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Feeding Poultry for Special Purpose: Omega-3 Polyunsaturated Fatty Acid Table Eggs as Functional Food: A Review Article

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Abstract: At the beginning of the twenty- first century, the science of human nutrition has been considered as a way for improving life quality and wellness. The role of food in human health and the awareness of consumers for healthy food directed research towards the production of food that has specific health effects on disease prevention and treatment. These foods are satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutrition. These foods are termed functional foods. Production of omega-3 table eggs as functional food is a new paradigm in poultry for. The ability of monogastric animals to deposited dietary fatty acids in their tissues without significant modifications on the sensory value of these products was the foundation stone and the starting point to produce omega-3 eggs. Several research activities have been conducted to increase the level of omega-3 polyunsaturated fatty acids in poultry products. The working knowledge of current literature concerning this topic made the strong foundation to produce this type of functional foods. The dietary sources of omega-3 fatty acids used for feeding laying hens modified the fatty acid content of the egg yolk. Some sources deposited amounts of fatty acids made those eggs suitable to be served as functional food. Increasing omega-3 polyunsaturated fatty acid content of eggs could be achieved either by enrichment of the diet with alpha-linolenic rich sources such as flaxseed, linseed or by EPA and DHA rich fish oil and fish meal.

Keywords: Functional foods, omega-3 polyunsaturated fatty acids, table eggs, health benefits.

Introduction

The science of human nutrition has been changed, in the twentieth century, dietary guidelines and food guides established with the aim of preventing deficiencies and supporting body growth, maintenance and development. Recommendations have also been made that we should aim to avoid excessive consumption of some nutrients such as fat, sugar and salt since their potential role in the etiology of miscellaneous (mostly chronic) diseases has been recognized. At the beginning of the twenty-first century, the science of nutrition has been considered not just for improving life expectancy but went to be a way for improving life quality and wellness. The awareness of consumers for healthy food directed the research in poultry nutrition towards the production of healthy table eggs and chicken meat. The advances in poultry nutrition resulted in more specific purposes for poultry nutrition. Layers are now fed to produce products with special characteristics by dietary modification such as the production of omega-3 eggs. As consumers became more informed about the health benefits of omega-3 fatty acids, the popularity of the enriched (functional) eggs became more widespread (Sossidou, 2007). It has been estimated that nutrient-enhanced eggs now account to five percent of eggs consumed in the European market. Clearly, there is a growing market for nutrient enhanced eggs (Rich, 2003). Some egg producers today supply new-type or speciality eggs (organic eggs, free-range eggs, omega-3 eggs, etc.). These eggs may be slightly different in nutritive value from regular eggs or they may come from hens housed or fed in a special way (Yannakopoulos, 2007). The potential health benefit of omega-3 fatty acids in the human diet has drawn attention since the original publication of Dyerberg & Bang (1979) who reported a link between dietary omega-3 fatty acid consumption and decreased incidence of cardiovascular diseases in Eskimos. Now, eggs are a potential source of omega-3 PUFA because they can be easily enriched with omega-3 PUFA by dietary modifications of the laying hen`s diet. This article highlights the production of table eggs with omega-3 content as a functional food.

Problem Statement

1. What are the research efforts that have been done to produce omega-3 table eggs as functional food?
2. Have these researchers succeeded in producing omega-3 table eggs as functional food?

Method

A review -with no meta- analysis- has been made on the production of omega-3 table egg as a functional food. According to the typical first step for an integrative review of literature stated by Cooper & Hedges (2009), a list of potential articles that address this topic was made. Research papers were collected via Google Scholar under the key word combinations: omega-3 fatty acids, functional foods, health benefits, enrichment of hens` eggs with omega-3 fatty acids, fatty acid synthesis and metabolism, dietary fatty acid and fatty acid composition of eggs. The most relevant articles were included.

