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# POULTRY MEAT AS FUNCTIONAL FOOD: MODIFICATION OF THE FATTY ACID PROFILE – A REVIEW*

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**Abstract**

**Functional foods, defined as "foods that may provide health benefits beyond basic nutrition", became increasingly popular in the past twenty years with numerous practical applications. In Europe, functional foods must be accompanied by scientifically substantiated health claims. Products which aspire to that category include poultry meat and processed meat products which have been modified through bird nutrition. This article reviews the existing knowledge about foods fortified with health-promoting additives. It discusses the physiological, economic and legal aspects of modifying poultry meat, including turkey meat which has been poorly investigated in this context. The addition of oils rich in PUFA (polyunsaturated fatty acids), e.g. linseed oil, to poultry diets has been found to increase LC *n-3* PUFA (long-chain omega-3 PUFA) concentrations in chicken and turkey meat. LC *n-3* PUFAs participate in many processes that condition metabolism and health, and the nutritional value of meat, including poultry, is most commonly enhanced by increasing the proportion of LC *n-3* PUFAs in the product's fatty acid composition. However, it increases feed costs and may cause a deterioration in the sensory attributes and oxidative stability of meat. Turkey breast meat is characterized by a relatively low fat content, which is why the fulfilment of health claim requirements is difficult in the European Union.**

**Key words: poultry nutrition, functional food, *n-3* PUFA, turkey meat**

The fortification of foods with health-promoting additives is a new trend in the food processing industry that has been intensively developed in the past decade and has attracted growing consumer interest (Horska and Sparke, 2007). The functional

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food concept has emerged from growing knowledge about the importance of a balanced diet to health and wellbeing. The report of the Joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases (WHO/FAO, 2003) summed up many years of population-based research to indicate that diet and nutrition are important determinants of health and that inadequate dietary habits are the main risk factors in lifestyle diseases. The results of recent research suggest that dietary and lifestyle factors contribute to the development of many non-infectious diseases, including obesity, cardiovascular and degenerative diseases (Harris et al., 2007; Robinson et al., 2007; Jenkins et al., 2011; Bosma-den Boer et al., 2012; Tan et al., 2012). These findings contribute to the popularity of functional foods, and they prompt industrial manufacturers to develop new products that confer health benefits for consumers. The functional food sector is additionally stimulated by the fact that developed countries have a rapidly aging population. It seems that older consumers perceive the use of functional foods as more beneficial than younger consumers (Landström et al., 2007; Herath et al., 2008).

According to the Leatherhead Food Research (2011) report, the European functional food market has a 28% share of the global market, and it approximates the size of the US market. The world market for functional food is valued at more than $150 billion with a yearly growth potential of 10% (Granato et al., 2010). It accounts mostly for functional dairy products and non-dairy beverages (Menrad, 2003; Granato et al., 2010). Attempts are being made to expand the range of functional foods to include meat and processed meat products, including chicken and turkey meat, through the modification poultry diets.

**Functional foods: concept and implementation**

The term “functional food” and associated concepts such as designer foods, pharmafoods and nutraceuticals made their way into the mainstream nearly 20 years ago (Goldberg, 1994) as products whose consumption can prevent and treat various diseases. Analyses of the European food market indicate that the functional food sector continues to grow with regard to both product volume and the number of offered products. In the early 2000s, more than 1500 new products, including 300 functional food items, were introduced to the German food market each year (Menrad, 2003). They were represented mainly by soft drinks (30%), confectionery (21%) and dairy products (20%). Products such as margarine containing phytostanol esters, low-cholesterol butter and eggs enriched with omega-3 fatty acids and antioxidants (Siro et al., 2008) enjoy steady demand on many markets.

The development of functional foods can be analysed in two aspects: (1) their purpose, i.e. the product’s role in health promotion, and (2) the type and range of changes in the product’s chemical composition. A product serves a given purpose in view of its specific properties that affect metabolic processes (antimicrobial, anti-inflammatory, immunomodulatory or cancer-protective) or the anticipated health benefits, including reduced risk of cardiovascular diseases through lower LDL and total cholesterol concentrations (e.g. isoflavones of soy-based products and margarine containing phytostanol esters), improved quality and stability of intestinal microbiota (e.g. dairy products containing probiotic bacteria), neutralization of free radicals and reduced risk of cancer and atherosclerosis. The above properties are found in natural products which are rich in non-nutritive components, including soluble fibre in psyllium seeds, isoflavones in soy foods, proanthocyanidins in cranberry juice, resveratrol in purple grape juice, lycopene in tomatoes and catechins in tea (Hite and Berstein, 2012). The content of those bioactive compounds may be increased or they may be added to traditional foods. In meat, there are two groups of bioactive compounds which are classified as functional food ingredients: essential vitamins and minerals (vitamins A, C and E, iron, potassium, magnesium, calcium) as well as non-essential nutrients such as LC *n-3* PUFAs, CLA (conjugated linoleic acids) dietary fibre, antioxidants and probiotics (Decker and Park, 2010).

