Review Article

Beneficial Effects of n-3 Fatty Acids as Feed Additive on Broiler Chicken

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ABSTRACT Omega-3 polyunsaturated fatty acids (n-3 PUFA) associated with several health advantages for prevention of human diseases. The Western diet tends to have high omega-6 polyunsaturated fatty acid (n-6 PUFA) and low n-3 PUFA, indicating that the required consumption of these essential fatty acids is rarely met. The n-3 PUFA dietary enrichment of animal meat and eggs may aid in boosting the consumption of these fatty acids. Eicosapentaenoic acid and docosahexaenoic acid (DHA) are two long-chain n-3 PUFAs that are abundant in fish oils, linseed oil, and micro-algae. Giving these marine products to animals enhanced the amount of DHA in their tissues and yolks. Moreover, increasing DHA has been associated with positive effects on animal performance, reproduction, immunity, and bone strength in chickens. The results of feeding DHA-rich foods to monogastric animals improved human diets and also benefiting the animal. Currently, commercial chicken meat has more omega-6 fatty acids than omega-3 fatty acids. According to published research, altering the broiler feed can change the lipid profile of commercial chickens. The lack of n-3 FAs in the diet can increase in some degenerative illnesses, including mental illness, cancer, diabetes, arthritis, and cardiovascular disease. It is important to address several issues linked to the commercial production of omega-3 chicken meat, including the choice of fatty acid source for the feed, production costs, customer acceptance, and stability of the chicken meat. The studies conducted in this area, as well as the potential effects of producing omega-3 chicken meat or poultry production and human health, are briefly reviewed in the current article.

Keywords: n-3 PUFA, n-6 PUFA, reproduction, immunity, performance.

INTRODUCTION

The fastest-growing segment of the world's meat demand is chicken meat. Due to its higher protein content, lower cholesterol, and fat content, chicken meat is consumed more frequently than other meats due to its perceived health benefits. Chicken flesh has less saturated fat than other meats. Commercial chicken flesh is known to be low in n-3 FA. Therefore, adding n-3 fatty acids to chicken flesh is important.

Because customers are growing more health concerned, functional foods are becoming more1 important **(Sloan, 2004)**. For a person to maintain normal health and well-being, his daily diet must contain more than forty important elements.

Omega 3 fatty acids (n-3 FA) are thought to be one of these essential nutrients. Deficiencies in n-3 FA have been linked to recent increases in the prevalence of some degenerative illnesses **(Simopoulos, 2001)**. Consuming more polyunsaturated fatty acids (PUFA), particularly n-3 FA, may help consumers to lower their risk of developing cardiovascular disease and other degenerative disorders **(Gebauer et al., 2006; Harris et al., 2007; Schacky and Harris, 2007)**. As a result, adding n-3 FA to meat and other meals has been a hot point and difficult area of research. As a result, efforts are being made to add n-3 FA to dairy, poultry, and bakery products.

Among these, chicken flesh has a great deal of potential to develop into an omega-3 functional food that is sustainable **(Hasler, 1998)**.

According to several researches (**Pawel and Pisulewski, 2005; Betti et al., 2009; Zuidhof et al., 2009),** providing n-3 FA-enriched poultry feed to poultry is an efficient way to produce n-3 FA-enriched chicken meat.

Numerous studies on the health advantages of n-3 PUFA and their effects on conditions like cardiovascular disease, diabetes, cancer, Alzheimer's disease, dementia, and depression as well as retinal and neurological development and immune function, have been published **(Shahidi and Ambigaipalan, 2018).**

This increased interest in increasing n-3 PUFA consumption is a result of their possible health benefits. Most n-3 PUFA-containing oils come from marine sources such fish, shellfish, and microalgae (MA). While fatty fish like salmon store lipid in the flesh, lean fish like cod store lipid in the liver. The amount and the type of lipid will vary between fish due to a variety of interspecies variations, including metabolism, food, and growth environment. For instance, cod liver oil has more Eicosapentaenoic acid (EPA) than docosahexaenoic acid (DHA), whereas tuna oil has more DHA than EPA **(Calder and Yaqoob, 2009).** As a result, not all sources of n-3 PUFA will offer the same quantity or quality of these vital FA**.**