Definitions of functional foods

Japan is the birthplace of the term "functional food" (Kubomara, 1998; Roberfroid,2001). Since 1980`s, Japan has been at the lead of the development of functional foods systematic and large-scale research programs were launched and funded by the Japanese government on systemic analysis and development of functional foods, analysis of the physiological regulation of function by food and analysis of functional foods and molecular design (Roberfroid,2001). In 1991, the concept of foods for specified health use (FOSHU) was established in Japan. According to the Japanese Ministry of Health and Welfare, FOSHU is:

1. Foods that are expected to have a specific health effect due to relevant constituents, or foods from which allergens have been removed, and

2. Foods where the effect of such an addition or removal has been scientifically evaluated and permission has been granted to make claims regarding the specific beneficial effects on health expected from their consumption.

Functional food has many definitions as the number of authors refer to it.

1. Foods that may provide health benefits beyond basic nutrition (IFIC, 1995).
2. Foods or food products marked with the message of the benefit to health (Riemersma, 1996).
3. Everyday food transformed into a potential lifesaver by the addition of a magical ingredient (Coghlan, 1996).
4. Food and drink products derived from naturally occurring substances consumed as part of the daily diet and possessing particular physiological benefits when ingested (Hillian, 1995).
5. Food derived from naturally occurring substances that can and should be consumed as part of the daily diet and that serve to regulate or otherwise affect a particular body process when ingested (Smith et al., 1996).
6. Food and Nutrition Board (1994) defined functional foods as "Food that encompasses potentially helpful products including any modified food or food ingredient that may provide a health benefit beyond that of the traditional nutrient it contains". From the mentioned definitions, it could be concluded that:

"A food can be regarded as "functional" if it is satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutrition, in a way that improves health and well- being or reduces the risk of disease". This definition suggests that a product must remain a food to be included within the category (Functional foods: concept to product, 2001).

Omega-3 table eggs as functional food

The egg is generally considered a complete food since it is an excellent source of easily digestible proteins, vitamins, minerals, carotenoids and fatty acids and forms part of proper nutrition for all ages, especially, children (Song & Kerver, 2000; Ayim-Akonor & Akonor, 2014; Brown, 2016). Commercial table eggs are a poor source of omega-3 polyunsaturated fatty acids and contain a high proportion of omega-6 polyunsaturated fatty acids (PUFA). Since eggs are easily available food for the large population, increasing eggs omega-3 fatty acid content considered as a good option of increasing worldwide consumption of these acids, thus increasing their beneficial effects regarding the vascular diseases. The effects of diet on the fatty acid composition of the poultry products led to the production of table eggs high in omega-3 PUFA. Dietary fatty acids are absorbed by monogastric animals and deposited in their tissues without significant modification of the sensory values of these products (Coetzee, 2002). Several research activities have been conducted to increase the levels of omega-3 polyunsaturated fatty acids (PUFA) eicosapentaenoic acid

