The effect of dietary linseed oils with different fatty acid pattern on the content of fatty acids in chicken meat

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ABSTRACT: Effects of 1, 3, 5 or 7% of linseed oil in the diet on the content of fatty acids in breast and thigh meat were studied in broiler chickens. Oils made either of seeds of the linseed cultivar Atalante (A) with a high content of α-linolenic acid or of the cultivar Lola (L) with a predominating content of linoleic acid were fed from 25 to 40 days of age. When feeding A, the contents of all n-3 polyunsaturated fatty acids (PUFA), including eicosatrienoic acid, were significantly higher, those of n-6 PUFA were lower, and the ratio of n-6/n-3 PUFA was narrower ($P < 0.001$) than when L was fed. The narrowest n-6 to n-3 PUFA ratio was observed at the content 36 g of α-linolenic acid (58 g A) per kg of the diet while the widest one at 2 g of α-linolenic acid (70 g L) per kg of the diet. When using L, the increasing level of linoleic acid in feed was associated with significantly increasing levels of all n-6 PUFA in meat. The content of all n-3 PUFA increased after the application of oil A, but the dependence for eicosapentaenoic acid in thigh meat was expressed significantly more precisely by the second degree parabola with the maximum at the level of 37 mg of α-linolenic acid and for clupanodonic and docosahexaenoic acids by parabolas with maxima at the level of α-linolenic acid in the diet 41 g and 30 g for breast meat and 35 g and 27 g for thigh meat, respectively. By means of the inclusion of linseed oil with a high content of α-linolenic acid in the feed mixture it would be possible to produce poultry meat with a high content of n-3 PUFA as a functional food.

Keywords: chicken meat; fatty acids; linseed oils; functional food

Among polyunsaturated fatty acids (PUFA), fatty acids (FA) essential for man are linoleic acid (C18:2n-6; LA) and α-linolenic acid (C18:3n-3; LNA), the precursors of PUFA n-6 and n-3 series, respectively. Lands et al. (1992) showed in experiments on rats that serum levels of the precursors of eicosanoids, i.e. arachidonic acid (C20:4n-6; AA) and dihomo-γ-linolenic acid (C20:3n-6), were directly related to the dietary intake of LA. At dietary intakes of LA higher than approximately 5% of total energy intake, serum levels of AA and C20:3n-6 approached their maxima, i.e. eicosanoid production was maximal. An excess of eicosanoid production is undesirable as illustrated, for example, by the extensive use of steroidal and non-steroidal anti-inflammatory agents to block eicosanoid production in many human disorders, including cardiovascular and inflammatory disorders and cancer (Sargent and Tacon, 1999). To depress substantially the production of eicosanoids from arachidonic acid requires a dietary intake of LA lower than 2% of total energy intake. Fortunately, the desired effect can be achieved by modest dietary intakes of LNA amounting to approximately 1% of total energy intake. It is so because LNA competes very effectively with LA for the common fatty acid desaturases and elongases that convert C18 PUFA to their C20 and C22 homologues (Sargent and Tacon, 1999). The current ratio of n-6/n-3 PUFA in European people diets is 10–20:1 instead of recommended 1–4:1 (Simopoulos, 1999). Okuyama et al. (1997) proposed the ratio 2:1 or below.

Flax seed contains approximately 40% of oil which can be used as a component of feed mixtures for poultry. Some flax varieties are rich in LNA while some others in LA. The feeding of linseed oil rich in n-3 PUFA can be an effective method of increasing the tissue levels of these FA in broiler chickens

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(Olomu and Baracos, 1991; Crespo and Esteve-Garcia, 2001; Lopez-Ferrer et al., 2001; Cortinas et al., 2004; Dublecz et al., 2004; Villaverde et al., 2006).

The aim of this study was to evaluate the effect of increasing doses of linseed oil manufactured from seeds of varieties with markedly different contents of n-6 and n-3 PUFA on the fatty acid pattern in poultry meat. This was the same experiment in which the effect of linseed oils on basic production parameters of broilers was studied (Zelenka et al., 2006).

MATERIAL AND METHODS

The experiment was performed with 192 cockerels of Ross 308 hybrid combination that were fattened from Day 25 of age to Day 40 on feed mixtures containing 1, 3, 5 and 7% of linseed oil made either of seeds of the cultivar Atalante (A) with a predominating content of LNA (A1, A3, A5, A7) or of seeds of the cultivar Lola (L) with a predominating content of LA (L1, L3, L5, L7). The content of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), LA, and LNA was 75, 104, 116, 612 g, and 77, 106, 728, 19 g in 1 kg of oil A and L, respectively. To maintain the required nutrient ratios the feed mixtures with a higher content of energy were fortified also with higher levels of crude protein. All mixtures were formulated in such a way that the energy/protein ratios remained practically unchanged, i.e. 69.3–69.7 kJ of AME_n per 1 g of crude protein (Table 1). The supplement of oils changed the contents of essential FA in individual diets.

