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Importance essential fatty acids (n-6 and n-3) in animal nutrition: II: Poultry

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ABSTRACT

*There is considerable interest in the n-3 long-chain polyunsaturated fatty acids (PUFAs) in human health. It has been demonstrated that the FA composition of broiler meat can be altered by changing the content of the broiler's diet.The lipid composition of broiler meat can be modified by adding linoleic and linolenic acids and fish oils (**FO**). Fish oil may inhibit the desaturation of n-6 FA, with a subsequent lowering of plasma lipids. The FA composition of the broiler chicken carcass may be influenced considerably by the diet administered. Dietary n-3 FA has been reported to aid in the prevention of certain diseases, especially cardiovascular disorders. The present paper will discuss the essential fatty acid useful for enrichment of laying-hen and broiler rations and provide guidelines on how these sources can best be used in the development of a healthful, n-3 FA-rich whole egg and meat.*

Key words: essential fatty acids, (n-6 and n-3) polyunsaturated fatty acids, eggs, chicken meat.

Abbreviations: EFA, essential fatty acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; FA, fatty acid; ALA, α-linolenic acid; LA, linoleic acid; LNA,linolenic acid; PUFA, polyunsaturated fatty acids; AA, TBA, thiobarbituric acid; arachidonic acid; LC, long chain; MO, menhaden oil; FO, fish oil; FM, fish meal; FS, flax seed; CS, canola seed.

INTRODUCTION

The fatty acid composition of poultry muscle is an important quality parameter especially with respect to potentially affecting human health from poultry meat consumption. In this regard, n-3 group of poly-unsaturated fatty acids (PUFA) is one of the most important fatty acid (FA) groups. Dietary n-3 FA has been reported to aid in the prevention of certain diseases, especially cardiovascular disorders.

It has been demonstrated that the FA composition of broiler meat can be altered by changing the content of the broiler's diet Therefore, many studies are directed towards the manipulation of the FA composition of broiler chicks in order to increase n-3 PUFA content and decrease n-6/n-3 ratio in poultry meat. This is desirable because of the action of n-6 PUFA as a pro-inflammatory factor and the action of n-3 PUFA as an anti-inflammatory factor on immune functions and inflammatory processes in animals and humans [1].

There are some reports in the literature that deal with the effects of terrestrial sources of dietary n-3 fatty acids (FA) on the yolk FA composition. Enrichment of hens' diets with sources rich in linolenic acid (LNA) has resulted in the production of eggs with significantly increased levels of yolk LNA and small but significantly higher increases in the 20-carbon family (long chain; LC) of n-3 FA [LCPUFA (polyunsaturated FA)], mainly as eicosapentanoic acid (EPA) and docosahexanoic acid (DHA) However, the increase in these FA in yolk has not been in a similar proportion to that of LNA [2].

To compare the beneficial effects of fish oil on the enrichment of n-3 LC-PUFA in eggs with the effects when other fat sources were used in egg production, an experiment with laying hens was carried out. The goal of this experiment was to improve knowledge about the relationship between precursors given in the diet and the content in egg of the different n-3 and n-6 PUFA families. Birds were fed with fish oil or with alternative mixtures of fish oil and other fat sources [linseed oil (LO), rapeseed oil (RO), sunflower oil (SO), or tallow (T)] in different proportions to attain a wide range of relative amounts of the different PUFA studied in eggs [2].

In addition, for poultry production full-fat flaxseed and canola seed might serve as an alternative source of dietary energy. However, the drawbacks with dietary inclusions of full-fat flaxseed and canola seed are the presence of anti-nutritional factors and the low available nutrient content, which may limit its in poultry diets. The literature shows that more than 10-15% dietary inclusion of full-fat flaxseed may depress broiler growth [1].

Vegetable sources, such as linseed oils (LO) and rapeseed oil, may clearly increase the n-3 FA content in the form of linolenic acid (LNA), the precursor of the whole n-3 family. Several studies with diets mildly rich in LNA have failed to increase the n-3 LC-PUFA content in chicken tissues [3].

The lipid composition of broiler meat can be modified by adding linoleic and linolenic acids and fish oils (**FO**). Fish oil may inhibit the desaturation of n-6 FA, with a subsequent lowering of plasma lipids. The FA composition of the broiler chicken carcass may be influenced considerably by the diet administered [4].

Longer chain fatty acids, such as linolenic acid, have a characteristic "fishy" or "paint-like" aroma, and so there is concern that enrichment of products, such as eggs, with n-3 fatty acids may cause some degree of off-flavor. There was a general perception by taste panelists that eggs from flax-fed birds had a slight off-flavor [5]. However, the present paper will discuss the essential fatty acid useful for enrichment of laying-hen and broiler rations and provide guidelines on how these sources can best be used in the development of a healthful, n-3 FA-rich whole egg and meat.