(EPA) and docosahexaenoic acid (DHA) in poultry products. EPA and DHA have been shown to have beneficial effects on human health (Kinsella, 1990; Knap, 1991). Increasing omega-3 fatty acid content of eggs and broiler meat could be achieved either by enrichment of the diet with alpha-linolenic rich sources such as flaxseed, linseed (Jiang & Sim, 1991; Ferrier, 1995; Schideler,1996; Sari,2002; Beynen,2004; Sparks, 2006) or by EPA and DHA rich fish oil (Baucells, 2000; Husveth, 2003; Sparks, 2006; Kralik, 2008) and fish meal (Phetteplace, 1990; Chanmugam, 1992; Scaife et al.,1994; Nash, 1995). Marshall et al. (1994) reported that omega-3 fatty acids- enriched eggs could be incorporated as an omega-3 PUFA source into the diet of health- conscious consumer. It is reported that inclusion of various sources of omega-3 PUFA in hens` feed resulted in up to 220mg of omega-3 PUFA per egg yolk, equivalent to the amount of omega-3 PUFA in a 100g serving of lean fish (Hargis & Van Elswyl, 1993). An interesting strategy to reduce the cholesterogenic effects of eggs has been developed to augment the omega-3 fatty acids eggs and these eggs are called "designer egg". Scientists and nutritionists believe that the designer eggs can be a realistic approach to help people in eating more omega-3 fatty acids, to reduce the risk of heart diseases (Ramakrishnan et al., 2009). Sim et al (1992, 1993) and Jiang et al. (1992) have carried out a series of studies to enhance the value of chicken eggs enriched in omega-3 fatty acids (500-600 mg/egg) with a significantly elevated PUFA: SAFA ratio (from 0.6 to 1.02), and lowering the omega-6: omega-3 fatty acid ratio (from 10:1 to 1:1). One large egg can supply about 600 mg of total omega-3 fatty acids (balanced with DHA, DPA and EPA) equivalent to approximately 100 g serving of fish. A consumer survey indicated the public's interest in omega-3 fatty acid enriched eggs as a dietary alternative to fish (Marshall et al., 1994). Although α-Linolenic acid (ALA) was the major omega-3 fatty acids deposited in the egg yolk, a considerable amount of long chain omega-3 fatty acids were also incorporated into the phospholipid fractions of the yolk lipids. The hens fed flaxseed produced eggs enriched with omega-3 fatty acids (7-12% of yolk lipids) in the following order: ALA > DHA > DPA >EPA (Sim et al., 1995). This indicates that laying hens can convert dietary ALA to EPA, DPA and DHA via the desaturase and elongase enzyme systems (Garg et al., 1988). Arachidonic acid, the metabolite of linoleic acid (omega-6 fatty acid), was significantly reduced. Consequently, the ratio of omega-6 to omega-3 fatty acid was significantly decreased in the omega-3 fatty acid enriched eggs (from 10:1 to 1:1).

Functional effect of fatty acids

Fatty acids in the form of oils and fats are a good way to store energy in both plant and animals. They retain more energy than either proteins and carbohydrates. Fatty acids play a vital role in many biological functions and structures. Possibly the most important is as one of the fundamental components of the biological membranes (nerve, muscle and blood vessel cells). These membranes must be semipermeable, allowing passage through of some molecules while restricting others. The properties of the membranes formed will depend on the nature of the fatty acids incorporated. EPA and DHA possess distinct physical and biological properties that generally impart properties to cell and tissues, which underlie their ability to promote health and prevent disease. Although active in many areas of human biology, mechanisms of action of EPA and DHA are perhaps best defined in cardiovascular disease (Deckelbaum and Torrejon, 2012). The major omega-6 and omega-3 PUFA are summarized in Table (1).

Table 1. Major omega-6 and omega-3 fatty acids

Common Name	Abbreviation	Typical Sources
Linoleic acid (LA)	C18:2n6	most vegetable oils
Arachidonic acid (AA)	C20:4n6	animal fats, liver, egg lipids, fish
α- Linolenic acid (ALA)	C18:3n3	flaxseed oil, canola oil, soybean oil
Eicosapentaenoic acid (EPA)	C20:5n3	fish, especially oily fish (salmon, herring, anchovy, smelt and mackerel)
Docosapentaenoic acid (DPA)	C22:5n3	fish, especially oily fish (salmon, herring, anchovy, smelt and mackerel)
Docosahexaenoic acid (DHA)	C22:6n3	fish, especially oily fish (salmon, herring, anchovy, smelt and mackerel)

Source: Sim and Sunwoo (2002)

The essential fatty acids

Neither linoleic nor linolenic can be synthesized in the animal`s body hence, they must be obtained in the diet and are thus known as essential fatty acids (James, 2000; Convington, 2004; Defilippis, 2006). Only plants can produce omega-3 PUFA fatty acids. Humans and animals depend on getting Omega-3 fatty acids through their diet. omega-6 fatty acids as arachidonic acid (AA) can be synthesized by humans and animals from linoleic acid (C18:2-6, LA), whereas omega-3 fatty acids represented by eicosapentaenoic acid (EPA), Docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA) are synthesized from α- linolenic acid (C18:3n-3, ALA) (Rubio- Rodriguez et al., 2010; McCusker & Grant- Kels, 2010).