The experimental scheme involved altogether 16 groups of chickens: four groups in two replications received increasing amounts of linseed oil produced from the cultivar A while the other groups were fed a mixture containing L. The feed mixture was supplied *ad libitum* and its consumption was recorded.

Eight chickens with the body weight that was close to the average body weight of their group were slaughtered at the end of experiment. Breast meat (BM) and thigh meat (TM) without skin were separated from carcasses after cooling. All visible external fat was removed from sample muscles while the intermuscular fat remained intact. Muscles were homogenized in a Moulinex blender (model D56, Moulinex, France), put into dark glass powder bottles, frozen and stored at –20°C until fatty acid analyses.

Total lipids were determined gravimetrically after extraction by the modified method published by Hara and Radin (1978) using a hexane:2-propanol mixture. The extract was used for FA determinations by gas chromatography. The method of extraction and FA determination was described in detail in the paper by Komprda et al. (2005).

Fatty acid content was expressed in g/kg of meat using the recovery of internal standard and the known total lipid content.

The data from all determinations were subjected to the analysis of variance by means of statistical package Statistica, version 6.1 (StatSoft, Inc.) applicable to multifactorial experiments, and the comparison of means was made using Duncan's Multiple Range Test. The regression analysis of determined values was performed according to Snedecor and Cochran (1989).

RESULTS AND DISCUSSION

The effect of increasing doses of linseed oil made from seeds of the varieties Atalante and Lola with markedly different proportions of n-6 and n-3 PUFA and constant energy/protein ratio in the diets on the basic production parameters of broilers and on the content of protein and fat in poultry meat in this experiment was already reported in Zelenka et al. (2006) and it can be shortly summarized as follows: compared to groups receiving 1% and 3%, body weight gains were higher in groups receiving 5% and 7% of dietary oils ($P < 0.01$). A lower feed consumption per unit of body gain was also recorded in groups with 7% and 5% of oils than in groups receiving 1% and 3% ($P < 0.01$). The content of protein in BM in the group with 7% was lower than in groups with 1% and 5% of oils ($P < 0.05$). There were no differences in the contents of protein in TM. Similarly, no differences were found out between the groups in the contents of fat in TM and BM. There were no significant differences in basic production parameters, BM and TM percentages in live body weight, and in dry matter, ether extract and crude protein contents in meat between the groups receiving linseed oil with different levels of n-6 and n-3 PUFA.

The evaluation of measured contents of lipids and FA by the three-way analysis of variance is presented in Table 2. With the exception of docosahexaenoic acid (C22:6n-3; DHA), the content of all FA under study and also of lipids was highly

Table 1. Composition of the diets (g/kg)

	Diets							
	A1	A3	A5	A7	L1	L3	L5	L7
Components								
Maize meal	400	400	400	400	400	400	400	400
Wheat meal	100	100	100	100	100	100	100	100
Soybean meal	276.4	296	315.7	335.3	276.4	296	315.7	335.3
Maize starch	173.2	133.3	93.2	53.3	173.2	133.3	93.2	53.3
Atalante linseed oil	10	30	50	70	0	0	0	0
Lola linseed oil	0	0	0	0	10	30	50	70
DL-methionine	3	2.9	2.9	2.8	3	2.9	2.9	2.8
L-lysine	1.4	1.1	0.8	0.5	1.4	1.1	0.8	0.5
Ground limestone	9	9.2	9.4	9.6	9	9.2	9.4	9.6
Mono- + dicalcium phosphate	15	15.5	16	16.5	15	15.5	16	16.5
Sodium chloride	2	2	2	2	2	2	2	2
Supplementary premix[1]	10	10	10	10	10	10	10	10
Nutrient composition								
AME_n (calculated), MJ	12.4	12.7	13.0	13.3	12.4	12.7	13.0	13.3
Crude protein	178.6	183.2	186.4	191.5	177.9	182.5	187.3	191.9
E/P ratio[2]	69.4	69.3	69.7	69.5	69.7	69.6	69.4	69.3
Linoleic acid	7.57	9.89	12.01	14.53	14.22	28.78	43.61	58.44
α-linolenic acid	6.48	18.72	30.97	43.21	0.44	0.83	1.23	1.65

