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Influence of linseed oil feeding on performance and fatty acid composition of muscles in broiler chicks

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Abstract
Interest on the enrichment of poultry meat with n-3 fatty acids has increased given its important role in human health. Recently there is shift from quantity production to quality production. Linseed oil is the main plant origin sources of n-3 fatty acids, and contains between 45 to 71% of total fatty acids of the oil as omega-3 i.e. α-linolenic acid. Dietary composition and feeding strategies may offer practical and efficient solutions for altering type of fat deposition in broiler meat. This paper reviews the possibility of n-3 enrichment of broiler meat. Its focus is on the inclusion of linseed oil and linseed and begins by summarizing the benefits of supplementation on broiler performance. The literature on its effect on different growth parameters, blood parameters and also on altering the FA deposition in different tissues is then reviewed. Flaxseed supplementation caused a reduction in the abdominal fat pad, and the main fatty acid deposited in the tissue is LNA. The blood serum parameter are also altered with reduced blood cholesterol and LDL whereas, increased HDL level. The use of fold-change analysis allowed interpreting and determining the variation of results within experiments that do not report data in similar units of measure. The fold change analysis identified three categories of desaturation response to feeding flaxseed to broilers, resulting in different values for EPA and DHA in both breast and thigh tissues: high, medium and low fold-changes. The use of linseed oil, whole or ground flaxseed before slaughter is recommended to poultry producers as feeding strategies to optimize n-3 enrichment, without compromising animal performance.

Keywords: α-linolenic acid, omega-3, EPA and DHA

Introduction
Poultry has a crucial place in India, as the eggs and chicken meat are important and rich sources of protein, vitamins and minerals. Poultry provides rich organic manure and is an important source of income and employment to millions of farmers and other persons engaged in allied activities in the poultry industry. Chicken is the most widely accepted meat in India. Unlike beef or pork, it does not have a religious taboo. World-wide health professionals are emphasizing the need to increase intake of n-3 polyunsaturated fats, while reducing trans-fatty acids, saturated fatty acids and cholesterol due to its role in the prevention and treatment of coronary heart disease, major depression, aging and Crohn’s disease, ulcerative colitis, and lupus erythematosus. Alpha-linolenic acid (LNA; 18:3n-3), which serves as a precursor for EPA and DHA synthesis [1, 7, 8]. the most important n-3 fatty acids in human nutrition are eicosapentaenoic acid (EPA; 20:5n-3), docosahexaenoic acid (DHA; 22:6n-3), and α-linolenic acid (LNA; 18:3n-3), which serves as a precursor for EPA and DHA synthesis [10]As people become more concerned about health issues, demand for more healthy chickens and eggs has risen. Nowadays, farmers are looking at the possibilities to include in the feed of chickens more flaxseed due to its nutritional properties. Flaxseed is unique among oilseeds because of its exceptionally high content of α-linolenic acid (18:3, n-3), contains 35 to 45% oil, of which 45 to 52% is α-linolenic acid [7, 2]. In monogastric species such as poultry, the fatty acid profile of the meat and fat is directly affected by the source of fat in diet. The quality and quantity of lipids and their fatty acid composition in meat are influenced by internal (age, gender, genotype and castration) and external (temperature, feeding) factors [30, 4]. The exact content and ratio between α-linolenic acid (ALA) and linoleic acid (LA) in linseed depends on the flax variety and could range from 14% to more than 60% of ALA [52]. Humans have very limited capacity of conversion of LNA to EPA and DHA. There is a theory that poultry has a relatively low capability to transfer LNA to EPA and DHA [13, 42, 47]. Despite that theory, comparing the results of feeding strategies, the fold change analysis showed that the source of LNA, and feeding time affected the capacity of LNA to desaturate and elongate.

The main reason for incorporating linseed oil in mixtures for broiler chicken is the favourable effect of polyunsaturated fatty acid (PUFA) on animal and human health. The first effect of adding linseed oil is a high increase in α-linolenic acid content [19, 22, 52] and a possible increase in other n-3 PUFA [55]. Consequently, the ratio between competing n3 and n6 lines is also changed in favour of n3 fatty acids, which are essential for normal growth and development [45]. There is increasing recognition of the health benefits of PUFA in general, and of n3 fatty acids in particular, because these fatty acids are essential for humans [6, 16, 46]. Today we know that n-3 fatty acids are important in the prevention and treatment of coronary disease, hypertension, diabetes and arthritis. It has been reported that feeding omega-3 enriched diets to poultry increases the omega-3 content of eggs and meat and thus enriched poultry products offer consumers an alternative to enhance their omega-3 daily intake [25].

