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Nutritional potential for improving meat quality in poultry

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This review presents current opinions on health-related effects of meat consumption, emphasizing associations between meat (red meat and processed meat) and colo-rectal cancers. It indicates that consumption of poultry and fish has not been found to be associated with increased risk of cancers.
The idea of functional foods in Europe is described and poultry meat is shown as a target for modification by means of nutritional strategies. These strategies include enrichment with polyunsatutated fatty acids (PUFAs), notably *n*-3 acids, conjugated linoleic acid (CLA) and antioxidant vitamines. It is shown that feeding fish oils or fish meals (n-3 fatty acid sources) to growing poultry leads to their subsequent deposition in adipose and muscle tissue (mainly C20:5, C22:5, and C22:6) at the expense of decreasing incorporation of *n*-6 fatty acids. At the same line, dietary CLA isomers are deposited in poultry tissues. Moreover, since the increasing amout of polyunsaturates in meat increases their oxidation, efforts aiming at improving the oxidative stability of modified poultry meat (notably nutritional enrichmemnt with vitamin E) are described.
Finally, the potentially detrimental effects of dietary PUFAs and CLA on broiler productive performance (feed intake, growth rate, feed conversion) and sensory meat quality (off-flavours) are analysed. Also, available means are discussed to reduce or to prevent these effects.

KEY WORDS: antioxidant vitamins / conjugated linoleic acid / functional food / nutritional

strategies / polyunastutared fatty acids / poultry meat

It is generally accepted that from a strictly nutritional point of view, meat (including poultry meat) is an optional and non-essential component of a human diet [Millward 1999]. Moreover, there is considerable evidence showing a close association between meat consumption and cancer incidence [WHO 2004]. However, potential harmful effects of meat consumption should be analysed in more detail. First, the term *meat* refers to red meat and processed meat in particular, and includes beef, lamb and pork, but excludes poultry and fish. Second, a positive association between meat consumption and cancer is largely limited to cancers of colon and rectum (colo-rectal cancers). Possible causes underlying this associations include the effects of carcinogenic N-nitroso compounds [Bingham 1999] produced in the human large intestine. Interestingly, these effects are closely associated with consumption of red meat, whereas white meat has no effect on N-nitrosation [Bingham *et al*. 2002]. Despite the above associations, it is known that vegetarians do not have reduced risk of colo-rectal cancer. Also, more recent epidemiological, case-control and cohort studies, particularly those from Europe, tend to show no such relationships [Bingham 1999, Hill 1999]. Not surprisingly, the most recent European dietary guidelines prudently recommend: "*Those who are not vegetarians are advised to moderate consumption of preserved meat e.g. sausages, salami, bacon, ham"* [WHO/FAO 2003]. Poultry and fish consumption has not been found to be associated with increased risk of cancer.

In spite of available evidence indicating carcinogenic effects of meat consumption (red and processed meat in particular) meat occupies a pivotal position in the global food chain, which is rather unlikely to change in the future, at least in Europe. This position of meat is certainly due to its social, political, and economic role in our societies [Millward 1999]. The above opinion holds also true for Poland. In Poland, total meat consumption amounts to 65 kg/year *per capita.* Interestingly, in the last decade, pork consumption per year has been relatively stable varying from 36.4 to 39.2 kg, whereas beef consumption decreased from 17.4 kg to 5,2 kg and that of poultry meat increased from 8.1 to 19.8 kg. Currently, pork contributes 56,2%, poultry meat 28.4 and beef only 7.4% of total meat consumption in this country**.**

In this context animal scientists, instead of considering their products, including meat, to be a crying shame, should develop efficient strategies to improve composition and enhance health-related effects of milk, meat and eggs. For instance, these products can be made better by modifying their lipid content and composition and improving their oxidative stability. Available methods for modifying the composition of poultry meat to improve its quality, including enhancement of health-related (*i.e.* functional) properties are discussed below.

The idea of functional foods

The idea of functional foods is a new frontier in nutritional sciences. It reflects the changing concepts of food in human nutrition, from a past emphasis on meeting nutrient requirements to an emphasis on health-related effects of foods, helping to reduce the risk of chronic diseases. In view of the above, functional foods can be defined as those containing specific nutrients and (or) non-nutrients that affect human health, beyond what is traditionally known as nutritional effects. Thus, there is no precise and universally accepted definition of these foods. Consequently, it has been suggested to understand the term "a functional food" as a new idea, rather than a defined product [Bellisle *et al*. 1998, Diplock *et al*. 1999, Roberfroid 2000, 2002]. Accordingly, an ideal functional food is considered to be: (1) a conventional or everyday food; (2) consumed as a part of the conventional diet; (3) composed of naturally occurring components; (4) enhancing target function(s) beyond its nutritive value; (5) reducing the risk of disease, and (6) having sound, scientifically-based and verified claims. As such, the above definition covers all major features of functional foods and is meant to set guidelines for research and development in the field of modern human nutrition. In a more practical way, a functional food is defined as: (1) a natural food in which one of the components (nutrient or non-nutrient) has naturally been enhanced through special growing conditions; (2) a food to which a component has been added to provide benefits (e.g. the addition of selected probiotic bacteria to improve gut health); (3) a food from which a component has been removed (e.g. the reduction of saturated fatty acids); (4) a food in which the nature of one or more components has been modified (e.g. protein hydrolysates in infant formulas); (5) a food in which the bioavailability of one or more components has been increased, and (6) any combination of the above possibilities.

As indicated in the European Consensus Document [Diplock *et al*. 1999], the most pertinent aspect in communicating of health-related benefits of functional foods is that any claim of their functionality must be scientifically based, *i.e*. it must be both objective and appropriate. Therefore the development of functional foods must rely on identification and validation of relevant biological markers of particular target functions and (or) the risk of a particular disease. More precisely, these markers can be classified according to whether they relate to: (1) exposure to the food component under study (e.g. the level of this component itself or its metabolites in the body fluids or tissues); (2) enhanced target function(s) or biological responses (e.g. changes in concentrations of relevant metabolites, specific proteins, enzymes or hormones as possible responses to a functional component); (3) an appropriate endpoint of the reduced disease risk (e.g. progression and regression of atherosclerotic lesions), and (4) individual susceptibility or genetic polymorphism controlling the effect of the functional component under study (e.g. nutrient-gene interactions).