A1–A7 = diets containing 1–7% of Atalante oil

L1–L7 = diets containing 1–7% of Lola oil

[1]The premix supplied the following (mg/kg diet): retinyl acetate 4.47; cholecalcipherol 0.125; DL-α-tocopherol acetate 50; menadione 3; thiamine 5; riboflavin 7; pyridoxine 6; hydroxycobalamine 0.02; niacin amide 75; pantothenic acid 14; biotin 0.2; folic acid 2; choline chloride 250; betaine 100; ethoxyquin 100; lasalocid sodium 125; copper 20; iron 50; zinc 80; manganese 100; iodine 1; cobalt 0.4; molybdenum 1; selenium 0.3

[2]AME_n (kJ/kg)/crude protein (g/kg)

significantly higher ($P < 0.001$) in TM than in BM. The n-6/n-3 PUFA ratio was significantly ($P < 0.001$) better in BM, in which the content of fat was low, than in TM, in which the level of reserve fat was higher. From this aspect the food quality of BM lipids is higher.

As far as the levels of SFA, MUFA and lipids were concerned, no significant differences ($P > 0.05$) between the groups fed A and L were found out. This fact corroborated the observation of Crespo and Esteve-Garcia (2001), who concluded that the supply of flax oil containing a high level of LNA did not influence the content of SFA in meat. Olomu and Baracos (1991) performed an experiment with feeding linseed oil with a high content of LNA. Their observation that the amounts of MUFA, especially oleic acid, were depressed, was not proved.

As no long-chain PUFA were found in the feed mixtures, they had to be formed from their maternal LA and LNA. If higher eukaryotes are not able to elongate LNA to eicosatrienoic acid (Leonard et al., 2004), this acid found in the meat had to be produced by the microbial population of the digestive tract.

When feeding A, contents of all n-3 PUFA were highly significantly higher, those of n-6 PUFA were lower, and the ratio of n-6/n-3 PUFA was narrower ($P < 0.001$) than when L was fed. The supply of flax oil containing high levels of LNA resulted in an increased accumulation of n-3 PUFA in both BM and TM in experiments conducted by Olomu and

Table 2. The effect of tissue, oil and level of oil on the fatty acids content in mg/100 g of the meat – ANOVA

Factor		*n*	**Lipids**[1]	**14:0**	**16:0**	**16:1**	**18:0**	**18:1n-9**	**18:2n-6**	**18:3n-6**	**18:3n-3**
Tissue	Breast meat	64	1 174	4.66	163.25	24.35	69.00	223.10	216.61	1.71	67.12
	Thigh meat	64	3 765	8.97	633.66	124.10	229.81	961.42	834.01	6.74	235.22
Oil	Atalante	64	2 396	6.74	387.24	74.75	145.52	599.65	382.91	2.98	265.01
	Lola	64	2 543	6.89	409.66	73.70	153.29	584.87	667.72	5.47	37.33
Oil level (g/kg)	10	32	2 112	7.61	375.89	81.95	130.67	581.19	344.67	3.52	52.42
	30	32	2 660	7.77	452.74	94.37	153.48	674.91	504.31	4.30	138.77
	50	32	2 442	6.27	376.23	61.78	150.35	544.19	561.68	4.14	177.08
	70	32	2 664	5.61	388.94	58.82	163.12	568.75	690.60	4.95	236.42
	PSEM		59.793	0.226	10.798	2.868	3.260	17.325	16.338	0.155	6.628
Effect	Tissue, *T*		***	***	***	***	***	***	***	***	***
	Oil, *O*		NS	NS	NS	NS	NS	NS	***	***	***
	Oil level , *L*		**	**	*	***	**	*	***	*	***
	TO		NS	NS	NS	NS	NS	NS	***	***	***
	TL		NS	NS	NS	*	NS	NS	**	NS	***
	OL		NS	NS	NS	NS	NS	NS	***	***	***
	TOL		NS	NS	NS	NS	NS	NS	*	NS	***
		n	**20:1**	**20:3n-3**	**20:4n-6**	**20:5n-3**	**22:4n-6**	**22:5n-3**	**22:6n-3**	**n-6/n-3**	
Tissue	Breast meat	64	2.10	1.93	33.04	7.10	8.22	13.75	11.78	5.70	
	Thigh meat	64	8.64	2.89	64.36	15.57	13.99	21.15	11.91	7.52	
Oil	Atalante	64	5.12	4.49	35.02	18.86	5.19	25.88	13.45	1.59	
	Lola	64	5.62	0.33	62.38	3.81	17.02	9.02	10.25	11.63	
Oil level (g/kg)	10	32	5.56	0.88	46.44	7.16	9.85	12.49	9.79	5.83	
	30	32	6.02	2.13	47.50	11.79	10.17	17.28	12.92	5.89	
	50	32	4.87	2.90	51.70	12.62	12.96	20.25	13.90	6.54	
	70	32	5.04	3.72	49.16	13.78	11.43	19.78	10.77	8.18	
	PSEM		0.179	0.087	1.002	0.317	0.275	0.311	0.466	0.132	
Effect	Tissue, *T*		***	***	***	***	***	***	NS	***	
	Oil, *O*		NS	***	***	***	***	***	***	***	
	Oil level, *L*		NS	***	NS	***	***	***	**	***	
	TO		NS	***	***	***	***	***	NS	***	
	TL		NS	NS	NS	NS	NS	NS	NS	NS	
	OL		NS	***	***	***	***	***	NS	***	
	TOL		NS	NS	*	NS	NS	NS	NS	NS	

