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Manipulating the Fatty Acid Composition of Eggs and Poultry Meat for the Human Health

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건강을 생각하는 계란과 닭고기 생산을 위한 지방산 조성방안

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ABSTRACT

Among polyunsaturated fatty acids (PUFAs) targeted for manipulation in animal tissues (poultry eggs and meat), omega-3 PUFAs (n-3 PUFAs) are discussed in this review. 3 or 5% dietary menhaden oil (MO) supplemented layer diets was reported to increase docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) contents in the egg. MO at 1.5% also increased the deposition of up to 180mg total omega-3 fatty acids/yolk. Utilization of 5% ground flax seed (FS) resulted in similar total omega-3 fatty acid (FA) deposition as 1.5% MO. However, the basic feed formulations used in the Canadian feed industry usually include 10 to 20% FS in the egg laying diets. Recently several studies reported that addition of tocopherols in layer diets increased the tocopherol content more in the egg than any other tissue. One of reports said that 3.5% dietary oil with added tocopherols resulted in increasing tocopherol deposition and FA composition of the egg and other tissues.

In the poultry meat, redfish meal (RM; 4, 8, 12, 15 and 30% of diet) or redfish oil (RO; 2.1 or 4.2% of diet) added to the practical corn-wheat-soybean based diets resulted in an increase in omega-3 FA and docosapentaenoic acid (DPA) contents in broiler meat lipids. Linseed oil (LO; 1.0, 2.5, and 5.0% of broiler diet) supplemented in broiler diets also resulted in omega-3 FA and the ratio of omega-3 : omega-6 being significantly higher in poultry meat lipid than MO. Concern about fish flavor resulted in research about fish oil (FO) supplementation in broiler diets. Without the use of antioxidants, no more than 1.5% FO should be fed to broilers due to unacceptable orders from the chicken carcasses. One recent research project found that over 50mg/kg of vitamin E was required for maintaining the stability of unsaturated lipids in the meat. In regards to 'fishy' or 'crabby' taint in the eggs and poultry meat, poultry products remained acceptable when dietary fish oils were stabilized with antioxidants.

(Key words: Omega-3 PUFAs, flax seed, fish oil, antioxidant, EPA, DPA, DHA)

INTRODUCTION

It has been recognized that there is excess fat in the human diet and there is a definite need to produce leaner meats, especially chicken. The amount of fat we consume is not only too much, but the types of fat we consume is incorrectly balanced. For many years we have heard that the cholesterol in eggs is the major killer. Many national heart foundations have recognized their error in saying this and are now allowing four eggs to be consumed each week/person. We now know that dietary cholesterol for 98% of the population is not an important risk factor in heart disease. The normal human produces cholesterol for its own cellular requirements irrespective of dietary cholesterol(Van Elswyk, 1994).

Dutch scientists have found that people who consumed an average of 32g of fish daily, compared to those who did not consume fish, had a 50% less chance of dying from coronary heart disease. But what is so special about fish? The important omega-3 fatty acids (FA) are found exclusively in fish in significant quantities. Fish is expensive and may often not be in regular supply; it can be contaminated with heavy metals, pesticide residues and contain pathogenic microorganisms. Some people do not like the taste of fish. This causes their supply of omega-3 polyunsaturated fatty acids(PUFA) to be small and they have large imbalance of omega-6 : omega-3 PUFA(Farrell, 1993).

It is well known that the composition of fat in the egg yolk and poultry meat can be changed. Changing these fat compositions may provide an answer, which allows us to design foods to create designer eggs and designer poultry meat (Farrell, 1993).

Health-conscious consumers have raised a number of questions about the potential for altering the composition of poultry products through feed formulation-designing food, creating the so called "designer foods"(Barlow and Pike, 1991). Until now several research papers have explored the feasibility of using various oils such as fish oil, ground flaxseed, flax oil and other oils to produce eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) enriched poultry products under laboratory as well as commercial conditions. Their research results have been strongly positive and will be discussed in this review.

THE CHEMICAL STRUCTURE OF OMEGA-3 AND-6 LIPID

Even though alpha-linolenic acid is required for nervous tissue and the retina, the primary FA for poultry is linoleic acid. Linoleic (18:2n6) and alpha linolenic (18:3n3) acids have two and three double bonds, respectively, and both are 18 carbons in length. Linoleic acid belongs to the omega-6 series of PUFA since the terminal double bond is located at the sixth carbon from the methyl end of the molecule. In the same manner, alpha-linolenic acid is a member of the omega-3 series of PUFA since the terminal double bond is at the third carbon from the methyl end. The principle PUFA are summarized in Figure 1 and Table 1(Chung, 1991).

Linoleic acid, found in many seeds, is the parent member of the omega-6 family. The other essential fatty acid(EFA), linolenic acid, is present in leaves and green plants. It is the parent member of the omega-3 family. In animal studies, linoleic acid is converted to arachidonic acid. Alpha-linolenic acid is converted to EPA and DHA. The end products of desaturation and

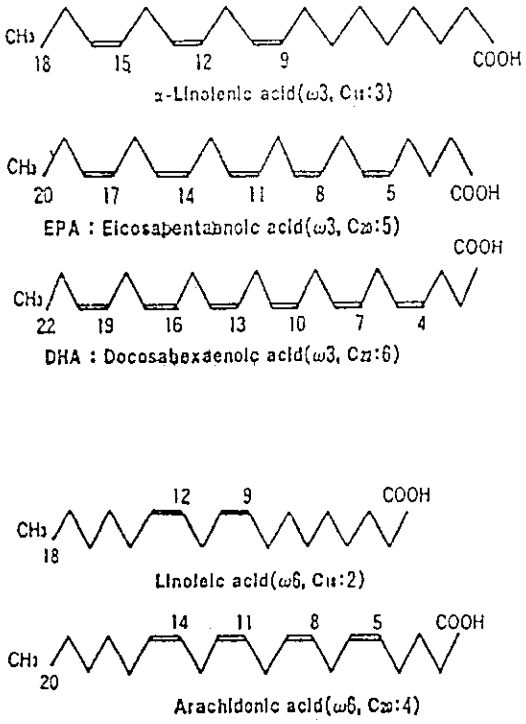

Figure 1. The chemical structure of omega-3 and omega-6 family.

