

The Role of Dietary Fat to Produce Chicken Meat as a Functional Food: A Review

Review Article

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Received on: 11 Apr 2014

Revised on: 18 Jun 2014

Accepted on: 30 Jun 2014

Online Published on: Mar 2015

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Online version is available on: www.ijas.ir

ABSTRACT

Production of chicken meat is an important branch of food industry. Generally, poultry meat farmers aim to produce birds with superior body weight and feed conversion ratio. However, in line with current developments, there are other parameters that must to be taken into account such as lower body fat deposition and improvement in the nutrient composition of products corresponding to consumer requirements. Nowadays, extra focus has been given to designing and enrichment foods as functional foods, with components that have beneficial effects on human wellbeing. In definition, functional foods contain particular nutrients and / or non-nutrients that have an effect on human health, beyond what is usually known as nutritional effects. There are several compounds in foods that improve consumer's health status. Among them the polyunsaturated fatty acids (PUFAs, n-6 and n-3 series) and conjugated linoleic acid (CLA) are the most functional and bioactives components of lipids. Chicken meat has been a common objective of nutritional modification because the absorbed dietary fatty acids from the small intestine directly enter into the chicken tissue lipids. This paper tries to review the recent findings in the area of chicken meat enrichment using dietary fats.

KEY WORDS chicken meat, CLA, enrichment, n-3 PUFAs.

INTRODUCTION

It seems that in human rations and most animal feeds there is an unbalanced fatty acid composition, so that the content of n-3 has decreased whereas the content of n-6 fatty acids has increased. One approach to restore this balance is by supplementing food with fish originated fats, which are rich in long chain n-3 PUFA (Bezard *et al.* 1994; Tuncer *et al.* 1987; Manilla *et al.* 1999 and Lopez Ferrer *et al.* 2001). Fatty acids originated from diet can be directly integrated into body tissues intact (Klasing, 1998), a fact sometimes known as verify feeding grounds using fatty acid signatures (Williams and Buck, 2010). Moreover, dietary fats are recognized to determine the composition of various bird

tissues, ranging from muscle membranes to eicosanoids (McCue *et al.* 2009). The importance of human diet in the maintenance of the healthy status is an ancient subject. In 500 before christ (BC), Hippocrates was quoted to say that "Food is medicine, and medicine is food". Human foods as a lifestyle factor, is involved in the incidence of many types of diseases such as cardiovascular diseases and cancer. Actually, atherogenesis and occurrence of different types of cancers can be influenced by human foods and nutrition pattern (Russo, 2009). Recent evidence suggests that not only the quantity but also the composition of dietary fat is important factor to preventsuch diseases (Sealls *et al.* 2008). Tables 1 and 2 show the recommended intake levels of some important fatty acids in human ratiosas well as the

majour fatty acids groups' concentrations in some common foods, respectively.

Fats and fatty acids

Fats are the main storage source of energy in animal body. These components are important dietary ingredients with important roles in cell membranes structure and synthesis of important regulatory molecules (Goldman, 1994). The lipid is a general term that describes a group of fatty substances insoluble in water (or poorly soluble) and soluble in non-polar organic solvents (Gunstone *et al.* 1994). Triglycerides, as the common fats, are consisted of three fatty acids estrified to a 3-carbon molecule glycerol. The fatty acids unit in the structure of triglycerides determines fats texture, taste, and physical properties. There is a variety of naturally occurring fatty acids, which basic structure consists of a carboxyl group and a methyl group at the two ends of a long hydrocarbon chain. The most common natural fatty acids have straight chains of an even number of carbon atoms.

Fatty acids based on the number of double bonds in the molecule are also classified as saturated or unsaturated fatty acids. Saturated fatty acids (SFA) are free of double bond and unsaturated fatty acids (USFA) acids contain at least one double bond. Monounsaturated fatty acids (MUFA) containing only one double bond and fatty acids with more than one double bond are named polyunsaturated fatty acids (PUFA). The position and the number of double bonds define the chemical properties of fatty acids (Gunstone *et al.* 1994). Delta-9 desaturase enzyme converts SFA such as stearic acid (18:0) to MUFA. The synthesis of MUFA in animals and plants takes place in the same manner, but further desaturation to PUFA uses different mechanisms (Neuringer and Connor, 1986).

Essential fatty acids

Linoleic acid (LA; 18:2 n-6), linolenic acid (LNA; 18:3 n-3) and arachidonic acids (AA; 20:4 n-6) cannot be synthesized by either mammalian or avian cells and therefore must be supplied in diet (Stevens, 1996). These fatty acids are called "essential fatty acids" (EFA). Basically, animals lack the delta-12 and delta-15 desaturase enzymatic activity required to insert double bonds at n-6 or n-3 positions of fatty acids to *de novo* synthesis of EFAs (Sargent *et al.* 2002). Therefore, palmitic acids (16:0) or stearic acid (18:0) cannot be transformed to n-6 or n-3 series fatty acids by the *de novo* synthesis pathway (Field, 2003; Trugo and Torres, 2003).