PSEM = pooled standard error of the mean

[1]hexane/2-propanol extract

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS = not significant

Baracos (1991), Crespo and Esteve-Garcia (2001) and Dublecz et al. (2004).

Differences in average values found in the same tissue after feeding the same oil were tested by Duncan's test. Regarding the fact that all feed mixtures showed practically the same energy/protein ratios and that the content of oils in the feed mixtures did not influence the intake of energy and consumption of energy per unit of weight gain (Zelenka et al., 2006), the content of lipids in the meat of chickens receiving various dietary fat levels was not different. The only exception was their decreased content in TM of chickens receiving the dose of 10 g of L per kg of feed (Table 3).

In groups fed oil with a high content of LNA, the ratio of n-6 to n-3 PUFA ranged from 0.85:1 to 2.65:1 and from 1.01:1 to 3.26:1, and when the chickens were fed oil with a high level of LA, the ratio ranged from 7.31:1 to 13.63:1 and from 10.09:1 to 17.22:1 in BM and TM, respectively.

Dependences of the content of lipids, total SFA, MUFA, PUFA, n-3 and n-6 PUFA (Y) on the level of linseed oil in the diet (X) in the range from 1% to 7% as expressed by means of linear regression equations are presented in Table 4. Regarding the fact that their composition was rather different, calculations were carried out separately for each type of oil. Regression coefficients were significant only in the case of PUFA. The observation of Cortinas et al. (2004) and Villaverde et al. (2006) that an increase in PUFA content in the diet significantly decreased total content of FA in TM and total content of MUFA and SFA in BM and TM was not corroborated. However, similarly like in experiments performed by these authors, also in our experiment the amount of retained PUFA was significantly increased. Each percent of L in the diet increased the content of lipids in 100 g of BM by 55 mg ($P < 0.05$).

The mean contents of all PUFA in meat are presented in Table 5. Dependences of n-6 and n-3 FA content in meat on the level of LA and LNA in grams per kg of diet were expressed by means of linear regression equations and the 2nd degree parabola equations. The reduction in the sum of squares of deviations was tested against the mean square remaining after curvilinear regression by F-test (Snedecor and Cochran, 1989). In case that this reduction was significant, parameters a, b and c of the parabola equation are presented in Table 5. If the deviation from linearity was insignificant, parameters a and b of linear regression are presented.

When using L, the increasing level of LA in feed was associated with significantly increasing levels of all n-6 PUFA in meat. When using A, which is not so rich in LA, neither the increase in LA content in TM nor changes in the content of γ-linolenic acid in BM and TM and AA in BM were significant. The content of AA in TM and adrenic acid (C22:4n-6; ADA) significantly ($P < 0.01$) decreased in both tissues. The downtrend of ADA in TM was stopped at the level of 14 g of LA/kg of diet. This was a consequence of the high content of LNA in A. The same enzymatic system is functioning in the metabolism of n-6 and n-3 PUFA. As the production of n-3 metabolites is preferred to that of n-6 metabolites (Bezard et al., 1994), the observed decrease in ADA production could be explained on the basis of a rapid increase in the production of competitive clupanodonic acid. It is obvious that in enzymatic competition between n-6 and n-3 FA families there was a lack of the enzyme required for the elongation of AA (Holman and Mohrhauer, 1963; Crespo and Esteve-Garcia, 2001).