Health benefits of dietary omega-3 fatty acids and mechanisms of action

The omega-3 fatty acids are very important nutrients for both young and old (Holman et al., 1982; Bjerve, 1991; Brown, 2016). The two-main long chain highly unsaturated fatty acids in the omega-3 series are eicosapentaenoic acid (EPA 20:5) and docosahexaenoic (DHA 22:6). They directly used in the body. The long chain unsaturated omega-3, EPA and DHA, are vital for a wide range of biological functions. EPA and DHA are found in the phospholipid layer of membranes keeping them mobile. Around 25% of the fat in the brains of humans and animals is DHA and this proportion seems to be independent of diet (Crawford & Sinclair, 1972), which would indicate that it plays a very important role in neural membranes. DHA is the preferred fatty acid for the correct construction and functioning of membranes particularly those in very active tissue such as nerves and active muscles. Dyerberg & Bang (1979) found that Eskimos has a significantly longer bleeding-time due to a reduction in platelet aggregation. It is suggested that C20:5 in the platelet in converted by the vascular-wall tissue to an anti- aggregatory prostacyclin. That is mean that omega-3 PUFA increased in the platelets. Howe (1997) suggested that omega-3 PUFA can be used as a diet strategy to control blood pressure as nonpharmacological therapies. There is both epidemiologic and experimental evidence that the long-chain omega-3 fatty acids, especially those occurring at high levels in some fish oils, exert protective effects against breast, colon, and, perhaps, prostate cancers. The mechanisms involved in this chemo-preventive activity, including suppression of neoplastic transformation, cell growth inhibition and enhanced apoptosis, and anti-antigenicity; however, a common feature of most of these biological effects is the inhibition of eicosanoid production from omega-6 FA precursors. Several of the known risk factors for breast, colon cancers may be favorably modified by dietary omega-3 fatty acids supplementation, and the implementation of clinical chemoprevention trials is now feasible (Rose & Connolly, 1999). Mohan and Das (2001) found that omega-3 and omega-6 can prevent chemically induced diabetes mellitus by enhancing the antioxidant status and suppressing production of cytokines. Kelley (2001) Supplementation of human diets with omega-3 fatty acids reduced several aspects of neutrophil, monocyte, and lymphocyte functions, including the production of inflammatory mediators. Omega-3 fatty acids, EPA and DHA, reduce symptoms in many inflammatory skin diseases (Balbas et al., 2011). Omega-3 fatty acids have been found to normalize blood pressure, blood cholesterol levels and fat metabolism, decrease insulin dependence and increase metabolic rate and membrane fluidity (Deckelbaum and Torrejon, 2012; Brown, 2016).

Fatty acid synthesis and metabolism in animal system

In the hen`s liver, linoleic acid (18:2) is elongated to its n-6 product, arachidonic acid (20:4), whereas α-Linolenic acid (C18:3n-3) is elongated to the n-3 products, EPA (20:5) and DHA (22:6). These elongation products are deposited in eggs (Aymond, 1995). The microsomal enzyme reactions do not permit crossover between fatty acid metabolites from linoleic acid and α-Linolenic acid sequences (Bezard,1994). The desaturation and elongation steps are influenced by numerous nutritional and hormonal factors (Bezard, 1994). A competitive interaction between linoleic acid and α-Linolenic acid exists such that n-3 PUFA suppresses the metabolism of n-6 PUFA and n-6 PUFA suppresses the metabolism of n-3 PUFA, although less strongly. Dietary α-Linolenic acid not readily incorporated into tissue lipid. It mainly oxidized to CO2 and water. Some are converted to EPA and DHA, but a small portion of the α-Linolenic acid enters this pathway. Jiang (1991) reported that the dietary α-Linolenic acid was deposited mainly in triglycerides, but the long chain n-3 polyunsaturated fatty acids such as eicosapentaenoic, docosapentaenoic, and docosahexaenoic acids were preferentially deposited into yolk phosphatidylethanolamine (PE) fraction. An abundance of arachidonic acid and, especially C20:3 n-3 and DHA in the diet markedly decreased the Δ-6 desaturation of linoleic acid, less markedly influenced the Δ-5 desaturation of C20:3 n-6 to arachidonic acid, and did not alter the Δ-6 desaturation of α-Linolenic acid.