Table 1. Types of unsaturated fatty acids

Types	Unsaturated Fatty Acid
Omega-3	Linolenic acid(C18:3), EPA(C20:5), DHA(C22:6), DPA(C22:5)
Omega-6	Linoleic acid(C18:2), Arachidonic acid(C20:4)
Omega-9	Oleic acid(C18:1)
Omega-7	Palmitoleic acid(C16:1)

elongation serve as the eicosanoid precursors of the 2-series and 3-series lipid modulators of cell function. These lipid modulators include prostaglandins, thrombaoxanes, lipoxins and leukotrienes(Farrell, 1993).

FUNCTIONS OF POLYUNSATURATED FATTY ACIDS FOR EICOSANOID BIOSYNTHESIS

The PUFA are derived mainly from 18-carbon EFA of dietary origin. The most important of the long-chain PUFA are the 20 carbon fatty acids of the omega-6 and omega-3 series. The majority of eicosanoids (prostaglandins, leukotrienes and lipoxins) are biosynthesized from arachidonic acids that are maintained in membrane phospholipids. The long-chain PUFA are recognized as components of structural phospolipids in membranes of cells and subcellular organelles where they serve as precursors to prostaglandins. Arachidonic acid is the precursor for the 2-series of prostaglandins, but 20 : 3n6 and 20 : 5n3 are substrates of the 1-and 3-series prostaglandins, respectively. Prior to eicosanoid formation, phopholipase A2 cleaves arachidonic acid from the sn-2 position on the glycerol backbone of phospholipids(Watkins, 1991; Watkins et al., 1993). Once arachidonic acid is liberated, it can undergo controlled oxidative metabolism to form various eicosanoids that have different physiological effects. Prostaglandins have been described as "local" hormones synthesized in organs and cells in response to specific stimuli that exert their effect generally at the site of production.

There are two primary requirements for PUFA in developing embryonic tissues. The first is to provide a supply of PUFA for glycerolipid synthesis during membrane formation. The second is for maintenance of adequate precursors for eicosanoid biosynthesis. The rapid tissue proliferation during mitosis requires that sufficient substrate be available to form cell membranes and organelles. It is vital that sufficient amounts of EFA and PUFA are supplied to the chick embryo. The immense metabolic conversion of yolk lipids provides PUFA for activities occurring in embryonic tissue growth, membrane formation in the brain and retina and eicosanoid synthesis during myoblast and chondrocyte cell differentiation(Van Elawyk et al., 1991; Watkins, 1994).

Prostaglandins are mediators of cellular activity during oviposition in hens. Most of these compounds cause contractions of the uterine muscular wall. Prostaglandin F may also take part in ovulation by acting on the preovulatory follicle. Prostaglandins have also been known to have a role in long-bone development. At the cellular level, logically produced cytokines, growth factors and prostaglandins orchestrate the events of bone formation and resorption (Watkins, 1992). There is considerable evidence for a role of eicosanoids in immune regulation. Although the relationship between eicosanoids and cellular and humoral immunity is complex, there appears to be opportunities to utilize dietary lipids to modulate immune responses.

THE ESSENTIALLITY OF OMEGA-3 FATTY ACIDS IN HUMANS

1. Proper amounts of omega fatty acids

The minimum requirements of omega-3 and omega-6 fatty acids are that these essential fatty acids (the sum of omega-3 and omega-6) should proved at least 3% of the energy intake of humans. In pregnant women, the fatty acids should provide 4.5% and for lactating women at least 6% of the energy. The omega-3 PUFAs should provide at least 0.5, 0.8 and 1.0% of the energy for these population groups, respectively (Nordic Council of Ministers, 1989; Bjerve, 1991).

In reality, the typical North American consume about 17g of omega-3 and omega-6 PUFA per day. The above requirements indicate the amount of omega-3 PUFA needed is about 3.0g per day. In practice, the average U.S. citizen consumes 1.7g of omega-3, with 90% of this being linolenic acid(C18:3 omega-3). This means that there is a deficiency in these diets of at least 1g per day of omega-3 PUFA, principally of the long-chain type, namely EPA and DHA (Barlow et al., 1990).

What is the optimum ratio of omega-6 PUFA to omega-3 PUFA in our diet? These fatty acids work together at the cellular level. The ratio in most of our diets of omega-6 to omega-3 is 25 or 30:1; the ideal ratio is less than 10:1(Farrell, 1993). The proposed ratio of 5:1 between omega-6 and omega-3 fatty acids was based on the ratio found in fetal and neonatal structural lipids in the human, as well as the ratio found in some human milk(Nordic Council of Ministers, 1989).

What happens if there is an imbalance? In a variety of circumstances, if the smooth surface of the arterial wall is damaged, the repair mechanism may go wrong if there is a gross imbalance of omega-6 : omega-3. This imbalance may also cause arteries to constrict, resulting in high blood pressure, which in turn damages the cells on the surface of the arterial wall(Farrell, 1993).

2. Healthy people

Animal experiments have shown that the brain, retina and nervous tissue have very high concentrations of DHA. A deficiency of omega-3 fatty acids decreases the animal ability to learn and its ability to see properly(Crawford et al., 1988). Limited observations have shown that there is a dramatic increases in DHA in the human brain during the last trimester of human fetus development, with the DHA level doubling during this period(Neuringer et al., 1988; Campbell et al., 1996). Babies fed infant formula milk with high ratios of linoleic to linolenic acid have poorer electroretinogram responses than those fed breast milk with lower ratios of linoleic acid to linolenic acid (9:1). The addition of fish oil to infant formulas improves some electroretinogram responses, even though fish oil is not recommended for infant milk formula. Visual activity also improved with fish oil supplementation during the first half of infancy, compared with formula containing between 1.5 and 2.5% of the energy as linolenic acid. Thus, there seems to be a need for the preformed DHA(Carlson and Salem, 1991).

