence their nutritional value and suitability as a dietary energy source in poultry diets. In addition, poultry fat is often economically advantageous compared with vegetable oils, which may contribute to reducing feed costs while maintaining adequate dietary energy levels [33].

Beef tallow and pork fat are also commonly used animal-derived lipid sources in poultry nutrition and are generally characterized by higher proportions of saturated fatty acids, particularly palmitic and stearic acids. This higher saturation level is associated with lower digestibility compared with vegetable oils and more unsaturated lipid sources, especially in young birds with limited digestive capacity. As a result, the inclusion of these fats may require careful formulation strategies, such as blending with unsaturated oils or

the use of emulsifiers, to improve lipid utilization and energy availability. Despite these limitations, beef tallow and pork fat can be valuable energy sources due to their availability and relatively low cost, contributing to more economical feed formulations when properly balanced [34,35].

In contrast to other animal fats, fish oil is characterized by a high content of long-chain n-3 polyunsaturated fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids play important roles in modulating lipid metabolism, inflammatory responses, and membrane function. In poultry nutrition, fish oil is primarily used not as a conventional energy source but as a functional lipid ingredient aimed at enriching poultry products, especially eggs, with omega-3 fatty acids. However, its inclusion must be carefully managed, as high levels may negatively affect feed palatability, oxidative stability, and egg sensory characteristics [36,37].

In addition to conventional lipid sources such as vegetable oils and animal fats, alternative lipid ingredients (commonly referred to as specialty lipids), have gained increasing attention in poultry nutrition. These sources are typically characterized by unique fatty acid profiles or functional properties, which may offer specific nutritional and metabolic advantages when included in poultry diets.

3.3. Specialty Lipids

Specialty lipids comprise non-conventional or functionally classified lipid sources that are included in poultry diets primarily for their specific metabolic and physiological properties rather than their origin. Although some of these lipids, such as flaxseed oil and coconut oil, are of plant origin, they are categorized as specialty lipids due to their unique fatty acid profiles and targeted functional effects. Certain lipid sources can influence immune function depending on their fatty acid composition, as essential fatty acids play a key role in cellular processes involved in immune responses.

In addition, medium-chain fatty acids are characterized by rapid digestion and absorption, as they are readily hydrolyzed by pancreatic lipase and do not require micelle formation for intestinal uptake. Furthermore, structured lipids are designed to provide specific fatty acid profiles, allowing more precise nutritional modulation and improving the delivery of targeted fatty acids in poultry diets [38].

Lipid sources rich in omega-3 fatty acids have been widely explored in poultry nutrition due to their ability to modulate lipid metabolism and improve the fatty acid composition of eggs. Among these, flaxseed and its derivatives are important sources of α-linolenic acid, contributing to improved yolk lipid profiles and immune-related parameters without negatively affecting productive performance when included at moderate levels [39,40]. Fish oil represents a traditional source of long-chain n-3 polyunsaturated fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and is highly effective in increasing their deposition in egg yolks. However, its inclusion is generally limited to low levels (e.g., 1–3%) due to potential negative effects on feed palatability, oxidative stability, and egg sensory characteristics [41,42].

More recently, algal oil has gained increasing attention as a direct and sustainable source of DHA. As microalgae are the primary producers of long-chain n-3 fatty acids, algal oil represents a more consistent and potentially sustainable alternative to fish oil. Its inclusion (typically 0.5–2%) has been shown to effectively enhance DHA deposition in egg yolks without compromising production performance or egg quality and may offer advantages in terms of oxidative stability and sensory characteristics [43,44].

In addition to omega-3-rich sources, other specialty lipids have been explored in poultry nutrition due to their functional and metabolic properties. Medium-chain fatty acids are characterized by rapid digestion and absorption, as they do not require micelle

formation for intestinal uptake, which may improve energy utilization under specific dietary conditions. In this context, lipid sources such as coconut oil have been associated with improvements in growth performance, feed efficiency, and antioxidant status, as well as modifications in egg characteristics under certain inclusion levels [27,45].

Specifically, structured or functional lipids are designed to provide targeted fatty acid profiles, allowing more precise nutritional modulation and potentially enhancing lipid utilization [46]. Although these lipid sources are not commonly used as primary energy ingredients, they may be strategically included in poultry diets to optimize metabolic efficiency and support specific nutritional objectives.

The diversity in biochemical characteristics among lipid sources directly influences their digestion, absorption, and metabolic utilization in poultry. These differences are also reflected in their practical application, inclusion levels, and effects on productive performance and egg yolk fatty acid composition, as summarized in Table 1.

Table 1. Main dietary lipid sources used in poultry nutrition, their inclusion levels, and effects on performance and egg yolk fatty acid composition.

Lipid Source	Main Fatty Acids	Typical Inclusion Level (%)	Main Nutritional/Metabolic Role	Reported Effects	Effects on Egg Yolk Fatty Acid Profile	References
Soybean oil	Linoleic, oleic, linolenic acids	2–6	Highly digestible energy source; source of essential fatty acids	May improve feed efficiency and energy utilization	Increases omega-6 PUFAs deposition	[41,47]
Canola oil	Oleic and α-linolenic acids	2–5	Source of MUFAs and moderate n-3 fatty acids	May support performance and egg quality	Can improve yolk unsaturated FAs profile	[48,49]
Sunflower oil	Linoleic and oleic acids	2–5	Energy source rich in unsaturated fatty acids	Maintains performance depending on inclusion level	Increases omega-6 PUFAs; high omega-6:omega-3 ratio	[35,50,51]
Poultry fat	Oleic, palmitic, linoleic acids	2–6	Economical energy source; intermediate saturation profile	Can maintain performance when properly formulated	Limited/moderate effect depending on FAs profile	[34,52]
Beef tallow/pork fat	Palmitic, stearic, oleic acids	2–5	Energy source richer in saturated FAs	May reduce digestibility at higher levels	Limited enrichment of PUFAs	[34,35]
Fish oil	EPA and DHA	1–3	Direct source of long-chain n-3 PUFAs	Variable effects; excessive levels may affect quality/sensory traits	Strongly increases yolk EPA/DHA	[36,37]
Algal oil	DHA	0.5–3	Sustainable direct DHA source	Generally maintains performance and egg quality	Strongly increases yolk DHA	[43,44]
Coconut oil	Medium-chain fatty acids, lauric acid	1–4	Rapidly absorbed lipid source; functional effects	May improve antioxidant status and energy utilization	Limited FA enrichment; may alter egg traits	[27,28]

PUFAs = Polyunsaturated fatty acids; MUFAs = Monounsaturated fatty acids; FAs = Fatty acids; EPA = Eicosapentaenoic acid; DHA = Docosahexaenoic acid.

