Poultry meat production as a functional food with a voluntary n-6 and n-3 polyunsaturated fatty acids ratio

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ABSTRACT: We studied the effect of different levels of linseed oils made either of the flax cultivar Atalante with a high content of α-linolenic acid (612 g/kg) or of the cultivar Lola with a predominating content of linoleic acid (708 g/kg) in a chicken diet upon the fatty acid pattern in meat. Cockerels Ross 308 were fed the diets containing 1, 3, 5 or 7 per cent of oil in the last 15 days of fattening. Breast meat (BM) and thigh meat (TM) without skin of 8 chickens from each dietary group were used for analyses. The relative proportions of fatty acids were expressed as percentages of total determined fatty acids. When feeding Atalante oil, the proportions of n-6 fatty acids were highly significantly lower while those of n-3 fatty acids were higher; the ratio of n-6/n-3 polyunsaturated fatty acids in meat was narrower ($P < 0.001$) than in chickens fed oil with a low content of α-linolenic acid. In BM and TM, the relative proportions of α-linolenic and γ-linolenic acids were nearly the same, the proportion of linoleic acid in BM was lower, and the proportions of the other polyunsaturated fatty acids in BM were higher than in TM. In BM, the ratio of n-6/n-3 polyunsaturated fatty acids was significantly ($P < 0.001$) more favourable than that found in TM. The relative proportions of total saturated and monounsaturated fatty acids in meat decreased and those of polyunsaturated fatty acids increased significantly ($P < 0.01$) in dependence on the increasing level of dietary oils. When feeding Atalante oil, a significant increase in the proportion of linoleic acid in BM but not in TM was observed. The proportions of the other n-6 fatty acids decreased and those of all determined n-3 fatty acids, with the exception of docosahexaenoic acid, significantly increased with the increasing level of oil in the diet. When feeding Lola oil, its increasing content in the diet increased the relative proportion of linoleic acid as well as its elongation to γ-linolenic acid; however, the proportions of arachidonic and adrenic acid did not change significantly ($P > 0.05$). The proportion of α-linolenic acid increased in both BM and TM. The proportion of eicosapentaenoic and clupanodonic acids in BM significantly decreased. The ratio of n-6 to n-3 polyunsaturated fatty acids ranged from 0.9 to 13.6 and from 1.0 to 17.2 in BM and TM, respectively. An increase in the level of Lola oil in the diet by 1% caused that the n-6/n-3 polyunsaturated fatty acid ratio extended by 1.00 and 1.19 units in BM and TM, respectively. Dependences of n-6/n-3 ratio on the level of Atalante oil were expressed by equations of convex parabolas with minima at the level of oil 5.8 and 5.9% for BM and TM, 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 as a functional food with a very narrow ratio of n-6/n-3 polyunsaturated fatty acids.

Keywords: chicken meat; fatty acid pattern; linseed oils

From the aspect of human health, the fatty acid (FA) composition of meat products is an important parameter of meat quality. With the recognition that the groups of polyunsaturated fatty acids (PUFA) each play their own metabolic roles in health promotion, the role of the polyunsaturated/saturated FA ratio has decreased while the importance of the total n-6/n-3 ratio or even only linoleic acid/α-linolenic acid ratio has increased (Bruckner, ex Dublecz et al., 2004).

In human diets, there is a considerable lack of n-3 PUFA and also an imbalance in the ratio of

Supported by the Ministry of Education, Youth and Sports of the Czech Republic (Project No. MSM 6215648905).

n-6/n-3 PUFA. Current estimates in Western cultures suggest the ratio of n-6 to n-3 fatty acids of 10 to 20:1 instead of recommended 1–4:1 (Simopoulos, 1999). The intake of n-3 PUFA is low because of a low consumption of sea fish which represent the major source of n-3 PUFA, especially of eicosa-pentaenoic and docosahexaenoic acids. A partial solution of this situation could be reached on the basis of production of suitable functional foods with an adjusted content of PUFA which can provide beneficial physiological effects beyond the widely accepted nutritional effects. The enrichment of poultry products with n-3 PUFA may provide an excellent alternative source of these acids in the human diet due to their relative availability and affordability (Van Elswyk, 1997).