Egg n-3 FA enrichment

An average egg also provides about 6 g of lipids which are contained exclusively in the yolk. More than 66 percent of the total yolk mass are fats, thus the yolk from these n-3 PUFA enriched egg can be regarded as a potential oil crop rich in long chain PUFAs, the both DHA and AA essential for infants. Designer egg yolk oil may be regarded as an essential oil base for infant formula because it resembles the fatty acid composition of human milk. Designed egg yolk oils provide an adequate amount of n-3 and n-6 precursors and long chain PUFAs including DHA still sustaining a significant level of AA in the egg with various ratios of n-6/n-3 in a range of 22.1 to 1.4 [6].

Following the vigorous campaign of Simopoulos to reduce n-6 fatty acid intake and increase intake of n-3 fatty acids in the human diet, the poultry industry was quick to join the chase. So-called "designer eggs," containing increased amounts of n-3 fatty acids, especially DHA, are now found readily in the market. To maintain optimal egg size, laying hens require a minimum of 1% LA in the diet (NRC, 1994), which is often satisfied by corn in corn-soybean diets, whereas diets based on barley or wheat require additional oil. Rarely is more than 2% vegetable oil added to the diets of commercial laying flocks [8].

Grobas et.al (2001), investigate the influence of source and percentage of fat added to diet on performance and fatty acid composition of egg yolks of two strains of laying hens and reported that the enrich eggs with DHA by using vegetable sources, only moderate amounts of LNL in the diet are required (less than 1%). Also, it is possible to moderately increase arachidonic acid and DHA in the egg yolk at the same time, provided that an adequate source of fat, such as soy oil, rich in LIN and with moderate amount of LNL, is used as substrate. Saturation of the different Δ-unsaturases seems to be dependent on the concentration of dietary FA [9].

Scheideler, (1998), reported that the percentage yolk and total yolk lipids can be substantially reduced to produce a lower fat n-3 fatty acid enriched egg. Strain effects on yolk composition also indicate varying efficiencies of fatty acid metabolism and lipid store turnovers in the hens fed different types of diets [10].

Van Elswyk et al (1992) showed that there is no alteration in the fatty acid composition of eggs enriched with n-3 PUFAs when they are cooked [11].

Bean and Leeson (2003), investigate the Long-term effects of feeding flaxseed on performance and egg fatty acid composition of brown and white hens and reported that the both strains performed equally when fed flaxseed, and both strains of hen deposited comparable amounts of n-3 fatty acids into their eggs when fed flaxseed. However, with the brown producing a significantly larger egg, there are potentially more n-3 fatty acids deposited. Consequently, an n-3 enriched brown egg could provide a greater proportion of a person's daily requirement of n-3 fatty acids [12].

Sim (1998) reported a 4-fold increase in n-3 fatty acids in designer eggs (diet undefined); he acknowledged that fishy off-flavors of the eggs occurred, but stated that these could be controlled by including tocopherols in the hens' diets [6].

When eggs are to be enriched with LNA, flaxseed, flaxseed oil and to a lesser extent canola could be considered. When the aim of enriching eggs with n-3 FA is incorporating long chain n-3 FA [mainly eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA) LCn-3] fish oil [most commonly menhaden oil (MO)], fish meal (FM), and marine algae (MA) are ingredients frequently used. Table 1 illustrates the fatty acid composition of these sources of n-3 FA for use in poultry diets. Dietary concentrations of flaxseed directly affect yolk LNA deposition. However, the deposition of LCn-3, synthesized, from LNA, by increasing dietary flaxseed does not follow the same trend suggesting a limited LNA-LCn-3 conversion [13].

Table 1. Potential sources of omega-3 fatty acids for inclusion in poultry diets

	% total fatty acids						
Source	**18:3n-3**	**20:5n-3**	**22:5n-3**	**22:6n-3**	**Sn-3**	**Sn-6**	**Sn-3:Sn-6**
Flaxseed oil	**53.3**	**–**	**–**	**–**	**53.3**	**12.7**	**4.2**
Menhaden oil	**0.3**	**11.0**	**1.9**	**9.1**	**25.1**	**1.5**	**16.73**
Marine algae	**–**	**–**	**3.8**	**7.4**	**11.2**	**–**	**–**
Canola oil	**12.0**	**–**	**–**	**–**	**12.0**	**20.2**	**0.59**

Adapted by: González-Esquerra and Leeson. 2001 [13]

Scheideler and Froning (1996) reported that with levels up to 15%, flaxseed has little effect on yolk LCn-3 deposition [14].