4. Lipid Digestion, Absorption, and Metabolism in Poultry

The digestibility of lipids is a key factor determining the efficiency of fatty acid absorption in poultry, directly influencing productive performance, physiological health, and the quality of animal-derived products [18,38]. Variations in fatty acid composition, degree of saturation, and molecular structure affect lipid digestion and metabolic utilization, thereby influencing their effectiveness as dietary energy sources.

Lipids are primarily composed of fatty acids, which are typically present as triglycerides consisting of three fatty acids esterified to a glycerol backbone [25]. In most lipid sources used in animal nutrition, triglycerides represent approximately 90% of the lipid fraction. During digestion, these compounds are hydrolyzed in the intestinal lumen by pancreatic lipases, generating free fatty acids, monoglycerides, and glycerol [53].

Lipid digestion in poultry occurs in an aqueous environment and therefore requires emulsification to increase the surface area available for enzymatic action. Bile salts secreted by the liver play a central role in this process by dispersing lipid droplets and facilitating lipase activity. The presence of lipids in the small intestine stimulates the release of digestive secretions, including bile and pancreatic enzymes, which are essential for efficient lipid hydrolysis [54,55].

The products of lipid digestion combine with bile salts to form micelles, which transport lipids through the intestinal lumen to the microvilli, where absorption occurs. Fatty acids, monoglycerides, cholesterol, and fat-soluble vitamins are then absorbed by enterocytes, a process facilitated by intracellular transport proteins [52,56]. Once absorbed, the metabolic fate of fatty acids depends largely on their carbon chain length. Short-chain fatty acids and glycerol are transported directly to the portal circulation, whereas long-chain fatty acids are re-esterified within enterocytes before further metabolic utilization.

The efficiency of lipid digestion and absorption is influenced by several factors, including fatty acid saturation, carbon chain length, positional distribution within triglycerides, and the proportion of free fatty acids. In general, unsaturated fatty acids are more efficiently emulsified, incorporated into micelles, and absorbed than saturated fatty acids, which contributes to higher digestibility and improved metabolizable energy values in poultry diets. Long-chain saturated fatty acids may be less efficiently absorbed because of their lower solubility and greater tendency to form insoluble complexes in the intestinal lumen. In contrast, the presence of monoglycerides can enhance micelle formation and facilitate the incorporation of lipids into absorbable complexes [12,57].

At the cellular and molecular levels, lipid metabolism in poultry is tightly regulated by coordinated processes of fatty acid transport, intracellular trafficking, and hepatic lipid synthesis. The uptake of long-chain fatty acids into enterocytes is mediated by membrane-associated transport proteins such as cluster of differentiation 36 (CD36) and fatty acid-binding proteins (FABPs), which facilitate both transmembrane transport and intracellular lipid trafficking [52].

Once absorbed, fatty acids are re-esterified and transported to the liver, the primary site of lipogenesis in birds [9]. Hepatic lipid metabolism is regulated by key transcription factors, including peroxisome proliferator-activated receptors (PPARs), which promote fatty acid oxidation, and sterol regulatory element-binding proteins (SREBPs), which control lipogenesis and lipid synthesis pathways [9,58]. In laying hens, the liver plays a central role in the production of very low-density lipoproteins (VLDL), which are structurally adapted for selective uptake by ovarian follicles. These VLDL particles are transported via the bloodstream to the ovary, where they are internalized by developing oocytes and contribute directly to egg yolk lipid deposition [46]. This mechanism represents a fundamental physiological distinction between avian and mammalian species, as lipogenesis in birds occurs predominantly in the liver, whereas in mammals it is largely localized in adipose tissue [9]. These regulatory and transport processes collectively determine the efficiency of lipid utilization and the deposition of fatty acids in poultry tissues and egg yolks.

The main mechanisms involved in lipid digestion, absorption, hepatic metabolism, and yolk fatty acid deposition in poultry are summarized in Figure 2. These processes directly influence how different lipid sources affect nutrient utilization, physiological responses, and productive performance in poultry.

Variability in reported lipid digestibility values among studies may be associated with differences in fatty acid composition, dietary formulation, bird age and physiological stage, inclusion level, oxidative status of lipid sources, and methodological approaches used to estimate digestibility coefficients.