Adult diets deficient in omega-3 fatty acids resulted in scaliness and lesions of the skin of patients, which were cured when thesacids were added to the diet(Bjerve, 1991). He concluded that optimally 5.4% of the energy of the diet should be in form of total PUFA and 0.6% as linolenic acid with 0.2% as EPA and DHA.

Most of the effects of linoleic acid are directly related to eicosanoid biosynthesis. The type and amounts of eicosanoids produced vary between cells and tissues involved in regulating immune response, bone remodeling and oviposition. It must be recognized that linoleic acid will not substitute for alpha-linolenic acid in providing omega-3 PUFA to tissues. The long chain omega-3 PUFA derived from alpha-linolenic acid are present in the retina and nervous tissue (Rezanka, 1989). Recognized deficiency symptoms of omega-3 fatty acids in mammals include defective vision and impaired learning ability.

The long chain PUFA such as EPA and DHA are used to build structural lipids with varying degrees of fluidity to meet different structural and functional needs. These fatty acids may be found in areas of rapid biochemical reactions such as in signal transmitters and receptors in the brain and nervous, vascular and visual systems. In the photoreceptors, DHA represents 60% of the fatty acids(Watkins et al., 1991).

Several studies have evaluated the effects on blood characteristics of consuming eggs containing an increased level of long chain omega-3 PUFA. In one study, eggs from hens fed a 10% menhaden oil diet were tested(Oh et al., 1991). Healthy male volunteers consumed either four control eggs or four omega-3 fatty acid-enriched eggs per day for a four week period. The plasma levels of both cholesterol and triglycerol were increased in the volunteers who ate the control eggs and their blood pressure was unchanged. In contrast, the consumption of the omega-3 fatty acid-enriched eggs generated no change in blood cholesterol concentration, while the level of triglycerol was significantly reduced. Furthermore, both systolic and diastolic blood pressures were significantly reduced in subjects who consumed the fatty acid-modified eggs. Similar results were obtained in another study where marked increases in the omega-3 fatty acid levels in the blood were also noted(Jiang and Sim, 1993).

3. Patients with disease

Many human diseases have been associated at the biochemical level with a change in prostaglandins and leukotrienes. The metabolic half-life of the derivative of prostaglandin, prostacyclin, is less than one circulation time. Fish oils have been shown to change the balance of these powerful physiological agents(Lands, 1986). And prostacyclines and leukotrienes have been shown to play important roles in the development of coronary heart disease, strokes, inflammatory disease and tumors(Salem, 1989; Cane, 1991; Ferretti et al., 1991; Simopoulos et al., 1991).

ESSENTIAL FATTY ACIDS(EFA) IN POULTRY

1. Lipid composition of the egg yolk

All of the lipids of the egg are confined within the yolk. The yolk exists basically as an oil-water emulsion in the form of lipid spheres (25~150 um diameter) held within an aqueous-protein phase(Noble et al., 1987). Almost all of the lipid is present as lipoprotein complexes, with the overall lipid : protein ratio being approximately 2:1. Two major yolk lipoprotein fractions have been identified based on their different physical properties and consequent separation during centrifugation. Thus "low" and "high" density fractions exist, with the most of the yolk lipid (over 90%) found within the low density fraction.

Yolk lipid is made up almost entirely of triacylglycerol (63% of total lipid) and phospholipid(30%). Free cholesterol (i.e. cholesterol not esterified to fatty acids) forms approximately 5% of the total weight of the yolk (Stadelman and Pratt, 1989).

The fatty acid composition of the triacylglycerol and phospholipid fractions of the yolk form a standard egg. In both fractions, oleic acid is the major fatty acid present. Together, palmitic and stearic acids account for more than one-third of the fatty acids, while substantial levels of linoleic acid are also present(Whitehead, 1984).

The fatty acids in the triacylglycerols of the yolk display a preferential distribution of the glycerol moiety. High levels of arachidonic and docosahexaenoic acids are present in the phospholipid fraction. In all of the lipid classes, palmitic and stearic acids together account for approximately 50% of the total fatty acids. The posphotidylcholine fraction contains the highest level of linoleic acid. The phophotidylethanolamine fraction contains high levels of arachidonic and docosahexaenoic acids(Brown, 1991).

The phospholipid contains higher levels of stearic, linoleic, arachidonic and docosahexaenoic acids than the triacylglycerol which contains a higher level of 2-linolenic acid. In both the triacylglycerol and phospholipid fractions, the chicken, turkey and quail were characterized by higher levels of linoleic acid than the duck, goose and pheasant. The level of DHA was highest in the yolk of eggs of the domestic fowl and goose(Whitehead, 1984; Stadelman and Pratt, 1989).

2. EFA deficiency symptoms and requirements

EFA deficiency symptoms in chicks include retarded growth, increased water consumption, reduced resistance to disease, enlarged liver with increased lipid content and an alteration of tissue fatty acid composition(Balnave, 1970). In males there may be a reduced testicle size and delayed development of the secondary sexual characteristics. In layers, linoleic acid deficiency results in decreased egg size, lowered egg weight and changes in egg yolk fatty acid composition. However, reproductive failure and increased susceptibility to disease might be more related to defective eicosanoid biosynthesis than to strictly EFA deficiency(Watkins, 1991).

For optimal growth in poultry, the linoleic acid requirement is suggested to be 1% of the diet (Oh et al., 1988), although other reports (Whitehead, 1984) concluded that 0.8% may satisfy the growth requirement in chickens. It is more difficult to determine the recommended levels for adult poultry since tissue reserves of the essential fatty acids are influenced by the composition of diets used for growth. Other investigators have suggested that the laying hen has two requirements for linoleic acid. Physiological maintenance may require 0.9% (Balnave, 1971), while an additional 2 to 4% may be needed for maximum egg size(Whitehead, 1984).