Ferrier et al. (1995) utilized flax seed to increase the n-3 PUFA in eggs. They fed a control diet or linolenic acid (LNA) diet that contained 10 or 20% flaxseed. In the modified eggs, the n-3 PUFA, LNA, increased from 28 mg per egg in the control to 261 and 527 mg per egg in the modified eggs, respectively. The DHA content increased from 51 mg per egg to 81 and 87 mg per egg [15].

Scheideler and Froning reported that the incorporation of linolenic acid (C18:3n-3) into the egg increased linearly as the level of dietary flaxseed increased (2.31, 4.18, or 6.83% of the yolk fatty acids for 5, 10, and 15% flaxseed diets, respectively) [14].

Scheideler and Froning (1996) have also produced n-3 PUFA-enriched eggs from hens fed flaxseed. The modified egg contains 350 mg of n-3 PUFA compared with the standard egg that contains 60 mg of n-3 PUFA. The LNA content is 250 mg and the DHA content is 100 mg in the modified egg compared with the standard egg that contains 40 mg and 20 mg, respectively. The ratio of n-6/n-3 PUFA is 13.0 in a standard egg compared with a ratio of 2.6 in the modified egg[14].

Cachaldora et al. (2008) reported that increase of dietary inclusion of FO from 0 to 30 g/kg increased linearly egg yolk content of C20:5 n-3 (EPA) and linear and quadratically those of C22:5 n-3 (DPA) and C22:6 n-3 (DHA) and decreased those of C20:4 n-6 and C22:4 n-6. An interaction was found between the level of inclusion of FO and the type of basal diet, as the effects of FO addition on EPA, DPA and DHA yolk fat deposition were greater in the control and lard-added than in the linseed and soybean- added diets. Soybean and linseed oil addition to the basal diet increased respectively the level of total n-6 FA (from 127 to 226 g/kg total yolk FA) and total n-3 FA (from 33 to 108 g/kg, mainly of C18:3 n-3), at the expense primarily of monounsaturated FA [16].

Increasing the amount of dietary fish oil results in sequential increases in LCn-3 deposition in eggs. It is interesting to note that in spite of the higher concentrations of EPA (11%) relative to DHA (9.1%) in menhaden oil, the concentration of the latter found in yolks from hens fed menhaden oil is much greater than the former. For instance, in birds fed 3% menhaden oil [13].

Van Elswyck, (1997) reported that the laying hens were fed on diets supplemented with graded levels of menhaden oil (MO), rich in both eicosapentaenoic acid (EPA; 20: 5n-3) and docosahexaenoic acid (DHA; 22: 6n-3), for 4 weeks to determine maximal yolk fatty acid deposition attainable without sensory compromise. Dietary MO levels between 15 and 30g/kg yielded the greatest yolk n-3 fatty acid content [17].

Farrell (1998) reported the results of feeding eggs enriched with n-3 polyunsaturated fatty acids (PUFAs) were produced by hens fed diets containing fish oil (up to 5%) or a combination of fish and vegetable oils. A 60-g egg from a hen fed the enriched diet will contain a minimum of 300 mg n23 PUFAs, of which 50% is EPA [18].

Herber and Van Elswyck (1996), reported that utilization of marine algae as a direct source of dietary n-3 FA may provide an efficient alternative to current sources of n-3 FA available for the production of poultry products rich in n-3 FA [19].

Nash et al. (1996) reported that hens fed 12% menhaden meal (10.2% total fat) had EPA and DHA concentrations of 7 and 84 mg yolk–1, respectively [20].

Herber and Van Elswyk (1996), scoring yolk fatty acid profiles weekly from hens fed 1.5% MO or MA at either 2.4 or 4.8% of the diet reported that yolk total n-3 FA stabilised 14 d after feeding the test diets, regardless of the n-3 FA source [19].

Scheideler and Froning (1996) conducted a study to determine how modifying hen diets would change the fatty acid composition of the egg yolks. The hens were assigned to control, 15% fish oil, or 5, 10, or 15%flaxseed dietary rations. The n-3 PUFA were significantly higher in eggs produced from hens fed fish oil or flaxseed as compared with the control. The amount of n-3 PUFA in the egg yolks of the control and treatment groups were 1.2% of fatty acids, or 2.0 to 7%, respectively [14].

Ferrier et al. (1995) compared the effects of four n-3 PUFA eggs per day or four standard eggs per day on serum lipids in 28 normolipidemic subjects. After 2 wk, no significant changes were observed in total cholesterol, high-density lipoprotein cholesterol, or plasma triglyceride (TG) concentrations. However, consumption of modified eggs resulted in a significant increase in DHA and total n-3 PUFA in the blood platelet phospholipids [15].