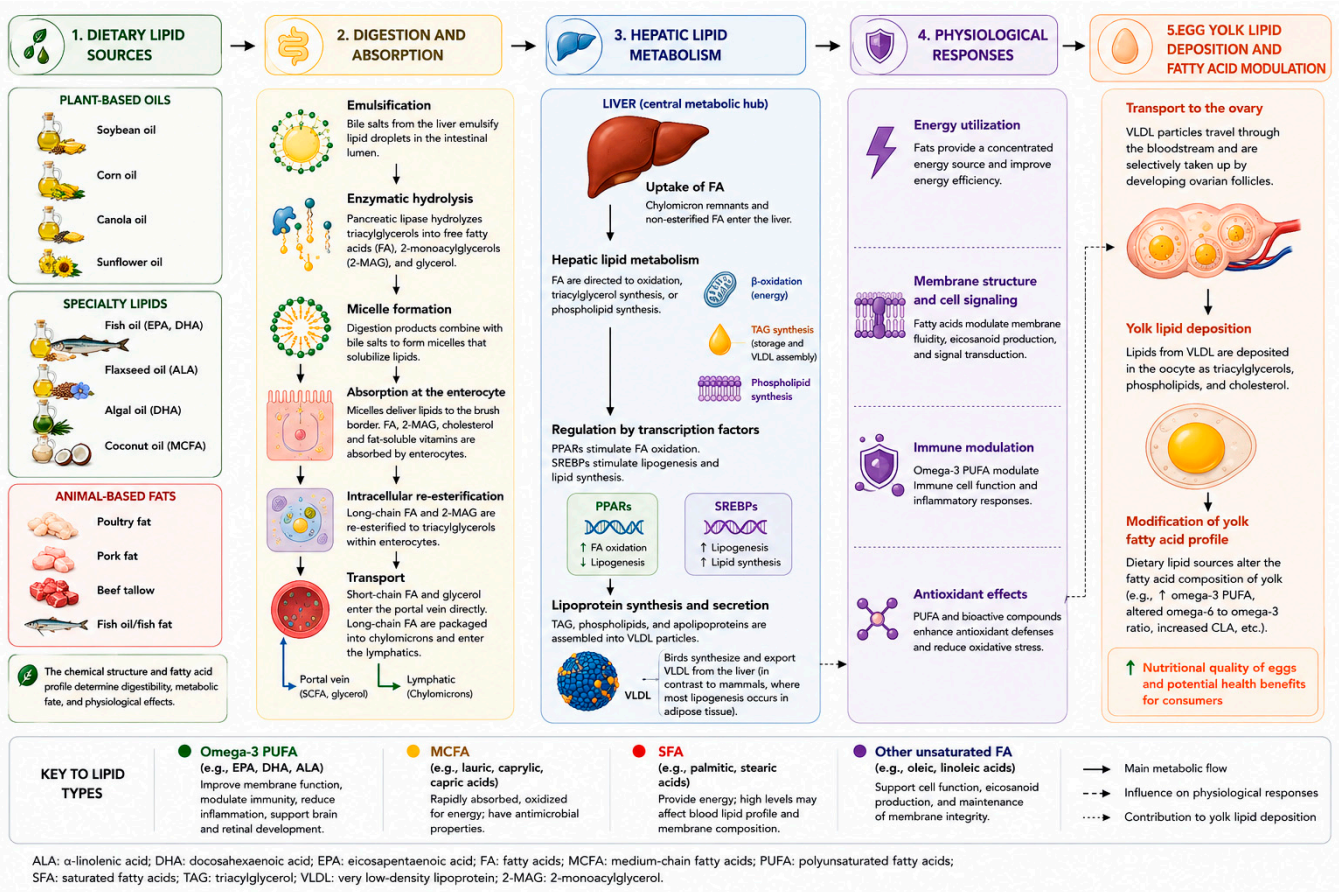


Figure 2. Schematic representation of the main mechanisms involved in lipid digestion, absorption, hepatic metabolism, physiological responses, and egg yolk lipid deposition and fatty acid modulation in poultry. Different dietary lipid sources may influence fatty acid utilization, lipoprotein synthesis, immune modulation, antioxidant responses, and yolk lipid composition according to their biochemical characteristics and fatty acid profiles. *This figure was generated with the assistance of artificial intelligence tools and subsequently reviewed and refined by the authors to ensure scientific accuracy.*

5. Effects of Lipid Sources on Physiological Responses and Productive Performance

Beyond their energetic contribution, dietary lipids influence several physiological functions in poultry. They can slow gastrointestinal transit, improve nutrient absorption, and participate in the synthesis of eicosanoids, which regulate metabolic and immune processes [59]. Among these, lipids contribute to vascular integrity and enhance feed palatability by reducing dustiness and improving particle aggregation, which may positively affect feed intake and overall performance. Due to these multiple roles, the inclusion of fats and oils in poultry diets has been widely investigated in both broilers and laying hens [60–62]. The practical implications of different lipid sources on poultry performance and product quality are summarized in Table 1.

The productive responses of poultry to dietary lipid supplementation depend on several factors, including inclusion level, fatty acid composition, and lipid quality. For example, improvements in broiler performance have been reported with increasing levels of soybean oil during growth and finishing phases [63]. However, lipid inclusion must be carefully managed, as excessive levels or poor oxidative stability may negatively affect feed quality and animal performance [24]. Additionally, the chemical structure of fatty acids, including their presence as triglycerides or free fatty acids, influences digestibility and metabolic utilization in poultry [64].

In practical terms, dietary lipid supplementation has been associated with improvements in feed efficiency, energy utilization, and growth performance in broilers, as well as enhanced egg production and egg quality in laying hens [5,27,39,45]. Lipid sources rich in unsaturated fatty acids may contribute to improved metabolic efficiency and health status, whereas saturated fats are generally less digestible and may result in lower performance under certain conditions. However, these responses are not universally consistent. The magnitude and direction of effects vary depending on lipid source, fatty acid composition, inclusion level, bird age, and basal diet characteristics. In general, lipid sources rich in unsaturated fatty acids, such as soybean and canola oils, are associated with improved digestibility and energy utilization due to enhanced micelle formation and intestinal absorption. In contrast, sources with higher proportions of saturated fatty acids, such as beef tallow and pork fat, may present reduced digestibility, particularly in young birds with limited bile salt secretion and lipase activity or when used at higher inclusion levels. These findings highlight that the effects of dietary lipids are context-dependent and reinforce the importance of selecting appropriate lipid sources according to production goals and physiological requirements.

Additionally, omega-3-rich lipid sources, including flaxseed, fish oil, and algal oil, are more specifically associated with modifications in egg yolk fatty acid composition, particularly increasing the deposition of α-linolenic acid, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), rather than consistently improving performance parameters. Variability among studies may also be attributed to differences in oxidative stability, experimental design, and duration of feeding trials.

Therefore, the effects of dietary lipids should not be interpreted as inherently uniform, but rather as context-dependent responses influenced by both nutritional characteristics of the lipid source and physiological conditions of the birds [65]. In addition to their metabolic effects, dietary lipids may also influence intestinal health and function. Certain fatty acids, particularly unsaturated and medium-chain fatty acids, have been associated with improved intestinal integrity, modulation of inflammatory responses, and enhanced nutrient absorption. These effects may contribute to improved gut health and overall physiological resilience in poultry, potentially reducing the need for therapeutic interventions under specific production conditions.