Effect of dietary treatment on the performance of broilers
Feed intake-

Researchers have consistently observed positive performance and meat quality results when linseed oil is added to broiler diets. There are great benefits and application of linseed oil in the poultry ration. Some authors compared the feed intake of Cobb broilers fed diets supplemented with 8.2% fish oil or 8.2% linseed or canola oil and obtained higher ($P<0.05$) daily feed intake in those fed vegetable oils [27].

Researchers performed an experiment to study the effect of different dietary fatty acid profiles on abdominal fat deposition in broilers. Diets with four types of fats (tallow, olive oil, sunflower oil, and linseed oil), at two levels of fat inclusion (either 6 or 10%), were administered to males from 21 to 42 d and to females from 21 to 49 d of age. Feed intake decreased significantly ($P<0.05$) as dietary fat increased. This can be explained due to high energy content of ration which decreases the overall feed intake of birds [15].

The effect of linseed and rapeseed or respective oils on performance indices, nutrient digestibility, metabolizable energy of diets, with particular attention to n-3 PUFA was done. The source of added fat was in control diet lard (61 g/kg), half of the lard was substituted by: linseed oil (LO) or full-fat linseed (L), rapeseed oil (RO) or full-fat rapeseed (R). Feeding diet with linseed caused an increase in feed intake of broilers as compared to the broilers fed with animal origin fat which may be attributed because of more digestibility of PUFA as compared to the saturated fatty acid [36].

The feeding of flaxseed up to 6% of the total dietary matter had no effect on dry matter intake and on body weight. This may be partially explained by the fact that digestibility of unsaturated fats is higher than saturated fats [21]. Some scientist [29] also revealed that the inclusion of n-3 PUFA rich oil sources in Japanese quail diet had no significant influence on cumulative feed consumption. Similar findings were reported [37] that the body weight gain, feed consumption as well as feed conversion ratio were not affected by dietary incorporation of linseed oil up to 2 and 3% during starter (1–21 d) and finisher (22–42 d) phases, respectively.

A study carried out to evaluate the effect of the inclusion of different linseed oil levels (0.0, 3.3, 6.6, or 9.9%) on feed and metabolizable energy intakes they found there was linear increase in feed intake as dietary linseed oil level increased [17]. Poorghasemi *et al*. [40] conducted an experiment to determine the effects of three different fat sources and their combination on growth performance. They found that feed intake of broilers did not vary significantly ($P>0.05$) among control diet of broilers containing 4% tallow or diet containing 4% linseed oil. Starcevic *et al*. [48] reported that the diet of chicken with 5% of linseed oil diet did not influence the feed efficiency, feed intake.

Body weight gain

It is known that the incorporation of flaxseed into livestock feed, especially for poultry, serve as source of energy, protein and -linolenic acid. Whereas some researchers found some negative effect of feeding linseed oil broilers weight gain [41]. A number of studies have been conducted to determine how feeding flaxseed oil to broilers influences their performance. In general, flaxseed oil is readily accepted by broilers, and feeding up to 6% of the total dietary matter had no effect on dry matter intake and on body weight. This may be partially explained by the fact that digestibility of unsaturated fats is higher than saturated fat [54]. Some researchers used the source of added fat in control diet lard (61 g/kg), in experimental diets half of the lard was substituted by: linseed oil (LO) or full-fat linseed (L), rapeseed oil (RO) or full-fat rapeseed (R). Feeding diet with rapeseed did not significantly affect BWG or FCR while linseed caused an increase in feed intake [36]. Also in a study [53] the effects of 1, 3, 5 or 7% of linseed oil in the diet of broiler and reported that body weight gains were higher ($P < 0.05$) in groups receiving 5% and 7% of dietary oils as compared to groups receiving 1% and 3%.