In the above context, the most thoroughly investigated, physiologically-active (*i.e.* functional) components of animal origin are polyunsaturated fatty acids (PUFAs) *n*-6 and *n*-3). Among them *n*-3 fatty acids have attracted particular attention. Indeed, in a number of clinical studies these compounds were shown to reduce the risk of several chronic diseases; including their best-evidenced beneficial role in cardiovascular disease

[Connor 2002, Hasler 2002, Kris-Etherton *et al*. 2004, Lopez-Garcia *et al*. 2004]. Another bioactive (*i.e.* functional) component of animal origin is conjugated linoleic acid (CLA). In fact, the term CLA refers to a group of positional and geometric (*cis, trans*) isomers of octadecaenoic acid (C18:2), of which the *cis*-9, *trans*-11 (rumenic acid) and *trans*-10, *cis*-12 are the most abundant. These compounds are naturally found in ruminant milk and meat [Lawson *et al*. 2001, Raes *et al*. 2004]. Moreover, when fed to experimental animals and humans, they exert anti-obesity, anti-atherogenic, anti-carcinogenic, and immuno-modulatory effects [Fritche and Steinhart 1998, Pisulewski *et al*. 1999, Roche *et al*. 2001, Azain 2003). Consequently, a number of nutritional strategies have been used to obtain PUFAs-enriched or CLA-enriched poultry meat. This meat is considered to be functional *i.e.* to exert, at least potentially, beneficial effects on human health and resistance to disease [Pisulewski *et al*. 2002, Pisulewski and Kostogrys 2003].

Nutritional strategies to improve poultry meat composition and quality

The nutritional strategies to improve the quality of food products of animal origin are a relatively new approach that has emerged at the interface of animal nutrition, food science and human nutrition. This approach has been effectively used to alter animal product composition to be more consistent with human dietary guidelines. Equally, it has been used to enhance health-related, *i.e.* functional properties of foods of animal origin.

Poultry meat has been a frequent target of nutritional modification. Since a close relationship between fatty acid profile of the poultry diet and that of deposited lipids exists, the majority of efforts focused on: (1) alteration of fatty acid carcass composition and (2) improvement of poultry meat oxidative stability. In poultry, dietary fatty acids are absorbed unaltered from the small intestine and directly incorporated into tissue lipids. In more detail, saturated (SFA) and monounsaturated (MUFA) fatty acids are synthesized endogenously (in part), and their concentrations in carcass lipids are less influenced by dietary fat. On the other hand, PUFAs cannot be synthesized in the body and their carcass concentrations respond rapidly to dietary alterations. Moreover, according to a recent survey on consumption of PUFAs by Polish population [Dybkowska *et al*. 2004], it seems necessary to increase the intake of long-chain *n*-3 PUFAs by greater consumption of fish or fish products or EPA (C20:5*n*-3)- and DHA (C22:6*n*-3)-enriched foods or supplements.

Enrichment of poultry meat with PUFAs (*n*-6 and *n*-3)

In preliminary studies on the above subject, reviewed by Leskanich and Noble [1997], Wood and Enser [1997], Wenk *et al*. [2000], and more recently by Gonzales-Esquera and Leeson [2001], feeding growing poultry with rich sources of PUFAs (plant and fish oils or fish meals) resulted in their subsequent incorporation into carcass lipids. As could be expected, fatty acid profiles of carcass fat closely reflected those of the dietary fat. As indicated by Leskanich and Noble [1997], marked changes in muscle and adipose tissue fatty acid composition were obtained without any effects on the total fat content of the carcass or relative proportions of major lipid classes, including cholesterol. The finding that the adipose tissue composition was more altered by dietary lipid profile than breast muscle was probably due to the physiological lipid storage function of the former tissue. It was also found that feeding fish oils or fish meals (*n*-3 fatty acid sources) led to their subsequent deposition in adipose tissue and muscles (mainly C20:5, C22:5, and C22:6) at the expense of decreasing incorporation of *n*-6 fatty acids. At the same time, no effect of sex or genotype on total lipid content, lipid composition or muscle fatty acid composition was noted in birds fed either standard or modified diets.

In view of the above findings, the nutritional modification of poultry meat could be considered an effective means of producing functional poultry meat. However, it should be remembered that among *n*-3 fatty acids, ALA (C18:3) is present in vegetable oils (mainly flaxeed and canola) whereas EPA (C20:5) and DHA (C22:6) are present in fish and fish oils. It is also known that consumption of ALA leads to significant increase of tissue EPA, but not DHA. Therefore, dietary fish and fish oils are recommended to increase both EPA and DHA in animal tissues [Manzioris *et al.* 2000, Burge *et al*. 2002].

Alteration of a standard diet composition may result in several adverse effects. First, although animal performance (e.g. feed intake, growth rate, feed conversion efficiency) was not affected by feeding PUFAs sources in majority of such studies, several reports showed adverse effects of fish oil or fish meal. Second, the enrichment of poultry meat with PUFAs results in development of undesirable odours ("fishy taints"). These taints are associated with the presence of volatile substances resulting mainly from oxidative deterioration the polyunsaturates present in modified poultry meat. Fortunately, the fishy taints can be reduced, at least partly, by several ways. First, by restricting the levels of fish oil and fish meal to the maximum of 1% and 10% by weight of the diet, respectively. Indeed, feeding excessive levels of fish oil (8.2% !) in broiler diets led to rejection of the derived meat by sensory panelists [Loopez-Ferrer *et al*. 1999]. Second, by improving the quality and purity of fish oils. Third, by introducing alternative sources of *n*-3 fatty acids (e.g. DHA-rich marine algae). Fourth, by increasing the levels of dietary antioxidants (e.g. vitamin E), to improve the oxidative stability of the modified meat (see below). In addition, a more technical way to improve the sensory characteristics of meat from broiler chickens fed fish by-products is to remove these components from the feeding mixture, at least 5 days before slaughter [Koreleski *et al*. 1997].