Yet these marine oils seem to be a promising way to raise the level of n-3 PUFA in human diets, given the imbalance between the consumption of fish and poultry meat in modern diets. According to the required dietary requirement (2 g/day for an adult male), the European Meal Safety Authority (EFSA) advised that for a food to be labelled as an omega-3 source, it must have more than 0.30 g/100 g, or more than 0.60 g/100 g for high omega-3 **(Commission, 2005).** In recent years, there has been a lot of interest in fortifying animal products, such as dairy, meat, and poultry products, with n-3 PUFA for everyday use. The price (**Watters et al., 2012)** and consumer acceptance **(Ganesan et al., 2014)** are two factors to be considered.

Because of our Health-Conscious Society, which prefers properly balanced diets to minimize negative health issues, fatty acids, especially essential fatty acids, are becoming more important in poultry feeding systems. This is true both for improving the health and the productivity of birds as well as for other reasons **(Cherian, 2015; Simopoulos, 2016; Lee et al., 2019).** Omega-6 (n-6) and omega-3 (n-3) fatty acids, among other fatty acids, are proven essential for a variety of biological **(Simopoulos, 2011)**, physiological **(Simopoulos, 2016)**, developmental **(Kalakuntla et al., 2017),** reproductive (Feng et al., 2015), and overall health functions (**Konieczka et al., 2017; Arias-Rico, 2018; Lee et al., 2019).** It is becoming more and more important to adequately supplement the diets of poultry with unique and advantageous feed additives or supplements since it considerably increases overall poultry production and performance and maintains the health of the birds **(Dhama et al., 2014; Dhama et al., 2015; and Laudadio et al., 2015).** The benefits of utilizing oils in diets in poultry production include, a decrease in feed dust and an improvement in the hydrolysis and absorption of the lipoproteins that deliver fatty acids **(Nobakht et al., 2011).** Additionally, among all dietary ingredients, oils have the largest caloric content and are the primary energy source for birds. Moreover, they can make diets more palatable, improve the utilization of the energy consumed, and boost the absorption of fat-soluble vitamins. Furthermore, by slowing down food's passage through the digestive tract, all nutritional components can be absorbed more effectively **(Poorghasemi et al., 2013).**

It's interesting to note that omega-3 eggs are already widely consumed by people who value their health and are willing to pay a premium price. Omega-3 eggs contain less cholesterol (up to 220 mg of cholesterol per 100 g of egg yolk) than ordinary eggs do on average (360-400 mg of cholesterol per 100 g of egg). However, a serving of chicken meat weighing 100 g has a maximum cholesterol content of 100 mg. Chicken flesh that has been given an n-3 FA boost therefore has the potential to become a highly sought-after omega-3 functional meal. As a result, efforts are being made to add n-3 FA to dairy, poultry, and bakery goods.

The possible advantages of increasing the n-3 oil content of the diets on growth performance, fertility, immune indices, and anti-oxidative qualities will be discussed in this article.

Applications of n-3 FA for Poultry Improvement

Omega-3 fatty acid supplementation has gained importance recently **(Irving et al., 2009; Lee et al., 2019).** Studies on the advantageous effects of long-chain PUFAs (LC-PUFAs) in biological processes have been carried out for at least the last three decades. N-3 dietary supplementation has the potential to affect chicken immunity and results in the production of poultry products that are beneficial to consumer health **(Mousa et al., 2017).** The functional impact of various long chain polyunsaturated fatty acids (LC-PUFA) types and their dietary quantities on the metabolism of lipids in birds has therefore been the focus of research on broiler chickens. When broiler chickens are under oxidative stress due to genetic selection, elevated quantities of fatty acids, particularly of the n-3 family, promote increased lipid oxidation in addition to the LC-PUFA source **(Wu et al., 2019).**

The amount of cholesterol and total lipids in the blood and egg yolk is dramatically reduced when PUFAs are used as a component of chicken diets. To reduce the negative effects of triglycerides and total cholesterol in poultry products, several studies have been carried out. According to **Ahmad et al. (2012)**, n-3 fatty acids added to the diet of the birds resulted in a decrease in the cholesterol content of their eggs. Additionally, increasing the intake of flaxseed oil (FO) and milled flaxseed boosted the amount of linoleic acid (LA), EPA, and DHA in the yolk, and it was discovered that when administered at the same dietary levels, the number of fatty acids deposited from FO was two times higher than that from milled flaxseed **(Ehr et al., 2017).**