Effects of n-3 fatty acid sources on production parameters in hens

Scheideler and Froning (1996), investigate the effects of ground vs whole flaxseed at dietary levels of 5, 10, or 15% compared to a corn-soybean or fish oil control on egg production of Leghorn hens over a period of 8 wk. Dietary flaxseed decreased feed consumption, weight gain, and egg weights compared to the control diets; however, flaxseed and fish oil significantly improved egg production (88.9 and 93.0%, respectively) compared to the control (83.1%).

Flaxseed and fish oil significantly increased percentage white and decreased percentage yolk compared to the control treatment but had no effects on egg cholesterol [14].

Yannakopoulos et al. (1998) reported reduced daily feed consumption and weight gain of birds fed flaxseed. This experiment was conducted to examine for 12 weeks the effect of feeding a mixture of ground or whole flaxseed (5% and 10%) with other fiber ingredients on the hen performance and egg quality as well as the fatty acid composition of egg yolk. The diets varied especially in linolenic acid [21].

Bean and Leeson, (2003) reported that feed intake was less for hens fed flaxseed compared to those consuming the control diet. Flax-fed hens were also lighter compared to the control birds. Egg production, egg weight, shell weight, albumen height, and shell thickness were not significantly different for hens consuming 0 and 10% flaxseed; however, yolk weight was reduced in hens fed flaxseed [12].

The researchers attributed the former effect to a reduction in metabolisable energy (ME) of the flaxseed diet, resulting initially in loss of body weight and subsequently loss in egg size [13].

Van Elswyk (1997) suggested that the yolk weight reduction is related to changes in circulating oestradiol brought about by either n−3 PUFA or the phyto-oestrogens characteristic of flax seed [17].

Caston et al. (1994) reported that birds fed 20% flax ate significantly more feed at each period than did birds fed 0 or l0% dietary flax. As ground flax was increased in the diet there was a concomitant decrease in apparent metabolizable energy. Thus, the experimental diet provided 2970 kcal kg–1, while adding 20% flaxseed decreased the ME to 2440 kcal kg–1, suggesting that the animals inefficiently digested flaxseed or the whole diet per se [22].

Shafey et al. (1992) were interested in egg production, cholesterol and the FA profile of the eggs mofbirds fed different diet ingredients, including soybean oil, production was measured over 3 wk [23].

Scheideler et al. (1998), was conducted to study the effects of strain, age, and diet on egg production, egg composition, and yolk fatty acid incorporation .The researchers reported that at 50 wk of age, when the hens went on the two different diets, egg production was significantly less for hens on flax + oats than for those on flax oats [10].

Van Elswyk (1997) reported that a reduction in yolk weights was observed in response to the 15g menhaden oil kg diet and the 48g marine alga /kg diet. Interestingly, the 24 g marine alga /kg diet did not reduce yolk weights. This researcher also reported that with reproductively mature hens, no changes in egg or yolk weights were observed in response to any n-3 FA-rich diet [17].

N-3 FA and metabolic disorders

Whether n-3 FA may have significance for fatty liver syndrome and/or fatty liver haemorrhagic syndrome in hens remains to be clarified. Histopatological evidence of a greater hepatocellular lipid infiltration in hens fed 3% menhaden oil vs. diets with no supplemented fat was reported by

Hargis et al. (1991) suggesting a role of n-3 FA. Nevertheless, no difference in gross liver rank (assessed by liver integrity and friability) was found [24, 13].

Van Elswyk et al. (1994) investigate the dietary menhaden oil contributes to hepatic lipidosis in laying hens. In the present study, reproductively active females but not males exhibited increased hepatic lipidosis following 6 mo of feeding 3% menhaden oil. Hens fed 3% animal-vegetable oil (AV) did not exhibit hepatic lipid accumulation. Serum triglyceride and cholesterol concentrations were reduced in hens fed menhaden oil. These data suggest that dietary menhaden oil and estradiol may interact in a manner that enhances the lipogenic activity of the liver, thereby inducing hepatic lipidosis in laying hens [25].

Schumann Squires and Leeson (2000) were carried out to investigate the effect of dietary flaxseed, flax oil and n-3 fatty acid supplementation (Dry n-3) on hepatic fat content, plasma triglycerides, hepatic haemorrhage score, egg production, food intake and body weight in an inbred line of Single Comb White Leghorns (UCD-003) predisposed to fatty liver haemorrhagic syndrome (FLHS) and normal Single Comb White Leghorns hens.This researcher reported that:

1: Feeding diets containing 100 g/kg ground flaxseed, 40 g/kg flax oil, or 100 g/kg Dry n-3 reduced body weight and significantly reduced hepatic fat content compared to feeding the control diet with animal and vegetable oil as a fat source.