A number of workers have observed some adverse effects on the performance of feeding diets containing varying amounts of fish meal or fish oil. It has been observed that the feeding of isoenergetic and isonitrogenous redfish meal and redfish oil diets to broilers caused lowered feed consumption, body weights and poorer feed conversion efficiency than feeding the control diet (Hulan et al., 1989). These authors attributed the reduced performance of chickens given redfish meal to lower palatability and higher calcium levels.

Several studies have reported a lowering of egg or yolk weights or egg number when fish meal or fish oil diets were fed, although a number of other studies have observed no such effect. In one study, a linear decrease in egg weights with increasing amounts of dietary herring meal was observed(Nahm, 1996).

Effects on blood characteristics of chickens receiving fish oil or fish meal have been observed in line with changes which have been observed in mammals(Fritsche et al., 1993). Thus, as a result of omega-3 PUFA intake, the FA composition of the blood has shown dose response increases in the levels of omega-3 FA, while the levels of omega-6 FA have decreased (Huang et al., 1990; Hargis and Elswyk, 1993). Others have observed that as the level of dietary omega-3 FA increased, the amount of triacylglycerol decreased in the plasma and in the very low density plus low density lipoprotein fraction (VLDL+LDL) (Phetteplace and Watkins, 1990). The ratio of omega-6 to omega-3 FA in the plasma was reduced form 7.7 to 3.7 in chickens fed increasing amounts of herring meal and there was no effect of the modified diets on plasma total cholesterol(Nash et al., 1995).

3. The pattern of EFA absorption

Most poultry diets should provide adequate amounts of linoleic acid since plant oils in grains are usually rich sources of this EFA. Under certain conditions these diets may not contain adequate amounts of EFA. Certain nutrients and dietary factors may increase the EFA requirements. Biotin, antioxidants, fat soluble vitamins and trans-fatty acids effect the metabolism of EFA in poultry(Stadelman and Pratt, 1989).

Commercially blended feed-grade fats can be variable in their concentrations of linoleic and alpha-linolenic acid and they should be analyzed for fatty acid composition before use(Al-Athari and Watkins, 1988). Both linoleic and alpha-linolenic aicds are readily absorbed through the intestinal wall where resynthesis of triacylglycerols and packaging of lipids into portomicrons occurs for transport to the liver(Krogdahl, 1985). Long-chain omega-3 PUFA present in marine oils and fish meals seem to be absorbed and metabolized to the same extent as the omega-6 PUFA(Phettplace and Watkins, 1990). Since varying the levels of EFA and PUFA in diets will modify the composition of long-chain PUFAs(omega-3 and omega-6 fatty acids)in poultry tissues, enriching poultry meat and eggs with specific PUFA may be done to meet consumer demands.

FATTY ACID MODIFICATION IN EGG PRODUCTION

For years we have been told that dietary cholesterol is a major killer and we should avoid foods high in cholesterol such as eggs. Today, we know that dietary cholesterol is not an important risk factor in heart disease. There are many other factors that are more important such as the amount and nature of the fat in the diet. A good example of this is the case of the Greenland Eskimo. They consume almost twice as much cholesterol in their diet than do their neighbors the Danes, but the incidence of deaths from heart disease is almost seven times higher in the Danes. The answer lies, in part, in the source and nature of the fat consumed (Farrell, 1993).

Changing the quantity and or quality of the fat-rich components in the egg lipids has potential for manipulation of eggs to design the "modified" egg(Leeson, 1993). He stated that linolenic acid intake is important in its role as a precursor of docosahexaenoic acid, a metabolite found to reduce blood platelet aggregation and adhesiveness and plasma triglyceride levels. The current sources of linolenic acid are fish products and oil seeds, such as flax. When hens are fed flax, there is a considerable accumulation of linolenic acid in the egg, to the extent that the consumption of one or two "modified" eggs per day would provide most of the adult requirement for this nutrient.

One research paper has shown that inclusion of various fish oils, seeds, and seed oils in layer rations readily results in the incorporation of up to 220mg of omega-3 FA per egg yolk(Hargis and Van Elswyk, 1993). This level of omega-3 FA is equivalent to that which would be consumed in a 100g serving of lean fish; therefore consumption of one omega-3 fatty acid-enriched egg potentially could replace consumption of fish.

1. Feed-grade fats for poultry feeds

The addition of feed-grade fat (yellow grease or vegetable frying oil) to the poultry feed improves growth rate and feed conversion. Industry analysts predict that vegetable frying oil use will increase at the expense of animal tallow, resulting in an increase in the hydrogenated oil content in yellow grease. Since the primary component of blended fats is yellow grease, the concentration of trans-fatty acids (present in hydrogenated vegetable oils) will increase significantly in these products and in poultry feed. Trans-fatty acids form a side reaction isomerization during catalytic hydrogenation of vegetable and marine oils. Feeding experiments with hydrogenated soybean oil and native soybean oil indicated that hydrogenated oil had a lower ME value in broiler chicks (Brown, et al., 1993). The lower ME value may be due to the trans-fatty acids in the hydrogenated soybean oil.

The nutritive value of rendered fats in animal feeds has been questioned due to the harsh treatment they undergo during processing. To prevent peroxidation, which decreases the feeding value of rendered fats, nutritionists recommend that antioxidants be added during processing. Antioxidants help prevent oxidative damage to unsaturated fatty acids and fat-soluble vitamins. They also insure that ingredient quality is maintained until the feed is consumed(Kim et al., 1995).

2. Feeding to produce essential fatty acids in eggs

The findings that the consumption of omega-3

PUFA can have beneficial effects on important aspects of human health and disease have stimulated interest in the possible increase in the levels of these fatty acids in foods by the inclusion of dietary fish oil. Several investigations have been conducted with the aim of increasing the omega-3 PUFA composition of the egg yolk.

Since the chicken is a monogastric animal, much of the dietary fat is assimilated directly with minimal modification(Watkins, 1991).

Scientists (Reiser, 1951; Rhodes, 1958) reported the following.