Given the above, the lipid classes in broilers are unevenly distributed in different marketable cuts, *i.e.* breast (white meat rich in phospolipids) and thigh (dark meat reach in triacylglycerols). In addition, *n*-3 PUFAs are preferentially incorporated into breast phospholipids. Consequently, feeding these fatty acids may affect the sensory quality of the above cuts differently, thus complicating further poultry meat enrichment with the polyunsaturates [Esquera and Leeson 2001].

In view of the above findings, the effects of different dietary combinations of PUFAs sources and vitamin E levels, on histochemical characteristics [Smolińska *et al*.

2002] and composition of fatty acids in poultry meat (white *vs*. dark cuts), have been analysed [Zanini *et al*. 2003, 2004]. It was found that of five sources of polyunsaturated oils (soybean, canola, sunflower, linseed, and fish), only canola and fish oil reduced the content of fat in the thigh meat. In the breast meat, fat content was reduced by sunflower oil whereas it was elevated by linseed oil. These observations could be explained by differences in fatty acids deposited preferentially in each type of meat. What is more [Zanini *et al.* 2004], canola and fish oil fed to broilers reduced the content of saturated and polyunasturated (mainly *n*-6) fatty acids in the thigh meat, with fish oil increasing the content of C22:6 in this cut. Consequently, the ratio of *n*-6 to *n*-3 was reduced in the thigh meat. In contrast, the use of soybean oil increased saturated and polyunsaturated (mainly *n*-6) fatty acid content in the thigh meat. In both experiments, significant interactions between dietary oils and vitamin E were observed.

Enrichment of poultry meat with conjugated linoleic acid (CLA)

A number of studies have examined the effects of dietary conjugated linoleic (CLA) isomers on the fatty acid composition of the broiler carcass. These studies were largely aimed at increasing CLA content in broiler tissues as a means to develop functional properties of poultry meat destined for human consumption.

There are several general features emerging from the experiments conducted so far. First, CLA isomers are easily absorbed and readily incorporated into adipose tissue and cell mebrane phospholipids in monogastric animals [Kramer *et al*. 1998]. Indeed, feeding CLA oils to poultry resulted in its linear deposition in adipose tissue and intramuscular fat. This relationship was true even at high concentrations of dietary CLA, ranging from 0-2% [Simon *et al*. 2000, Szymczyk *et al*. 2001], 0-3% (Du and Ahn 2002, 2003, 0-4% (Aletor *et al*. 2003, Siri *et al*. 2003], to 0-5% [Badinga *et al*. 2003]. Second, in the above experiments, the increased incorporation of CLA into carcass lipids inevitably led to higher relative concentrations of saturated fatty acids and lower relative concentrations of MUFAs in adipose tissue and intramuscular fat, whereas PUFAs (including CLA isomers) were not affected. In view of negative effects of SFAs consumption on human health [WHO/FAO 2003, WHO 2004], this effect could be interpreted as detrimental. However, it has also been indicated that the above changes, in relative proportions of fatty acids in broiler carcass, may reduce the suceptibility of lipids to oxidation, thus increasing their oxidative stability [Aletor *et al*. 2003]. Third, although the total sum of PUFAs remained unchanged, the content of essential individual *n*-6 (e.g. C20:4, C22:4) and *n*-3 (e.g. C22:5, C22:6) fatty acids was decreased. These negative effects were probably associated with inhibitory action of CLA isomers on Δ^9-desaturase activity [Smith *et al*. 2002], thus explaining the observed low proportion of MUFAs (mainly C18:1*n*-9) in the modified carcass. In the same line, a decrease in concentrations of *n*-6 and *n*-3 fatty acids could have been caused by inhibition of Δ^6-desaturase, involved in desaturation of linoleic and α-linolenic acid to their long-chain derivatives [Bretillon *et al*. 1999].

In several trials, feeding CLA isomers to broilers had negative effects on their production performance, mainly feed intake and growth rate. For instance, Szymczyk *et al*. [2001], reported reduced feed intake and weight gain over the range of dietary CLA levels of 0-1.5%. Non-significantly reduced weight gain was also observed by Du and Ahn [2002] in broilers, as the levels of dietary CLA increased from 0 to 4%. At the same time no such changes were observed by Sirri *et al*. [2003] over the same dietary CLA concentrations.

The results of our own studies shown in Tables 1, 2 and 3 [Szymczyk *et al*. 2001], correspond fairly closely to the above general picture.

Finally, the question of sensory quality of CLA-enriched poultry meat should be addressed. According to available evidence, dietary CLA improves oxidative stability of this meat. These isomers (dietary treatments: 0-5%), by increasing the content of SFAs and decreasing that of PUFAs in chicken meat, improved lipid and colour stabil-