2: Hepatic malondialdehyde, an indicator of lipid peroxidation within the liver, was not significantly affected by dietary treatment. The result suggested that dietary flaxseed, flax oil and dry n-3 decrease hepatic fat content and reduce body weight, 2 of the predisposing factors believed to contribute to FLHS onset. However, haemorrhages were still apparent in both strains regardless of treatment, indicating that other unknown underlying mechanisms may also be responsible for FLHS [26].

Walton et al .(1999) expression that EPA and DHA might be further metabolized to prostacyclins, PGI3 and PGI2, which function as coronary relaxants, it was suggested that the higher dietary ratio of n3/n6 fatty acids increase the production of compounds that reduce the resistance to blood flow. Thus, decrease the incidence of ascites [27].

Aftab and khan (2005) reported oils rich in n-3 fatty acids have been shown to reduce pulmonary hypertension and, consequently, ascites incidence [28].

Oxidative stability and sensory quality of n-3 FA enriched eggs

Chain length and number of double bonds compromise n-3 FA oxidative stability. The inclusion of n-3 FA into diets increases the birds vitamin E requirements because once in eggs and tissues, n-3 FA increase their susceptibility to peroxidation [29,31] . The hazard to lipid oxidation is higher in eggs enriched in LCn- 3 rather than LNA. Both LNA and LCn-3 eggs are shown to be stable over a period of 4 wk of storage; however, fresh n-3 FA eggs contain higher thiobarbituric reactive substances, used as an indicator of the extent of lipid oxidation. Dietary vitamin E supplementation has been shown to alleviate this problem with eggs [13]. Cherian et al. (1996) investigate the effect of dietary oils [menhaden (MO), flax (FL), palm (PO), and sunflower oils (SF)] with added tocopherols on the tocopherol deposition, fatty acid composition, and

thiobarbituric acid (TBA) values of egg or tissues (liver, adipose tissue, white meat, and dark meat). Addition of tocopherols increased the total egg or tissue tocopherol content. The enhancement of total tocopherols in the different tissues in the order of magnitude were egg yolk > liver > adipose tissue > dark meat > white meat. Dark meat contained higher total tocopherols than white meat. Dietary menhaden oil or flax oil resulted in a significant incorporation of C20:5 n-3 and c22:6 n-3 with a concomitant reduction in C20:4 n-6 in liver, egg, white meat and dark meat. Dietary SF resulted in a significant incorporation of C18:2 n-6 and C20:4 n-6 in all the tissues. Addition of palm oil did not result in any change in the yolk saturated fatty acid content. The content of monounsaturated fatty acids were greater in all the tissues from palm oil diets than in diets with other oils [30].

González-Esquerra and Leeson.(2001) Suggested a maximum of 1 to 1.5% fish oil or 2 to 10% fishmeal in diets to prevent potential off-flavor problems; this translates to approximately 2.5% marine algae oil for equal results [13].

Van Elswyk et al. (1995) investigate the eggs from hens fed graded levels (0, 0.5, 1.5, 3.0%) of menhaden oil (MO) were evaluated for fatty acid composition, sensory characteristics, and headspace volatiles. Eggs from hens fed 1.5% and 3.0% MO contained the greatest n-3 FA content and were not different. Changes in headspace volatile profiles were quantitative. No unique volatiles characterized eggs from hens fed MO. however, concentration differences were noted between eggs from hens fed all levels of dietary MO. Changes in volatile profiles in response to dietary MO may be responsible for perception of fishy notes in such eggs [31].

Leeson et al. (1998) reported that a very significant difference among panelists for all attributes tested and off-flavors were detected in eggs from hens fed 10 and 20% flaxseed with 10 mg vitamin E/kg. The researchers suggest that high levels of flaxseed used in the bird's diet will result in some decrease in overall egg acceptability as assessed by aroma and flavor. These effects seem to be accentuated by using high levels of vitamin E in the bird's diet [5].

Surai et al. (1995 reported on feeding exceptionally high levels of vitamin E to laying hens in order to enrich this nutrient in shell egg and processed egg products. Feeding up to 20,000 IU vitamin E/kg diet resulted in egg yolk with 15,000 mg vitamin E/g, although there was no indication of any taint or aroma problem with these eggs [32].

Herber and Van Elswyk (1998) reported that the eggs from hens fed both levels of marine algae (MA) received acceptable flavor scores (2.4% MA = 5.6 ± 0.3; 4.8% MA = 5.2 ± 0.3) that were not significantly different than control (5.7 ± 0.2). The authors concluded that using MA in diets at levels of 4.8% would allow the incorporation of similar quantities of LCn-3 to using 3% MO, but without decreasing flavors quality [33].

The flavor and stability of eggs were acceptable when hens were fed 15 g menhaden oil / kg diet, but not when fed 30 g/kg. The deposition of DHA in eggs was more efficient for marine algae oil than for menhaden oil [17].