The content of LNA in meat increased significantly ($P < 0.01$) in dependence on its increasing content in the feed ration; the response to an increase in the LNA level in feed containing low levels of this acid (L; 0.4–1.7 g LNA/kg) by one gram was approximately twice higher than in chickens receiving the ration containing A (6.5–43.2 g LNA/kg). The influence of L on the long-chain n-3 PUFA was not significant ($P > 0.05$). The application of A increased the content of all n-3 PUFA; however, the dependence for eicosapentaenoic acid (C20:5n-3; EPA) in TM was more exactly described by the second degree parabola with the maximum at the level of 37 mg of LNA, and for clupanodonic and DHA by parabolas with maxima at the level of LNA in the diet 41 g and 30 g for BM, and 35 g and 27 g for TM, respectively. It is probable that the performance of this enzymatic system is not sufficient for higher levels. Lopez-Ferrer et al. (2001) found out that increasing dietary levels of LNA resulted in an increase in the contents of EPA and DHA in TM; in our experiment, however, this observation for DHA was not corroborated. Our results support the theory that broiler chickens show a limited capacity to desaturate and elongate the chain of LNA (Chanmugam et al., 1992; Lopez-Ferrer et al., 1999).

The application of linseed oil rich in LNA (i.e. A) resulted in a very narrow n-6/n-3 ratio in meat. The dependences on the level of LNA were not linear,

Table 3. Fatty acid contents in mg/100 g of the meat – Duncan's test

Oil	Tissue	Dietary oil level (g/kg)	*n*	**Lipids**[1]	**14:0**	**16:0**	**16:1**	**18:0**	**18:1n-9**	**18:2n-6**	**18:3n-6**	**18:3n-3**
Atalante	Breast meat	10	8	1 054.77^{a}	4.18^{a}	151.42^{a}	26.09^{a}	58.34^{a}	223.76^{a}	111.13^{a}	1.09^{a}	28.22^{a}
		30	8	1 319.77^{a}	5.61^{a}	183.87^{a}	34.26^{a}	68.35^{a}	271.01^{a}	164.99^{a}	1.25^{a}	104.93^{ab}
		50	8	1 025.59^{a}	4.77^{a}	140.93^{a}	19.70^{a}	63.31^{a}	195.31^{a}	142.63^{a}	0.96^{a}	129.29^{b}
		70	8	1 278.46^{a}	4.30^{a}	167.09^{a}	20.47^{a}	81.05^{a}	234.47^{a}	200.90^{a}	1.22^{a}	215.27^{c}
	Thigh meat	10	8	3 217.03^{a}	10.76^{b}	596.90^{ab}	135.14^{bc}	198.22^{a}	945.13^{ab}	513.08^{a}	5.23^{a}	130.07^{a}
		30	8	3 872.31^{a}	9.89^{b}	715.11^{b}	155.99^{b}	237.25^{a}	1 146.09^{b}	667.25^{a}	5.35^{a}	379.99^{b}
		50	8	3 638.26^{a}	8.05^{ab}	597.54^{ab}	117.11^{ca}	220.79^{a}	931.88^{ab}	601.45^{a}	4.43^{a}	496.37^{c}
		70	8	3 759.93^{a}	6.40^{a}	545.07^{a}	89.27^{a}	236.87^{a}	849.53^{a}	661.82^{a}	4.33^{a}	635.93^{d}
Lola	Breast meat	10	8	980.15^{a}	4.96^{a}	154.73^{a}	27.61^{a}	59.73^{a}	213.03^{a}	147.48^{a}	1.52^{a}	8.29^{a}
		30	8	1 231.55^{a}	5.35^{a}	169.02^{a}	29.57^{a}	66.38^{a}	216.65^{a}	222.78^{a}	2.15^{a}	11.44^{a}
		50	8	1 112.96^{a}	4.25^{a}	156.02^{a}	17.07^{a}	71.71^{a}	192.23^{a}	308.44^{ab}	2.26^{a}	17.91^{a}
		70	8	1 386.89^{a}	3.89^{a}	182.89^{a}	20.04^{a}	83.14^{a}	238.33^{a}	434.56^{b}	3.23^{a}	21.64^{a}
	Thigh meat	10	8	3 197.38^{a}	10.55^{a}	600.52^{a}	138.95^{bc}	206.39^{a}	942.81^{a}	606.98^{a}	6.22^{a}	43.09^{a}
		30	8	4 214.37^{b}	10.23^{a}	742.98^{b}	157.67^{c}	241.93^{ab}	1 065.91^{a}	962.21^{b}	8.43^{b}	58.70^{a}
		50	8	3 991.56^{b}	8.01^{a}	610.41^{a}	93.22^{a}	245.58^{ab}	857.35^{a}	1 194.20^{c}	8.91^{b}	64.75^{a}
		70	8	4 232.32^{b}	7.86^{a}	660.73^{ab}	105.49^{ab}	251.43^{b}	952.67^{a}	1 465.11^{d}	11.02^{c}	72.85^{a}
			n	**20:1**	**20:4n-6**	**20:3n-3**	**20:5n-3**	**22:4n-6**	**22:5n-3**	**22:6n-3**	**n-6/n-3**	
Atalante	Breast meat	10	8	2.28^{a}	23.90^{a}	1.01^{a}	5.70^{a}	4.77^{a}	11.18^{a}	8.61^{a}	2.65^{b}	
		30	8	2.43^{a}	21.84^{a}	3.01^{b}	10.68^{b}	4.04^{a}	18.85^{b}	16.85^{b}	1.27^{ab}	
		50	8	1.48^{a}	22.86^{a}	4.23^{c}	14.44^{c}	3.21^{a}	25.27^{c}	16.13^{b}	0.94^{a}	
		70	8	1.88^{a}	23.38^{a}	5.52^{d}	16.98^{c}	2.97^{a}	25.45^{c}	14.99^{b}	0.85^{a}	
	Thigh meat	10	8	8.92^{a}	55.72^{b}	2.07^{a}	15.13^{a}	9.84^{b}	21.26^{a}	10.86^{a}	3.26^{b}	
		30	8	9.14^{a}	49.58^{ab}	4.97^{b}	27.48^{b}	6.96^{ab}	32.46^{b}	13.08^{a}	1.61^{a}	
		50	8	7.29^{a}	41.03^{a}	6.37^{c}	29.12^{bc}	5.12^{a}	36.60^{c}	15.30^{a}	1.13^{a}	
		70	8	7.57^{a}	41.83^{a}	8.72^{d}	31.36^{c}	4.60^{a}	36.01^{c}	11.76^{a}	1.01^{a}	
Lola	Breast meat	10	8	2.20^{a}	37.06^{a}	0.31^{a}	2.58^{a}	8.87^{a}	7.37^{a}	8.98^{a}	7.31^{a}	
		30	8	2.31^{a}	42.18^{a}	0.41^{a}	1.98^{a}	11.31^{a}	7.33^{a}	10.78^{a}	8.99^{b}	
		50	8	1.95^{a}	47.53^{a}	0.54^{a}	2.66^{a}	16.12^{b}	7.40^{a}	10.49^{a}	9.94^{b}	
		70	8	2.30^{a}	45.61^{a}	0.39^{a}	1.77^{a}	14.45^{b}	7.15^{a}	7.44^{a}	13.63^{c}	
	Thigh meat	10	8	8.81^{a}	69.09^{a}	0.14^{a}	5.22^{a}	15.93^{a}	10.16^{a}	10.73^{a}	10.09^{a}	
		30	8	10.22^{a}	76.39^{ab}	0.12^{a}	7.01^{a}	18.35^{a}	10.47^{a}	10.98^{a}	11.70^{b}	
		50	8	8.76^{a}	95.36^{c}	0.47^{a}	4.25^{a}	27.39^{c}	11.72^{a}	13.68^{a}	14.14^{c}	
		70	8	8.41^{a}	85.84^{bc}	0.23^{a}	5.00^{a}	23.72^{b}	10.51^{a}	8.89^{a}	17.22^{d}	