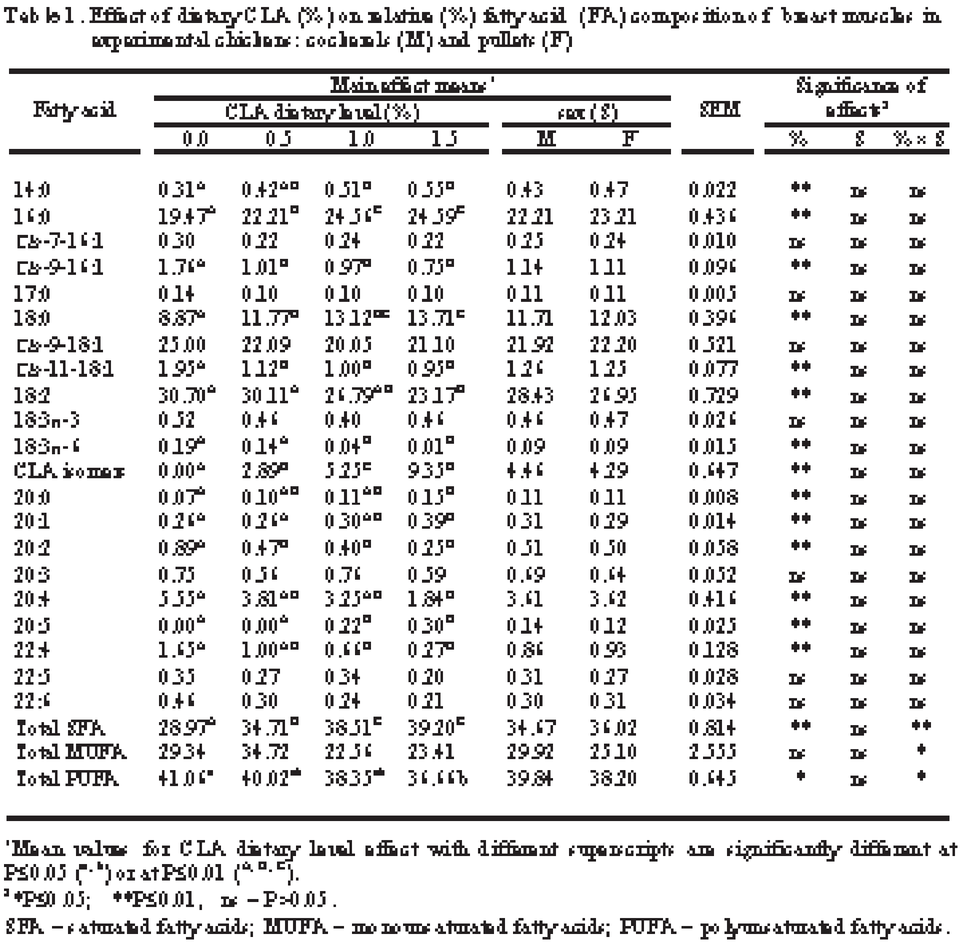


Table 1. Effect of dietary CLA (%) on relative (%) fatty acid (FA) composition of breast muscles in experimental chickens: cockerels (M) and pullets (F)

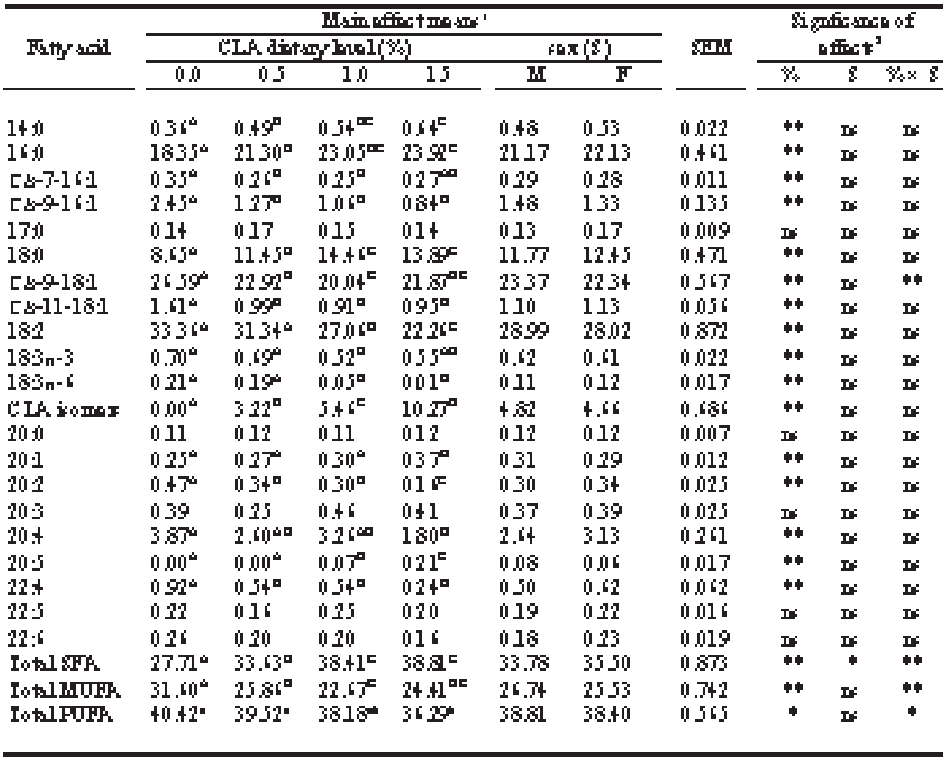
Fatty acid	Main effect means[1]						SEM	Significance of effects[2]		
	CLA dietary level (%)				sex (S)					
	0.0	0.5	1.0	1.5	M	F		%	S	% × S
14:0	0.31^{A}	0.42^{AB}	0.51^{B}	0.55^{B}	0.43	0.47	0.022	**	ns	ns
16:0	19.47^{A}	22.21^{B}	24.56^{C}	24.59^{C}	22.21	23.21	0.436	**	ns	ns
cis-7-16:1	0.30	0.22	0.24	0.22	0.25	0.24	0.010	ns	ns	ns
cis-9-16:1	1.76^{A}	1.01^{B}	0.97^{B}	0.75^{B}	1.14	1.11	0.096	**	ns	ns
17:0	0.14	0.10	0.10	0.10	0.11	0.11	0.005	ns	ns	ns
18:0	8.87^{A}	11.77^{B}	13.12^{BC}	13.71^{C}	11.71	12.03	0.396	**	ns	ns
cis-9-18:1	25.00	22.09	20.05	21.10	21.92	22.20	0.521	ns	ns	ns
cis-11-18:1	1.95^{A}	1.12^{B}	1.00^{B}	0.95^{B}	1.26	1.25	0.077	**	ns	ns
18:2	30.70^{A}	30.11^{A}	26.79^{AB}	23.17^{B}	28.43	26.95	0.729	**	ns	ns
18:3n-3	0.52	0.46	0.40	0.46	0.46	0.47	0.026	ns	ns	ns
18:3n-6	0.19^{A}	0.14^{A}	0.04^{B}	0.01^{B}	0.09	0.09	0.015	**	ns	ns
CLA isomers	0.00^{A}	2.89^{B}	5.25^{C}	9.35^{D}	4.46	4.29	0.647	**	ns	ns
20:0	0.07^{A}	0.10^{AB}	0.11^{AB}	0.15^{B}	0.11	0.11	0.008	**	ns	ns
20:1	0.26^{A}	0.26^{A}	0.30^{AB}	0.39^{B}	0.31	0.29	0.014	**	ns	ns
20:2	0.89^{A}	0.47^{B}	0.40^{B}	0.25^{B}	0.51	0.50	0.058	**	ns	ns
20:3	0.75	0.56	0.76	0.59	0.69	0.64	0.052	ns	ns	ns
20:4	5.55^{A}	3.81^{AB}	3.25^{AB}	1.84^{B}	3.61	3.62	0.416	**	ns	ns
20:5	0.00^{A}	0.00^{A}	0.22^{B}	0.30^{B}	0.14	0.12	0.025	**	ns	ns
22:4	1.65^{A}	1.00^{AB}	0.66^{B}	0.27^{B}	0.86	0.93	0.128	**	ns	ns
22:5	0.35	0.27	0.34	0.20	0.31	0.27	0.028	ns	ns	ns
22:6	0.46	0.30	0.24	0.21	0.30	0.31	0.034	ns	ns	ns
Total SFA	28.97^{A}	34.71^{B}	38.51^{C}	39.20^{C}	34.67	36.02	0.814	**	ns	**
Total MUFA	29.34	34.72	22.56	23.41	29.92	25.10	2.555	ns	ns	*
Total PUFA	41.06^{a}	40.02^{ab}	38.35^{ab}	36.66b	39.84	38.20	0.645	*	ns	*