Functional foods can be divided into five categories subject to the degree of modification of their chemical composition (Table 1).

Table 1. Categories of functional foods (based on Spence, 2006 and Siro et al., 2008)

| Category of functional food | Definition | Example |
|---|---|---|
| Non-altered products | foods with naturally high concentrations of nutrients or components | fish products as a source of LC *n-3* PUFAs |
| Fortified products | foods fortified with additional nutrients | fruit juice fortified with vitamin C |
| Enriched products | foods with added new nutrients or components which are not normally found in a particular food | margarine with plant sterol esters, prebiotics, probiotics |
| Altered products | foods whose harmful components have been removed, reduced or replaced with a substance delivering beneficial effects | fibre as a fat releaser in meat and ice cream |
| Enhanced commodities | foods where one component has been naturally enhanced through special growing conditions, foods with a new composition, foods modified by genetic manipulation or other methods | eggs whose omega-3 content has been increased through modification of chicken feed |

In many countries, functional foods had been introduced to the market before the implementation of laws providing a detailed regulatory framework for this category of products. Many scientific attempts to define functional foods (Siro et al., 2008; Kaur and Das, 2011) rely on highly generalized descriptions, such as “foods that may provide health benefits beyond basic nutrition” (Bech-Larsen and Grunert, 2003) or “foods that contain a non-essential substance with potential health benefits” (Hite and Berstein, 2012), whereas other studies offered more comprehensive definitions of the term: “a food product can only be considered functional if, together with the basic nutritional impact, it has beneficially affected one or more functions of the human organism, thus either improving the general and physical condition or/and decreasing the risk of the evolution of diseases” (Diplock et al., 1999).

The above definitions, including the broader definition adopted by the European Commission's Concerted Action on Functional Food Science in Europe, fail to precisely identify the boundary between conventional and functional foods. For this reason, most countries do not have a legally binding definition of the term, and European legislation does not consider functional foods as specific food categories, but rather as a concept (Coppens et al., 2006).

**Status of functional food in Europe**

The regulations governing the market introduction of foods bearing nutritional and health claims are laid down by Regulation (EC) No. 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on food. The above regulatory document and EU legislation relevant for nutrition and health claims have been discussed in detail by Verhagen et al. (2010).

The Annex to Regulation (EC) No. 1924/2006 identifies the specific conditions that must be met for a nutritional claim to be made on a product, including claims made on "low energy" foods (max. 40 kcal/100 g for solids) and "low-fat" foods (max. 3 g of fat per 100 g of solids). The above annex also regulates the conditions for making health claims on products with a reduced (saturated fatty acids) or increased (omega-3 fatty acids) fatty acid content (Table 2).

Table 2. Examples of health claims and the conditions applying to them (Regulation (EC) No. 1924/2006)

| Health claim | Condition of use |
|---|---|
| Low in saturated fats | if the sum of saturated fatty acids and trans-fatty acids in the product does not exceed 1.5 g per 100 g for solids or 7.5 g per 100 g for liquids |
| Source of omega-3 fatty acids | at least 0.3 g alpha-linolenic acid per 100 g and per 100 kcal, or at least 40 mg of the sum of eicosapentaenoic acid and docosahexaenoic acid per 100 g and per 100 kcal |
| High in omega-3 fatty acids | at least 0.6 g alpha-linolenic acid per 100 g and per 100 kcal, or at least 80 mg of the sum of eicosapentaenoic acid and docosahexaenoic acid per 100 g and per 100 kcal |
| High in monounsaturated fats | min. 45% of fatty acids are derived from MUFA: min. 20% of energy is derived from MUFA |
| High in polyunsaturated fats | min. 45% of fatty acids are derived from PUFA: min. 20% of energy is derived from PUFA |

A claim stating that a product is enriched with vitamins, excluding vitamin C and folic acid, can only be made in respect of items that contain minimum 15% and maximum 50% of RDI values for a given vitamin. Pursuant to the provisions of the Regulation of the Health Minister of 16 September 2010 on foods considered to be of special value as a nutrient source (Journal of Laws of 2010, No. 180, item 1214), the RDI for vitamin A for adult consumers has been set at 800 μg, and this legal standard applies to the production of food supplements. In fats, excluding milk fat, the vitamin A content of the final product may not exceed 900 µg (3000 IU).

Detailed provisions of the Annex to Regulation (EC) No. 1924/2006 have been introduced to ensure that marketing experts do not overstate the health benefits of the advertised products and that health claims on food products are not misleading for consumers. The conditions applying to nutritional claims (Table 2) indicate that the health benefits of foods of animal origin can be enhanced by lowering their fat content and improving their fatty acid composition.