By adding specific dietary supplements to the diets of laying hens, such as flaxseed, fish oil, sunflower oil, linseed, fish meal, or algae, the amount of n-3 fatty acids in eggs can be enhanced. Through these designer eggs, omega-3 fatty acids can be supplied to the human consumer's body; they are crucial for maintaining the body's regular functioning because they shield the body from heart problems like heart attacks. They can also take the place of fish items in consumers' diets **(Horrocks and Yeo, 1999).** According to **Ebeid et al. (2008),** chickens fed diets containing various concentrations of n-3 PUFA displayed a linear decline and rise (p <0.05) in the amount of n-6 PUFA and n-3 PUFA found in egg yolks, respectively, compared to the control hen group.

In comparison to the un-supplemented hen group, laying hens given linseed meal and fish oil as dietary supplements had egg yolks with higher concentrations of alpha-Linolenic acid (ALA), EPA, DHA, and docosapentaenoic acid (DPA) **(Yalcin & Unal, 2010).** Comparatively to the control group, hens fed diets with n-3 fatty acid nutritional supplements had egg yolks with greater levels of ALA **(Ahmad et al., 2012). Buitendach et al. (2013)** examined the effects of dietary fatty acid saturation on the production performance of laying hens at the end of the lay period with regard to egg production performances (58–74 weeks of age). In terms of hen-day egg production, egg weight, egg output, feed efficiency, and end-of-lay body weights, these authors observed no significant differences.

Similar findings were reported by **Cachaldora et al. (2006; 2008)**, who came to the conclusion that dietary fatty acid saturation had no appreciable effects on layer hens' ability to produce eggs. In contrast, **Shang et al. (2004)** reported that throughout the 8-weeks experimental period between 40 and 48 weeks of age, body weight gain, rate of egg production, egg weight, and feed efficiency decreased linearly with an increase in dietary fatty acid unsaturation levels. At 50–58 weeks of age, **Yin et al. (2008)** observed a decrease in egg and body weights and an increase in dietary unsaturated fatty acids (UFAs). According to **Shang et al. (2004)** and **Yin et al. (2008),** the performance parameters of hens have decreased.

It appears that conjugated linoleic acid (CLA), a particular kind of unsaturated fatty acids, has a similar detrimental impact on the body weights of laying hens and, consequently, on egg production and egg size, as it does weight loss in humans **(Yin et al. 2008).**

The effects of Omega-3 fatty acids on productive performance and growth

By adding fatty acids or their sources, poultry's growth and production performance are boosted. When fats and oils (as an omega source) are added as a supplement, the growth and performance were improved because of enhanced feed and energy use (**López-Ferrer et. al., 2001**). Through nutritional supplementation with sunflower and soybean oil over the course of 12 weeks, the body mass and percentage body mass gain of quails were both improved (**Donaldson et al., 2017**). Sunflower and canola oil supplements were used to increase the feed conversion ratio (FCR) and growth performance of broilers (**Nobakht et al., 2011**). In contrast to heat-stressed broilers that weren't supplemented, (**Smith et al., 2003**) found that adding animal fat, corn oil, fish oil, and a combination of vegetable and animal oils to the diet had a favorable impact on body growth and FCR. According to **Jalali et al. (2015)**, the addition of soybean oil—high in n-3 PUFA—improved the FCR and increased the body weight of broilers during the total and growth rearing periods significantly (P < 0.05).

According to **Abdulla et al. (2017)**, adding soybean oil to broiler diets boosted weight gain and body weight at 6 weeks of age compared to the diets supplemented with linseed oil (P < 0.05).