Jiang et al. (1992) evaluated data from trained and untrained panelists and found in both groups that approximately one third detected a fish flavors in eggs from birds fed a 15% full-flax diet [34].

Caston et al. (1994) reported the data from taste-panel studies involving fresh and stored eggs were somewhat inconclusive, although in general there was a slight perception of off-flavors in eggs from flax-fed birds [22].

Van Elswyk (1997) reported that the dietary menhaden oil levels between 15 and 30g/kg yielded the greatest yolk n-3 fatty acid content; however, only eggs from birds fed with 15g menhaden oil kg were considered acceptable by trained flavor panelists [17].

Poultry meat n-3 FA enrichment

Somewhat greater levels of fat are used in broiler rations than in layer rations, to a maximum of approximately 6% total fat [8]. The fat in broiler white meat contains 33.5% of saturated, 30.5% unsaturated and 32% polyunsaturated fatty acids [35].

Newman et al. (2002) investigate the effects of dietary saturated fatty acids and polyunsaturated fatty acids (PUFA) of the n-3 and n-6 series on weight gain, body composition and substrate oxidation were investigated in broiler chickens and reported that there were no significant differences between treatments in total feed intake or final body mass. Birds fed the PUFA diets had lower respiratory quotients and significantly reduced abdominal fat pad weights compared with those fed tallow. The dietary lipid profile changes resulted in significantly greater partitioning of energy into lean tissue than into fat tissue (calculated as breast lean tissue weight: abdominal fat mass) in the PUFA groups compared with the saturated fat group (with no difference between the n-3 and n-6 PUFA groups) [36].

Lṕez-Ferrer et al. (2001) to assessed the effect of supplying linseed oil (LO) in the diet on performance, fatty acid (FA) composition, and quality objective parameters of broiler meat, diets enriched with 0, 2, or 4% LO plus tallow (T) up to 8% added fat (T1, T2, and T3, respectively). Performance parameters showed little difference between treatments. The differences in carcass yield values or inthe objective quality parameters of the meat between treatments were not significant. Increased levels of LO clearly decreased the saturated (SAT) and monounsaturated FA (MUFA) contents. LO increased the amount of polyunsaturated FA (PUFA), mainly because of the linolenic (LNA) and linoleic (LA) acid content in the T3 samples, but they hardly reflected the wide range given in the experimental diets. The n-3 long-chain (LC) PUFA content of T3 thighs was slightly higher than in T1 thighs. Thus, increasing dietary linseed oil did not increase DHA in muscle in the same manner that it increased in the yolk of laying hens. Feeding linseed oil did not change the flavor or other measures of meat quality [3].

Özpinar et al. (2003) fed supplemental fat to broilers as follows: 6% soybean oil, 2% fish oil + 2% sunflower oil, 4% fish oil + 2% linseed oil, or 6% fish oil. Feeding 2% fish oil with sunflower oil increased EPA and DHA in thigh muscle only modestly from those in the soybean oil diet at either 21 or 42 d of feeding, whereas diets with 4 or 6% fish oil increased these fatty acids substantially, to maxima of 6.3% DHA and 4.7% EPA in thigh muscle fatty acids at 42 d of age with the 6% fish oil diets. Concentrations of malondialdehyde (known also as the TBA test), as an indicator of tissue lipid peroxidation, increased as the contents of EPA and DHA in tissues increased. Malondialdehyde reached critical levels (>1 μmol/g meat) within minutes of initiating the test for all groups that were fed fish oil. According to the diet descriptions, no significant amounts of vitamin E or other antioxidants were provided in the feed. From these limited studies,

one can conclude that DHA and EPA can be increased in broiler muscle only by feeding fish oil (or marine algae), and that oxidative off-flavors are an inherent problem unless vitamin E is supplemented in generous amount [37].

Rahimi et al.(2011) reported that inclusion of FS and CS significantly increased ($P< 0.01$) the concentration of omega-3 fatty acid (ALA) and decreased the content of the arachidonic acid (AA). Total omega-6 to omega-3 polyunsaturated fatty acid (PUFA) ratio was significantly lower for all FS and CS fed groups compared with the control [1].

Ajuyah et al (1991) investigate changes in the yield and in the fatty acid composition of whole carcass and selected meat portions of broiler chickens fed full-fat oil seeds. In this experiment broiler chicks were fed eight experimental diets containing two levels (10 and 20%) of either full-fat flax seed (FFS) or full-fat canola seed (FCS), and two levels (3.5 and 7.0%) of canola oil (CO) in combination with either flax meal (FM) or canola meal (CM) at 6.5 or 13%. The researchers reported that carcass LNA enrichment was moderate after including 10% full-fat canola in contrast to flaxseed supplementation. Thus, meat from birds fed a 10% flaxseed diet contained 260% more LNA compared to birds fed 10% canola [38].