[1] Mean values for CLA dietary level effect with different superscripts are significantly different at P≤0.05 (^{a,b}) or at P≤0.01 (^{A,B,C}).

[2] *P≤0.05; **P≤0.01, ns – P>0.05.

SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids.

Table 2. Effect of dietary CLA (%) on relative (%) fatty acid (FA) composition of leg muscles in experimental chickens: cockerels (M) and pullets (F)



Fatty acid	Main effect means[1]						SEM	Significance of effect[2]		
	CLA dietary level (%)				sex (S)					
	0.0	0.5	1.0	1.5	M	F		%	S	%× S
14:0	0.36^{A}	0.49^{B}	0.54^{BC}	0.64^{C}	0.48	0.53	0.022	**	ns	ns
16:0	18.35^{A}	21.30^{B}	23.05^{BC}	23.92^{C}	21.17	22.13	0.461	**	ns	ns
cis-7-16:1	0.35^{A}	0.26^{B}	0.25^{B}	0.27^{AB}	0.29	0.28	0.011	**	ns	ns
cis-9-16:1	2.45^{A}	1.27^{B}	1.06^{B}	0.84^{B}	1.48	1.33	0.135	**	ns	ns
17:0	0.14	0.17	0.15	0.14	0.13	0.17	0.009	ns	ns	ns
18:0	8.65^{A}	11.45^{B}	14.46^{C}	13.89^{C}	11.77	12.45	0.471	**	ns	ns
cis-9-18:1	26.59^{A}	22.92^{B}	20.04^{C}	21.87^{BC}	23.37	22.34	0.567	**	ns	**
cis-11-18:1	1.61^{A}	0.99^{B}	0.91^{B}	0.95^{B}	1.10	1.13	0.056	**	ns	ns
18:2	33.36^{A}	31.34^{A}	27.06^{B}	22.26^{C}	28.99	28.02	0.872	**	ns	ns
18:3n-3	0.70^{A}	0.69^{A}	0.52^{B}	0.55^{AB}	0.62	0.61	0.022	**	ns	ns
18:3n-6	0.21^{A}	0.19^{A}	0.05^{B}	0.01^{B}	0.11	0.12	0.017	**	ns	ns
CLA isomers	0.00^{A}	3.22^{B}	5.46^{C}	10.27^{D}	4.82	4.66	0.686	**	ns	ns
20:0	0.11	0.12	0.11	0.12	0.12	0.12	0.007	ns	ns	ns
20:1	0.25^{A}	0.27^{A}	0.30^{A}	0.37^{B}	0.31	0.29	0.012	**	ns	ns
20:2	0.47^{A}	0.34^{B}	0.30^{B}	0.16^{C}	0.30	0.34	0.025	**	ns	ns
20:3	0.39	0.25	0.46	0.41	0.37	0.39	0.025	ns	ns	ns
20:4	3.87^{A}	2.60^{AB}	3.26^{AB}	1.80^{B}	2.64	3.13	0.261	**	ns	ns
20:5	0.00^{A}	0.00^{A}	0.07^{B}	0.21^{C}	0.08	0.06	0.017	**	ns	ns
22:4	0.92^{A}	0.54^{B}	0.54^{B}	0.24^{B}	0.50	0.62	0.062	**	ns	ns
22:5	0.22	0.16	0.25	0.20	0.19	0.22	0.016	ns	ns	ns
22:6	0.26	0.20	0.20	0.16	0.18	0.23	0.019	ns	ns	ns
Total SFA	27.71^{A}	33.63^{B}	38.41^{C}	38.81^{C}	33.78	35.50	0.873	**	*	**
Total MUFA	31.60^{A}	25.86^{B}	22.67^{C}	24.41^{BC}	26.74	25.53	0.742	**	ns	**
Total PUFA	40.42^{a}	39.52^{a}	38.18^{ab}	36.29^{b}	38.81	38.40	0.565	*	ns	*

[1] Mean values for CLA dietary level effect with different superscripts are significantly different at P≤0.05 ($^{a, b}$) or at P≤0.01 ($^{A, B, C}$).