Both linoleic acid and α-Linolenic acid are substrates of the Δ-6 desaturase, allowing α-Linolenic acid to establish a competitive inhibition of the linoleic acid desaturation (Bezard, 1994).

Enrichment of hen`s eggs with omega-3 fatty acids

It`s widely accepted that dietary manipulation especially lipid modifications, can alter lipid composition of the different animal products (Hargis et al.,1991). Manipulation of lipid profile by adding omega-3 dietary sources in poultry diets is now widely applied to produce omega-3 poultry products. Egg yolk is composed mainly of fats (lipids) and proteins, an average 60 grams' egg contains 5.5to 6 grams of fat (Cherian,2002). which combine to lipoproteins, of which 60% of the dry yolk weight is of low-density lipoprotein (LDL). Yolk lipids are primarily in the form of triacylglycerol (TAG), phospholipids (PL) and free cholesterol. Monounsaturated fatty acids (44%) dominate egg fatty acid profile followed by saturated fatty acids (29%) and polyunsaturated fatty acids (11%) (Sparks, 2006). Dietary sources and de novo lipid synthesis are major factors influencing the composition of egg`s lipid (Sim & Sunwoo,2002). The level of deposition of omega 3 (n;3 PUFA) and omega 6 (n;6 PUFA) in the 3% inclusion of flaxseed oil was 2.58-fold higher than the control which had no flaxseed oil. For individual n-3 PUFA levels, the fold increases from control diet to the 3% oil inclusion were: 18:3 n-3 (α-linolenic acid, (ALA) = 1.55; 20:3 n-3 (Eicosatrienoic acid, (ETA) = 16.79; 20:5 n-3 (Eicosapentaenoic acid, (EPA) = 0.15; 22:3 n-3 (Docosatrienoic acid) = 27.81; 22:5 n-3 (Docosapentaenoic acid, (DPA) = 1.6; and 22:6 n-3 vi (Docosahexaenoic acid, (DHA) = 3.22 (Brown,2016). These findings reflect that unsaturated healthy fatty acid content in poultry eggs can be increased with dietary supplementation of flaxseed. The highest total polyunsaturated fatty acid (PUFA) and total omega-3 PUFA were recorded (Sultan et al., 2015). Flaxseed enriched feed mainly results in ALA enrichment, up to 200 mg per egg, but also substantial increases in the DHA content, up to 90 mg per egg, this with overdosing the amount of flaxseed (Aymond & Van Elswyk, 1995; Bean and Leeson; 2003; Fraeye et al., 2012; Lemahieu et al. (2015). Fish oil, as source of EPA and/or DHA, for example, can be supplemented to the diet of the laying hens and mostly results in DHA enrichment in the egg yolk (up to ± 100 mg per egg), while the EPA content increases to a much lesser extent (Bovet et al., 2007; Cachaldora et al., 2008; Carrillo et al., 2008; Fraeye et al., 2012; Gonzalez-Esquerra & Leeson, 2000; Van Elswyk et al., 1995; Batal & DeSmet, 2012; Lemahieu et al., 2015).