Broiler development performance was not significantly different between diets supplemented with sunflower oil (SO) or lard, according to **Fébel et al. (2008)**. Compared to the control diet, adding fish oil to poultry diets had no effect on feed intake, live weight, or weight gain (**López-Ferrer et al., 2001**). **Ebeid et al. (2011)** concluded that the dietary n-3 PUFA in Japanese quail did not negatively impact growth outcomes like ultimate body weight, feed intake, or FCR. Also, **Raj Manohar and Edwin (2015)** stated that dietary n-3 PUFA in quails exhibited a non-significant difference in feed intake and feed efficiency but a substantial (P < 0.01) impact on body weight gain.

Additionally, **Qi et al. (2010)** showed that reducing dietary n-6/n-3 increased FCR, with the best outcome coming from a diet with a 5:1 n-6/n-3 ratio. Four dietary ratios of linoleic acid (LA) to ALA (17:1, 8:1, 4:1, and 2:1) did not significantly affect the body weight of hens during a 16-week period. **(Ayerza and Coates, 2001; Puthpongsiriporn and Scheideler, 2005)** observed that broilers fed chia and flaxseed (high in ALA) showed a considerable loss in body weight and FCR which may be related to one or more of the anti-nutritional properties of flaxseed. **Crespo and Esteve Garcia (2002); Newman et al. (2002)** and **Ferrini et al. (2008)** stated that the amount of unsaturation in fat had an impact on how easily it could be digested. This is in line with the better growth performance seen by **Lopez-Ferrer et al. (2001); Huo et al. (2019)** with rising unsaturated fatty acids (UFA) content. Generally, adding a PUFA-rich item to the diet improves the live weight, weight gain, and FCR of the fowl. However, practically all planned investigations have not yet revealed any negative impacts on feed intake.

The effects of n-3 fatty acids on Immune Reaction and Antioxidative Characteristics

In poultry, fatty acid supplementation has an impact on both oxidative and immunological state. Through both cellular and humoral immunological reactions, it can influence the immune system. Omega fatty acids also affect the generation of IgM and IgG antibodies, as well as the proliferation, maturation, function, and cytokine production of lymphocytes, heterophils, and splenocytes. Similar to this, fatty acids reduce the risk of oxidative stress by neutralizing oxidants and raising antioxidant levels, either directly or indirectly. The regulation of one can influence the other because the immune response and oxidative processes are connected and affect one another. Natural antioxidant supplementation has grown in importance as a study area (**Elwan et al., 2019; Huo et al., 2019**). Numerous studies have supported the numerous positive effects of dietary n-3 PUFA, including their anti-oxidative and anti-lipid peroxidation capabilities as well as their impact on immunological response (**Hamosh, 2008, Velmurugan, et al., 2018**). For example, n-3 PUFA in the diet can influence the immunological response in chickens (**Wang et al., 2000**). **Ebeid et al. (2008)** reported that the dietary FO supplementation below a level of 35 g/kg in the diet caused chickens to develop antibody titers.

The levels of antibodies were higher in laying hens given n-3 PUFA-rich oils (FO or LO) compared to laying hens fed n-6 PUFA-rich oils (maize oil) (**Yuming et al., 2004**). When compared to the control diet, **Ebeid et al. (2011)** found that dietary n-3 PUFA (FO or LO) increased humoral immunity ($P < 0.05$) at 42 days of life as determined by antibody titers against Newcastle disease virus (NDV). **Al-Khalifa et al. (2012)** found that fish oil substituted for sunflower oil (SO) at low doses had no negative impact on broilers' immune systems. **Jameel et al. (2015)** noted that chickens fed a diet supplemented with FO had significantly greater antibody titers ($P < 0.05$) than control chicks.

Fritsche et al. (1991b) conducted one of the early studies on the effects of fatty acid supplementation on immunological tissues. They found that supplementing chicken meals with n-3 fatty acids resulted in a 50–75% reduction in the amounts of arachidonic acid (AA) (C20:4n–6) in the serum and immunological organs. However, the concentrations of EPA (C20:5n-3) and DHA (C20:6n-3), which may have an impact on the immune system, increased (**Fritsche et al., 1991a**). Since they are regulators of inflammation and contribute to cellular and humoral immunity in the early stages of development, n-3 and n-6 fatty acids are more necessary for immunity in chicks (**Cherian, 2011; Cherian, 2015**). They measure the amount of immunoglobulin G (IgG), which is necessary for passive immunity, in chicks produced by mother hens (**Wang et al., 2004**). Also (**Wang et al., 2002**) observed that these fatty acids play an inflammatory effect in delayed-type hypersensitivity. They also support the maintenance of membrane integrity, preventing infection or pathogen entrance.