Some scientists [31] conducted an experiment in which the bird were fed with 5% packed fat (control), 2.5% packed fat + 2.5% sunflower oil (T_1), 2.5% packed fat + 2.5% rapeseed (T_2) and 2.5% packed fat + 1.5% rapeseed + 1.5% sunflower oil (T_3). There were insignificant differences ($P > 0.05$) for live weight and daily weight gain at all periods of breeding except finisher male where there were significant differences ($P <0.05$) and highest value of live weight was obtained in control group as compared to others. In a study [32, 33] use of flaxseed meal at 0, 5, 10 and 15% in the diet of broilers. Flaxseed meal did not affect the weekly body weight of broiler chicks during the first two weeks but thereafter weekly body weight reduced among flaxseed meal groups. At the end of 6th week, birds fed on 15% flaxseed meal showed a reduction of 8% in body weight compared to the control group. A study carried out to evaluate the effect of the inclusion of different linseed oil levels (0.0, 3.3, 6.6, or 9.9%). Dietary linseed oil linearly increased weight gain and feed and energy intakes [17]. Lopes *et al*. [26] evaluated the effects of diets with partial and total substitution of soya bean oil (SO) with flaxseed (linseed) oil at level of 50, 75 and 100%. No significant differences were observed in body weight (BW), body weight gain (BWG), feed intake (FI), feed conversion ratio (FCR). Researchers used two different feed containing either 4% soybean oil or 2% rapeseed oil + 2% linseed oil. Final body weight in the soya oil group was 2137.6 gram and in the rapeseed plus linseed oil group 2019.6 gram, and liver weight was 64 gram in the soybean oil group and 58 gram in the rapeseed plus linseed oil group [38]. Starcevic *et al*. [48] reported that there were no significant differences between the broilers groups fed linseed or sunflower oil (5%). Increase of dietary α-linolenic acid in linseed oil diet did not influence the feed conversion, feed intake and daily weight gain. Some scientist conducted an experiment on the effect of dietary 18:2n-6/18:3n-3 ratio (by the replacement of corn oil with linseed oil) with diets containing 5% corn oil (CO), 3.75% corn oil + 1.25% linseed oil (CL1), 2.5% corn oil + 2.5%

linseed oil (CL2), and 5% linseed oil (LO) based on the basic diets, respectively. Dietary 18:2n-6/18:3n-3 ratio did not affect body weight 42-day and 0–42-day feed conversion efficiency (feed/gain, $P < 0.05$) of broiler chickens [11].

Feed conversion ratio

Effect of feeding linseed oil on broilers performance has no negative effects. In many studies it also proved to be beneficial in terms of feed intake and weight gain whereas in other studies depression in FCR may be due to reduced feed intake because 0f higher energy content of the diet. Some scientists [24] found that there were no influence of dietary treatment on dry matter and protein retention. However, they reported that diets containing 10 or 20% full fat flaxseed oil depressed FCR and dietary metabolizable energy in the broiler chicken.