Biochemical pathways for EFAs synthesis exist only in the chloroplasts of plant cells; thus plants are the source of EFAs in foods. Animals are only able to elongate and desaturate the parental EFAs to synthesise long-chain polyun-

saturated fatty acids (LCPUFAs). In the endoplasmic reticulum, the delta-6 desaturases activity is responsible for the conversion of PUFA to LCPUFA (Barceló-Coblign and Murphy, 2009). The *de novo* synthesis of PUFA is dependent on some hormones, on the relative concentration of precursor fatty acids, and their intermediated products. Arachidonic acid, the 20 carbons PUFA, is particularly important because of its function in membrane synthesis and embryonic development (Holman, 1986; Ching, 2000).

Parental essential fatty acids are substrate for other useful derivatives too. The 20 °C derivative, arachidonic acid (AA) is produced from linoleic acid. α -linolenic acid (ALA) undergoes elongation and desaturation to form n-3 PUFAs, the eicosapentaenoic acid (EPA 20:3 n-3) and docosahexaenoic acid (DHA 22:5 n-3). These conversions are take place mainly in liver, lung, heart, kidney and brain (Ricardo and Valenzuela, 2000). The special biological effects of marine foods and human milk are based on the direct supply of EPA and DHA, by passing the controlling step of the delta-6 desaturase (Ricardo and Valenzuela, 2000).

Animals lack the enzymes required to convert n-3 and n-6 fatty acids into each other; consequently, the dietary ratio of 18:2 n-6 to 18:3 n-3 fatty acids is important (Barceló-Coblign and Murphy, 2009).

In humans, the recommend ratio of n-6:n-3 EFAs ranges from 4:1- 10:1 (Sanchez and Malo, 1995). There is an interaction between different fatty acids so that the n-3 and n-6 fatty acid families suppress the metabolism of each other and both families suppress the metabolism of the n-9 fatty acids (Darshan, 2001).

Liquid vegetable oils originated from soybean, corn, sunflower, safflower, cottonseed and nuts and grains are dietary sources of n-6 PUFA, while, linseed and canola oils are rich in n-3 PUFAs. Marine animal's oils are the richest sources of n-3 series of LCPUFAs, EPA and DHA (Russo, 2009). Poultry, like most other animals, have an absolute dietary requirement for linoleic and α -linolenic acids. Dietary deficiency in EFAs can cause lower growth and harmful effects on membrane biology, nervous system, bone formation, visual function and reproduction (Watkins, 1995; Calder, 1997). The NRC (1994) recommends a minimum of 1% of linoleic acid in chicken diets, but there is no recommendation for lenolenic acid requirements of chicken.

Effects of dietary fats on the fatty acid composition of poultry tissues

The fatty acid profile of chicken meat can simply be modified by feed and chicken products could then offer a more economical source of health effective fatty acids (Phetteplace and Watkins, 1989).

Table 1 Common forms, recommended intakes and research findings related to Omega-3 and Omega-6 fatty acids

	Omega-3 fatty acids	Omega-6 fatty acids
Most common forms	Eicosapentaenoic (EPA), Docosahexaenoic (DHA) and α -linolenic acids (ALA)	Linoleic acid (LA) accounts for 85 percent to 90 percent of dietary omega-6 fatty acids
Common food sources	EPPA and DHA-fatty fish such as salmon, white tuna, mackeret, rainbow trout, herring, and sardines ALA-canola or soybean oil, walnuts, and ground flaxseed or flaxseed oil	Vegetable oils (e.g. corn, sunflower, safflower and soy), salad dressin, nuts, whole wheat bread and chicken
2005 dietary reference intake (DRI) Adequate identified as (AI)	ALA recommendations 1.6 grams per day for men 19 years or older 1.1 grams per day for women 19 years or older	Linoleic acid (LA) recommendations 17 grams per day for men between 19 and 50 years old 14 grams per day if over 50 for men 12 grams per day for women between 19 and 50 years old 11 grams per day if over 50 for women
Research suggests potential health promoting benefits	Reduce inflammation in heart disease, inflammatory bowel disease, and rheumatoid arthritis Help prevent blood from clotting and sticking to artery walls Prevent hardening of the arteries Decrease risk of sudden death and abnormal heart rates Decrease triglyceride levels Lower blood pressure	Neutral or lower levels of inflammatory markers Replacing saturated and trans- fat with omega6 fatty acids associated with decreasing risk of heart disease Improve Insulin resistance and reduce the incidence of diabetes Lower blood pressure Lower cholesterol levels

Source: USDA (1988); available at: <http://fnic.nal.usda.gov/food-composition/macronutrients/fats-and-cholesterol>.

Table 2 Percentage of different fatty acids in some common fats

Common fats / oils	Saturated fatty acids (%)	Monounsaturated fatty acids (%)	Polyunsaturated fatty acids (%)
Corn	13	25	55
Olive	17	71	10
Palm	52	38	10
Rapeseed (canola oil)	7	53	22
Soybean	15	23	51
Butter	65	26	1-3
Lard	42	46	6-8
Tallow	53	42	2

Source: USDA (1988); available at: <http://fnic.nal.usda.gov/food-composition/macronutrients/fats-and-cholesterol>.