Mooney et al. (1998) investigate lipid and flavor quality of stored breast meat from broilers fed marine algae. In the current study, broilers were fed either 2·8 or 5·5% natural golden marine algae (MA) or 2·1% menhaden oil in an effort to produce an *n*-3 fatty acid (FA) enriched broiler breast product with acceptable flavor and lipid quality.

The theoretical improved meat lipid stability of birds fed MA was not observed in this experiment because carcass thiobarbituric reactive substances values were similar [39].

Hargis et al. (1993) reported that the FA composition of broiler chicken carcasses may be influenced considerably by diet [40].

Effects of feeding n-3 FA sources on production parameters in broilers

Farhoomand and Checaniazer, (2009), evaluate the effects of adjusting the fish oil (FO) and poultry fat (PF) balance in broiler chicken diets on the resulting yield and fatty acid (FA) composition of the meat. Two hundred and forty 21-d-old broilers were assigned to 1 of 4 dietary groups, 3% PF, 2% PF + 1% FO, 1% PF + 2% FO, or 3% FO, over a 21-d growth period. The highest final BW, highest daily BW gain, and best FCR were recorded for the 1% PF + 2% FO dietary group, followed by 3% FO group. By supplementing the diets of these birds with FO, the FA composition of the breast tissue was altered and the long-chain n-3 FA contents (C22:6n-3, C22:5n-3, and C20:5n-3) increased. The good performance of FO-fed broilers may be related to the FA composition of the FO. In this regard, the effects of different types of fat on feed efficiency could be related to their degree of unsaturation because some authors have reported that the digestibility of fat increases as the degree of unsaturation increases [4].

Olomu and Baracos (1991), investigate the the effect of feeding flaxseed oil on the performance, muscle protein deposition, and fatty acid composition of broiler chicks. Four levels of dietary flaxseed oil were fed in combination with animal tallow to give a total of 6% added fat in the diets. The diets were isonitrogenous and isocaloric Dietary treatments had no significant effects

on the relative weights of the Extensor digitorum communis and Sartorius muscles nor on their protein or lipid contents. Feeding flaxseed oil resulted in increased accumulation of omega 3 fatty acids in skeletal muscle lipids. Increased amounts of desaturation and elongation products (C20:3, C20:5, C22:5, and C22:6) of alpha-linolenate (C18:3 omega 3) were observed in the Sartorius muscle lipids of chicks fed flaxseed oil. Amounts of these omega 3 fatty acids increased with duration of feeding. The amounts of omega 6 fatty acids (C20:2, C20:3, C20:4) were significantly depressed in muscle lipids after 21 days of feeding flaxseed oil. In general, no adverse effects on production performance of broilers are seen when birds are fed flaxseed oil [41].

Bond et al. (1996) investigate the Effect of dietary flaxseed on broiler growth, erythrocyte deformability, and fatty acid composition of erythrocyte membranes. The effectiveness of flaxseed as a source of flax oil in broiler diets was determined in two separate experiments. Broiler growth, fatty acid composition of erythrocyte membranes and hematological variables were measured. The result of this experiment suggested that the incorporation of flaxseed into broiler diets is not a practical source of flax oil for poultry due to decreased growth, possibly due to the presence of antinutritional factors. The effect of flaxseed on the fatty acid composition of the erythrocyte membranes may be dependent on the fat content of the diet [42].

Flaxseed contains phytic acid, which is known to: a) reduce the availability of minerals such as calcium, magnesium, zinc and iron; b) affect proteins by forming electrostatic linkages with lysine, arginine and histidine; and c) inhibit proteolitic enzymes. In addition, flaxseed contains cyanogenic glycosides, mainly linamarin, linustatin and neolinustatin. These substances can form hydrogen cyanide which is potentially toxic. Flaxseed also contains linatine, which is a vitamin B6 antagonist, and this impairs growth in chickens and its antinutritional effect can be compensated by supplementing pyridoxine. Other components such as allergens and mucilage present in flaxseed could also interfere with the utilisation of nutrients affecting production parameters [13].

González-Esquerra and Leeson (2000a) investigate the metabolizable energy content of ground full-fat flaxseed fed in mash, pellet, and crumbled diets assayed with birds of different Ages. In this experiment meal basal diet was prepared, in which the energy yielding ingredients were substituted with ground flaxseed at 5, 10, 15, or 20%. the AMEn (nitrogen-corrected apparent metabolizable energy) of flaxseed obtained from mash diets containing 10% flaxseed when tested with mature Single Comb White Leghorn roosterswas 3,654 kcal/kg. However, this value increased significantly when feed was pelleted or crumbled (4,578 and 4,277 kcal/kg, respectively). There was no difference in AMEn value between flaxseed fed to roosters as pellets vs. crumbles [43].