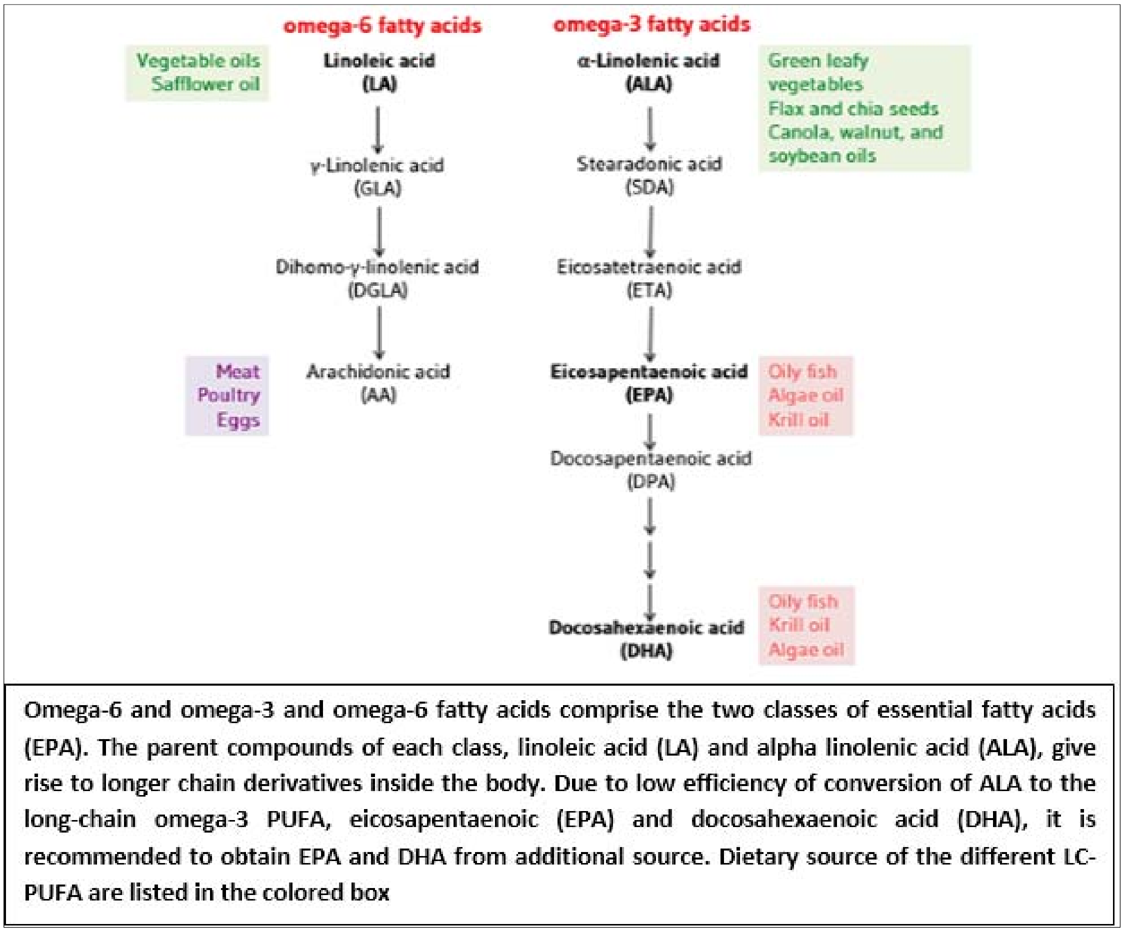

Fig 1: Classes of essential fatty acids

An experiment conducted with four types of fats (tallow, olive oil, sunflower oil and linseed oil) at the level of 6 and 10% in the diet of broilers and suggested that that feed efficiency (FE) was better in animals fed diets with 10% fat because of the higher ME content and further also reported that sunflower and linseed oil showed better value of feed efficiency [15]. Ferrini *et al.* [18] experimented on chickens fed a low-fat diet (0.5% of added fat) or diets supplemented with 10% of tallow, sunflower oil rich in oleic acid, sunflower oil rich in linoleic acid, linseed oil rich in linolenic acid, or a mix of fats that contained one-third each of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids. There was significant differences (P<0.05) in FCR of dietary treatment. The group containing 5% packed fat had better FCR than other groups which might be due to higher body weight gain [31]. Researchers also observed no effect of flaxseed supplementation on carcass weight, yield and breast weight in broiler chickens. These result may attributed to isocaloric diet, equal feed intake by all birds of all groups. Linseed oil was not showing any harmful effect on carcass traits at all level [39].

Effect of dietary treatments on blood and serum parameters in broilers

Hematological parameter

Using linseed oil in broiler diet showed positive effect on hematological parameters due to presence of n-3 PUFA in oil which has immune modulating effect [34, 39]. Bond *et al.* [9] found that an increase in the omega-3 fatty acids in the erythrocyte membranes particularly 18:3(n-3) and 20:5(n-3) with inclusion of flaxseed in the diet of broilers. Also some scientists [3] reported significant differences (P<0.05) of blood picture including RBC counts, WBC counts, PCV between treatments containing 5 and 10% flaxseed supplementation and control group without flaxseed. Within groups, significant ($P < 0.05$) increase in WBC counts were recorded in 10% flaxseed group as compared with 5% flaxseed group but on the other hand the RBC count and PCV count were also increased significantly.

Serum Parameter

Using linseed oil in broilers diet has serum cholesterol, LDL and triglyceride reducing effects. The reduction in the plasmatic triglyceride concentration in broilers given diets containing PUFA-rich oils compared to those given animal fat can be explained by the increase in the β- oxidation rate of unsaturated fatty acids, resulting in the removal of triglycerides from the blood to the tissues. Bond *et al* [9] investigate the effect of dietary flaxseed on broiler growth, erythrocyte deformability, and fatty acid composition of erythrocyte membranes. He suggested that there was reduction in total saturated fatty acid in erythrocyte membranes with the use of 20% linseed. In many studies [12, 20, 28, 43, 35, 49, 50], comparing PUFA-rich oils with saturated fatty acid-rich oils in broiler diets, observed a decrease in the triglyceride, CHO and HDL concentrations when the birds were given PUFA-rich oils compared to saturated fatty acid-rich oils. Alparslan and Özdogan [2] investigated the effect of feed containing 0%, 2% and 4% fish oil in the diet. It was found that HDL in blood parameters of female, AST (Aspartate aminotransferase) in males were higher ($p<0.01$) in the group containing 4% fish oil compared to the control group. Kartikasari [23] reported that the proportion of ALA in both erythrocytes and plasma increased as the dietary LA to ALA ratio is lowered ($P< 0.001$). However level of ALA in erythrocytes were nearly twice than in plasma. The metabolites of dietary ALA, EPA, DHA, increased in response in response to increased availability of dietary ALA in the blood tissue ($P<0.001$), n3 LCPUFA level were higher in plasma than erythrocytes.