[1]hexane/2-propanol extract

^{abcd}means with different superscripts differ significantly $P < 0.05$

Table 4. Dependence of fatty acid contents in the meat on the level of linseed oil in the diet

X – level of linseed oil in the diet (%)	*Y* – content in mg/100 g of meat[1]			*Y* = *a* + *bX*		
				a	*b*	*r*
A1–A7	Lipids[2]	BM	1 169.6 ± 51.58	1 094.3	18.845	0.147
		TM	3 621.9 ± 158.46	3 343.0	69.732	0.177
L1–L7		BM	1 177.9 ± 52.63	957.6	55.081*	0.420
		TM	3 908.9 ± 173.55	3 332.5	144.100	0.333
A1–A7	Σ SFA	BM	232.6 ± 12.78	219.8	3.195	0.100
		TM	845.7 ± 36.09	883.4	–9.423	0.105
L1–L7		BM	240.5 ± 10.41	212.0	7.137	0.275
		TM	878.6 ± 42.80	826.9	12.936	0.121
A1–A7	Σ MUFA	BM	257.4 ± 17.53	273.5	–4.042	0.093
		TM	1 100.8 ± 57.72	1 237.5	–34.171	0.238
L1–L7		BM	240.8 ± 12.81	237.6	0.809	0.025
		TM	1 065.8 ± 59.01	1 117.6	–12.964	0.088
A1–A7	Σ PUFA	BM	345.5 ± 26.34	161.7	45.959**	0.701
		TM	1 150.1 ± 68.95	740.8	102.330**	0.596
L1–L7		BM	366.7 ± 27.12	166.3	50.090**	0.742
		TM	1 234.1 ± 85.96	632.7	150.348**	0.702
A1–A7	Σ n-6 PUFA	BM	181.6 ± 10.51	134.5	11.769**	0.450
		TM	669.4 ± 32.63	607.6	15.451	0.190
L1–L7		BM	333.2 ± 25.99	139.9	48.331**	0.747
		TM	1 149.1 ± 82.21	563.8	146.333**	0.715
A1–A7	Σ n-3 PUFA	BM	164.0 ± 17.01	27.2	34.190**	0.807
		TM	480.7 ± 43.32	133.2	86.879**	0.805
L1–L7		BM	33.5 ± 1.69	26.4	1.759*	0.418
		TM	85.0 ± 4.42	69.0	4.015*	0.365