- Egg pentaenoic and hexaenoic acids are increased by dietary cod liver oil.
- There is preferential insertion of marine fatty acids in egg phospholipids.
- The selective incorporation is at the expense of monounsaturated and diunsaturated fatty acids and yolk fatty acid can be modified by :

a) dietary lipids in different systems of husbandry
b) different strains of chickens, and
c) different species of birds.

Several egg producers are marketing omega-3 PUFA enriched shell eggs and others are beginning to produce them. Canola oil, olive oil, flax seed oil and fish oils, such as menhaden oil, are available to the poultry industry for inclusion of omega-3 PUFA in the laying hen rations(Van Elswyk et al., 1991; Watkins and Elkin, 1992; Leeson, 1993).

Concentrations of omega-3 PUFA in poultry meat and eggs have been elevated to produce foods with new concepts by the commercial poultry industry through the feeding of flax seed and flax seed oil(Stadelman and Pratt, 1989). The overall nutrient content of feeds can be improved by adding flax seed due to its relatively high protein and energy levels. Flax seed oil is high in linolenic acid (omega-3 fatty acid), which has been shown to have positive health effects on people. Flax seed is included in animal feed mainly to increase the levels of omega-3 fatty acids in the animal products and increase the value of these products as sources of omega-3 fatty acids for human diets. The main difference from other oil seeds is its high levels of linolenic aicd, with approximately 55% of it oil being omega-3 fatty acid. This is four times the level found in canola and eight times the level in soybeans.

Flax seed in the laying hen diet sigificantly increases the linolenic acid content in the yolk. Dietary flax was shown to increase the proportion of linolenic acid and decrease the proportion of shorter chain saturated fatty acids in the yolk(Hickling, 1997). A typical western Canadian feed formula for layers containing flax seed increased the level of omega-3 fatty acids in the egg yolk from less than 1% to more than 5% of the total oil. The basic feed formulations used in the Canadian feed industry usually include 10 to 20% flax seed in the egg laying diets.

Most feeding programs use ground flax seed, but the chicken has a gizzard capable of grinding the seed so that whole flax seed can be used in the diet. There does not seem to be an effect of egg production, but the level of omega-3 fatty acids may be reduced when whole seed is fed(Scheideler and Froning, 1996). Other reports, however, have shown that flax seed yielded no differences in total yolk omega-3 PUFA deposition as compared to equivalent amounts of ground flax seed. The advantage of using whole flax seed is that the feed will not go rancid and therefore will require less antioxidant stabilization. There may be problems with the mixing of the whole flax seed so it does not separate out in handling or the bird does not selectively consume more or less of the flax than is intended.

Ground flax seed has been promoted as being a more stable alternative to marine oils, but oxidative stability tests conducted with eggs from hens fed ground flax seed indicate an increase in the lipid peroxidation products in the egg yolk. Antioxidants are usually added to the feed in order to prevent rancidity from the oxidation of the dietary omega-3 fatty acids in the flax seed oil. Egg production and the sensory eating quality of the egg can both be affected by rancidity of the flaxseed oil. The ability to change the fatty acid composition through addition of flaxseed depends on the choice of antioxidant and the flaxseed processing methods(Hickling, 1997).

Dietary menhaden oil at 3% for 18 weeks increased egg EPA and DHA contents without altering egg output and total egg lipids(Hargis et al., 1991). 5% dietary menhaden oil also was reported to increase DHA content in the egg from 2.9 to 11.8%(Couch and Saloman, 1973). Inclusion of 1.5% menhaden oil in a laying hen ration has also been reported to result in the deposition of up to 180mg total omega-3 fatty acids/yolk. According to these results, it is possible to increase DHA contents of eggs. Another comparison of undeodorized and deodorized menhaden oil at 4% in layer diets showed that both sources were similar with respect to yolk content of EPA and DHA (Maurice, 1994).

Dietary fish oil has been indirectly implicated in "fishy" or "crabby" taint in eggs from hens fed different types of fish meal at different concentrations(Koehler and Bearse, 1975). In one study in which hens were fed a 3% menhaden oil diet, taste panelists were able to differentiate between omega-3 enriched and control scrambled eggs on the basis of flavor differences; some of the panelists reported that they noticed a "fish-like" flavor in the scrambled egs(Van Elswyk et al., 1991). Hard boiled eggs were not distinguished on the basis of dietary treatment by panelists, but this was attributed to the fact that the scrambled eggs were presented to the panelists warm whereas the hard boiled eggs were presented at room temperature.

One alternative to feeding fish oil as a way of increasing the content of omega-3 PUFA without any off-flavors is to increase the levels of dietary alpha-linolenic acid. It has been observed that the feeding of high levels of alpha-linolenic acid does not entirely remove the threat of off-flavors(Hargis and Van Elswyk, 1993). In recent studies with fish oils, egg remained acceptable with up to 3% (the maximum concentration studied) dietary fish oil stabilized with antioxidant (Huang et al., 1990). Feeding fish oil at or above 3% of the weight of the diet without adding antioxidants should be avoided (Van Elswyk et al., 1991).

Storage of feed containing 4 % fish oil at 40℃ resulted in a significant decline in EPA and DHA after one week (Maurice, 1994). Therefore, egg producers should regularly turnover stored feed to prevent degradation of fish oil in the feed and to maximize egg enrichment of EPA and DHA. Eggs should be assayed during the egg production period to estimate variances in EPA and DHA to assure the desired concentrations of these in the eggs.

There has been some research done which has reported on the differences between feeding flax seed and fish oil. Hens fed flax seed laid eggs with 486 mg of omega-3 fatty acids per 60g egg compared to 282mg per egg from hens fed fish oil. However, eggs from hens fed menhaden oil contained 262mg EPA and DHA per 60g egg compared to 94mg EPA and 23mg DHA from hens fed flax seed(Maurice, 1994). It has also been reported that utilization of 5% ground flax seed resulted in similar total omega-3 fatty acid deposition as 1.5% menhaden oil. However, composition of the egg yolk profile is much different, which means the predominant omega-3 fatty acid deposited in response to dietary flax seed is linolenic acid, a shorter chain omega-3 fatty acid.