**Methods for improving the functional value of poultry products**

The functional value of animal-derived products can be enhanced during the production of raw materials (eggs and meat) or during processing (mostly meat) (Table 3).

Table 3. Strategies for designing novel functional products (based on Arihara, 2006; Jimenez-Colmenero, 2007; Kassis et al., 2010; Zhang et al., 2010)

| Sector | Strategy | Example |
|---|---|---|
| Animal farms | modification of raw materials, meat and eggs | supplementation of animal diets with functional ingredients such as LC *n-3* PUFAs, vitamin E, selenium, CLA, lutein |
| Food industry | supplementation of raw materials and/or reformulation of meat products during processing | direct addition of functional ingredients to meat products (vegetable proteins, dietary fibres, herbs, spices, etc.), modification during processing (e.g. to produce bioactive peptides during fermentation or curing) and reformulation to reduce fat, cholesterol, sodium and nitrite levels or to improve fatty acid composition through the use of vegetable oils |

According to recent review articles (Arihara, 2006; Jimenez-Colmenero, 2007; Decker and Park, 2010; Zhang et al., 2010), the processing of meat involves various treatments aiming to enhance the health benefits of the final product. The purpose of indirect fortification is to enrich the composition of carcasses by modifying animal diets. By contrast, direct fortification involves the use of functional additives in meat processing, including plant proteins, whey, fibre, herbs, spices, probiotics, prebiotics, minerals and vitamins (Decker and Park, 2010; Zhang et al., 2010). The composition of meat products may also be changed through reformulation to lower fat and cholesterol content, modify fatty acid composition, lower the product's energy value, reduce salt and nitrate concentrations and introduce health-promoting additives (Arihara, 2006; Jimenez-Colmenero, 2007).

Dietary supplementation strategies had been used to modify the chemical composition of eggs long before the introduction of the functional food concept. Already in the 1960s, researchers demonstrated that the use of feedstuffs rich in PUFAs, such as fishmeal, fish oil and flaxseed, increased PUFA concentrations in egg yolks, including *n-3* PUFAs whose mean daily intake is generally below the recommended levels.

The administration of feed containing 3.5% fish oil to chickens for four weeks increased *n-3* PUFA concentrations in egg yolks to 230 mg in comparison with 58 mg in the control group (van Elswyk, 1997). The results of another experiment which evaluated the effects of oil-enriched chicken diets on the fatty acid profile of egg yolks are shown in Table 4.

Table 4. Concentrations of *n-3* PUFAs in eggs laid by hens fed different diets (Farrell, 1998)

| Fatty acid | Source of PUFAs in hen diets | | | |
|---|---|---|---|---|
| | sunflower oil (4%) | fish oil (5%) | fish oil (3%), linseed oil (1%) | fish oil (2%), linseed oil (1%), canola oil (1%) |
| ALA (18:3) | 0.20 a | 0.36 a | 2.26 b | 2.32 b |
| EPA (20:5) | 0.20 c | 1.00 a | 0.58 b | 0.45 b |
| DPA (22:5) | 0.06 c | 0.63 a | 0.52 a | 0.42 a |
| DHA (22:6) | 0.44 c | 5.27 a | 3.80 b | 3.38 b |
| Total | 0.94 b | 7.34 a | 7.24 a | 6.60 a |
| *n-6/n-3* PUFA ratio | 25.75 b | 1.25 a | 1.52 a | 1.80 a |

a, b, c – $P \leq 0.05$.

The *n-6/n-3* PUFA ratios were determined at 1.25–1.80 in eggs laid by hens which were fed fish oil alone or in combination with linseed oil and at 25.75 in eggs laid by hens whose diets were supplemented with sunflower oil. In many experiments, PUFAs found in linseed oil and flaxseed were effectively transferred from feed into eggs (López-Ferrer et al., 2001; Grobas et al., 2001; Silva et al., 2009; Sosin-Bzducha and Krawczyk, 2012).

In one of earlier experiments, high PUFA levels in egg yolks were noted following the enrichment of chicken diets with CLA, a natural product of linoleic acid (C18:2) degradation (Chamruspollert and Sell, 1999). Egg yolks and poultry meat contain small amounts of CLA (0.6–0.9 mg/g fat). Higher CLA concentrations are found in milk and the meat of ruminants due to intensive biohydration of fatty acids in the bovine rumen. CLA and *n-3* PUFAs share similar biological properties, which is why CLA supplementation increases the health benefits of animal-derived foods. In Poland, the enrichment of poultry diets with CLA was investigated by Szymczyk et al. (2003) and Pisulewski et al. (2005). The results of later studies indicate that eggs laid by hens whose diets were enriched with oil containing CLA may deliver anti-inflammatory effects on the consumer's cardiovascular system (Franczyk-Żarów et al., 2008).