A1–A7 = diets containing 1–7% of Atalante oil; L1–L7 = diets containing 1–7% of Lola oil

BM = breast meat; TM = thigh meat

a, *b* = parameters of equation; *r* = correlation coefficients

[1]mean ± standard error of the mean; [2]hexane/2-propanol extract

Significance of the difference between A and L and of regression coefficient *b*: $^{*}P < 0.05$, $^{**}P < 0.01$

they were expressed more exactly ($P < 0.01$) by the 2nd degree parabola equations

$$Y_{BM} = 3.51 - 0.154\,X + 0.002158\,X^2;\ r = 0.942$$

$$Y_{TM} = 4.31 - 0.185\,X + 0.002529\,X^2;\ r = 0.970$$

with the minimum values of the n-6/n-3 ratio 0.77:1 and 0.93:1 at LNA content 36 g and 37 g per kg of the feed mixture for BM and TM, respectively. These amounts of LNA were assured by the inclusion of 5.8% and 5.9% of A into the diet. Regarding the limited capacity of the enzymatic system, the supply of higher levels of oil is already too high.

It can be concluded that by means of the inclusion of linseed oil with a high content of LNA in the feed mixture it would be possible to produce poultry meat with a high content of n-3 PUFA as a functional food. It was demonstrated that flax oil originating from classical cultivars can be a very attractive component of feed mixtures while that originating from cultivars that were intentionally developed for a low content of α-linolenic acid can be unsuitable.

Table 5. Dependence of fatty acid contents in the meat on the level of linoleic acid and α-linolenic acid in the diet