This meat is considered to be functional i.e. to exert, at least potentially, beneficial effects on human health and resistance to disease (Pisulewski *et al.* 2002; Pisulewski and Kostogryś 2003; Pisulewski, 2005). Regardless of the differences in fat content and fatty acid composition, thigh and breast meat of poultry have more than 35% saturated and about 25% mono-unsaturated fatty acids (Cantor *et al.* 2000).

Generally, chicken meat contains lower levels of SFA and MUFA, but higher concentrations of PUFA compared to pork or beef (USDA, 1988). Indeed, SFA and MUFA are mainly synthesized endogenously, and their concentration in the carcass is fairly influenced by dietary fats (Barton *et al.* 2007).

In contrast, there is no indigenous synthesis of PUFAs in birds, thus its concentrations in chicken meat respond rapidly to the dietary manipulation. Therefore, the fatty acid profile of thigh and breast meat typically reflects the composition of dietary fatty acids (Pisulewski, 2005).

As noted earlier, these compounds could also affect chicken production efficiency. High fat deposition in chicken body reduces the effective energy use and can lead to lower feed efficiency (Grashorn, 2007).

There are reports that PUFAs and CLA could reduce fat deposition, but saturated fatty acids from animal origin tend to deposit more fat in chicken body (Crespo and Esteve-Garcia, 2002; Zanini *et al.* 2006). These reports obviously showed that dietary fats are important factors that influence both the functional properties of chicken meat and the efficiency of chicken production. It has been hypothesized that the dietary n-3 fatty acids and CLA would induce changes in different aspect of lipid metabolism in broiler chickens. This would alter both the fatty acid profile of the produced meat, and whole body fat deposition.

n-3 polyunsaturated fatty acids for chicken meat enrichment

Today, there is more attention on the effect of dietary choices on long-term human health. Consuming higher levels of n-3 PUFAs, may reduce the risk of cardiovascular diseases (Gebauer *et al.* 2006; Harris *et al.* 2007; Von Schacky and Harris, 2007). The most important n-3 fatty acids in human nutrition are eicosapentaenoic acid (EPA; 20:5 n-3) and docosahexaenoic acid (DHA; 22:6 n-3), which are called long chain n-3 polyunsaturated fatty acids (LC-n3 PUFA). α -linolenic (LNA; 18:3 n-3) serves as a

precursor for the synthesis of EPA and DHA (Burdge, 2004; Arterburn *et al.* 2006; Gebauer *et al.* 2006).

Chicken meats normally have higher n-3 PUFAs content than other meats (Ackman *et al.* 1988). The effects of dietary n-3 PUFAs on manipulation of the fatty acids profile of chicken meat have been examined in several studies (Hulan *et al.* 1988; Phetteplace and Watkins, 1989; Ajuyah *et al.* 1993), most of them developed with the aim of improving the dietary intake of n-3 PUFAs in human consumers. The n-3 PUFAs level in chicken meat can be increased to levels comparable to the flesh of a lean fish such as cod (Ackman *et al.* 1988; Hulan *et al.* 1988; Ratnayake *et al.* 1989).

Royan *et al.* (2013) showed a remarkable increase of long chain n-3 fatty acids (EPA and DHA) levels in the meat of birds fed with diets containing fish oil. Apparently, an interaction between CLA and long chain n-3 fatty acids resulted in an increased deposition of EPA and DHA in breast tissue of chickens fed the diet containing the mixture of CLA + fish oil, without a similar effect on thigh. More lipids in breast tissue (white meat) are as phospholipids, but in thigh tissue (dark meat), the main lipids are triglycerides (Gonzalez-Esquerria and Leeson, 2001). Then, because of its smaller potential for fat deposition, the enrichment of breast meat with n-3 PUFAs may be more difficult than thigh meat enrichment. According to CFIA (2003) to label a product as n-3 PUFA-enriched, concentration of total n-3 PUFA must be at least 300 mg per 100 g of meat. The considerable reduced n-6 / n-3 fatty acids ratios in the meat of birds fed fish oil containing diets is reported (Miller and Robisch, 1969; Royan *et al.* 2013) and it was more obvious in breast tissue than in thigh. This difference was mainly because of the higher DHA concentration in the extracted fat of breast tissue than of thigh tissue. It is well known that an increase in n-6 / n-3 ratio in dietary fat results in pathological changes in humans. For this reason, nutritionists recommend that not more than 30% of human dietary energy should supply from fat; and the most favorite dietary fat has a 1:1:1 ratio between saturated, monounsaturated and polyunsaturated fatty acids, and an n-6 / n-3 ratio lower than 5:1 (Grashorn, 2007).