The relationship between the dietary n-3polyunsaturated fatty acids and the fatty acid composition of eggs.

There is a clear relationship between the proportions of n-3 PUFA in the dietary fat and the lipid yolk deposits (Beynen 2004; Leskanich & Noble, 1997; Von Schacky & Harris, 2007 Huyghebaret et al. ,2007; Poureslami et al. 2012; Sultan et al., 2015). It is found out that egg yolk EPA can be modified through diets containing EPA, while egg yolk DHA can be modified by a diet rich in α-linolenic acid or by a diet containing DHA (Beynen 2004). Hen`s ability to convert α-linolenic acid into DHA probably influenced the deposition of DHA in egg yolk lipids. The DHA content in egg yolk was in appositive relation with the content of α-linolenic acid and EPA+DAH in diets (Cherian and Sim, 1991; Leskanich & Noble, 1997 Beynen, 2004; and Kralik et al., 2008). This confirms the fact that increasing the level of linoleic acid or α-linolenic acid from different vegetable fat sources result in increases in their concentrations in the yolk lipid (Leskanich & Nobel, 1997). The limited efficiency of conversion of α-linolenic acid to EPA and DHA in birds is also mentioned by (Aymond & Van Elswyk, 1995). Only a very small part of dietary α -linolenic acid is converted into EPA and excreted as such in egg, and the maximum egg yolk contents of DHA of about 1.5% of total fatty acids were attained at a dietary α-linolenic acid concentration higher than 7% of total fatty acids (Beynen 2004). Barlow et al. (1990) stated that not all n-3 fatty acids are biologically equivalent, but what should be considered are the specific fatty acids provided by food sources enriched with n-3 fatty acids.

Conclusion

Feeding poultry to only produce high-quality protein does not become the main goal for poultry nutrition in the new millennium. Poultry nutrition for producing poultry products possessing specific active substances that have more target functions in the body besides adequate nutrition become the new paradigm tell now. It is new in establishing effective methods to produce omega-3 table eggs, but the idea has been published to the world about long ago as 500 BC when Hippocrates wrote: "Let food be your medicine and medicine be your food".

Recommendation

More researches are needed to establish mathematical relations to determine the effect of dietary intake of fatty acids on the fatty acid composition of eggs.

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الملخص

في بداية القرن الحادي و العشرين تم إعتبار علم تغذية الإنسان وسيلة لتحسين نوعية الحياة و الصحة العامة. دور الغذاء في صحة الإنسان و وعي المستهلكين للأغذية الصحية وجه البحوث نحو انتاج أغذية لها آثار صحية محددة على الوقاية من الأمراض و علاجها. هذه الأغذية أثبتت بشكل مرض أثرها المفيد على واحد أو أكثر من وظائف الجسم، بجانب توفير التغذية الكافية. تسمى هذه الأغذية بالأغذية الوظيفية. إنتاج بيض المائدة الغني بالأحماض الدهنية غير المشبعة أوميغا-3 كغذاء وظيفي هو نموذج جديد في تغذية الدواجن. قدرة الحيوانات وحيدة المعدة على ترسيب الأحماض الدهنية في أنسجتها دون التأثير على القيمة الحسية لهذه المنتجات يعتبر حجر الأساس و نقطة البداية لإنتاج بيض أوميغا-3. الأدبيات المختصة بهذا الموضوع وضعت أساسا قويا لإنتاج هذا النوع من الأغذية الوظيفية. المصادر الغذائية للأحماض الدهنية غير المشبعة المستخدمة في تغذية الدجاج البياض عدلت محتوى هذه الأحماض في صفار البيض مما جعل البيض المنتج مناسبا لتقديمه كغذاء وظيفي. ويمكن زيادة محتوى صفار البيض من هذه الأحماض عن طريق إضافة مصادر علفية غنية بألفا لينولينك مثل بذر الكتان أو غنية ب DHA و EPA مثل زيت السمك و مسحوق السمك.