The LA to ALA ratio, according to **Wang et al. (2000)**, may have an impact on the IgG-receptor activity in yolk sac membranes and, consequently, on the transmission of yolk IgG from the mother to the embryo. Because n-3 plays a part in the synthesis of immunomodulators and is present in fish oil, broiler diets supplemented with it dramatically increased antibody titers for the La Sota vaccine at 35 days following vaccination against Newcastle disease (leukotriene and prostaglandin). Additionally, fish oil could control cytokine production in an immune cell population via modulating signal transduction and lymphocytes (**Al-Mayah, 2009**).

According to **Al-Mayah (2009)**, compared to the control group, hens fed a diet supplemented with fish oil at a level of 50 g/kg produced more antibodies (IgM and IgG) and globulins in the blood and maintained immune function. Consuming n-3 PUFAs in moderation improves anti-oxidative qualities in laying hens, such as glutathione peroxidase (GSH-Px) activity and lowers lipid peroxidation in belly fat and serum (**Ebeid et al., 2008; Shen et al., 2018**). **Ebeid et al. (2011)** stated th add of FO and LO to Japanese quail diets at a level of 20 g/kg resulted in a significant ($P<0.05$) increase in GSH-Px activity and total antioxidant capacity, as well as a decrease in reactive compounds to thiobarbituric acid, as compared to the negative control.

Abdominal fat accumulation decreased as a result of SO-enriched meals (**Fouad and El-Senousey, 2014**). Additionally, the adding of sunflower (SO) and linseed oil (LO) to the diet of birds caused a larger reduction in the deposition of belly fat (**Changxing et al., 2019**). The relative weight of the abdominal fat pad rose ($P < 0.05$) when SO was added to broiler diets, whereas fish oil lowered the abdominal fat of broilers (**Yang et al., 2010**). Consuming a lot of n-3 fatty acids increased their absorption into tissue lipids, which made cells more susceptible to oxidative stress (**Mousa et al., 2017**). The gene expression of lipin-1, which controls the production of triglycerides, was enhanced in chicken belly fat by an n-3 PUFA-rich diet (**Chen et al., 2012**).

Ibrahim et al. (2018) reported that the malondialdehyde (MDA) concentration in broilers was significantly affected ($P < 0.05$) by the addition of FO and LO. Glutathione S. transferase was found to be significantly ($P < 0.05$) induced when the ratios of n-6:n-3 PUFAs were reduced (GSH-ST). Additionally, with the n-3 PUFA-rich therapy, superoxide dismutase, GSH-ST, and cardiac GSH-Px activities were increased, while MDA was decreased (**Chen et al., 2012**). When broilers with infectious bursal disease were challenged, omega-3 PUFAs showed positive immunological responses (**Maroufyan et al., 2012**). To avoid negative effects on immunological function, these fatty acids must be examined, and their ratios properly managed notwithstanding the indicated improvements (**Al-Khalifa et al., 2012**).

The effect on fertility rates and sperm quality

Supplementing with fatty acids, particularly n-3 and n-6, helps to increase fertility and the quantity and quality of semen. **Kelso et al. (1996)** concluded that the supplementation of chickens' diets with 50 g/kg of fish oil or corn oil increased reproductive rates significantly ($P<0.05$) (96%) over baseline levels (89%). Due to the increased amount of n-3 fatty acids in the phospholipids of sperm, **Kelso et al. (1997)** observed that adding ALA to male diets enhanced fertility at 39 weeks of age. **Cerolini et al. (2000)** revealed that the dietary FA supplementation can affect the characteristics of spermatozoa. Menhaden oil at a rate of 30 g/kg supplemented in the meals (**Hudson and Wilson, 2003**).

Bongalhardo et al. (2009) reported that the supplementation of cockerel diets with fish oil increased fertility, which was linked to the spermatozoa's membrane's lower fatty acid ratio (n-6:n-3), which may alter the membrane's physical features or susceptibility to oxidative damage (**Blesbois et al., 2005**).