Linoleic acid (C18:2 n-6) and linolenic acid (C18:3 n-3) act as precursor molecules which are transformed to the other n-6 or n-3 fatty acids through a series of elongation and saturation reactions. An enzymatic system including fatty acyl-CoA synthetases, D-6 and D-5 desaturases and respective elongases is involved in this conversion (Wang *et al.* 2005). It's known that these two fatty acid families share and even compete for the same enzymes (Mohrhauer *et al.* 1967). Arachidonic acid is the most important metabolite of linoleic acid. Therefore, arachidonic acid content in phospholipids membranes normally decreases when dietary ratio of long chain n-3 PUFAs increases (Komprda *et*

al. 2005). This opposite alteration in dietary n-3 PUFAs supply and arachidonic acid concentrations in chicken meat was observed in the study of Royan *et al.* (2013), so that arachidonic acid decreased in breast and thigh meat fat in chicks fed dietary fish oil. It seems that in broiler chickens fed with dietary fish oil the conversion of 18:2n6 to 20:4n6 is decreased while in birds fed the diet contained high levels of 18:2n6 (soybean oil containing diets) formation of 20:4n6 is increased.

Holmer and Beare-Rogers (1985) and Phetteplace and Watkins (1989) found that fish oil effectively reduced the 20:4n6 content in rat and chicken meat. In the body, EPA (C20:5 n-3; precursor of series 3 eicosanoids) is produced from linolenic acid and it has been observed that an opposite change take place in EPA / linolenic acid and arachidonic acid / linoleic acid ratios (Benatti, 2004). In a report on the effect of n-3 fatty acids on changing the Δ 5-desaturase activity, Betti *et al.* (2009) showed a reduced Δ 5-desaturase activity with duration of flaxseed feeding as n-3 fatty acid source which indicates that linolenic acid suppressed bioconversion of arachidonic acid from linoleic acid (Garg *et al.* 1988).

Conjugated linoleic acid for chicken meat enrichment

Supplementation of chicken diets with CLA has been an attractive approach to improve the meat quality and simultaneously increase the production of CLA enriched meat and meat products (Suksombat *et al.* 2007). It's known that the CLA metabolism in biological systems is similar to that of other fatty acids. CLA incorporate into both triacylglyceride and phospholipid fractions (Park *et al.* 1999; Sisk *et al.* 2001). There are different recommendations for human CLA daily requirement. Ip *et al.* (1994) reported that the daily CLA intake of the occidental population is about 1 g/day. According to Grashorn (2007), the recommended daily intake of CLA in humans is 0.1% of daily food, which in Europe is estimated as 2.4 kg in males and 2.0 kg in females, resulting in a daily CLA intake of 2.4 and 2 g, respectively. Whilst some authors have suggested a range of 0.5-1.5 g/day for CLA intake (Fritsche *et al.* 1998), some other reports indicated considerably lower intakes, including a Swedish report suggesting CLA intakes in the range of 0.16 g/day (Jiang *et al.* 1999). There are reports of higher CLA levels in the meat of chickens fed CLA containing diets (Du *et al.* 2001; Sirri, *et al.* 2003; Royan *et al.* 2013).

Banni *et al.* (1995) reported that CLA isomers of diet are absorbed and entered in both the adipose and membrane phospholipids and also that the deposition of CLA in animal tissues is a function of the dietary CLA level and length of consumption. It was also reported that the meat fat possess greatly higher levels of CLA than lean meat (Fogerty *et al.* 1988).

In the study of Royan *et al.* (2013), the fat content of breast and thigh tissues in birds fed the diet containing 2.1% CLA + 3.5% soybean oil was higher than in the diets containing 4.2% CLA and they suggested that the increase in CLA deposits in the tissue is not simply a consequence of increased fat deposition. Similar interactions between dietary CLA and soybean oil were also reported by Zanini *et al.* (2008), who concluded that the intake of soybean oil, associated with increasing levels of CLA, resulted in rise in lipid deposition in edible portions, as observed by an increase in the overall content of fatty acids, including CLA. Apparently, they did not observe differences in CLA content of meat as a percent of total fatty acids of extracted oil. Royan *et al.* (2013), found that the diet containing 4.2% CLA and especially the combination of 2.1% CLA + 3.5% soybean oil in the diet of broiler chickens enhanced the CLA content of breast and thigh tissues up to 161-176 and 207-235 mg/100 g meat respectively, which is considerably higher than the common values found in chicken meat and is comparable to the values reported for veal, but still lower than the common values of beef and lamb (Chin *et al.* 1992). They found a possible interaction between dietary fats so that CLA in combination with other fats (2.1% CLA+3.5% fish oil and 2.1% CLA+3.5% soybean oil diets) was more effective on reducing the oleic acid and increasing the stearic acid contents of the both breast and thigh tissues; while the 4.2% CLA diet increased more effectively the C16:1 deposition in breast compared with the diets containing CLA in combination with fish oil or soybean oil.