Recently, one study showed that feeding pearl millet which was substituted for corn produced eggs significantly enriched in omega-3 FA and dietary treatments (corn, equal amounts of corn and pearl millet) had no effect on feed intake, body weight, egg production, egg weight and yolk weight(Collins et al., 1997). These results reported that feeding millet to layers in place of corn significantly decreased yolk pigmentation and the ratio of omega-6 FA to omega-3 FA in eggs was 13.1, 10.1 and 8.3 for hens fed corn, corn + pearl millet and pearl millet, respectively. Pearl millet, the world's most drought resistant grain, has been studied for its possible use in the production of egg yolks high in omega-3 FA. Compared to common cereals, pearl millet is rich in oil, with a typical fat content above 5%. Linolenic acid (C18:3, n-3) comprises 4% of the total fatty acids in this oil, giving it a higher content to omega-3 FA than other cereal grains, which means further research is needed for this grain (Rooney, 1978).

There was a study utilizing four diets, including a control, cod liver oil, canola (rapeseed) oil or linseed oil at 7% of the diet. Forty-four human volunteers consumed 14 of the egg types weekly for nine weeks(Farrell, 1993). There were no significant changes in the blood parameters that could be attributed to the egg types. High density lipoprotein cholesterol (HDL) did show a small decline and there was a small increase in low density lipoprotein cholesterol(LDL), on the 7% fish oil diet. A sensory panel in this trial was unable to distinguish between the four different egg types, but they were evaluated in only one way, as scrambled eggs microwave cooked. Further testing should be undertaken.

When adding dietary oils or seeds to the hen's diet in order to increase omega-3 PUFA in eggs, the use of antioxidants in the hens feed is still important. One report has indicated that incorporating antioxidants into poultry products, especially eggs, would increase oxidative stability and also provide a natural dietary source of antioxidants(Ajuyah et al., 1993). Recently, the effect of each 3.5% dietary oil(menhaden, flax, palm and sunflower oils) with added tocopherols was studied for their effect on the tocopherol deposition and fatty acid composition of the egg and other tissues(Cherian et al., 1996). Addition of tocopherols increased the tocopherol content more in the egg than any other tissue(liver, adipose tissue, dark meat and white meat).

3. Eggs from free range hens

There has been some debate as to the benefits or otherwise in terms of nurtrition of consuming free range eggs. The observations of some scientists of an increased content of long chain omega-3 PUFA in eggs from free range hens in Greece are noteworthy(Simopoulos and Salem, 1991). These hens were said to consume large amouts of purslane(Which is rich in alpha-linolenic acid) and other food sources such as grass, twigs, cereals and insects. The fatty acid composition of the eggs from the free range hens has been compared with that of a U. S. supermarket egg. The Greek eggs contained higher contents of saturated and monosaturated fatty acids than the supermarket eggs. In addition, The total content of omega-6 fatty acids was lower and that of the omega-3 fatty acids was markedly higher in the Greek eggs, with the result that the total omega-6 to total omega-3 fatty acid ratios were 1.3 to 19.4 for the Greek and supermarket eggs, respectively.

However, it is doubtful whether "free range" hens raised in large commercial numbers within a limited space on commercial diets would have access to sufficient quantity and variety of vegetation to give rise to omega-3 fatty acic enriched eggs. One review article noted the marked difference in fatty acid composition depending on the rearing conditions(Leskanich et al., 1997). In nearly all cases (chicken, duck, pheasant and ostrich), the contents of oleic and linoleic acids were higher in the commercial than in the free living animals.

4. The amount of omega fatty acids supplied by one designed egg

The optimal human dietary requirement of 18:3 omega-3 fatty acid, in the absence of EPA and DHA, has been estimated at 860 to 1220mg per day or 1.0 to 1.2% of the total energy intake. The optimal requirement of EPA and DHA has been estimated at 350 to 400mg per day or 0.4% of energy intake(Bjerve, 1991). Based to these estimates, one designer egg, enriched with EPA and DHA from feeding 3 to 4% menhaden oil, would provide about 50 to 65% of the estimated requirement.

Such designer eggs could be promoted in all markets or to specifically targeted groups. Eggs enriched in EPA and DHA will provide consumers with the opportunity to exercise personal choice. The three top motivators in purchasing food-taste, price and healthfulness-will determine the demand for designer eggs(Nahm and Chung, 1995).

Anticipated success of omega-3 PUFA shell eggs in the marketplace was demonstrated recently in a survey(Marshall et al., 1994). 73% out of five hundred consumers indicated they would be interested in purchasing omega-3 PUFA eggs. They would be willing to pay more for the eggs: 60% would pay an additional $0.50/dozen, 40% would pay $1.00/dozen more (Elswyk, 1994).

FATTY ACID MODIFICATION IN POULTRY MEAT PRODUCTION

Consumers are striving to reduce fat consumption in their diet. As a result, there has been a great deal of interest in investigating methods that are effective in reducing abdominal fat in broilers. Most research has shown that increasing energy levels tends to increase the carcass fat content, while increasing levels of protein tends to decrease carcass fat content. Health conscious consumers are going one step further. Their behaviors regarding food choices are changing and they are continuing to be interested in the composition of food and the diet as a whole. A good example of this is the interest in omega-3 fatty acids which have been recognized for their benefits to human health, as the dietary lipids exert a marked effect on the composition of poultry meat lipids. This provides broiler producers with a technological option to manipulate broiler meat fatty acids and create "modified" meats for specific markets.

1. Feed manipulation for fatty acid modification in poultry meat

Scientists have insisted that dietary manipulation has the potential for modifying the fatty acid content and protein content of poultry meat. When the dietary protein level was increased from 24 to 36%, the absolute quantity of carcass protein increased only one gram(from 233 to 234g), while the absolute quantity of carcass fat decreased 31g(from 210g to 179g) (Barlow et al., 1990; Leeson, 1993). Dietary energy levels have the same basic effect, except in the opposite manner. Increasing the dietary energy levels significantly increases the percentage of carcass fat. Increasing the levels of dietary energy significantly reduces the percentage of carcass protein(because of the increase in fat content) while the absolute quantity of carcass protein changes very little (Leeson, 1993).