Sperm quality and fertility have both been proven to be impacted by cryopreservation, and fatty acids act as sperm protectors. Semen survival is impacted by cryopreservation, which is more reliant on spermatozoa's lipid composition (**Blesbois et al., 2005**). As a result of cryopreservation, the cholesterol/phospholipid ratio in chicken sperm decreased, and this had an impact on survivability (**Blesbois et al., 2005**). Sperm damage, including chemical and physical damage (cryopreservation) (oxidative) can be avoided by fatty acids. **Zaniboni and Cerolini (2009)** stated that the dietary n-3 LC-PUFA treatment of turkey enhanced in-vitro peroxidation and sperm mortality while preventing the detrimental effects of sperm storage on sperm sensitivity and quality. Additionally, between 26 and 60 weeks of age, dietary maize oil supplementation reduced the concentration of spermatozoa per ejaculate by 50%. **Al-Daraji et al. (2010)** found that treatments with corn oil and SO had the worst effects on these characteristics, while dietary fish oil supplementation produced the best results for sperm concentration ($P < 0.05$) based on the ejaculate volume, live sperm, total sperm count, and sperm quality factors. **Al-Daraji (2001)** found that there was a highly significant association between the number of spermatozoa and the level of glucose in the seminal plasma.

Al-Daraji (2002) also discovered that spermatozoa required the seminal plasma's glucose for metabolism. Regarding the findings for flax oil and fish oil, **Al-Daraji et al. (2010)** explained that dietary supplementation with sunflower oil or corn oil had a significant impact ($P<0.05$) on the semen glucose content, alanine aminotransferase activity, and semen protein content.

In rooster sperm, a meal supplemented with a reasonable ratio of n-3: n-6 fatty acids boosted DHA and n-3 PUFAs while lowering AA and docosatetraenoic acid (**Al-Daraji, 2001**). A greater conception rate was seen, as well as significant improvements in sperm motility, progressive motility, membrane functioning, and viability (**Al-Daraji, 2002**). The testis index was not significantly affected, **Feng et al. (2015)** concluded that but the spermatogonia growth, germ cell layers, and gonadotropin-releasing hormone, luteinizing hormone (LH), follicle-stimulating hormone (FSH), and testosterone hormone levels increased. They also stated that PUFAs control the expression of steroid acute regulator protein and hormone receptors (StAR). All hormone-related genes had their mRNA levels dramatically raised by PUFAs (GnRHR, FSHR, LHR, and StAR mRNA levels).

Effect of Omega-3 fatty acids on Growth

Fats are crucial in the diet to boost the caloric density of feeds to meet requirements because all animals need energy for maintenance and productive functions. The source of fat will differ in terms of saturation and chain length in addition to providing energy, which can all have an impact on functionality. To support the animal's optimum health, development, and growth, the food must contain long chain PUFA (**Zhang et al., 2010**). One topic of relevance in this context is digestion and nutritional absorption. It has been hypothesized that n-3 PUFA intake can increase piglets' absorption of glucose (**Gabler et al., 2007; 2009**).

Increased n-3 PUFA levels, 50 AMPK-activated protein kinase activity, and a high concentration of glucose transporters (glucose transporter type 2 [GLUT2] and sodium-dependent glucose transporter 1 [SGLT1]) in intestinal tissues were all linked to this improvement. It has been shown that n-3 PUFA increases the activity of AMPK, a crucial cell energy status sensor, in rats (**Suchankova et al., 2005**). When AMPK is turned on, it promotes GLUT2 translocation to the brush border in mice, which improves glucose absorption (**Walker et al., 2005**). The performance of animals fed diets with increased levels of n-3 PUFA may be improved by such processes.

Numerous research has looked into how the addition of n-3 PUFA to diets affected animal performance. Feeding 7.4% DHA Gold (derived from Schizochytrium MA, Novus) to broilers from 21 to 35 days of age could significantly improve body weight gain by 195 g (22%) when compared to the control without influencing feed consumption (**Ribeiro et al. 2013**). FCR was not significantly affected by this treatment despite the DHA supplementation had a significant impact on weight gain (**Ribeiro et al. 2013**).