The results of research studies have many practical applications. The production of Columbus® eggs enriched with omega-3 fatty acids and vitamin E exceeds 50 million per year in Europe (Siro et al., 2010). New methods of modifying the composition of eggs and increasing their health benefits have been proposed in recent years. It has been shown that target-fortified eggs are a unique nutritional supplement for peak brain development during pregnancy, nursing and infancy (Shapira, 2009). Various methods for producing nutraceutical eggs containing omega-3 oils (Kassis et al., 2010) or supplementing eggs with other health-promoting additives, such as vitamin C, choline and dietary fibre, have been proposed (Singh et al., 2012). Comprehensive reviews of studies investigating the functional modification of eggs have been published by Yannakopulos (2007), Fisinin et al. (2008), Ganesan et al. (2012) and Singh et al. (2012). Most recently, researchers analysed the supplementation of diets with potential substitutes of α-tocopheryl acetate, including hesperetin and naringenin (Ting et al., 2011), daidzein (Ni et al., 2012) and olive leaves (Botsoglou et al., 2012), to enhance the antioxidant properties of eggs enriched with *n-3* PUFAs.

**Broiler meat as a source of *n-3* PUFAs**

Diets rich in LC *n-3* PUFAs, including EPA (eicosapentaencic fatty acid [C20:5*n-3*]) and DHA (docosahexanoic fatty acid [C22:6*n-3*]), and, to a certain extent, ALA (α-linoleic fatty acid [(18:3*n-3)*], the metabolic precursor of EPA and DHA, reduce the risk of cardiovascular disease. LC *n-3* PUFAs modulate factors that contribute to the metabolic syndrome, including abdominal obesity, insulin resistance, dyslipidemia and hypertension (Carpentier et al., 2006; Robinson et al., 2007). The consumption of foods rich in omega-3 PUFAs helps prevent heart disease (Harris et al., 2007) by lowering plasma triacylglycerol concentrations, decreasing the production of chemoattractants and growth factors, increasing endothelial relaxation, heart-rate variability and atherosclerotic plaque stability (Calder, 2004). Recent research focused on the potential role of *n-3* PUFAs in the prevention of neurological diseases, including age-related cognitive decline and dementia, but the studies conducted to date did not offer conclusive findings (Gibbs, 2010; Pottala et al., 2012; Tan et al., 2012).

In the human diet, the demand for LC *n-3* PUFAs is expressed in terms of recommended daily intake (RDI) and *n-6/n-3* PUFA ratio values. In Europe, RDI values for LC *n-3* PUFAs range from 300 to 400 mg (Grashorn, 2007), but higher consumption levels at 450–500 mg are recommended (Givens, 2009). The optimal *n-6/n-3* PUFA ratio has been set at 2:1 (Simopoulos, 1999, 2011), and it should not exceed 4:1 (Lands et al., 2005; Simopoulos, 2008). According to some authors, the *n-6/n-3* PUFA ratio in human diets should reach 10:1 to 5:1, but recent research indicates that the above levels increase the risk of certain diseases, including cardiovascular ailments. Simopoulos (2009) reviewed numerous studies to conclude that in secondary prevention of cardiovascular diseases, a ratio of 4:1 was associated with a 70% decrease in total mortality. A lower *n-6/n-3* PUFA ratio decreased the risk of breast cancer in women and suppressed inflammations in patients with rheumatoid arthritis. The ratio of 2.5:1 reduced rectal cell proliferation in patients with colorectal cancer, whereas the ratio of 4:1 with the same amount of omega-3 PUFAs had no effect (Simopoulos, 2009). Lands and Lamoreaux (2012) have observed that using 3–6 differences in essential fatty acids rather than 3/6 ratios gives useful food balance scores.

A typical Western diet is characterized by a very high *n-6/n-3* PUFA ratio of 10:1 to 30:1 (Hibbeln et al., 2006) or even 50:1 (Grashorn, 2007). The above results from very high levels of *n-6* PUFAs and relatively low consumption of *n-3* PUFAs. In the past decade, this problem has been discussed extensively by Givens (2005), Pisulewski (2005), Givens and Gibbs (2006), Grashorn (2007), Gibbs et al. (2009, 2010), Kouba and Mourot (2011). The above authors have observed that fortification with *n-3* PUFAs is the most popular method of maximizing the health benefits of animal-derived foods, including poultry meat.

In developed countries, the main sources of *n-3* PUFAs are raw and processed meat (Howe et al., 2006) with an estimated 40% share of poultry meat (Rymer and Givens, 2005). For this reason, the consumption of *n-3* fatty acids should be increased to achieve an *n-6/n-3* PUFA ratio which is optimal for human health (Russo, 2009). According to Givens (2009), the potential mean intake of EPA and DHA by adult consumers in the UK from enriched animal-derived foods is 231 mg/person/day. The main sources of the above fatty acids are dairy products (71.5 mg), eggs (54.3 mg), meat and other products (105.4 mg), including poultry meat (74.8 mg). The above indicates that poultry meat is responsible for the highest potential intake of EPA and DHA in the diet.