6. Dietary Lipids and Egg Yolk Fatty Acid Modulation

In laying hens, dietary lipid supplementation has been associated with improvements in egg production parameters, particularly egg and yolk weight. These effects are largely related to the presence of linoleic acid, which stimulates the synthesis of triacylglycerols and lipoproteins in the liver. These lipoproteins are subsequently transported to the ovary, contributing to follicular development and yolk formation [66].

Beyond productive responses, dietary lipids play a central role in modulating the fatty acid composition of egg yolks. The fatty acid profile of eggs reflects the composition of the diet, allowing targeted nutritional strategies to enhance the quality of poultry products. Studies have demonstrated that different lipid sources, including vegetable oils and animal fats, can influence the deposition of polyunsaturated fatty acids and improve the omega-6:omega-3 ratio in poultry products [67].

Therefore, the enrichment of eggs with omega-3 fatty acids has received considerable attention due to its implications for human nutrition. This can be achieved through the inclusion of lipid sources rich in α-linolenic acid, such as flaxseed oil, or direct sources of long-chain polyunsaturated fatty acids, such as fish oil and algal oil, which provide eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) [64]. Laying hens have the

physiological capacity to efficiently incorporate dietary fatty acids into egg yolks, making them an effective biological system for producing value-added foods [38,68].

The nutritional relevance of this strategy is closely linked to human health, as essential fatty acids such as linoleic (omega-6) and α-linolenic (omega-3) acids cannot be synthesized by the human body and must be obtained through the diet [69]. Conversely, omega-3 fatty acids have been associated with protective effects against several chronic diseases, while an imbalance in the omega-6:omega-3 ratio may contribute to metabolic and inflammatory disorders [50,51,70,71]. Therefore, improving the fatty acid profile of poultry products through dietary manipulation represents an effective strategy to enhance the nutritional quality of foods and contribute to a more balanced intake of essential fatty acids in human diets.

7. Limitations and Research Gaps

Despite the substantial body of literature evaluating lipid sources in poultry nutrition, several limitations remain that constrain a comprehensive and integrative understanding of their effects. A major limitation is the considerable variability in experimental conditions among studies, including differences in bird genotype, age, production phase, dietary composition, lipid inclusion levels, and environmental conditions. This heterogeneity limits direct comparisons across studies and contributes to inconsistent or contradictory findings.

Similarly, a large proportion of studies focus primarily on performance outcomes, such as growth rate, feed efficiency, and egg production, while providing limited insight into the underlying metabolic and molecular mechanisms regulating lipid utilization and deposition. As a result, the interpretation of observed responses often lacks mechanistic support, particularly regarding hepatic regulation of lipid metabolism, lipoprotein dynamics, and fatty acid partitioning. Another important limitation is the lack of standardization in methodologies used to evaluate lipid digestibility, metabolizable energy, and fatty acid deposition, which further complicates the comparison of results across studies. Moreover, interactions between lipid sources and other dietary components, such as emulsifiers, antioxidants, protein levels, and feed processing conditions, are not consistently addressed, despite their potential influence on lipid utilization and oxidative stability.

Similarly, most available studies are conducted under controlled experimental conditions and focus on short-term responses, which may not fully represent commercial production systems or long-term metabolic adaptations in poultry. There is also limited information regarding emerging and sustainable lipid sources, such as insect-derived oils and microalgae, particularly in terms of their economic viability, long-term effects, and impact on product quality. Future research should prioritize more integrative and standardized experimental approaches, combining performance evaluation with mechanistic analyses at the molecular and physiological levels. In addition, greater emphasis should be placed on long-term studies, the interaction between lipid sources and dietary components, and the development of precision nutrition strategies aimed at optimizing both production efficiency and the nutritional quality of poultry-derived foods.

8. Conclusions

Dietary lipid sources play a central role in poultry nutrition by modulating energy utilization, digestibility, and metabolic pathways involved in lipid absorption and deposition. Differences in fatty acid composition, degree of saturation, and molecular structure among vegetable oils and animal fats directly influence nutrient utilization and metabolizable energy, ultimately affecting bird performance and product quality. In laying hens, these effects are closely associated with hepatic lipoprotein synthesis and transport, which regulate the deposition of dietary fatty acids into the egg yolk. The strategic inclusion of lipid sources enables the modulation of fatty acid profiles in poultry products, particularly

through the enrichment of polyunsaturated fatty acids such as omega-3, representing an effective approach to producing foods with improved nutritional value. However, responses to dietary lipids depend on factors such as inclusion level and oxidative stability, highlighting the importance of selecting appropriate lipid sources to optimize production efficiency and enhance the nutritional quality of poultry-derived foods. Future research should focus on the integration of precision nutrition strategies, including the use of lipid sources tailored to specific production phases and physiological conditions. Additionally, emerging sustainable lipid sources, such as insect-derived oils and microalgae, represent promising alternatives that require further investigation. Understanding the molecular mechanisms regulating lipid metabolism in poultry will be essential to optimize both production efficiency and the nutritional quality of animal-derived foods.