Marine n-3 FA sources, when well stabilised and used appropriately in commercial diets, do not usually influence broiler production. Fish meal specifically could reduce performance in broilers if its actual calcium and phosphorus content is miscalculated. Another cause for concern is the threat of salmonella contamination and problems associated with overheating during processing. If all of these conditions are avoided and/or monitored, FM should not affect production [13].

Oxidative stability and sensory qualiy of n-3 FA enriched meat

Saleh et al. (2010), investigae the effect of dietary fish oil on oxidative stability and lipid composition of broiler chickens breast and thigh meat. Total four diets were provided with of 0.0, 1.5, 3.0 and 6% of fish oil in this experiment. The omega-3 fatty acid profiles linolenic acid (LNA) and long chain unsaturated fatty acid, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) of skinless breast meat and thigh meat were determined. The birds in diet contained 6% fed group had the highest level of n-3 fatty in breast and thigh. Lipid oxidation (malondialdehyde concentration) in breast and thigh meat after storage was higher in birds fed supplemented of FO diet than those fed control diet. These results demonstrated that the supplementation FO in broiler diet may increase long-chain n-3 PUFA content of chicken meat. Supplementation of 3% fish oil led to enrich the meat with n-3 FA with little deterioration of oxidative stability. Addition of >3% FO to diet increased the level of meat n-3 content that was coincided with increase in oxidative susceptibility [44].

Sanz et al. (2000) reported that broilers fed on diets containing animal fat showed higher whole-body fat retention and lower protein accretion than those fed on diets containing vegetable oils. The findings suggest that the degree of saturation of dietary fats affects their metabolic use and fat accumulation in broiler chickens [45].

Crespo and Esteve-Garcia (2001) reported that the muscle fat content was lower for birds fed tallow or olive oil but not significantly. The fatty acid profile of the different tissues reflected dietary fatty acid profile. Monounsaturated fatty acids were higher in abdominal fat, whereas polyunsaturated fatty acids were higher in muscle fat. These results suggest that polyunsaturated fatty acids produce lower abdominal fat deposition than saturated or monounsaturated fatty acids [46].

Kirchgessner et al. (1993) found an increase of fat content in breast muscle with increasing levels of linoleic acid in the diet [47].

Scaife et al. (1994) observed that the lowest levels of muscle fat content were for tallow, in comparison with soybean, rapeseed, or marine oil [48].

Whitfield, (1992) reported that there are many volatile products derived from lipid oxidation that may exert a significant effect on flavour characteristics in meat [49].

Mooney et al. (1998) reported rate of thiobarbituric acid production during storage of cooked breast meat was increased by *n*-3 FA, but this was curtailed by storing samples raw. These data indicate that 2·8% MA is useful for enhancing poultry tissue *n*-3 FA with minimal compromise in flavour or lipid quality [39].

O'Keefe et al. (1995) reported higher thiobarbituric reactive substances in LCn-3 enriched pre-cooked meat after 2 d of refrigeration. The highest concentrations of lipid oxidation products were found in meat with higher LCn-3, and this effect increased over time [50].

González-Esquerra and Leeson (2000b), reported that the breast meat sensory quality was not affected in birds given 100 g/kg flaxseed for 14 d (treatment 3), 7.5 g/kg MO for 14 d (treatment

5) or 100 g/kg flaxseed +0.75 g/kg MO for 7 d (treatment 6). In contrast, thigh meat sensory quality decreased in treatments 5 and 6. 3. Feeding flaxseed and MO to birds for just 7 d prior to slaughter resulted in significant omega-3 meat enrichment depending on their dietary concentrations. These findings imply that LNA is more palatable than LCn-3 once incorporated into poultry meat [51].

CONCLUSION

Numerous dietary supplements are available and effective for enhancing yolk n-3 FA. Importantly, however, n-3 FA profiles vary dramatically depending on the dietary source utilized [52]. Feeding n-3 and n-6 PUFA resulted in a leaner bird, with an accompanying improvement in feed conversion efficiency, both important criteria for economically-sustainable animal production systems. These effects reflect changes in avian metabolism through the modulation of lipid deposition and oxidation by n-3 and n-6 PUFA, and concur with the results of studies in rats and man. In addition, the incorporation of these fatty acids into the tissues of birds could impact favourably on the health of consumers. The n-3 fatty acids are essential for the normal physiological functioning and health of humans and all domestic and commercially important food species. Intake of long-chain PUFA is less than recommended in all populations. The content of n-3 fatty acids in animal products can be increased by modifying animal diets and feeding practices, thereby providing a means to increase the n-3 fatty acid intake of populations through their consumption of traditional diets.

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