The CLA and CLA + fish oil diets have more efficiently increase SFA content in tissues than the CLA + soybean oil diet. Apparently, n-6 fatty acids reduce the CLA effect on SFA deposition as a result of more deposited CLA and PUFA in the meat of birds fed CLA + soybean oil diet. This finding was in agreement with previous reports on the effect of CLA on increasing the SFA content of meat (Choi *et al.* 2000; Du *et al.* 2001; Eder *et al.* 2002; Suksombat *et al.* 2007). Park *et al.* (2000) suggested that it is possible the part of the effects of CLA act through a decrease in the synthesis of MUFAs which are necessary components for phospholipid and triglyceride synthesis. $\Delta 9$ -cis desaturation of several fatty acids is carry out by the stearoyl-CoA desaturase enzyme (Cook, 1991), which typical substrates are palmitic (C16:0) and stearic (C18:0) acids that are transformed to palmitoleic (C16:1) and oleic acids (C18:1), respectively. Desaturation of these saturated fatty acids is required to produce mono-unsaturated fatty acids important for incorporation into the sn-2 position of triglyceride (Choi *et al.* 2000). ACLA down-regulation effect on the $\Delta 9$ -desaturase activity is observed in chicken (Du *et al.* 1999; Li and Watkins, 1998) and rat Lee *et al.* (1998). It seems that CLA inhibits either the stearoyl-CoA desaturase ($\Delta 9$ -

desaturase) gene expression or its activity in adipocytes (Choi *et al.* 2000). The ratios of palmitoleic acid to palmitic acid (16:1/16:0) and oleic acid to stearic acid (18:1/18:0) are suggested as the potential indices for stearoyl-CoA desaturase activity (Ntambi, 1999). The decrease in the ratio of palmitoleate: palmitate and oleate: stearate could be the main reasons for decreased stearoyl-CoA desaturase activity. There are reports that the CLA isomers are somewhat different on their effects. Bretillon *et al.* (1999) found that the $\Delta 6$ -desaturation of linoleic acid is reduced when the ratio of c9, t11 CLA isomer to linoleic acid increased, while the effect of t10, c12 CLA isomer on desaturation was slight. Enrichment of poultry meat with CLA may also affect meat quality. It has confirmed that the higher SFA deposition in tissues enriched with CLA resulted in more penetration resistance values of white meat (Du and Ahn, 2002). Peroxidizability index is a measure of the relative susceptibility of different fatty acids to autoxidation (Arakawa and Sagai, 1986) and is calculated using the equation $PI = (\% \text{ monoenoic} \times 0.025) + (\% \text{ dienoic} \times 1) + (\% \text{ trienoic} \times 2) + (\% \text{ tetraenoic} \times 4) + (\% \text{ pentaenoic} \times 6) + (\% \text{ hexaenoic} \times 8)$, where the concentration of fatty acids in a food or oil is expressed as percentage. This equation shows that the more unsaturated a fatty acid, the higher its susceptibility to oxidation and thereby, the more probable to occur an "off" flavor in a food. Royan *et al.* (2013) compared CLA and n-3 fatty acid concentrations in meat of experimental birds and suggested that tissue enrichment with CLA in is not as effective as the enrichment with n-3 PUFAs. These authors also suggested that the enrichment of chicken meat with n-3 PUFA or CLA is not always in a dose dependent manner and can affect by the dietary fat composition.

CONCLUSION

This review suggest that the dietary fats, especially n-3 PUFAa and CLA could be a useful tool to produce enriched chicken meat as a functional food for human consumption, however there are inconsistencies in the results of the different authors that need to be clarified in future research.

ACKNOWLEDGEMENT

We thank Dr. Goh Yang Meng, University Putra Malaysia, for useful discussions.

REFERENCES

- Ackman R.G., Ratnayake W.M.N. and Olson B. (1988). The "basic" fatty acid composition of Atlantic fish oils: potential similarities useful for enrichment of polyunsaturated fatty acids by urea complexation. *J. Am. Oil. Chem. Soc.* **65**, 136-138.