In recent years, most experiments relied on vegetable oils, mostly linseed oil (Has-Schön et al., 2008; Betti et al., 2009 b; Zuidhof et al., 2009), rapeseed oil (Koreleski and Świątkiewicz, 2006; Salamatdoustnobar et al., 2010; Betti et al., 2009 a, b) and olive oil (Gonzalez and Tejeda, 2007) due to dwindling fish oil resources as well as concerns that fish oil would deteriorate the sensory attributes of meat products. Some researchers used echium oil, whose fatty acid composition is similar to that of fish oil, to demonstrate that it more effectively enriches poultry meat with *n-3* PUFAs than rapeseed oil (Kitessa and Young, 2009).

It is known that fish oils and fish products are the direct sources of EPA and DHA, while vegetable oils containing ALA, are the metabolic precursors of EPA and DHA. The synthesis of long-chain fatty acids from ALA involves two processes: chain elongation (elongation process) and increase in the number of unsaturated bonds (desaturation process). At too high a ratio of *n-6/n-3* PUFA the efficiency of ALA conversion to LC *n-3* PUFA might not be sufficiently high to improve the nutritional value of poultry meat (Qi et al., 2010). It is also known that the application of ALA in a diet increases tissue EPA, but not DHA (Pisulewski, 2005).

The results of an experiment analysing the effects of various oils on the fatty acid composition of diets and whole-body synthesis of PUFAs in chickens (Poureslami et al., 2010) are presented in Table 5. In the cited study, the retention of *n-3* and *n-6* PUFAs was similar (excluding PUFAs supplied by linseed oil), and the proportions of both groups of fatty acids in the total fatty acid pool in chickens were similar to those observed in the administered diets. In another experiment (Zelenka et al., 2008), chicken diets were enriched with 1, 3, 5 or 7% linseed oil from flax cultivars with a high content of α-linolenic acid or linoleic acid. The narrowest *n-6/n-3* PUFA ratio (0.77:1 and 0.93:1 in breast and thigh meat, respectively) was observed in diets containing 36 g of α-linolenic acid per kg of diet (diets with 5% linseed containing high levels of α-linolenic acid), whereas the widest ratio (13.6: and 17.2:1 in breast and thigh meat, respectively) was noted in diets containing 2 g of α-linolenic acid (diets with 7% content of a conventional linseed cultivar).

In a Canadian study (Jia et al., 2010), the fortification of broiler diets with 12% flaxseed significantly increased LC *n-3* PUFA concentrations in the carcass. The consumption of 100 g of thigh and wing meat supplied approximately 2 g *n-3* PUFAs.

This significantly exceeds the RDI for *n-3* PUFAs which is set at 450–500 mg (Givens, 2009).

Table 5. Fatty acid composition of diets with different sources of PUFAs and whole-body concentration of PUFAs in chickens (based on Poureslami et al., 2010)

| | Source of LC *n-3* PUFAs | | | |
|---|---|---|---|---|
| | palm oil | soybean oil | linseed | fish oil |
| Fatty acid composition in the diet (%) | | | | |
| *n-6* PUFAs | 14.7 | 24.1 | 14.5 | 12.4 |
| *n-3* PUFAs | 0.9 | 2.4 | 14.1 | 9.8 |
| *n-6/n-3* PUFA ratio | 16.7 | 10.0 | 1.0 | 1.3 |
| Whole-body concentration of LC *n-3* PUFAs in chickens | | | | |
| *n-6* PUFAs | 11.9 | 22.7 | 14.4 | 10.5 |
| *n-3* PUFAs | 0.7 | 2.2 | 13.4 | 6.9 |
| *n-6/n-3* PUFA ratio | 17.0 | 10.3 | 1.1 | 1.5 |
| Accumulation (% of net intake) | | | | |
| *n-6* PUFAs | 73.1 b | 74.7 b | 85.2 a | 73.0 b |
| *n-3* PUFAs | 63.9 | 64.3 | 65.3 | 58.4 |

a, b – $P \leq 0.05$.

Zuidhof et al. (2009) studied the time period during which flaxseed-enriched diets have to be administered to achieve *n-3* PUFA concentrations that substantiate a health claim (3 mg/g). The anticipated result was reached by administering diets containing 17% or 10% flaxseeed over a period of 11.3 and 26.2 days, respectively. In 95% of cases, diets supplemented with α-linolenic acid increased the *n-3* PUFA content of meat. Despite a significant increase in LC *n-3* PUFA levels (20:5 *n-3*, 22:5 *n-3* and 22:6 *n-3*), their concentrations in tissue phospholipids and triglycerides were relatively low in comparison with ALA levels.