Fatty acid profile of muscles

It has been found that the flaxseed oil is an excellent source of polyunsaturated fatty acids of the n-3 family, which can be very efficiently converted from phospholipids in tissues lipids of poultry [27]. Similarly Zelenka [53] also concluded that with the exception of docosahexaenoic acid (C22:6n-3; DHA), the content of all n-3 PUFA and also of lipids was highly significantly higher ($P < 0.001$) in TM than in BM. The effect of supplying linseed oil in the diet of broilers @ 0, 2, or 4% linseed oil plus tallow up to 8% added fat. They found that increased level of linseed oil clearly decreased the saturated and monosaturated fatty acids in different tissues. N-3 content in thigh muscles of dietary treatment group at 4% linseed oil supplementation was higher ($P<0.05$) than the group without linseed oil [27]. Crespo and Esteve [14] conducted experiment where abdominal fat and cholesterol content of thigh muscle were significantly lower in animal fed sunflower oil and linseed oil than in those fed tallow or olive oil ($P<0.01$). PUFA were higher in muscle fat. An experiment conducted to determine the effect of different dietary fatty acid profiles on efficiency of energy, fat, nitrogen, and fatty acid deposition in broiler chickens. Sixty female broiler chickens were fed a basal diet without additional fat or with 4 other diets with different fats (tallow, olive, sunflower, and linseed oils) at 10% [15]. Nguyen *et al*. [36] used the source of added fat in control diet lard (61 g/kg), in experimental diets half of the lard was substituted by: linseed oil (LO) or full-fat linseed (L), rapeseed oil (RO) or full-fa rapeseed (R). The deposition of n-3 PUFA in the carcass was in groups L and LO 8 times greater than in the control group. The ratio of n-6/n-3 PUFA, which approximated 10 in edible parts of broilers from the control group, decreased to about 4.7 in groups R and RO, and to about 1.3 in groups L and LO. Similarly Starčević *et al*. [48] also reported that the dominant unsaturated fatty acids in the adipose tissue and thigh muscle of the linseed oil group were C18:1n9, C18:2n6 and C18:3n3. Mridula *et al*. [32] reported that with diet containing flaxseed meal at 0, 5, 10, 15%,the alpha-linolenic acid content in both breast and thigh meat was higher with an increasing level of flaxseed meal in the diets without affecting the sensory acceptability of meat. Phetteplace and Watkins were the first to show that flaxseed increased n-3 fatty acids deposition in chickens. In avian species, the amount of fat that accumulates in the body depends on the available plasma lipid substrate, which originates from the diet or *de novo* lipogenesis in the liver. Therefore, the sources of lipids in poultry diets may affect their total body fat deposition. Therefore, [14, 15] fed chickens diets supplemented with tallow (a rich source of saturated fatty acids), olive oil (a rich source of monounsaturated fatty acids), sunflower oil (a rich source of n-6 type polyunsaturated fatty acids), and linseed oil (a rich source of n-3 type polyunsaturated fatty acids). They reported that chickens fed diets supplemented with sunflower or linseed oils had a significant reduced in abdominal fat percentage and other fat depots, including mesenteric and neck fat, compared with chickens fed diets supplemented with tallow or olive oil. Linseed oil is a source of n-3 type polyunsaturated fatty acids while sunflower oil contains n-6 type polyunsaturated fatty acids. Thus, linseed oil could have reduced total body fat via the same mechanism as sunflower oil or other mechanisms. A similar result was reported by Newman et al. [35]who found that, compared with the addition of tallow, the addition of sunflower or fish oil to the diets of broilers from 21 to 56 days of age reduced abdominal fat deposition, increased the consumption of oxygen, and decreased the rate of oxygen consumption relative to the rate of carbon dioxide production, which showed that polyunsaturated fatty acids activate fatty acid β-oxidation.

Abdominal fatty acid profile

Flaxseed oil is not typically employed in poultry diets as the preferred source of alpha-linolenic acid (LNA; 18:3n-3) due to its oxidative potential during storage and mixing feeds [44]. In a study with ground flaxseed LNA and total n-3 fatty acids were increased, while eicosapentaenoic (EPA), docosahexaenoic (DHA) and other derivatives of n-3 acids were not found [5]. The absence of long-chain n-3 PUFA could be the result of the fact that long-chain n-3 PUFAs are deposited in muscle fat rather than in abdominal fat. PUFAs are preferentially incorporated into phospholipids which are in higher proportion in muscle fat than in adipose tissue fat [51].