For most animal species only linoleic acid (LA; C18:2n-6) and α-linolenic acid (LNA; C18:3n-3) can be considered as essential. The majority of n-6 and n-3 series PUFA are synthesised from LA and LNA supplied in food (Youdim et al., 2000). By means of a series of desaturation and elongation reactions LA is transformed to γ-linolenic (C18:3n-6), dihomo-γ-linolenic (C20:3n-6), arachidonic (AA; C20:4n-6) and adrenic (ADA; C22:4n-6) acids while LNA is changed to stearidonic (C18:4n-3), eicosatrienoic (C20:3n-3), eicosatetraenoic (C20:4n-3), eicosapentaenoic (EPA; C20:5n-3), clupanodonic (C22:5n-3) and docosahexaenoic (DHA; C22:6n-3) acids.

All fatty acids compete with essential fatty acids at all steps of the above cascades for metabolism of the essential fatty acids. The n-6 and n-3 PUFA compete for identical enzyme sites involved in these reactions. As the intake of LNA increases, metabolic products of LA are suppressed, and LA itself is increased in liver lipids. Conversely, with a constant supply of dietary LNA and an increasing supply of dietary LA, n-3 products are suppressed while the level of LNA itself in liver lipids increases (Holman and Mohrhauer, 1963).

Vegetable oils are generally used as a source of PUFA. Linseed oil made of common flax varieties contains ca 14% of LA and 63% of LNA of all fatty acids (Zelenka et al., 2003). However, relatively recently, the plant breeders selected some flax cultivars, the oil of which contains more than 77% of LA and only 2% of LNA.

The feeding of linseed oil rich in n-3 PUFA can be an effective method how to increase the tissue levels of these FA in broiler chickens (Olomu and Baracos, 1991; Chanmugam et al., 1992; Crespo and Esteve-Garcia, 2001; Lopez-Ferrer et al., 2001; Romboli et al., 2002; Nguyen et al., 2003; Dublecz et al., 2004; Valavan et al., 2006).

The objective of this experiment was to evaluate the effect of increasing doses of linseed oil manufactured from seeds of varieties with markedly different proportions 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 cockerels of Ross 308 hybrid combination that were fattened

Table 1. Content of oils and the fatty acid pattern of oils and diets

Feed	A	A1	A3	A5	A7	L	L1	L3	L5	L7
Content of oil (g/kg)										
Atalante (A)	1 000	10	30	50	70					
Lola (L)						1 000	10	30	50	70
Fatty acid pattern										
Σ SFA	8.24	16.50	12.45	11.28	10.47	.46	16.49	13.27	11.22	10.52
Σ MUFA	11.51	20.66	16.47	14.85	13.96	11.68	20.04	15.28	14.45	13.86
Σ PUFA	80.25	62.84	71.08	73.87	75.57	79.86	63.46	71.45	74.32	75.62
C18:2n-6	12.78	33.86	24.57	20.64	19.02	77.74	61.56	69.45	72.29	73.55
C18:3n-3	67.47	28.98	46.51	53.23	56.55	2.13	1.90	2.00	2.04	2.08

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

from Day 25 of age to Day 40 on feed mixtures containing 1; 3; 5 or 7% of linseed oil made either of seeds of the cultivar Atalante (A) with a predominating content of α-linolenic acid (A1; A3; A5; A7) or of seeds of the cultivar Lola (L) with a predominating content of linoleic acid (L1; L3; L5; L7). Different supplements of oils changed the contents of essential fatty acids and n-6/n-3 PUFA ratio in the particular diets (Table 1). For a detailed description of the experimental design see Zelenka et al. (2006).