- Ajuyah A.O., Hardin R.T. and Sim J.S. (1993). Studies on canola seed in turkey grower diet: effects on n-3 fatty acid composition of breast meat, breast skin and selected organs. *Can. J. Anim. Sci.* **73**, 177-181.
- Arakawa K. and Sagai M. (1986). Species differences in lipid peroxide levels in lung tissue and investigation of their determining factors. *Lipids*. **21**, 769-775.
- Arterburn L.M., Hall E.B. and Oken H. (2006). Distribution, interconversion and dose response of n-3 fatty acids in humans. *Am. J. Clin. Nutr.* **83**, 1467-1476.
- Banni S., Day B.W., Evans R.W., Corongiu F.P. and Lombardi B.B. (1995). Detection of conjugated diene isomers of linoleic acid in liver lipids of rat's feda choline-devoid diet indicates that the diet does not cause lipoperoxidation. *J. Nutr. Biochem.* **6**, 281-289.
- Barceló-Coblijn G. and Murphy E.J. (2009). α -linolenic acid and its conversion to longer chain n-3 fatty acids: benefits for human health and a role in maintaining n-3 fatty acid levels. *Prog. Lipid. Res.* **48**, 355-374.
- Barton L., Marounek M., Kudrna V., Bureš D. and Zahrádková R. (2007). Growth performance and fatty acid profiles of intramuscular and subcutaneous fat from Limousin and Charolais heifers fed extruded linseed. *Meat Sci.* **76**, 517-523.
- Benatti P., Peluso G. and Nicolai N.R. (2004). Polyunsaturated fatty acids: biochemical, nutritional and epigenetic properties. *Am. Coll. Nutr.* **23**, 281-302.
- Betti M., Schneider B.L., Wismer W.V., Carney V.L., Zuidhof M.J. and Renema R.A. (2009). Omega-3 enriched broiler meat: 2. Functional properties, oxidative stability and consumer acceptance. *Poult. Sci.* **88**, 1085-1095.
- Bezard J., Blond J.P., Bernard A. and Clouet P. (1994). The metabolism and availability of essential fatty acids in animal and human tissues. *Rep. Nutr. Dev.* **34**, 539-568.
- Bretillon L., Chardigny J.M., Gregoire O., Berdeaux O. and Sebedio J.L. (1999). Effects of conjugated linoleic acid isomers on the hepatic microsomal desaturation activities *in vitro*. *Lipids*. **34**, 956-969.
- Burdge G. (2004). α -linolenic acid metabolism in men and women: nutritional and biological implications. *Current. Opinion. Clin. Nutr. Metab. Care.* **7**, 137-144.
- Calder P.C. (1997). n-3 polyunsaturated fatty acids and cytokine production in health and disease. *Ann. Nutr. Metab.* **41**, 203-234.
- Cantor A.H., Decker E.A. and Collins V.P. (2000). Fatty Acids in Poultry and Egg Products. Marcel Dekker, Inc. New York.
- CFIA. (2003). Canadian Food Inspection Agency. Guide to Food Labelling and Advertising. Available at: <http://www.inspection.gc.ca/english/fssa/labeti/guide/ch7be.shtml#7.19>.
- Chin S.F., Liu W., Storkson J.M., Ha Y.L. and Pariza M.W. (1992). Dietary sources of conjugated dienoic isomers of linoleic acid, a newly recognized class of anticarcinogens. *J. Food Com. Anal.* **5**, 185-197.
- Ching K.C. (2000). Fatty Acids in Foods and Their Health Implication. Marcel Dekker, Inc. New York, USA.
- Choi Y., Kim Y.C., Han Y.B., Park Y., Pariza M.W. and Ntambi J.M. (2000). The trans-10, cis-12 isomer of conjugated linoleic acid down regulates stearoyl-CoA desaturase gene expression in 3T3-L1 adipocytes. *J. Nutr.* **130**, 1920-1924.
- Cook H.W. (1991). Fatty acid desaturation and chain elongation in eukaryotes. Pp. 141-169 in Biochemistry of Lipids, Lipoproteins and Membranes. D.E. Vance and J. Vance, Eds. Elsevier, Amsterdam, Holland.
- Crespo N. and Esteve-Garcia E. (2002). Nutrient and fatty acid deposition in broilers fed different dietary fatty acid profiles. *Poult. Sci.* **81**, 1533-1542.
- Darshan S. (2001). Modulation of human immune and inflammatory responses by dietary fatty acids. *Nutrition*. **17**, 669-673.
- Du M. and Ahn D.U. (2002). Effect of dietary conjugated linoleic acid on the growth rate of live birds and on the abdominal fat content and quality of broiler meat. *Poult. Sci.* **81**, 428-433.
- Du M., Ahn D.U. and Sell J.L. (1999). Effect of dietary conjugated linoleic acid on the composition of egg yolk lipids. *Poult. Sci.* **78**, 1639-1645.
- Du M., Ahn D.U. and Sell J.L. (2001). Volatile profiles and lipid oxidation of irradiated cooked chicken meat from laying hens fed with diets containing conjugated linoleic acid. *Poult. Sci.* **80**, 235-241.
- Eder K., Slomma N. and Becker K. (2002). Trans-10, cis-12 conjugated linoleic acid suppresses the desaturation of linoleic acid and α -linolenic acids in HepG2 cells. *J. Nutr.* **132**, 1115-1121.
- Field C.J. (2003). Fatty acids / dietary importance. Pp. 2317-2324 in Encyclopaedia of Food Sciences and Nutrition. B. Caballero, Ed. Oxford, UK.
- Fogerty A.C., Ford G.L. and Svoronos D. (1988). Octadeca-9, 11-dienoic acid in foodstuffs and in the lipids of human blood and breast milk. *Nutr. Repo. Int.* **38**, 937-944.
- Fritsche J. and Steinhart C. (1998). Amounts of conjugated linoleic acid (CLA) in German foods and evaluation of daily intake. *Zeitsch. Leben. Untersuch. Forsch.* **206**, 77-82.
- Garg M.L., Sebokoba E., Wierzbicki A.A., Thomson A.B.R. and Clandin M.T. (1988). Differential effects of dietary linoleic acid and α -linolenic acid in rat tissue. *Lipids*. **23**, 847-852.
- Grashorn M.A. (2007). Functionality of poultry meat. *J. Appl. Poult. Res.* **16**, 99-106.
- Gebauer S.K., Psota T.L., Harris W.S. and Kris-Etherton P.M. (2006). n-3 fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. *Am. J. Clin. Nutr.* **83**(6), 1526-1535.
- Goldman H. (1994). Reducing Overall Fat Intake. Baltimore: HTP Science Publications.
- Gonzalez-Esquerria R. and Leeson S. (2001). Alternatives for enrichment of eggs and chicken meat with n-3 fatty acids. *Can. J. Anim. Sci.* **81**, 295-305.
- Gunstone F.D., Harwood J.L. and Padley F.B. (1994). The Lipid Handbook. Chapman and Hall, London.
- Harris W.S., Poston W.C. and Haddock C.K. (2007). Tissue n-3 and n-6 fatty acids and risk for coronary heart disease events. *Atherosclerosis*. **193**, 1-10.
- Holman R.T. (1986). Nutritional and biochemical evidences of acyl interaction with respect to essential polyunsaturated fatty