Conclusion

Wide promotion of n-3 fatty acids spanned a research campaign on the use of flaxseed in animal production, while emphasizing the need to increase intake of n-3 PUFA. The knowledge achieved so far on enriching poultry meat with n-3 PUFA has made possible the availability of enriched poultry meat. Linseed oil supplementation considerably decrease serum total cholesterol, triglycerides and LDL cholesterol concentration. In addition to these findings present investigation confirmed that it may be possible to increase the n3 PUFAs content of chicken meat in order to decrease the n6/n3 ratio by adding linseed oil in dietary regime of broiler chicks, and thereby produce chicken meat more beneficial for human health. Increasing the concentration of n-3 PUFA in poultry diets results in an increase in the n-3 PUFA content of poultry meat. Nutritionally meaningful amounts of LNA and LCn-3 have been achieved in breast and thigh muscles by manipulating feeding time, flaxseed concentration in the diets, and using a proper processing method. Three feeding strategies and processing alternatives of flaxseed were identified to optimize enrichment: The use of flaxseed oil, whole or ground flaxseed 14 to 21 days before slaughter can be recommended to producers.

References

1. Ajuyah AO, Lee KH, Hardin RT, Sim JS. 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. Poultry. Science. 1991; 70(11):2304-2314.
2. Alparslan G, Özdogan M. The effects of diet containing fish oil on some blood parameters and the performance values of broilers and cost efficiency. International Journal of Poulry Science. 2006; 5(5):415-419.
3. Al-Zuhairy MA, Taher MG. Effects of feeding different levels of flaxseed on performance traits and blood parameters in broiler. Diyala Agriculture Science Journal. 2014; 6(2):1-10.
4. Arshami J, Pilevar M. Effects of long-term feeding flaxseed on growth and carcass parameters, ovarian morphology and egg production of pullets. International journal Poultry Science. 2010, 9.
5. Azcona JO, Schang MJ, Garcia PT, Gallinger C, Ayerza Jr R, Coates W. Journal of animal sciences. 2008; 88:257-269.
6. Bedeković D, Pintar J, Janječić Z, Mužic S, Kos I. Using Rapeseed Cake to Improve Fatty Acid Composition of Turkey Meat. Journal of Agriculture Science Technology. 2014; 16(6):1279-1287.
7. Bhatty RS. Nutrient composition of whole flaxseed and flaxseed meal. Flaxseed in Human Nutrition. 1995, 22-42.
8. Brenner RR. Factors influencing fatty acid elongation and desaturation. The Role of Fats in Human Nutrition 2nd edition. Ed: Vergroesen AJ, Crawford M. Academic Press: London, England, UK; Sand Diego, California, USA. ILLUS, 1989, 45-80.
9. Bond JM, Julian RJ, Squires EJ. Effect of dietary flaxseed on broiler growth, erythrocyte deformability and fatty acid composition of erythrocyte membranes. Canadian Journal. Anim. Sci. 1996; 77(2):279-286.
10. Burdge GC, Wootton SA. Conversion of α-linolenic acid to eicosapentaenoic, docosapentaenoic and docosahexaenoic acids in young women. British Journal of Nutrition. 2002; 88(4):411-20.
11. Chen W, Zhao R, Yan BX, Zhang JS, Huang YQ, Wang ZX, *et al*. Effects of the replacement of corn oil with linseed oil on fatty acid composition and the expression of lipogenic genes in broiler chickens. Czech Journal Animal Sciences. 2014; 59:353-64.
12. Celebi S, Utlu N. Influence of animal and vegetable oil in layer diets on performance and serum lipid profile. Int. Journal of Poultry Sciences. 2006; 5(4):370-3.