X – content of fatty acid in g/kg of diet		*Y* – content in mg/100 g of meat[1]			$Y = a + bX (+ cX^2)$						
					a	*b*	*c*	*r*	*P*	$X_{extr.}$	$Y_{extr.}$
C18:2n-6	A1–A7	C18:2n-6	BM	155 ± 10.3**	34.8	10.919**	–	0.490	> 0.05	–	–
	7.6–14.5		TM	611 ± 32.0**	426.7	16.749	–	0.242	> 0.05	–	–
	L1–L7		BM	278 ± 25.2	45.2	6.451**	–	0.755	> 0.05	–	–
	14.2–58.4		TM	1 057 ± 76.3	367.5	19.081**	–	0.738	> 0.05	–	–
	A1–A7	C18:3n-6	BM	1.1 ± 0.07**	1.1	0.005	–	0.035	> 0.05	–	–
	7.6–14.5		TM	4.8 ± 0.25**	6.5	–0.155	–	0.289	> 0.05	–	–
	L1–L7		BM	2.3 ± 0.18	1.0	0.036**	–	0.594	> 0.05	–	–
	14.2–58.4		TM	8.6 ± 0.60	5.0	0.101**	–	0.497	> 0.05	–	–
	A1–A7	C20:4n-6	BM	23.0 ± 0.83**	23.2	–0.023	–	0.013	> 0.05	–	–
	7.6–14.5		TM	47.0 ± 1.76**	70.8	–2.157**	–	0.565	> 0.05	–	–
	L1–L7		BM	43.1 ± 1.69	35.5	0.209*	–	0.364	> 0.05	–	–
	14.2–58.4		TM	81.7 ± 3.56	64.8	0.466*	–	0.386	> 0.05	–	–
	A1–A7	C22:4n-6	BM	3.7 ± 0.19**	6.7	–0.270**	–	0.651	> 0.05	–	–
	7.6–14.5		TM	6.6 ± 0.46**	28.3	–3.309	0.115266	0.806	< 0.05	14.36	4.57
	L1–L7		BM	12.7 ± 0.74	7.4	0.145**	–	0.583	> 0.05	–	–
	14.2–58.4		TM	21.3 ± 1.17	13.5	0.218**	–	0.553	> 0.05	–	–
	A1–A7	Σ n-6 PUFA	BM	182 ± 10.5**	66.7	10.446**	–	0.459	> 0.05	–	–
	7.6–14.5		TM	669 ± 32.6**	518.9	13.678	–	0.194	> 0.05	–	–
	L1–L7		BM	333 ± 26.0	95.4	6.579**	–	0.747	> 0.05	–	–
	14.2–58.4		TM	1 149 ± 82.2	430.3	19.888**	–	0.714	> 0.05	–	–
C18:3n-3	A1–A7	C18:3n-3	BM	119 ± 15.0**	0.6	4.782**	–	0.782	> 0.05	–	–
	6.5–43.2		TM	411 ± 40.7**	79.0	13.346**	–	0.807	> 0.05	–	–
	L1–L7		BM	14.8 ± 1.41	2.8	11.533**	–	0.662	> 0.05	–	–
	0.4–1.7		TM	59.8 ± 3.48	35.3	23.577**	–	0.549	> 0.05	–	–
	A1–A7	C20:3n-3	BM	3.4 ± 0.33**	0.4	0.121**	–	0.888	> 0.05	–	–
	6.5–43.2		TM	5.5 ± 0.51**	1.2	0.174**	–	0.834	> 0.05	–	–
	L1–L7		BM	0.4 ± 0.04	0.3	0.091	–	0.196	> 0.05	–	–
	0.4–1.7		TM	0.2 ± 0.10	0.1	0.148	–	0.122	> 0.05	–	–
	A1–A7	C20:5n-3	BM	12.0 ± 0.92**	4.3	0.307**	–	0.822	> 0.05	–	–
	6.5–43.2		TM	25.8 ± 1.41**	8.3	1.250	–0.016874	0.786	< 0.01	37.03	31.44
	L1–L7		BM	2.2 ± 0.23	2.7	–0.433	–	0.152	> 0.05	–	–
	0.4–1.7		TM	5.4 ± 0.69	6.3	–0.850	–	0.100	> 0.05	–	–
	A1–A7	C22:5n-3	BM	20.2 ± 1.17**	4.8	1.024	–0.012509	0.895	< 0.01	40.92	25.76
	6.5–43.2		TM	31.6 ± 1.42**	13.3	1.372	–0.019652	0.777	< 0.01	34.90	37.25
	L1–L7		BM	7.3 ± 0.28	7.5	–0.149	–	0.043	> 0.05	–	–
	0.4–1.7		TM	10.7 ± 0.51	10.1	0.549	–	0.087	> 0.05	–	–
	A1–A7	C22:6n-3	BM	14.1± 1.20**	3.7	0.927	–0.015639	0.468	< 0.05	29.65	17.44
	6.5–43.2		TM	12.8 ± 0.54	7.6	0.518	–0.009604	0.515	< 0.01	26.94	14.59
	L1–L7		BM	9.4 ± 0.82	10.7	–1.258	–	0.124	> 0.05	–	–
	0.4–1.7		TM	11.1 ± 1.15	11.9	–0.753	–	0.053	> 0.05	–	–
	A1–A7	Σ n-3 PUFA	BM	164 ± 17.0**	25.2	5.585**	–	0.807	> 0.05	–	–
	6.5–43.2		TM	481 ± 43.3**	128.1	14.192**	–	0.805	> 0.05	–	–
	L1–L7		BM	33.5 ± 1.69	24.5	8.651*	–	0.415	> 0.05	–	–
	0.4–1.7		TM	85.0 ± 4.42	64.5	19.735*	–	0.362	> 0.05	–	–
	A1–A7	n-6/n-3	BM	1.43 ± 0.136**	3.51	–0.154	0.002158	0.942	< 0.01	35.64	0.77
	6.5–43.2		TM	1.75 ± 0.165**	4.31	–0.185	0.002529	0.970	< 0.01	36.51	0.93
	L1–L7		BM	9.97 ± 0.567	4.81	4.958**	–	0.708	> 0.05	–	–
	0.4–1.7		TM	13.29 ± 0.578	7.12	5.921**	–	0.830	> 0.05	–	–

Explanations to Table 5

A1–A7 = diets containing 1–7% of Atalante oil; L1–L7 = diets containing 1–7% of Lola oil

BM = breast meat; TM = thigh meat

a, *b c* = parameters of equation; *r* = correlation coefficients; *P* = significance of the deviation from linearity

[1]mean ± standard error of the mean

Significance of the difference between A and L and of linear regression coefficient *b*: $^{*}P < 0.05$, $^{**}P < 0.01$

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