Author Contributions: Conceptualization, J.K.V., A.A.d.A., H.F.d.O. and R.G.G.; writing-original draft preparation, J.K.V., A.A.d.A. and R.G.G.; writing-review and editing, H.F.d.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: We would like to express our sincere gratitude to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil (Finance Code 001), for their support. We also extend our heartfelt appreciation to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the research grants (PQ 304806/2022-6) and the Early Career Postdoctoral Fellowship (PDJ)—Call No. 2021/2023 (Process: 150188/2022-6) and Call No. 32/2023 (Process: 177286/2023-7), which were instrumental in making this research possible.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
PUFAs	Polyunsaturated fatty acids
MUFAs	Monounsaturated fatty acids
FA	Fatty acids
BHT	Butylated hydroxytoluene
FABPs	Fatty acid-binding proteins
PPARs	Peroxisome proliferator-activated receptors
SREBPs	Sterol regulatory element-binding proteins
VLDL	Very low-density lipoproteins

References

1. Barzegar, S.; Wu, S.B.; Choct, M.; Swick, R.A. Metabolizable energy of corn, soybean meal, and wheat for laying hens. *Poult. Sci.* **2019**, *98*, 5876–5882. [CrossRef]
2. Omri, B.; Chalghoumi, R.; Izzo, L.; Ritieni, A.; Lucarini, M.; Durazzo, A.; Santini, A. Effect of dietary incorporation of linseed alone or together with tomato-red pepper mix on laying hens' egg yolk fatty acids profile and health lipid indexes. *Nutrients* **2019**, *11*, 813. [CrossRef]
3. Ngo Njembe, M.T.; Girard, A.; Larroque, H.; Rougière, N.; Lessire, M.; Narcy, A.; Bouvarel, I. The egg yolk content in omega-3 and conjugated fatty acids can be sustainably increased upon long-term feeding of laying hens with a diet containing flaxseeds and pomegranate seed oil. *Foods* **2021**, *10*, 1134. [CrossRef]

4. Fonseca, S.S.; da Silva, V.C.; Valentim, J.K.; Geraldo, A. Efeito da adição de diferentes emulsificantes na dieta sobre o rendimento de carcaça de frangos de corte. *Rev. Acad. Ciênc. Anim.* **2018**, *16*, 1–13. [CrossRef]
5. Oliveira, M.V.G.; Silva, J.M.S.; Batista, J.M.M.; Cafe, M.B.; Mello, H.H.C.; Oliveira, H.F.; Pires, M.F.; Leandro, N.S.M.; Jacob, D.V. Evaluation of the effects of an emulsifier and two lipid sources on growth performance and intestinal morphology of broiler chickens. *Rev. Bras. Zootec.* **2024**, *53*, e20230087. [CrossRef]
6. Silva, S.N.; De Castro, M.L.S.; Gomes, B.C.K.; Bavaresco, C.; Dias, R.C.; Roll, A.A.P.; Lopes, D.C.N.; Roll, V.F.B.; Rutz, F.; Junior, J.S.; et al. Arroz integral e complexo enzimático na dieta de codornas japonesas. *Rev. Cient. Rural.* **2019**, *21*, 372–387. [CrossRef]
7. Araújo, R.R.S.; Benfica, T.A.R.S.; Ferraz, V.P.; Santos, E.M. Nutritional composition of insects *Gryllus assimilis* and *Zophobas morio*: Potential foods harvested in Brazil. *J. Food Compos. Anal.* **2019**, *76*, 22–26. [CrossRef]
8. Cantor, A.H.; Decker, E.A.; Collins, V.P. Fatty acids in poultry and egg products. In *Fatty Acids in Foods and Their Health Implications*; Marcel Dekker Inc.: New York, NY, USA, 2000; pp. 125–151.
9. Nguyen, P.; Leray, V.; Diez, M.; Serisier, S.; Bloc'h, J.L.; Siliart, B.; Dumon, H. Liver lipid metabolism. *J. Anim. Physiol. Anim. Nutr.* **2008**, *92*, 272–283. [CrossRef] [PubMed]
10. Weiser, M.J.; Butt, C.M.; Mohajeri, M.H. Docosahexaenoic Acid and Cognition throughout the Lifespan. *Nutrients* **2016**, *8*, 99. [CrossRef] [PubMed]
11. Wang, J.; Si, W.; Du, Z.; Zhang, J.; Xue, M. Antioxidants in Animal Feed. *Antioxidants* **2022**, *11*, 1760. [CrossRef]
12. Lara, L.J.C.; Baião, N.C.; Aguilar, C.A.L.; Cançado, S.V.; Fiuza, M.A.; Ribeiro, B.R.C. Efeito de fontes lipídicas sobre o desempenho de frangos de corte. *Arq. Bras. Med. Vet. Zootec.* **2005**, *57*, 792–798. [CrossRef]