13. Chanmugam P, Boudreau M, Boutte T, Park RS, Hebert J, Berrio L, *et al*. Incorporation of Different Types of n-3 Fatty Acids Into Tissue Lipids of Poultry 1 2. Poultry Science. 1992; 71(3):516-21.
14. Crespo N, Esteve-Garcia E. Dietary fatty acid profile modifies abdominal fat deposition in broiler chickens. Poultry science. 2001; 80(1):71-8.
15. Crespo N, Esteve-Garcia E. Nutrient and fatty acid deposition in broilers fed different dietary fatty acid profiles. Poultry science. 2002; 81(10):1533-42.
16. Conquer JA, Holub BJ. Effect of supplementation with different doses of DHA on the levels of circulating DHA as non-esterified fatty acid in subjects of Asian Indian background. Journal of lipid research. 1998; 39(2):286-92.
17. Duarte KF, Junqueira OM, Borges LL, Rodrigues E, Filardi RD, Praes MF, *et al*. Performance, carcass traits, and body composition of broilers fed different linseed oil levels between 21 and 56 days of age. Revista Brasileira de Ciência Avícola. 2014; 16(1):55-60.
18. Ferrini G, Baucells MD, Esteve-Garcia E, Barroeta AC. Dietary polyunsaturated fat reduces skin fat as well as abdominal fat in broiler chickens. Poultry Science. 2008; 87(3):528-35.
19. Gebauer SK, Psota TL, Harris WS, Kris-Etherton PM. n−3 fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. The American journal of clinical nutrition. 2006; 83(6):S1526-1535S.
20. Gonzalez-Esquerra R, Leeson S. Effects of menhaden oil and flaxseed in broiler diets on sensory quality and lipid composition of poultry meat. British poultry science. 2000; 41(4):481-8.
21. Hernandez FI. Performance and Fatty Acid Composition of Adipose Tissue, Breast and Thigh in Broilers Fed Flaxseed: A Review. Current Research in Nutrition and Food Science Journal. 2013; 1(2):103-14.
22. Jia W, Rogiewicz A, Bruce HL, Slominski BA. Feeding flaxseed enhances deposition of omega-3 fatty acids in broiler meat portions in different manner. Canadian journal of animal science. 2010; 90(2):203-6.
23. Kartikasari LR. Assessment of omega-3 long chain polyunsaturated fatty acid incorporation in broiler chicken meat following the consumption of omega-3 rich vegetable oils (Doctoral dissertation).
24. Lee KH, Olomu JM, Sim JS. Live performance, carcass yield, protein and energy retention of broiler chickens fed canola and flax full-fat seeds and the restored mixtures of meal and oil. Canadian journal of animal science. 1991; 71(3):897-903.
25. Leskanich CO, Noble RC. Manipulation of the n-3 polyunsaturated fatty acid composition of avian eggs and meat. World's Poultry Science Journal. 1997; 53(2):155-83.
26. Lopes DC, Xavier EG, Santos VL, Goncalves FM, Anciuti MA, Roll VF, *et al*. Growth performance, carcass traits, meat chemical composition and blood serum metabolites of broiler chicken fed on diets containing flaxseed oil. British poultry science. 2013; 54(6):780-8.
27. Lopez-Ferrer S, Baucells MD, Barroeta AC, Grashorn MA. Influence of vegetable oil sources on quality parameters of broiler meat. Archiv Fuer Gefluegel Kunde (Germany). 1999; 63:3-9098.
28. Mandal GP, Ghosh TK, Patra AK. Effect of different dietary n-6 to n-3 fatty acid ratios on the performance and fatty acid composition in muscles of broiler chickens. Asian-Australasian journal of animal sciences. 2014; 27(11):1608.
29. Manohar GR, Edwin SC. Effect of dietary omega-3 PUFA rich sources on growth performance of japanies quail. International Journal of Science,Environment and Technology. 2015; 4(2):393-399.