The poultry carcass is primarily composed of protein, fat, moisture and ash. The absolute values of protein and ash do not appear to change much. The absolute values for fat and moisture can change markedly due to dietary composition, feeding programs and other management programs. Fat and moisture basically interchange.

Scientists observed that chickens could chain elongate and desaturate dietary sources of alpha-linolenic aicd(18:3n3) to form eicosapentaenoic acid(20:5n3)(Phetteplace and Watkins, 1990) These scientists reported that the omega-3 PUFA contained in these products are readily incorporated into tissue lipids of the broiler, when fish meal and menhaden oil are fed to broilers. Chickens fed linseed oil, which is also a rich source of long-chain omega-3 PUFA(18:3n3), accumulate these fatty acids in their tissues. The chicken can modulate its concentrations of PUFA by the types and amounts of fatty acids it consumes(Watkins, 1991).

The liver of the chicken contains desaturation and elongation enzymes to facilitate the formation of omega-3 PUFA. When the dietary concentration of 18:3n3 increases relative to the 18:2n6, there is an elevation in the omega-3 PUFA. Feeding sources of omega-3 PUFA to poultry increases the carcass concentration to 20:5n3 but lowers that for 20:4n6. When both 18: 2n6, 18:3n3 are deficient, Mead acid (20:3n9) is formed from oleic acid. In most practical poultry diets, the EFA linoleic acid (18:2n6) is at a higher concentration than alpha-linolenic acid(18:3n3). When this happens greater amounts of omega-6 PUFA are formed compared to the amounts of omega-3 PUFA (Watkins, 1991; Watkins et al., 1993).

Feeding incrementally higher levels of redfish meal or oil results in an increased accumulation of beneficial fatty acids in edible chicken meat lipid. The 5000 broiler chickens were fed practical corn-wheat-soybean based diets containing 0, 4, 8, 12, 15 and 30% redfish meal(RM) or 2.1 or 4.2% redfish oil(RO)(Hulan, 1988). The addition of RM and RO resulted in a substantial increase in omega-3 fatty acids and in the accumulation of significant amounts of docosapentaenoic acid in the edible meat lipids of the broilers. The breast meat was found to be lower in lipid and triglyceride but higher in free cholesterol and phospholipids than thigh meat. The carcass lipid content or composition was not affected by the dietary treatment. Breast meat contained more of the docosapentaenoic acid and total omega-3 PUFA.

The addition of plant seed or oil(flax seed or linseed oil) to the broiler diet also increased the level of omega-3 fatty acids in the poultry meat.

Studies have shown that levels of omega-3 PUFA as well as linoleic acid increased the lipid content of both dark and white meats. The proportion of oleic acid decreased to compensate. It appears that flax seed changes the pattern of fatty acid composition in broiler meat in a very similar manner that the fatty acid composition of egg yolks are altered by feeding flax seeds to layers(Ajuyah, et al., 1991). Many practical questions about the meat stability and sensory properties need to be studied before there will be commercial feeding of flax to broilers.

There has also been a report that birds supplemented with linseed oil(1.0, 2.5 or 5.0%), rich in linolenic acid(18:3n3), had significantly higher levels of omega-3 FA and higher omega-3:omega-6 ratios than those supplemented with the same level of menhaden oil, primarily due to an accumulation of 18:3n3 (Chanmugam et al., 1992). Levels of EPA were increased with the controls fed the same level of corn oil, in groups fed the two higher levels of linseed oil, and in all the groups fed menhaden oil. Linolenic acid is less susceptible to antioxidation, and is less likely to impart an off-flavor to the muscle.

Another recent research report showed that adding tocopherols to the 3% plant oils(menhaden, flax, palm and sunflower)increased the content of tissue tocopherols in the liver, adipose tissue, dark meat and white meat of the chicken(Cherian et al., 1996). Dietary tocopherols in this study resulted in a significant increase in the content of C20:5n3 and C22:6n3 in adipose tissue and white meat from birds fed menhaden plus tocopherol diets.

On the other hand, another researcher has calculated the amount of long chain omega-3 PUFA which could be supplied to human as a result of consuming the fatty acid modified meat (Hulan et al., 1988). In this study, it was stated that a 100g portion of fat-modifed chicken meat equally divided between 50g breast meat and 50g thigh meat would provide approximately 142mg of EPA+DPA(C22:5n3, docosapentaenoic acid)+DHA(61mg from the breast+81mg from the thigh). This provided slightly more than the 138mg of these fatty acids found in 100g of cod flesh. In their subsequent study, they also observed that feeding a 12% redfish meal diet would provide about 197mg of EPA+DPA+DHA per 100g of chicken(Hulan et al., 1989).

2. Conversion of omega-3 PUFA

Humans can convert omega-3 short-chain fatty acid (linolenic acid-C18:3) to long chain omega-3 fatty acids by desaturation and chain elongation steps(Brenner, 1989). This transformation is very slow, the delta 6-desaturation being the rate limiting step(Crawford et al., 1989). Therefore, the C18:3 omega-3 fatty acid (linolenic acid), through a precursor of EPA and DHA in humans, has not been considered a significant source. Enriching the diet with a linolenic acid does not appear to produce the clinical effects that EPA and DHA produce (Barlow et al., 1990).

Livestock animals are also believed to convert linolenic acid to EPA and DHA, but at a slow rate. This conversion is also influenced by the ratio of omega-6: omega-3 fatty acids; the higher the ratio the slower the conversion. In chickens, increasing the omega-3 long chain (LC)PUFA content of the diet increases the EPA and DHA content of chicken meat. A review of literature shows that there appears to be a linear relationship between the EPA plus DHA content of the diet and that in chicken meat(De Thomas and Mercuri, 1971). Consequently the amount of EPA and DHA in the tissues of land animals fed diets lacking in EPA and DHA are small (Huang et al., 1990).