13. Pop, F.; Mihalescu, L. Effects of α-tocopherol and citric acid on the oxidative stability of alimentary poultry fats during storage at low temperatures. *Int. J. Food Prop.* **2017**, *20*, 1085–1096. [CrossRef]
14. Calixto, R.C.; Costa, L.V.; Júnior, J.D.M.; Moura, M.I.; Duarte, F.O.S. Desempenho de frangos de corte alimentados com dietas contendo óleo de soja. *Braz. J. Anim. Environ. Res.* **2020**, *3*, 670–684. [CrossRef]
15. Valentim, J.K.; Campos, A.L.; Pereira, B.C.; Oliveira, A.S.; Mendes, M.S. Uso de emulsificante e óleo de macaúba em dietas para poedeiras comerciais e seus efeitos sobre desempenho e qualidade de ovos. *Rev. Cient. Rural* **2018**, *20*, 275–286.
16. Muramatsu, K.; Stringhini, J.H.; Café, M.B.; Jardim Filho, R.M.; Andrade, L.; Godoi, F. Desempenho, qualidade e composição de ácidos graxos do ovo de poedeiras comerciais alimentadas com rações formuladas com milho ou milheto contendo diferentes níveis de óleo vegetal. *Acta Sci. Anim. Sci.* **2005**, *27*, 43–48. [CrossRef]
17. Costa, F.A.D.; Tavernari, F.C.; Dalla Costa, O.A.; Castro, F.F.; Remus, A. Enriquecimento com ácidos graxos da série ômega 3 em carne de aves e ovos. *Pubvet* **2017**, *11*, 113–123. [CrossRef]
18. Bavaresco, C.; Nunes, A.P.; Forgiarini, J.; Alves, D.A.; Xavier, E.G.; Lopes, D.C.N.; Roll, V.F.B. Morfometria intestinal e qualidade óssea de codornas japonesas alimentadas por um período prolongado com coprodutos do óleo de soja. *Arch. Vet. Sci.* **2019**, *24*, 72–82. [CrossRef]
19. Valentim, J.K.; Garcia, R.G.; Burbarelli, M.F.D.C.; Caldara, F.R.; Komiyama, C.M.; Serpa, F.C.; Albino, L.F.T. Energy values and metabolizability of lipid sources of plant and animal origin in the diet of Japanese quail. *Rev. Bras. Zootec.* **2023**, *52*, e20220105. [CrossRef]
20. Almeida, A.A.; Valentim, J.K.; Silva, A.C.D.; Moraleco, D.D.; Zanella, J.; Fonseca, L.D.S. Dietary lipid sources for growing rabbits: A review on animal health and productivity. *Cienc. Anim. Bras.* **2023**, *24*, e-75704E. [CrossRef]
21. White, P.J.; Pollak, L.M.; Duvick, S. Improving the fatty acid composition of corn oil by using germplasm introgression. *Lipid Technol.* **2007**, *19*, 35–38. [CrossRef]
22. Balić, A.; Vlašić, D.; Žužul, K.; Marinović, B.; Bukvić Mokos, Z. Omega-3 versus Omega-6 Polyunsaturated Fatty Acids in the Prevention and Treatment of Inflammatory Skin Diseases. *Int. J. Mol. Sci.* **2020**, *21*, 741. [CrossRef]
23. Lin, L.; Allemekinders, H.; Dansby, A.; Campbell, L.; Durance-Tod, S.; Berger, A.; Jones, P.J.H. Evidence of health benefits of canola oil. *Nutr. Rev.* **2012**, *71*, 370–385. [CrossRef]
24. Reda, F.M.; El-Kholy, M.; El-Hack, M.A.; Taha, A.; Othman, S.; Allam, A.; Alagawany, M. Does the use of different oil sources in quail diets impact their productive and reproductive performance, egg quality, and blood constituents? *Poult. Sci.* **2020**, *99*, 3511–3518. [CrossRef]
25. Khatun, J.; Loh, T.C.; Akit, H.; Foo, H.L.; Mohamad, R. Fatty acid composition, fat deposition, lipogenic gene expression and performance of broiler fed diet supplemented with different sources of oil. *Anim. Sci. J.* **2017**, *88*, 1406–1413. [CrossRef]
26. Martin, C.A.; Almeida, V.V.; Ruiz, M.R.; Visentainer, J.E.L.; Matsushita, M.; Souza, N.E.; Visentainer, J.V. Ácidos graxos poliinsaturados ômega-3 e ômega-6: Importância e ocorrência em alimentos. *Rev. Nutr.* **2006**, *19*, 761–770. [CrossRef]
27. Elewa, M.S.; Abou-Kassem, D.E.; El-Hindawy, M.M.; Madkour, M.; Elsharkawy, M.S.; Afifi, M.; Alagawany, M. Effect of coconut oil on growth performance, carcass criteria, liver and kidney functions, antioxidants and immunity, and lipid profile of broilers. *Sci. Rep.* **2023**, *13*, 13974. [CrossRef]
28. Gao, Z.; Qin, Y.; Zheng, J.; Xu, G. Effects of the Oil and Fat Feeding Period on the Nutritional Composition and Functional Prop-erties of Eggs. *Agriculture* **2024**, *14*, 181. [CrossRef]