- acids. *Prog. Lipid. Res.* **25**, 29-39.
- Holmer G. and Beare-Rogers J.L. (1985). Linseed oil and marine oil as sources (n-3) fatty acids in rat heart. *Nutr. Res.* **5**, 1011-1014.
- Hulan H.W., Ackman R.G., Ratnayake W.M.N. and Proudfoot F.G. (1988). Omega-3 fatty acid levels and performance of broilers chickens fed redfish meal or redfish oil. *Can. J. Anim. Sci.* **68**, 533-547.
- Ip C., Singh M., Thompson H.J. and Scimeca J.A. (1994). Conjugated linoleic acid suppresses mammary carcinogenesis and proliferative activity of the mammary gland in the rat. *Cancer Res.* **54**, 1212-1215.
- Jiang J., Wolk A. and Vessby B. (1999). Relation between the intake of milk fat and the occurrence of conjugated linoleic acid in human adipose tissue. *Am. J. Clin. Nutr.* **70**, 21-27.
- Klasing K.C. (1998). Nutritional modulation of resistance to infectious diseases. *Poult. Sci.* **77**, 1119-1125.
- Komprda T., Zelenka J., Fajmonova E., Fialova M. and Kladroba D. (2005). Arachidonic acid and long-chain n-3 polyunsaturated fatty acid contents in meat of selected poultry and fish species in relation to dietary fat sources. *J. Agric. Food Chem.* **53**, 6804-6812.
- Lee K.N., Pariza M.W. and Ntambi J.M. (1998). Conjugated linoleic acid decreases hepatic stearoyl-CoA desaturase mRNA expression. *Biochem. Biophys. Res. Commun.* **248**, 817-821.
- Li Y. and Watkins B.A. (1998). Conjugated linoleic acids alter bone fatty acid composition and reduce ex vivo prostaglandin E2 biosynthesis in rats fed n-6 or n-3 fatty acids. *Lipids.* **33**, 417-425.
- Lopez-Ferrer S., Baucells M.D., Barroeta A.C. and Grashorn M.A. (2001). n-3 enrichment of chicken meat. 1. Use of very long-chain fatty acids in chicken diets and their influence on meat quality: fish oil. *Poult. Sci.* **80**, 741-732.
- Manilla H., Husveth A.F. and Nemeth K. (1999). Effects of dietary fat origin on the performance of broiler chickens and composition of selected tissues. *Acta. Agraria. Kaposváriensis.* **3**, 47-57.
- McCue M.D., Amitai O., Khozin-Goldberg I., McWilliams S.R. and Pinshow B. (2009). Effect of dietary fatty acid composition on fatty acid profiles of polar and neutral lipid tissue fractions in zebra finches, *Taeniopygia guttata*. *Comp. Biochem. Physiol.* **154**, 165-172.
- Miller D., Leong K.C. and Smith P. (1969). Effect of feeding and withdrawal of menhaden oil of broiler tissues' fatty acid composition and flavor. *J. Food Sci.* **34**, 136-141.
- Mohrhauer H., Christiansen K., Gan M.V., Deubig M. and Holman R.T. (1967). Chain elongation of linoleic acid and its inhibition by other fatty acids *in vitro*. *J. Biol. Chem.* **242**, 4507-4514.
- Neuringer M. and Connor W.E. (1986). n-3 fatty acids in the brain and retina: evidence for their essentiality. *Nutr. Rev.* **44**, 285-294.
- NRC. (1994). Nutrient Requirements of Poultry, 9th Rev. Ed. National Academy Press, Washington, DC., USA.
- Ntambi J.M. (1999). Regulation of stearoyl-CoA desaturase by polyunsaturated fatty acids and cholesterol. *J. Lipid. Res.* **40**, 1549-1558.
- Park Y., Albright K.J., Liu W., Storkson J.M., Lin M.E., Cook M.E. and Pariza M.W. (1999). Changes in body composition in mice during feeding and withdrawal of conjugated linoleic acid. *Lipids.* **34**, 243-248.
- Park Y., Storkson J.M., Ntambi J.M., Cook M.E., Sih C.J. and Pariza M.W. (2000). Inhibition of hepatic stearoyl-CoA desaturase activity by trans-10, cis-12 conjugated linoleic acid and its derivatives. *Biochem. Biophys. Acta.* **1486**, 285-292.
- Pchetteplace H.W. and Watkins B.A. (1989). Effects of various n-3 sources on fatty acid composition in chicken tissues. *J. Food Compos. Anal.* **2**, 104-117.
- Pisulewski P.M. (2005). Nutritional potential for improving meat quality in poultry. *Anim. Sci. Pap. Rep.* **23**, 303-315.
- Pisulewski P.M. and Kostogrys R.B. (2003). Functional properties of foods of animal origin and methods of their assessment. *Pol. J. Food Nutr. Sci.* **53**, 65-73.
- Pisulewski P.M., Szymczyk B. and Kostogrys R.B. (2002). Health-promoting properties of conjugated linoleic acid isomers and perspectives of production of CLA-enriched foods of animal origin. *Zywnienie Czlowieka.* **109**, 87-103.
- Ratnayake W.M.N., Ackman R.G. and Hulan H.W. (1989). Effect of redfish meal enriched diets on the taste and the n-3 PUFA of 42-day-old broiler chickens. *J. Sci. Food Agric.* **49**, 59-74.
- Ricardo U. and Valenzuela A. (2000). Marine oils: the health benefits of n-3 fatty acids. *Nutrition.* **16**, 7-8.
- Royan M., Meng G.Y., Othman F., Sazili A.Q. and Hanachi P. (2013). Effects of dietary combination of conjugated linoleic acid with fish oil or soybean oil on fatty acid composition of broiler meat. *Arch. Geflügelk.* **77**, 189-198.
- Russo G.L. (2009). Dietary n-6 and n-3 polyunsaturated fatty acids: From biochemistry to clinical implications in cardiovascular prevention. *Biochem. Pharmacol.* **77**, 937-946.
- Sanchez G. and Malo M. (1995). Recomendaciones nutricionales establecidas en la union europaea. *Rev. Nutr. Diet.* **3**, 7-12.
- Sargent J.R., Tocher D.R. and Bell J.G. (2002). The lipids. Pp. 181-257 in Fish Nutrition. J.E. Halver and R.W. Hardy, Eds. Academic Press, San Diego.
- Sealls W., Gonzalez M., Brosnan M.J., Black P.N. and Di Russo C.C. (2008). Dietary polyunsaturated fatty acids (C18:2 omega-6 and C18:3 omega-3) do not suppress hepatic lipogenesis. *Biochem. Biophys. Acta.* **1781**, 406-614.
- Sirri F., Minelli G., Iaffaldano N., Tallarico N. and Franchini A. (2003). Oxidative stability and quality traits of n-3 PUFA enriched chicken meats. *Italian J. Anim. Sci.* **2**, 450-452.
- Sisk M.B., Hausman D.B., Martin R.J. and Azain M.J. (2001). Dietary conjugated linoleic acid reduces adiposity in lean but not obese Zucker rats. *J. Nutr.* **131**, 1668-1674.
- Stevens L. (1996). Avian biochemistry and Molecular Biology. Cambridge University Press, Cambridge, UK.
- Suksombat W., Boonmee T. and Lounglawan P. (2007). Effects of various levels of conjugated linoleic acid supplementation on fatty acid content and carcass composition of broilers. *Poult. Sci.* **86**, 318-324.
- Trugo N.M.F. and Torress A.G. (2003). Fats / requirements. Pp. 2280-2281 in Encyclopaedia of Food Sciences and Nutrition. B. Caballero, Ed. Oxford, UK: Elsevier Sciences Ltd.
- Tuncer S.D., Asti R., Coskun B., Tekes M.A. and Erer H. (1987).