30. Mašek T, Severin K, Gottstein Ž, Filipović N, Stojević Z, Mikulec Ž. Effects of early castration on production performance, serum lipids, fatty acid profile and desaturation indexes in male chicken broilers fed a diet with increased fat content. Veterinarski arhiv. 2013; 83(2):233-43.
31. Mohammed AH, Horniakova E. The effect of different type of fats utilization in broiler (308) feeding on the performance parameter. Acta Fytotechnicaet Zootechnica. 2011; 4:102-107.
32. Mridula D, Kaur D, Nagra SS, Barnwal P, Gurumayum S, Singh KK. Growth performance, carcass traits and meat quality in broilers, fed flaxseed meal. Asian-Australasian Journal of Animal Sciences. 2011; 24(12):1729-35.
33. Mridula D, Kaur D, Nagra SS, Barnwal P, Gurumayum S, Singh KK. Growth performance and quality characteristics of flaxseed-fed broiler chicks. Journal of applied animal research. 2015; 43(3):345-51.
34. Murakami KTT, Pinto MF, Ponsano EHG, Neto MG. Productive performance and meat quality of broilers fed diets containing linseed oil. Brazilian Agricultural Research. 2010; 45(4):401-407.
35. Newman RE, Bryden WL, Fleck E, Ashes JR, Buttemer WA, Storlien LH, *et al*. Dietary n-3 and n-6 fatty acids alter avian metabolism: metabolism and abdominal fat deposition. British Journal of Nutrition. 2002; 88(1):11-8.
36. Nguyen CV, Smulikowska S, Mieczkowska A. Effect of linseed and rapeseed or linseed and rapeseed oil on performance, slaughter yield and fatty acid deposition in edible parts of the carcass in broiler chickens. Journal of Animal and Feed Sciences. 2003; 12(2):271-88.
37. Panda A, Sridhar K, Lavanya G, Prakash B, Rao SR, Raju M. Growth performance, carcass characteristics, fatty acid composition and sensory attributes of meat of broiler chickens fed diet incorporated with linseed oil. Indian Journal og animal sciences. 2015; 85(12).
38. Paudel S. Two Different Oils in Feeds For Broiler: Effects on Fat Digestion. Norwegian University of Life Sciences, 2013.
39. Pekel AY, Patterson PH, Hulet RM, Acar N, Cravener TL, Dowler DB, *et al*. Dietary camelina meal versus flaxseed with and without supplemental copper for broiler chickens: Live performance and processing yield. Poultry science. 2009; 88(11):2392-8.
40. Poorghasemi M, Seidavi A, Qotbi AA, Laudadio V, Tufarelli V. Influence of dietary fat source on growth performance responses and carcass traits of broiler chicks. Asian-Australasian journal of animal sciences. 2013; 26(5):705.
41. Rahimi S, Kamran Azad S, Torshizi K. Omega-3 enrichment of broiler meat by using two oil seeds. Journal of agricultural science and technology. 2011; 13:353-65.
42. Roth-Maier DA, Eder K, Kirchgessner M. Live performance and fatty acid composition of meat in broiler chickens fed diets with various amounts of ground or whole flaxseed. Journal of Animal Physiology and Animal Nutrition. 1998; 79(1-5):260-8.
43. Sanz M, Lopez-Bote CJ, Menoyo D, Bautista JM. Abdominal fat deposition and fatty acid synthesis are lower and β-oxidation is higher in broiler chickens fed diets containing unsaturated rather than saturated fat. The Journal of nutrition. 2000; 130(12):3034-7.
44. Scheideler SE. 14 Use of flaxseed in animal diets to create consumer products with modified fatty acid profiles. Flax: The genus Linum. 2003; 22:268.
45. Simopoulos AP. Human requirement for N-3 polyunsaturated fatty acids. Poultry Sciences. 2000; 79(7):961-970.
46. Simopoulos AP. N-3 fatty acids and human health: Defining strategies for public policy. Lipids. 2001; 36(1):S83-S89.
47. Stanaćev VŽ, Milošević N, Pavlovski Z, Milić D, Vukić-Vranješ M, Puvača N, *et al*. Effects of dietary soybean, flaxseed and rapeseed oil addition on broilers meat quality. Biotechnology in Animal Husbandry. 2014; 30(4):677-85.
48. Starčević K, Mašek T, Brozić D, Filipović N, Stojević Z. Growth performance, serum lipids and fatty acid profile of different tissues in chicken broilers fed a diet supplemented with linseed oil during a prolonged fattening period. Veterinarski arhiv. 2014; 84(1):75-84.
49. Velasco S, Ortiz LT, Alzueta C, Rebole A, Trevino J, Rodriguez ML. Effect of inulin supplementation and dietary fat source on performance, blood serum metabolites, liver lipids, abdominal fat deposition, and tissue fatty acid composition in broiler chickens. Poultry Science. 2010; 89(8):1651-62.
50. Viveros A, Ortiz LT, Rodríguez ML, Rebolé A, Alzueta C, Arija I, *et al*. Interaction of dietary high-oleic-acid sunflower hulls and different fat sources in broiler chickens. Poultry science. 2009; 88(1):141-51.
51. Whitehead CC. Essential fatty acids in poultry nutrition. Fats in Animal Nutrition. J Wiseman, ed. Butterworths, London, UK. 1984, 153-66.
52. Zelenka J, Schneiderová D, Mrkvicová E. Linseed oils with different fatty acid patterns in the diet of broiler chickens. Czech Journal of Animal Science. 2006; 51(3):117.
53. Zelenka J, Schneiderova D, Mrkvicova E, Dolezal P. The effect of dietary linseed oils with different fatty acid pattern on the content of fatty acids in chicken meat. Veterinarni Medicina-Praha. 2008; 53(2):77.
54. Wongsuthavas S, Terapuntuwat S, Wongsrikeaw W, Katawatin S, Yuangklang C, Beynen AC. Influence of amount and type of dietary fat on deposition, adipocyte count and iodine number of abdominal fat in broiler chickens. Journal of animal physiology and animal nutrition. 2008; 92(1):92-8.