29. Peña-Saldarriaga, L.M.; Fernández-López, J.; Pérez-Álvarez, J.A. Quality of chicken fat by-products: Lipid profile and color properties. *Foods* **2020**, *9*, 1046. [CrossRef] [PubMed]
30. Henriques, J.K.; Rodrigues, R.B.; Lazzari, R. Caracterização e uso das farinhas de abatedouros de aves em dietas para peixes. *Acta Tecnol.* **2018**, *12*, 103–115. [CrossRef]
31. Paula, K.L.C.; Pinheiro, S.R.F.; Valentim, J.K.; Castiblanco, D.M.C.; Santos, A.S.; Dallago, G.M.; Almeida, V.G.; Miranda, D.A. Sources of conjugated linoleic acid and lauric acid inoculated into the eggs of quails and its effects on immunity. *Semin. Ciênc. Agrár.* **2021**, *42*, 1759–1772. [CrossRef]
32. Sanches, L.E.F.; Hayashi, C. Substituição do óleo de soja pelo óleo de vísceras de aves, em rações para alevinos de tilápia do Nilo. *Pubvet* **2019**, *13*, 162. [CrossRef]
33. Martins, R.A.; Assunção, A.S.A.; Lima, H.J.D.; Martins, A.C.S.; Souza, L.A.Z. Óleo de soja e sebo bovino na ração de poedeiras semipesadas criadas em regiões de clima quente. *Bol. Ind. Anim.* **2017**, *74*, 51–57. [CrossRef]
34. Doppenberg, J.; Van der Aar, P.J. (Eds.) *Facts about fats: A Review of the Feeding Value of Fats and Oils in Feeds for Swine and Poultry*; Wageningen Academic Publishers: Wageningen, The Netherlands, 2010. [CrossRef]
35. Çelebi, Ş.; Karaoğlu, M. Effects of Various Fat Sources Added into the Diets of Laying Hens on Calcium and Phosphorus Metabolism. *J. Agri. Pro.* **2024**, *5*, 163–169. [CrossRef]
36. Li, L.; Zhang, F.; Meng, X.; Cui, X.; Ma, Q.; Wei, Y.; Liang, M.; Xu, H. Fish Oil Replacement with Poultry Oil in the Diet of Tiger Puffer (*Takifugu rubripes*): Effects on Growth Performance, Body Composition, and Lipid Metabolism. *Aquac. Nutr.* **2022**, *2022*, 2337933. [CrossRef]
37. Ghaderi-Chaparabad, H.; Mirghelenj, S.A.; Payvastegan, S.; Khalilvandi-Behroozyar, H.; Zadeh, A.M. Effects of the Different Dietary Fish Oil Calcium Salt on Production Performance, Blood Biochemical Parameters, Egg Quality Traits and Yolk Fatty Acid Profile in Laying Hens at Peak Production Period. *Vet. Med. Sci.* **2025**, *6*, e70610. [CrossRef] [PubMed]
38. Alagawany, M.; Elnesr, S.S.; Farag, M.R.; Abd El-Hack, M.E.; Khafaga, A.F.; Taha, A.E.; Tiwari, R.; Yatoo, M.I.; Bhatt, P.; Khurana, S.K.; et al. Omega-3 and Omega-6 Fatty Acids in Poultry Nutrition: Effect on Production Performance and Health. *Animals* **2019**, *9*, 573. [CrossRef] [PubMed]
39. Antruejo, A.; Azcona, J.O.; Garcia, P.T.; Gallinger, C.; Rosmini, M.; Ayerza, R.; Coates, W.; Perez, C.D. Omega-3 enriched egg production: The effect of α-linolenic ω-3 fatty acid sources on laying hen performance and yolk lipid content and fatty acid composition. *Br. Poult. Sci.* **2011**, *52*, 750–760. [CrossRef] [PubMed]
40. Attia, Y.A.; Al-Harthi, M.A.; Sagan, A.A.A.; Abdulsalam, N.M.; Hussein, E.O.S.; Olal, M.J. Egg Production and Quality, Lipid Metabolites, Antioxidant Status and Immune Response of Laying Hens Fed Diets with Various Levels of Soaked Flax Seed Meal. *Agriculture* **2022**, *12*, 1402. [CrossRef]
41. Gao, Z.; Zhang, J.; Li, F.; Zheng, J.; Xu, G. Effect of Oils in Feed on the Production Performance and Egg Quality of Laying Hens. *Animals* **2021**, *11*, 3482. [CrossRef]
42. Kralik, G.; Kralik, Z.; Grčević, M.; Galović, O.; Hanžek, D.; Biazik, E. Fatty acid profile of eggs produced by laying hens fed diets containing different shares of fish oil. *Poult. Sci.* **2021**, *100*, 101379. [CrossRef]
43. Maina, A.N.; Lewis, E.; Kiarie, E.G. Egg production, egg quality, and fatty acids profiles in eggs and tissues in Lohmann LSL lite hens fed algal oils rich in docosahexaenoic acid (DHA). *Poult. Sci.* **2023**, *102*, 102921. [CrossRef]
44. Chang, Y.; Xuan, Y.; Zhang, R.; Ding, X.; Zeng, Q.; Wang, J.; Bai, S.; Li, S.; Liu, Y.; Chen, Y.; et al. Effects of Dietary Schizochytrium Algae as ω-3 PUFA Source on the Egg-Laying Quail Performance, Serum Indexes, and Egg Yolk Fatty Acids Contents. *Animals* **2025**, *15*, 21. [CrossRef]
45. Dong, X.F.; Liu, S.; Tong, J.M. Comparative Effect of Dietary Soybean Oil, Fish Oil, and Coconut Oil on Performance, Egg Quality and Some Blood Parameters in Laying Hens. *Poult. Sci.* **2018**, *97*, 2460–2472. [CrossRef]
46. Van Eck, L.M.; Enting, H.; Carvalhido, I.J.; Chen, H.; Kwakkel, R.P. Lipid metabolism and body composition in long-term producing hens. *World's Poult. Sci. J.* **2023**, *79*, 243–264. [CrossRef]
47. Saleh, A.A.; Alharthi, A.S.; Alhotan, R.A.; Atta, M.S.; Abdel-Moneim, A.-M.E. Soybean Oil Replacement by Poultry Fat in Broiler Diets: Performance, Nutrient Digestibility, Plasma Lipid Profile and Muscle Fatty Acids Content. *Animals* **2021**, *11*, 2609. [CrossRef]
48. Gallardo, M.A.; Pérez, D.D.; Leighton, F.M. Modification of fatty acid composition in broiler chickens fed canola oil. *Biol. Res.* **2012**, *45*, 149–161. [CrossRef] [PubMed]
49. Gul, M.; Yoruk, M.A.; Aksu, T.; Kaya, A.; Kaynar, O. The Effect of Different Levels of Canola Oil on Performance, Egg Shell Quality and Fatty Acid Composition of Laying Hens. *Int. J. Poult. Sci.* **2012**, *11*, 769–776. [CrossRef]
50. Koçer, B.; Bozkurt, M.; Ege, G.; Tüzün, A.E. Effects of sunflower meal supplementation in the diet on productive per-formance, egg quality and gastrointestinal tract traits of laying hens. *Br. Poult. Sci.* **2021**, *62*, 101–109. [CrossRef] [PubMed]
51. Ruan, D.; Dai, Z.; Fouad, A.M.; Zhang, Y.; Li, C.; Wang, S.; Huang, X.; Li, K.; Sun, Y.; You, J.; et al. Effects of dietary sunflower meal supplementation on productive performance, antioxidative capacity, lipid metabolism, and gut microbiota in laying ducks. *Anim. Feed Sci. Technol.* **2022**, *285*, 115215. [CrossRef]