A later study by **Ribeiro et al. (2014)** added 7.4% DHA Gold to diets containing either standard (21%) or low (17%) crude protein (CP), which were then given to broilers between the ages of 21 and 35 days. At 28 and 35 days of age, respectively, adding DHA Gold to the regular CP diet resulted in considerable weight gain (by 188 and 319 g), feed intake (by 145.2 and 251 g), and FCR reduction (by 57 and 44 points).

The addition of DHA Gold to the low CP diet had no effect. However, it should be noted that birds given the low CP diet outperformed those fed the conventional protein diet, maybe as a result of the addition of synthetic amino acids and the higher energy content of maize. Additionally, it was shown that the DHA Gold diet's pellets were more intact than those from control diets, which may have contributed to increased feed consumption and weight gain. The performance of broiler growth, however, has not been impacted by feeding MA (**Rymer et al., 2010; Yan and Kim, 2013; Ao et al., 2015a**).

In a latest study, **Konieczka et al. (2018)** fed broilers different levels of fish/ linseed oil and maize oil, as well as vitamin E supplemented at 50 or 300 mg/kg, to achieve high n-6: n-3 ratios (starting, 43.1; grower, 62.2; finisher, 51.1) and low n-

6: n-3 ratios (beginning, 1.0; grower, 0.7; finisher, 0.5). From 1 to 9 days of age, birds with low FA ratios had lower body weights than those with high FA ratios, whereas birds with increased vitamin E levels had improved body weights regardless of FA ratio. Without regard to vitamin E, FCR was noticeably worse in birds fed low FA ratio diets.

Despite FCR being statistically worse (about 8 points) for birds fed low FA ratio, FA ratio and vitamin E level had no effect on the final body weight of the birds from 9 to 42 days of age. Low n-6: n-3 ratios have not been found to have a deleterious impact on broiler performance in other investigations (**Qi et al., 2010; Ibrahim et al., 2017**). Although n-6 also plays a significant role in birds, the ratio in these trials was not as low as it was in the earlier study, which may help to explain why some studies show adverse consequences of the low FA ratio. This may imply that maintaining some vegetable oil while supplementing meals with high amounts of DHA via MA is necessary to maintain the balance with n-6.

Wei et al. (2013) discovered that supplementing growing pigs' diets with MA DHA (7.5% Trevera, Novus International) increased muscle protein synthesis by increasing expression of muscle IGF-1 and insulin receptor activation, which may suggest a connection to enhanced growth performance with n-3 PUFA supplementation. The final four weeks of a 56-day study saw improvements in body weight gain and FCR for pigs with 2.5% and 5.0% MA supplementation (**Sardi et al., 2006**). In the loin and subcutaneous fat, MA raised the DHA levels as well. ADG or FCR were not affected by feeding MA (Omega Tech, Boulder, Colorado) at 0.5% or 1.0% in starter (0–21 day) diets and 0.09% or 0.18% in grower (22–42 day) diets, **Marriott et al. (2002)**.

The substantially lower inclusion rate of MA in the latter study may have contributed to the lack of performance effects. The DHA content of muscles did, however, significantly increase linearly as a result of this inclusion rate. Compared to pigs fed 0.06% and 0.60% MA, respectively, pigs fed 1.6% MA (18% DHA) for the final 25 days before slaughter had increased weight gain and FCR (**Jon Meadus et al., 2011**). However, therapy had no impact on pH, lean yield, or carcass weight. Additionally, it was discovered that a higher DHA incorporation rate dramatically boosted the expression of the adipose hormone leptin. Leptin reduces feed intake in response to more adipose cells, even if pigs' growth and FCR would simultaneously improve as a result.

The growth performance of pigs from 14 to 22 weeks of age did not change because of feeding 0.9%, 1.9%, or 3.7% MA (DHA Gold, DSM), **de Tonnac and Mourot (2017)**. This research implies that providing DHA to pigs and poultry may have positive effects on performance. More crucially, they demonstrate that, when dosed at the levels utilized in the aforementioned research, raising n-3 PUFA levels which have the potential to enhance oxidative stress does not have a deleterious impact on performance. However, care should be taken when lowering the n-6: n-3 ratio to take into account the significance of n-6 PUFA in the diet (**Schmitz and Ecker, 2008**).