Zduńczyk et al. (2011) observed that chicken diets fortified with selenium and vitamin E increased the concentrations of both antioxidants in breast muscles without affecting their fatty acid composition. Rozbicka-Wieczorek et al. (2012) reported, however, that supplementation of broiler chicken diet with lycopene and Se increased the value of the PUFA/SFA ratio in the muscles of pullets and, especially, cockerels. Al-Khalifa et al. (2012) demonstrated that modifications of the fatty acid composition of chicken meat could also stimulate immune functions in broiler chickens. An increase in dietary *n-3* PUFA levels, achieved through the addition of fish oil to chicken diets (0, 3, 5 and 6%), decreased phagocytosis and lymphocyte proliferation in broiler chickens. The results of the above experiment suggest that PUFA-rich oils, such as linseed oil, may be used in poultry diets to improve the health and welfare of birds.

**Modification of the fatty acid composition of turkey meat**

A review of the existing body of literature indicates that very few attempts have been made to modify the fatty acid composition of turkey meat. Due to the shortage of such studies, the effectiveness of dietary modification in chickens and turkeys cannot be reliably compared. To address this problem, Rymer and Givens (2005) compared the results of two experiments where chicken diets (Ratnayake et al., 1989) and turkey diets (Komprda et al., 2002) were supplemented with 4–5% fishmeal. A similar approach was adopted by Kouba and Mourot (2011) who analysed the results of different studies of chickens and turkeys.

A study by Rymer and Givens (2005) shows that the long-chain *n-3* PUFA content of chicken meat (white or dark) and white turkey meat was similar, despite a higher fishmeal content of turkey diets (49.5 g/kg fishmeal vs. 40 g/kg redfish meal fed to broilers). Those observations could support the conclusion that the DHA content of muscles is inherently higher in smaller than in larger birds (Hulbert et al., 2002). According to a comparative study by Komprda et al. (2005), when all chicken and turkey tissues were analysed as a single set, the percentage content of EPA + DHA in the analysed tissues decreased with an increase in their fat content. PUFA concentrations in chicken and turkey breast meat decreased linearly with an increase in live weight at slaughter.

The results of a study aiming to modify the fatty acid composition of turkey meat (Jankowski et al., 2012 a) are presented in Table 6. The supplementation of turkey diets with soybean oil, rapeseed oil and linseed oil at initial doses of 2% to final doses of 5% produced meat with a different proportion of *n-3* PUFAs in the fatty acid composition at 7.02, 7.96 and 30.6%, respectively, and a different *n-6/n-3* PUFA ratio of 7.3, 4.4 and 1.0, respectively.

Table 6. Fatty acid composition of diets supplemented with different fatty acid sources and fatty acid composition of turkey breast meat (Jankowski et al., 2012 a)

| | Experimental group | | |
|---|---|---|---|
| | SO | RO | LO |
| *n-3* PUFAs in diet (% Σ FA) | 7.02 | 7.96 | 30.6 |
| *n-6/n-3* PUFA ratios in diet | 7.3 | 4.4 | 1.0 |
| PUFAs in turkey breast meat (% FA) | 29.4 | 27.1 | 37.3 |
| *n-6/n-3* PUFA ratios | 5.6 | 5.1 | 1.2 |

SO – soybean oil, RO – rapeseed oil, LO – linseed oil.

In comparison with soybean oil, the addition of rapeseed oil and linseed oil to diets significantly increased PUFA concentrations in turkey breast meat. In the group of birds fed linseed oil, the proportion of PUFAs in the total fatty acid pool was significantly higher (37.3% vs. 29.4 and 27.1% in groups fed soybean and linseed oil), and the *n-6/n-3* PUFA ratio was significantly lower (1.2 vs. 5.71 and 5.13). Higher concentrations of retinol and α-tocopherol were found in the meat of turkeys fed rapeseed oil than in the meat of turkeys administered soybean and linseed oil.

The changes in the fatty acid profile observed by Jankowski et al. (2012 a, b) correspond to those noted in turkeys fed diets enriched with rapeseed oil (Has-Schön et al., 2008; Salamatdoustnobar et al., 2010). In another experiment (Delezie et al., 2010), diets supplemented with soybean oil, linseed oil and fish oil (3%) were administered to turkeys until the age of 4, 8, 12 and 16 weeks. The *n-6/n-3* PUFA ratio of breast and thigh meat fat in 16-week-old turkeys fed soybean oil exceeded 8, whereas diets enriched with linseed and fish oil produced *n-6/n-3* PUFA ratios of approximately 2 and less than 2, respectively. In the discussed experiment, diets fortified with fish oil resulted in higher levels of LC *n-3* PUFAs because the rate at which *n-3* precursors are converted to EPA and DHA is not increased by a longer feeding plan. Similar changes in the fatty acid profile of meat were observed in studies of turkeys and chickens.