52. Oketch, E.O.; Wickramasuriya, S.S.; Oh, S.; Choi, J.S.; Heo, J.M. Physiology of lipid digestion and absorption in poultry: An updated review on the supplementation of exogenous emulsifiers in broiler diets. *J. Anim. Physiol. Anim. Nutr.* **2023**, *107*, 1429–1443. [CrossRef]
53. Moraes, P.D.O.; Gopinger, E.; Bavaresco, C.; Catalan, A.A.S.; Dias, R.C.; Xavier, E.G. Desempenho produtivo, qualidade de ovos e características ósseas de codornas alimentadas com farelo e óleo de canola. *Acta Sci. Anim. Sci.* **2017**, *39*, 97–102. [CrossRef]
54. Alzawqari, M.; Moghaddam, H.N.; Kermanshahi, H.; Raji, A.R. The effect of desiccated ox bile supplementation on performance, fat digestibility, gut morphology and blood chemistry of broiler chickens fed tallow diets. *J. Appl. Anim. Res.* **2011**, *39*, 169–174. [CrossRef]
55. Rodrigues, J.F.; Cavali, J.; Bulcão, L.F.A. Lipídeos: Classificação e principais funções fisiológicas. *Rev. Electron. Vet.* **2017**, *18*, 1–14.
56. Rocha, J.S.R.; Lara, L.J.C.; Baião, N.C.; Cançado, S.V.; Triginelli, M.V.; Leite, J.F.C. Efeito da classificação dos ovos sobre o rendimento de incubação e os pesos do pinto e do saco vitelino. *Arq. Bras. Med. Vet. Zootec.* **2008**, *60*, 979–986. [CrossRef]
57. Raber, M.R.; Ribeiro, A.M.L.; Kessler, A.M.; Arnaiz, V. Suplementação de glicerol ou de lecitina em diferentes níveis de ácidos graxos livres em dietas para frangos de corte. *Ciênc. Anim. Bras.* **2009**, *10*, 745–753.
58. Zhu, L.; Liao, R.; Huang, J.; Yan, H.; Xiao, C.; Yang, Y.; Wang, H.; Yang, C. The miR-216/miR-217 Cluster Regulates Lipid Me-tabolism in Laying Hens With Fatty Liver Syndrome via PPAR/SREBP Signaling Pathway. *Front. Vet. Sci.* **2022**, *9*, 913841. [CrossRef]
59. Oliveira, M.L.M.; Pinheiro, D.C.S.N. Biomarcadores celulares e moleculares envolvidos na resposta imune-inflamatória modulada por ácidos graxos insaturados. *Acta Vet. Bras.* **2013**, *7*, 113–124. [CrossRef]
60. Costa, F.G.P.; Souza, C.J.; Goulart, C.C.; Lima Neto, R.C.; Costa, J.S.; Pereira, W.E. Desempenho e qualidade dos ovos de poedeiras semipesadas alimentadas com dietas contendo óleos de soja e canola. *Rev. Bras. Zootec.* **2008**, *37*, 1412–1418. [CrossRef]
61. Duarte, F.D.; Lara, L.; Baião, N.; Cançado, S.; Teixeira, J. Efeito da inclusão de diferentes fontes lipídicas em dietas para frangos de corte sobre o desempenho, rendimento e composição da carcaça. *Arq. Bras. Med. Vet. Zootec.* **2010**, *62*, 439–444. [CrossRef]
62. Ismail, I.B.; Al-Busadah, K.A.; El-Bahr, S.M. Effect of dietary supplementation of canola oil on egg production, quality and biochemistry of egg yolk and plasma of laying hens. *Int. J. Biol. Chem.* **2013**, *7*, 27–37. [CrossRef]
63. Andreotti, M.O.; Junqueira, O.M.; Barbosa, M.J.B.; Cancherini, L.C.; Araújo, L.F.; Rodrigues, E.A. Tempo de trânsito intestinal, desempenho, característica de carcaça e composição corporal de frangos de corte alimentados com rações isoenergéticas formuladas com diferentes níveis de óleo de soja. *Rev. Bras. Zootec.* **2004**, *33*, 870–879. [CrossRef]
64. Brito, C.O.; Junior, V.R.; Del Vesco, A.P.; Tavernari, F.d.C.; Calderano, A.A.; Silva, C.M.; Maciel, J.T.d.L.; de Azevedo, M.S.P. Metabolizable energy and nutrient digestibility of shrimp waste meal obtained from extractive fishing for broilers. *Anim. Feed. Sci. Technol.* **2020**, *263*, 114467. [CrossRef]
65. Valentim, J.K.; Garcia, R.G.; Burbarelli, M.F.C.; Léo, R.A.R.; Sousa, R.F.; Calderano, A.A.; Lima, I.L.; Nascimento, K.M.R.d.S.; da Silva, T.R.; Albino, L.F.T. Nutritional, Productive, and Qualitative Characteristics of European Quails Fed with Diets Containing Lipid Sources of Plant and Animal Origin. *Animals* **2023**, *13*, 3472. [CrossRef]
66. Wang, S.H.; Wang, W.-W.; Zhang, H.-J.; Wang, J.; Chen, Y.; Wu, S.-G.; Qi, G.-H. Conjugated linoleic acid regulates lipid metabolism through the expression of selected hepatic genes in laying hens. *Poult. Sci.* **2019**, *98*, 4632–4639. [CrossRef]
67. Alexandra, P.; Murakami, A.E.; Matsushita, M.; Visentainer, J.V.; Martins, E.N.; Furlan, A.C. Perfil lipídico e maciez da carne de coxa e sobrecoxa de frangos de corte alimentados com rações contendo diferentes fontes lipídicas. *Rev. Bras. Zootec.* **2010**, *39*, 1774–1783. [CrossRef]
68. Keum, M.C.; An, B.-K.; Shin, K.-H.; Lee, K.-W. Influence of dietary fat sources and conjugated fatty acids on egg quality, yolk cholesterol, and yolk fatty acid composition of laying hens. *Rev. Bras. Zootec.* **2018**, *47*, e20170303. [CrossRef]
69. Martins, T.S.; de Lemos, M.V.A.; Mueller, L.F.; Baldi, F.; de Amorim, T.R.; Ferrinho, A.M.; Muñoz, J.A.; Fuzikawa, I.H.d.S.; de Moura, G.V.; Gemelli, J.L.; et al. Fat deposition, fatty acid composition, and its relationship with meat quality and human health. In *Meat Science and Nutrition*; Arshad, M.S., Ed.; IntechOpen: London, UK, 2018; pp. 17–37. [CrossRef]
70. Saini, R.K.; Keum, Y.S. Omega-3 and omega-6 polyunsaturated fatty acids: Dietary sources, metabolism, and significance—A review. *Life Sci.* **2018**, *203*, 255–267. [CrossRef]
71. Watanabe, Y.; Tatsuno, I. Omega-3 polyunsaturated fatty acids focusing on eicosapentaenoic acid and docosahexaenoic acid in the prevention of cardiovascular diseases: A review of the state-of-the-art. *Expert Rev. Clin. Pharmacol.* **2021**, *14*, 79–93. [CrossRef] [PubMed]

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