[2] *P≤0.05; **P≤0.01, ns – P>0.05.

SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids.

ity and reduced production of volatile compounds in both irradiated and non-irradiated chicken meat, during refrigerated storage [Du *et al*. 2000].

Enrichment of poultry meat with antioxidants

As already indicated, feeding broilers with diets abundant in PUFAs, including *n*-3 acids, leads to their deposition in poultry carcasses. However, high content of these compounds in the modified meat (deposited mainly in cell membrane phospholipids), influences lipid oxidation and therefore affects colour, flavour, texture, nutritional value, and finally impairs oxidative stability of meat during refrigerated storage. Susceptibility of poultry meat lipids to oxidation can be controlled by the presence of antioxidants.

Table 3. Effect of dietary CLA level on growth performance and slaughter characteristics of chickens

Dietary level of CLA (%)	Body weight gain (g) in periods (days)			Feed conversion efficiency* for periods (days)			Feed intake (kg) for periods (days)			Dressing percentage	Abdominal fat deposition (%)	Proportion (%) in relation of eviscerated carcass	
	0-21	22-42	0-42	0-21	22-42	0-42	0-21	22-42	0-42			breast muscles	leg muscles
0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Mean values for CLA dietary level differ with different superscripts are significantly different at P≤0.05 (a, b) or P≤0.01 (A, B)
*Feed conversion efficiency = body weight gain/feed intake

As reviewed by Morrisay *et al*. [1994], Jensen *et al*. [1998] and Ruiz *et al*. [1999], antioxidants delay or prevent lipid oxidation during refrigerated storage and antioxidant supplementation of broiler feed is efficient for enhancing oxidative stability of broiler meat. Moreover, two categories of antioxidants can exert preventive effects during storage of meat: (a) antioxidant enzymes (*i.e.* glutathione peroxidase, superoxide dismutase, and catalase) and (b) low-molecular weight antioxidants *i.e.* α-tocopherol, ascorbic acid and β-carotene.

In this context, the majority of studies have focused on α-tocopherol as a free radical scavenger, localized in the highly unsaturated bilayer of phospholipids of cell membranes, thus providing means for controlling lipid oxidation. First, the vitamin is easily incorporated into carcass lipids, although its deposition may be strongly affected by the type of fat (oil) in the broiler diet and type of meat (white *vs*. dark). For instance, vitamin E deposition was more efficient in the thigh meat of broilers fed canola oil than fish oil. The opposite was true for the breast meat [Zanini *et al*. 2003]. Second, a protective, *i.e.* antioxidant, role of vitamin E was reported in studies with broilers. Dietary vitamin E, by increasing its content in tissues, improved oxidative stability of raw, cooked and stored thigh meat [Ruiz *et al*. 1999]. Also, it increased the deposition of PUFAs in the breast muscles of broilers fed dietary oils [Zanini *et al*. 2004]. Moreover, meat samples obtained from broilers fed fish oil (1.25 *vs*. 2.50%) and vitamin E (70 *vs*. 140 mg/kg) and stored for 5 months at -20°C, showed no adverse sensory effects [Bou *et al*. 2004].

Effects of dietary supplements of vitamin E, C, and β-carotene, were reviewed and compared by Wenk *et al.* [2000]. They concluded that incorporation of dietary vitamin E and selenium (Se) into the muscle and adipose tissue, depends directly on the intake of these nutrients (Se is a constituent of an endogenous antioxidant enzyme glutathione peroxidase). In contrast, dietary vitamin C and β-carotene, can be deposited only marginally in poultry meat. Moreover, β-carotene was reported to show antioxidant activity only if vitamin E in tissues reached a certain level [Ruiz *et al*. 1999]. There has also been a debate on the antioxidant effects of endogenous (*i.e.* nutritional) *vs*. exogenous (*i.e.* technological) enrichment of meat with vitamin E and C, reviewed by Mitsumoto [2000]. The main conclusion is, that for vitamin E to act as an antioxidant, it must be incorporated into the phoshpolipids of cellular membranes where it is particularly effective in scavenging free radicals produced by oxidation of fatty acids. On the other hand, exogenous addition of vitamin C, *i.e.* its application to meat cuts, is ineffective. Equally, it was also found that endogenous β-carotene is a much more effective antioxidant than exogenous β-carotene. With regard to dietary vitamin C, it is not as effective as dietary vitamin E.

More general aspects of natural antoxidants in poultry nutrition are described in the excellent monograph by Surai [2002].

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REFERENCES

1. ALETOR V.A., EDER K., BECKER K., PAUKLICKS 0 B.R., ROTH F.X., ROTH-MAIER D.A., 2003 – The effects of conjugated linoleic acid or an α-glucosidase inhibitor on tissue lipd concentrations and fatty acid composition of broiler chicks fed a low-protein-diet. ***Poultry Science*** 82, 796-804.
2. AZAIN M.J., 2003 – Conjugated linoleic acid and its effects on animal products and health in single stomached animals. ***Proceedings of the Nutrition Society*** 62, 319-328.
3. BADINGA L., SELBERG K.T., DINGES A.C., COMER C.W., MILES R.D., 2003 – Dietary conjugated linoleic acid alters hepatic lipid content and fatty acid composition in broiler chickens. ***Poultry Science*** 82, 111-116.
4. BELLISLE F., DIPLOCK A.T., HORNSTRA G., KOLEZKO B., ROBERFROID M.B., SALMINEN S., SARIS W.H.M., 1998 – Functional Food Science in Europe. ***British Journal of Nutrition*** 80 (Suppl. 1), 1-193.
5. BINGHAM S.A., 1999 – High-meat diets and cancer risk. ***Proceedings of the Nutrition Society*** 58, 243-248.
6. BINGHAM S.A., HUGHES R., CROSS A.J., 2002 – Effect of white versus red meat on endogenous N-nitrosation in the human colon and further evidence of a dose-response. ***Journal of Nutrition*** 132, 3522S-3525.
7. BOU R., GUARDIOLA F., TRES A., BARROETA A.C., CODONY R., 2004 – Effects of dietary fish oil, α-tocopherol acetate, and zinc supplementation on the composition and consumer acceptability of chicken meat. ***Poultry Science*** 83, 282-292.