Effect on Immune reaction

The immunological response of chicks to various immune stressors is significantly compromised by selection for rapid growth, according to a meta-analysis of chicken studies by **van der Most et al. (2011)**. However, dietary PUFA from a variety of sources can be a useful tool for altering immune response (**Calder, 2001**). The composition of the used dietary fat source is closely related to the FA content of immunological tissues (**Fritsche et al., 1991b**). Unsaturated FA increases cell flexibility in immune cells and modifies the activity of particular immune cells (**Pike, 2003; Calder, 2007**). **Craig-Schmidt et al. (1987)** stated that the type of PUFA present in these tissues can influence eicosanoid synthesis and inflammatory response, highlighting the need of n-6: n-3 balance for optimal immune system performance.

In chicks fed diets containing n-3 PUFA, **Fritsche et al. (1991a)** described reduction of spleen lymphocyte proliferation and better humoral immune response via increased antibody production. Additionally, **Selvaraj and Cherian (2004b)** showed that broilers fed diets containing n-3 PUFA (3.5% linseed or fish oil) had increased anti-bovine serum albumin (BSA) anti-body concentrations in the blood and a delayed hypersensitivity inflammatory response as a result of a decrease in pro-inflammatory cytokines. A considerable number of nutrients should be released from the inflammatory process as a result of such a response, allowing a higher percentage of digested nutrients to be directed toward growth. In fact, n-3 PUFA-fed birds gained more body weight and consumed more feed than n-6 PUFA-fed birds (conjugated linoleic acid [CLA] and sunflower oil).

The same authors observed a comparable response in laying hens (**Selvaraj and Cherian, 2004a**), and they also noted that the yolk anti-BSA antibody level was higher in hens fed 3% fish oil than it was in those fed CLA plus animal fat or sunflower oil. In pullets fed low n-6: n-3 PUFA ratio (linseed) diets, **Puthpongsiriporn and Scheideler (2005)** demonstrated enhanced humoral response through higher antibody production to infectious bursal illness and Newcastle disease without affecting performance. Additionally, **Guo et al. (2004)** found that hens fed diets high in n-3 PUFA (linseed or fish oil) had higher levels of anti-BSA antibodies and blood lysozyme activity and lower levels of in vitro leucocyte production of prostaglandin E2 (PGE2) than hens fed diets high in n-6 PUFA (maize oil), all without affecting performance.

According to the findings of these studies, increasing n-3 PUFA in the diet can enhance humoral immunity and decrease cell-mediated immunity, both of which have a good impact on immune function. This response, nevertheless, may not always translate into better growth performance (**Swiatkiewicz et al., 2015**).

Conclusion and Future Prospects

According to the current review, n-3 fatty acids can be successfully included into chicken diets to boost immunological responses, enhance the nutritional content of eggs, increase the quality of meat, and stimulate poultry growth. Because they can limit cytokine release, omega-3 fatty acids have anti-inflammatory or inflammation-reducing characteristics. High amounts of omega-6 fatty acids are linked to an increased occurrence of serious illnesses like depression and heart disease. However, a wide range of health advantages, including as lower cholesterol levels and a decreased risk of coronary heart disease, are provided by these fatty acids. The benefits of n-3 PUFA on bone strength, bone mineral content, and bone mineral density have been documented in numerous research.

Additionally, adding some dietary supplements to the diets of laying hens, such as groundnut oil, fish oil, sunflower oil, linseed, fish meal, or algae, might enhance the amount of n-3 fatty acids in eggs. Cockerels' semen quality, fertility, and hatchability were all improved by adding various sources of n-3 or n-6 to their diets. In the present review, we suggested that a feasible strategy for chickens raised for human consumption would be to supplement their diets with various sources of n-3 fatty acids. However, there were certain drawbacks connected to the oxidative stability of meat, where LC-PUFAs were more vulnerable to oxidation, resulting in tastes and aromas in poultry meat, which adversely affect meat quality and customer acceptance.

Future research should therefore focus on finding ways to make poultry products with higher PUFA concentrations and favorable fatty acid composition at cheap cost, without compromising the product's quality or palatability, which will ultimately affect how well it is received by customers

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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