**Factors restricting the modification of the *n-3* PUFA content of poultry meat**

The main factors which restrict the fortification of poultry meat with *n-3* PUFAs include deterioration of meat's sensory attributes, higher production costs, the availability of alternative methods of modifying the nutritional value of meat and legal restrictions applicable to the food industry.

The possibility that LC *n-3* PUFAs exert adverse effects on the oxidative stability of meat has been implied by numerous authors, including Cortinas et al. (2005) and Grashorn (2007). Rahimi et al. (2001) demonstrated that the inclusion of flaxseed and canola seed (7.5 or 15%) in broiler chicken diets decreased the oxidative stability of raw meat (breast and thigh) during freezer storage based on thiobarbituric acid levels. In a study by Jankowski et al. (2012 a), the optimal *n-6/n-3* PUFA ratio (2:1) was determined in cooked breast muscles of turkeys whose diets were supplemented with 5% linseed oil. In comparison with turkey groups fed soybean oil and rapeseed oil, cooked meat of turkeys administered linseed oil was characterized by a significantly lower *n-6/n-3* PUFA ratio (1.51 vs. 5.07 and 5.43, respectively), a higher content of thiobarbituric acid reactive substances (31.9 vs. 26.4 and 26.7 nmol/g) and less desirable sensory attributes (7.9 vs. 6.7 and 4.1 points) (Jankowski et al., 2012 b). The above results imply that in order to minimize linseed oil's adverse effects on the sensory attributes and oxidative stability of meat, linseed oil should be administered over shorter periods of time or that antioxidant levels should be increased in feed. Similar results were reported by Konieczka et al. (2012) who supplemented chicken diets with different types of fat: lard, rapeseed oil, linseed oil and fish oil. The meat of chickens administered linseed oil and fish oil had a higher LC *n-3* PUFA content, and it was characterized by less desirable sensory attributes. Other authors demonstrated that poultry diets, conventional or fortified with LC *n-3* PUFAs, should also be supplemented with antioxidants such as selenium and/or vitamin E (Barroeta, 2007; Haug et al., 2007; Mikulski et al., 2009; Zduńczyk et al., 2011). Higher prices of the available sources of LC *n-3* PUFAs, fishmeal, fish oil, flaxseed and linseed oil, increase the cost of a modified diet (Grashorn, 2007). In the experiment whose results are presented in Table 6 (Jankowski et al., 2012 a), the replacement of soybean oil with rapeseed oil led to a minor (3%) increase in the feed costs, whereas the use of linseed oil increased feed costs by 37% in comparison with diets supplemented with soybean oil and by 34% in comparison with diets containing rapeseed oil (Table 7).

The cost of modified poultry diets should be compared with the cost of other methods of increasing the nutritional value of meat. The increase in cost resulting from the use of linseed oil in feed was lower than the differences in the prices of conventional products, functional foods of animal origin and organic products. An analysis of the Spanish market of functional foods revealed a nearly 40% difference between the prices of conventional and functional milk, whereas the difference between the prices of traditional and fortified eggs reached 80% (Moran, 2007).

Table 7. The effect of oil prices on the cost of dietary ingredients and feed raw materials per kg body weight gain in turkeys (Jankowski and Zduńczyk, data not published)

| Parameter | Source of LC *n-3* PUFAs | | |
|---|---|---|---|
| | soybean | rapeseed | linseed |
| Cost of dietary ingredients (zloty/kg) | | | |
| weeks 0–4 | 1.43 | 1.44 | 1.67 |
| weeks 5–9 | 1.36 | 1.37 | 1.65 |
| weeks 10–13 | 1.31 | 1.33 | 1.87 |
| weeks 14–15 | 1.18 | 1.20 | 1.83 |
| Feed intake over the fattening period (%) | | | |
| weeks 0–4 | 5.60 | 5.49 | 5.65 |
| weeks 5–9 | 31.51 | 31.14 | 31.23 |
| weeks 10–13 | 38.96 | 39.04 | 39.22 |
| weeks 14–15 | 23.93 | 24.33 | 23.90 |
| Average cost of dietary ingredients (zloty/kg) | 1.30 | 1.32 | 1.78 |
| FCR in weeks 0–15 | 2.57 | 2.60 | 2.58 |
| Cost of feed raw materials per kg body weight gain | | | |
| zloty/kg | 3.34 | 3.43 | 4.59 |
| % relative to S group | 100 | 103 | 137 |
| % relative to R group | 97 | 100 | 134 |

In a Polish study, the estimated cost of producing 1 kg of organic broiler meat was nearly 100% higher in comparison with meat produced in a conventional system (Gornowicz and Lewko, 2010). High production costs of meat fortified with PUFAs could pose a barrier to the popularization of functional and organic foods.