8. BRETILLON L., CHARDIGNY J.M., GREGOIRE O., BERDEAUX O., SEBEDIO J.L., 1999 – Effects of conjugated linoleic acid isomers on the heatic microsomal desaturation activities in vitro. ***Lipids*** 34, 956-969.
9. BURDGE G.C., JONES A.E., WOOTTON S.A., 2002 – Eicosapentaenoic and docosapentaenoic asids are the principal products of a-linoleic acid metabolism in young men. ***British Journal of Nutrition*** 88, 355-363.
10. CONNOR W.E., 2002 – Importance of *n*-3 fatty acids in health and disease. ***American Journal of Clinical Nutrition*** 71 (Suppl.), 171S-175S.
11. DIPLOCK A.T., AGGETT P. J., ASHWELL M., BORNET F., FERN E.B., ROBERFROID M.B., 1999 – Scientific Concepts of Functional Foods in Europe: Consensus Document. ***British Journal of Nutrition*** 81, (Supl. 1), 1-27.
12. DU M., AHN D.U., NAM K.C., SELL J.L., 2000 – Influence of dietary conjugated linoleic acid on volatile profiles, color and lipid oxidation of irradiated and raw chicken meat. ***Meat Science*** 56, 387-395.
13. DU M., AHN D.U., 2002 – Effect of dietary conjugated linoleic acid on the growth rate of live birds an on the abdominalfat content ad quality in broiler meat. ***Poultry Science*** 81, 428-433.
14. DU M., AHN D.U., 2003 – Dietary CLA affects lipid metabolism in broiler chicks. ***Lipids*** 38, 505-511.
15. DYBKOWSKA E., WASZKIEWICZ-ROBAK B., ŚWIDERSKI F., 2004 – Assessment of *n*-3 and *n*-6 polyunsaturated fatty acid intake un the average Polish diet. ***Polish Journal of Food and Nutrition Science*** 13/54, 409-414.
16. FRITCHE J., STEINHART H., 1998 – Analysis, occurence, and physiological propereties of trans fatty acids (TFA) with particular emphasis on conjugated linoleic acid isomers (CLA) – a review. ***Fett/Lipid*** 100, 190-210.
17. GONZALES-ESQUERA R., LEESON S., 2001 – Alternatives for enrichment of eggs and chicken meat with omega-3 fatty acids. ***Canadian Journal of Animal Science*** 81, 295-305.
18. HASLER C.M., 2002 – Functional foods: benefits, concerns and challenges – a position paper from the American Council on Science and Health. ***Journal of Nutrition*** 132, 3772-3781.
19. HILL M.J., 1999 – Meat and colo-rectal cancer. ***Proceedings of the Nutrition Society*** 58, 261-264.
20. JENSEN C., LAURIDSEN C., BERTELSEN G., 1998 – Dietary vitamin E: quality and storage stability of pork and poultry. ***Trends in Food Science and Technology*** 9, 6-27.
21. KORELESKI J., ŚWIĄTKIEWICZ S., BYKOWSKI P., 1997 – Feeding broiler chickens with plant feeds supplemented with fish waste. In Polish, summary in English. ***Roczniki Nauk Rolniczych*** 24, 213-230.
22. KRAMER J.K.G., SEHAT N., DUGAN M.E.R., MOSSOBA M.M., YURAVETCH M., ROACH J.A.G., EULITZ K., AAALHUS J.L., SCHAEFER A.L., KU Y., 1998 – Distribution of conjugated linoleic acid (CLA) isomers in tissue lipid classes of pigs fed a commercial CLA mixture determined by gas chromatography and silver-ion-high-performance liquid chromatography. 33, 549-558.
23. KRIS-ETHERTON P.M., HECKER K.D., BINKOSKI A.E., 2004 – Polyunsaturated fatty acids and cardiovascular health. ***Nutrition Reviews*** 62, 414-426.
24. LAWSON R.E., MOSS A.R., GIVENS D.I., 2001 – The role of dairy products in supplying conjugated linoleic acid to man's diet: a review. ***Nutrition Research Reviews*** 14, 153-172.
25. LESKANICH C.O., NOBLE R.C., 1997 – Manipulation of the *n*-3 polyunsaturated fatty acid composition of avian eggs and meat. ***World's Poultry Science Journal*** 53, 155-183.
26. LOPEZ-GARCIA E., SCHULZE M.B., MANSON J.E., MEIGS J.B., ALBERT CH.M., RIFAI N., WILLETT W.C., HU F.B., 2004 – Consumption of (*n*-3) fatty acids is related to plasma biomarkers of inflammation and endothelial activation in women. ***Journal of Nutrition*** 134, 1806-1811.