- The effects of different energy sources on fattening performance, abdomen fat accumulation and liver fat in broiler. I. The effects of fattening performance and abdomen fat accumulation. University of Selçuk. *J. Vet. Facult.* **3**, 25-40.
- USDA. (1988). United States Department of Agriculture. Food and the Consumer. National Food Review. Washington, DC., USA.
- Von Schacky C. and Harris W.S. (2007). Cardiovascular benefits of omega-3 fatty acids. *Cardio. Res.* **73**, 310-315.
- Wang Y.M., Nagao K., Ujino Y., Sakata K., Higa K., Inoue N. and Yanagita T. (2005). Short-term feeding of conjugated linoleic acid does not induce hepatic steatosis in c57BL-6J mice. *J. Nutr. Sci. Vitaminol.* **51**, 440-444.
- Watkins B.A. (1995). Biochemical and physiological aspects of polyunsaturates. *Poult. Avian. Boil. Rev.* **6**, 1-18.
- Williams C.T. and Buck C.L. (2010). Using fatty acids as dietary tracers in seabird trophic ecology: theory, application and limitations. *J. Ornithol.* **151**, 531-543.
- Zanini S.F., Colnago G.L., Pessotti B.M.S., Bastos M.R., Casagrande F.P. and Lima V.R. (2006). Body fat of broiler chickens fed diets with two fat sources and conjugated linoleic acid. *Int. J. Poult. Sci.* **5**, 241-246.
- Zanini S.F., Vicente E., Colnago G.L., Pessotti B.M.S. and Silva M.A. (2008). Manipulation of the fatty acids composition of poultry meat and giblets by dietary inclusion of two oil sources and conjugated linoleic acid. *Arq. Bras. Med. Vet. Zootec.* **60**, 1388-1398.
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