The use of alternative processing methods, including reformulation, could also decrease the food industry's interest in the production of high quality meat through dietary supplementation. The aim of such treatments, which are endorsed by the EU Platform for Diet, Physical Activity and Health (EU Platform, 2005), is to lower the content of saturated fatty acids and trans fatty acids. According to a recent report of the European Commission (2010), such treatments effectively reduced the content of harmful ingredients (salt, trans isomers) by 25 to 50% in most products. The above implies that direct fortification with LC *n-3* PUFAs could be as effective as indirect methods of modifying the nutritional value of meat through dietary supplementation. An unquestioned advantage of direct modification is that the content of selected meat components, one of the key factors determining the nutritional value of foods, is much easier to standardize in the industrial environment. On the other hand, reformulation increases the degree of raw material processing, and it runs counter to the strategy of producing foods which are minimally processed. Organic food advocates could have a preference for meat and products modified through the supplementation of animal diets.

Stringent legal requirements applicable to the production of fortified meat could also pose a barrier to the development of functional foods. In line with the provisions of Regulation (EC) No. 1924/2006, for meat to be labelled as a source of omega-3 fatty acids, it has to contain 0.3 g α-linoleic acid per 100 g of the product (3 mg/g). Higher levels of *n-3* PUFA fortification can be achieved in meat with a higher fat content. The fat content of poultry carcasses varies subject to the analysed edible portion: 2.8 g/100 g in breast, 10 g/100 g in the whole carcass, 13 g/100 g in thigh with skin and 70 g/100 g in skin (Barroeta, 2007). In a study by Jia et al. (2010), 100 g of wings and thighs of chickens whose diets were supplemented with 12% flaxseed supplied 2 g of LC *n-3* PUFAs, which is significantly above the level required for a qualified health claim. The most widely eaten turkey meat product is skinless breast meat which is relatively lean. In a study by Jankowski et al. (2012 b), the breast meat of turkeys fed linseed oil had a 0.7% fat content, and α-linoleic acid had a 15.6% share of the total fatty acid pool in breast meat. In the above experiment, the proportion of ALA in the fatty acid profile was 14-fold higher than that reported by Komprda et al. (2003) where dietary supplementation with 5% meat meal was responsible for a minor increase in *n-3* PUFA levels. The breast meat of turkeys fed the above diet contained only 0.08 mg/g ALA. In the work of Jankowski et al. (2012 a), the ALA content of breast meat from turkeys reached 1.1 mg/g, as compared with the findings of Komprda et al. (2003). The results of the presented calculation were verified in successive studies (Jankowski et al., data not published), and they clearly indicate that the high ALA content of 3 mg per g of white turkey meat is unlikely to be achieved.

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ZENON ZDUŃCZYK, JAN JANKOWSKI

**Mięso drobiowe jako żywność funkcjonalna: modyfikacja profilu kwasów tłuszczowych – artykuł przeglądowy**

STRESZCZENIE

W ostatnim dwudziestoleciu koncepcja żywności funkcjonalnej, rozumianej jako żywność, która – poza wartością odżywczą – może zapewniać korzyści zdrowotne, znalazła liczne zastosowania praktyczne i trwałą pozycję na rynku żywności. Do tego typu żywności, wymagającej w Europie odpowiedniego oznaczenie zdrowotnego, pretenduje mięso i wyroby mięsne z drobiu, zmodyfikowane prozdrowotnie poprzez odpowiednie żywienie ptaków. Ze względu na fakt, że długołańcuchowe wielonienasycone kwasy tłuszczowe uczestniczą w wielu procesach warunkujących prawidłowy metabolizm i zdrowie organizmu, zwiększenie udziału tej grupy w produktach jest najbardziej popularnym kierunkiem prozdrowotnej modyfikacji produktów pochodzenia zwierzęcego, w tym mięsa drobiowego. W niniejszym przeglądzie piśmiennictwa podsumowano aktualną wiedzę na ten temat. W nawiązaniu do potrzeb profilaktyki zdrowotnej u ludzi przedstawiono fizjologiczne, ekonomiczne i prawne uwarunkowania żywieniowej modyfikacji mięsa drobiowego, w tym mięsa indyczego, którego dotyczą nieliczne doświadczenia. Wykazano, że skuteczną metodą zwiększenia zawartości wielonienasyconych kwasów tłuszczowych w mięsie kurcząt i indyków jest zastosowanie oleju lnianego w diecie tych ptaków. Taki zabieg zwiększa koszt paszy oraz może pogarszać cechy sensoryczne i stabilność oksydacyjną mięsa. Ze względu na mniejszą zawartość tłuszczu w piersi indyków spełnienie unijnych wymagań niezbędnych do oznaczenia zdrowotnego tego produktu jest znacznie trudniejsze.