27. LOOPEZ-FERRER S., BAUCELLS M.D., BARROETA A.C., GRASHORN M.A., 1999 – *n*-3 enrichment of chickem meat using fish oil: alternative substitution with rapeseed and linseed oils. ***Poultry Science*** 78, 356-365.
28. MILLWARD D.J., 1999 – The nutritional value of plant-based diets in relation to human amino acid requirements. ***Proceedings of the Nutrition Society*** 58, 249-260.
29. MANTZIORIS E., CLELAND L.G., GIBSON R.A., NEUMANN M.A., DEMASI M., JAMES M.J., 2000 – Biochemical effects of diet containing foods enriched with *n*-3 fatty acids. ***American Journal of Clinical Nutrition*** 72, 42-48.
30. MITSUMOTO M., 2000 – Dietary delivery versus endogenous addition of antioxidants. In: Antioxidants in Muscle Foods (E. Decker, C. Faustman, C.J., Lopez-Bote C.J., Eds.). John Wiley and Sons, Inc., New York, pp. 315-343.
31. MORRISAY P.A., BUCKLEY D.J., SHEEHY P.J.A., MONAHAN F.J., 1994 – Vitamin E and meat quality. ***Proceedings of the Nutrition Society*** 53, 289-295.
32. PISULEWSKI P.M., SZYMCZYK B., HANCZAKOWSKI P., SZCZUREK W., 1999 – Conjugated linoleic acid (CLA) as a functional component of foods of animal origin. In Polish, summary in English. ***Postępy Nauk Rolniczych*** 6/99, 3-16.
33. PISULEWSKI P.M., SZYMCZYK B., KOSTOGRYS R., 2002 – Health-promoting properties of conjugated linoleic acid isomers and perspectives of production of CLA-enriched foods of animal origin. In Polish, summary in English. ***Żywienie Człowieka*** XXIX (1/2), 87-103.
34. PISULEWSKI P.M., KOSTOGRYS R.B., 2003 – Functional properties of foods of animal origin and methods of their assessment. ***Polish Journal of Food and Nutrition Sciences*** 12/53 (S1), 65-73.
35. PISULEWSKI P.M., KOWALSKI Z.M., SZYMCZYK B., 2001 – Nutritional methods to modify the composition and functional properties of foods of animal origin (milk, meat and eggs). In Polish, summary in English. ***Postępy Nauk Rolniczych*** 2/200, 59-72.
36. RAES K., DE SMET S., DEMEYER D., 2004 - Effects of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat. ***Animal Feed Science Technology*** 113, 199-221.
37. ROBERFROID M., 2000 – Concepts and strategy of functional food science: the European perspective. ***American Journal of Clinical Nutrition*** 71, 1660-1664.
38. ROBERFROID M.B., 2002 – Global view on functional foods: European perspectives. ***British Journal of Nutrition*** 88, Suppl. 2, S133-S138.
39. ROCHE H.M., NOONE E., NUGENT A., GIBNEY M.J. 2001 – Conjugated linoleic acid: a novel therapeutic nutrient? ***Nutrition Research Review*** 14, 173-187.
40. RUIZ J.A., PEREZ-VENDRELL A.M., ESTEVE-GARCIA E., 1999 – Effect of β-carotene and Vitamin E on oxidative stability in leg meat of broilers fed different supplemental fats. ***Journal of Agricultural and Food Chemistry*** 47, 448-454.
41. SIMON O., MÄNNER K., SCHÄFER K., SAGREDOS A., EDER K., 2000 – Effects of conjugated linoleic acid on protein to fat proportions, fatty acids, and plasma lipids in broilers. ***European Journal of Lipid Science and Technology*** 102, 402-410.
42. SIRRRI F., TALLARICO N., MELUZZI A., FRANCHINI A., 2003 – Fatty acid composition and productive traits of broiler fed diets containing conjugated linoleic acid. ***Poultry Science*** 82, 1356-1361.
43. SMITH S.B., HIVELY T.S, CORTESE G.M., HAN J.J., CHUNG K.Y., CASTENADA P., GILBERT C.D., ADAMS V.L., MERSMANN H.J., 2002 – Conjugated linoleic acid depresses Δ^9-desaturase index and stearoyl coenzyme A desaturase activity in porcine subcutaneous adipose tissue. ***Journal of Animal Science*** 80, 2110-2115.

44. SMOLIŃSKA T., MALCZYK E., KRZOWSKI R., 2002 – Histochemical analysis of lipids of white and dark muscles of chickens fed with fodder enriched with plant oils and alpha-tocopherol. In Polish. ***Żywność.*** 1(30), 116-131.
45. SURAI P.F., 2002 – Natural Antioxidants in Avian Nutrition and Reproduction. Nottingham University Press. Nottingham.
46. SZYMCZYK B., PISULEWSKI P.M., SZCZUREK W., HANCZAKOWSKI P., 2001 – Effects of conjugated linoleic acid on growth performance, feed conversion efficiency and subsequent carcass quality in broiler chickens. ***British Journal of Nutrition*** 85, 465-473.
47. WENK C., LEONHARDT M., MARTIN R., SCHEEDER M.R.L., 2000 – Monogastric nutrition and potential for improving muscle quality. In: Antioxidants in Muscle Foods (E. Decker, C. Faustman, C.J. Lopez-Bote, Eds.]. John Wiley and Sons, Inc. New York, pp. 199-227.
48. WHO, 2004 – Food and Health in Europe; a New Basis for Action. WHO Regional Publications. European Series: no 96. Copenhagen.
49. WHO/FAO, 2003 – Diet, Nutrition and the Prevention of Chronic Diseases. WHO Technical Report Series: no 916. Geneva.
50. WOOD J.D., ENSER M., 1997 – Factors influencing fatty acids in meat and the role of antioxidants in improving meat quality. ***British Journal of Nutrition*** 78 (Suppl. 1), S49-S60.
51. ZANINI S.F., TORRES C.A.A., BRAGANOLO N., TURATTI J.M., SILVA M.G., ZANINI M.S., 2003 – Lipid composition and vitamin E concentration in cockerel meat. ***Lebensmittel-Wissenschaft uund Technologie*** 36, 697-702.
52. ZANINI S.F., TORRES C.A.A., BRAGANOLO N., TURATTI J.M., SILVA M.G., ZANINI M.S., 2004 – Effect of oil sources and vitamin E levels in the diet on the composition of fatty acids in rooster thigh and chest meat. ***Journal of the Science of Food and Agriculture*** 84, 672-682.