3. Use of antioxidants for poultry meat flavor

Fish oil and the oil in fish meal are a rich source of EPA and DHA(Young, 1986). However, they can cause off-flavors in the meat if included at high levels. These off-flavors and fishy taints occur through the oxidation of omega-3 LCPUFA. Some of the aldehydes produced like 2-trans, 4-cis, 7-cis-decatrienal and 4-cis-heptenal, have been isolated and are claimed to have a fishy flavor. Use of antioxidants to avoid the production of these compounds is necessary if the omega-3 LCPUFA in animal products are to be increased.

Without the use of antioxidants, unacceptable odors have been observed in the carcasses of chickens fed fish oil at level of 4%(Dansky, 1962), 2.5%(Holdas and May, 1966), 2%(Edwards and May, 1965) and 1.8%(Hardin et al., 1964). It has therefore been recommended that no more than 1.5% fish oil should be fed, and that this level should be reduced in proportion to the amount of fish meal in the diet(Fry et al., 1965). In broilers, no effect on off-flavor has been observed with respect to the sex or genotype. Recent reports showed that the levels of fish meal and fish oil in broiler diets should be no more than about 12% and 1% by weight of the diet, respectively(Klaus et al., 1995).

Antioxidant treatment is standard practice for livestock animals and farmed fish. There is evidence that increasing the vitamin E content of the animal's diet helps to stabilize the tissue lipids. It has been recommended that diets for broilers should be supplemented with 50mg/kg of vitamin E above that required for normal nutritional maintenance to improve the stability of unsaturated lipids in the meat(Klaus et al., 1995 ; Leskanich et al., 1997).

CONCLUSION

Growing interest in the role of dietary fat in development of chronic disease has promoted debate concerning the potential benefits of modifying polyunsaturated fatty acid(PUFA) composition of animal products. Among PUFA targeted for manipulation in animal tissues, omega-3 PUFA(n-3 PUFA) have received considerable attention. Omega-3 PUFA are long chain fatty acids proposed to reduce the incidence of coronary heart disease in humans. Recent findings indicate that omega-3 PUFA play an essential role in growth and development of brain and retinal tissue in the newborn infant.

Desires to design such egg and meat products has resulted in more research in the area of modifying fatty acid composition of eggs and poultry meat through feed manipulation, particularly of the omega-3 PUFA. Plant seeds or oils (flax seed, flax seed oil, canola oil, linseed oil, sunflower oil, and palm oil), and fish oils (such as menaden oil)have been focused on for this research as sources of omega-3 PUFA for feed rations. Scientists reported that 10 to 20% flax seed in the egg laying diets, less than 3% fish oil by weight in the diet without additional antioxidant, or substituting entirely corn with pearl millet in the layer diet increased the egg EPA and DHA content without altering egg output and total egg lipids, Studies have proven that these seeds and oils also have the potential for modifying the fatty acid content of poultry meat. 4, 8, 12, 15 and 30% redfish meal or 2.1 to 4.2% redfish oil in the broiler diet, up to 5% linseed oil, 3% palm oil or 3% sunflower oil in the broiler diet resulted in a substantial increase in omega-3 fatty acids and in the accumulation of significant amounts of docosapentaenoic acid in the edible meat lipids of broilers.

It is a common practice to add antioxidants to the feed in order to prevent rancidity from the oxidation of the dietary omega-3 fatty acids in the plant and fish oils. In recent studies with fish oils, poultry products remained acceptable (in regards to "fishy" or "crabby" taint in the eggs and poultry meat) when dietary fish oils were stabilized with antioxidants.

적 요

가축의 조직 세포(달걀과 닭고기) 내에서 조작의 대상으로 삼고 있는 불포화지방산(polyunsaturated fatty acids, PUFAS) 은 omega-3 계열의 PUFA이다. Manhaden oil (MO)을 3~5% 산란계 사료내에 첨가해서 급여시켰을 때 계란중의 docosahexaenoic acod (DHA)와 eicosapentaenoic acid (EPA) 함량은 늘어났다고 보고하였다. 1.5%의 MO를 가해도 난중의 omega-3 지방산의 함량은 180mg까지 늘어난다. 이러한 현상은 산란계 사료내에 5%의 ground flax seed (FS)을 첨가하여 급여하여도 마찬가지였다. 한편 카나다에서는 보통 FS를 산란계 사료내에 10~20% 첨가하여 급여하고 있는 것이 일반적인 현상이다. 토코페롤을 첨가하여 급여시키면 동물의 조직중 특히 계란속에 토코페롤 함량이 증가된다고 하였다. 한 보고서에 따르면 3.5%의 토코페롤을 산란계사료내에 첨가하여 급여하면 계란중의 토코페롤 함량은 훨씬 증가되었다.

한편 옥수수-밀-대두박 위주의 육계사료 중에 redfish meal (RM; 4, 8, 12, 15 와 30%)이나 redfish oil (RO; 2.1 또는 4.2%)을 첨가했을 때 계육중의 omeg-3 지방산이나 docosapentaenoic acid (DPA) 함량이 현저히 증가된다고 보고하였다. Linseed oil (LO; 1.0, 2.5 그리고 5.0%)을 육계사료에 첨가했을 때에도 계육중의 omega-3 지방산함량은 현저히 높아졌으며 omega-3 : omega-6 지방산의 비율도 현저히 높아졌다고 보고되어있다. Fish oil (FO) 첨가에 대한 논쟁은 어취 (생선냄새) 때문에 아직도 진행 중이다. 그러나 항산화제를 육계사료내에 첨가하지 않을 경우에는 FO은 1.5% 첨가하는 것이 바람직하다고 보고하였다. 또한 비타민 E를 50mg /kg 육계사료내에 첨가할 경우 계육 중의 불포화지방산의 안정도에 기여한다고 보고된 바 있다.

(Key words : Omega-3 계열 PUFA, flax seed, 어유, 항 산화제, EPA, DPA, DHA)

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