Eight chickens from each dietary group were sacrificed 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 ground in a Moulinex blender and frozen for further analyses.

Total lipids were determined gravimetrically after extraction by the modified method according to Hara and Radin (1978) using a hexane: 2-propanol mixture. The extract was used for fatty acid determinations by gas chromatography. The method of extraction and FA determination is described in detail in the paper by Fajmonová et al. (2003). The relative proportions of fatty acids were expressed as percentage of total determined fatty acids.

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

RESULTS AND DISCUSSION

The principal performance parameters of chickens are presented in our previous paper (Zelenka et al., 2006).

The evaluation of measured contents of lipids and proportions of individual FA by the three-way analysis of variance are presented in Table 2a,b. The content of lipids and proportions of monounsaturated fatty acids (MUFA) in TM were significantly higher than in BM. The relative proportion of LA was lower in BM and that of LNA and γ-linolenic acid was practically the same as in TM. The proportions of long-chain n-6 and n-3 PUFA were highly significantly higher ($P < 0.001$) in BM than in TM. The different distribution of FA in tissues can be connected with higher amount of FA deposited in cell membranes and lower content of depot fat in the lipids of BM.

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

As far as the levels of lipids and proportions of saturated fatty acids (SFA) were concerned, very small differences were found out between the groups fed oil A and oil L. This fact corroborated the observation of Crespo and Esteve-Garcia (2001), who concluded that the supply of a high level of LNA did not influence the relative proportions of SFA in meat. As far as MUFA were concerned, only the proportion of oleic acid (C18:1n-9) was changed; its level was significantly ($P < 0.001$) higher in chickens receiving rations containing oil A. Similar results were also published by Crespo and Esteve-Garcia (2001).

As the long-chain PUFA were not found in feed mixtures, they should be formed from their maternal LA and LNA.

In the meat of chickens receiving oil A, the relative proportions of all n-6 PUFA were highly significantly lower and those of n-3 PUFA were higher ($P < 0.001$) than in the group fed oil L (Table 2a,b). It is obvious that in the enzymatic competition between n-6 and n-3 FA families there was a lack of enzymes required for the elongation of n-6 FA family (Holman and Mohrhauer, 1963, Crespo and Esteve-Garcia, 2001). The supply of flax oil containing high levels of LNA resulted in an increased accumulation of n-3 PUFA in the fat of TM also in experiments performed by Chanmugam et al. (1992); their increased accumulation in BM was reported by Romboli et al. (2002) and in both BM and TM by Olomu and Baracos (1991), Crespo and Esteve-Garcia (2001), Nguyen et al. (2003), Dublecz et al. (2004) and Valavan et al. (2006).

Differences in average values found in the same tissue after feeding of the same oil were tested by Duncan's test. Significance of differences in the FA pattern between groups with different levels of dietary oil is presented in Table (3). Regarding the fact that all feed mixtures showed practically the same energy/protein ratios 69.3–69.7 kJ of AME_n per 1 gram of crude protein and that the content of oils in the feed mixture did not influence the intake of

Table 2a. The effect of tissue, oil and level of oil on the fatty acid pattern in meat – ANOVA

Factor		*n*	Lipids[1]	14:0	16:0	16:1	18:0	18:1n-9	18:2n-6	18:3n-6
Tissue	breast meat	64	1.17	0.59	19.52	2.92	8.29	26.50	24.80	0.20
	thigh meat	64	3.82	0.29	20.09	3.90	7.37	30.42	25.81	0.21
Oil	Atalante	64	2.44	0.45	19.57	3.48	7.77	29.34	18.95	0.15
	Lola	64	2.56	0.43	20.05	3.34	7.89	27.59	31.65	0.26
Level of oil	10 g/kg	32	2.11	0.56	22.54	4.53	8.21	33.65	20.18	0.20
	30 g/kg	32	2.70	0.47	20.93	4.05	7.58	30.14	23.38	0.20
	50 g/kg	32	2.49	0.41	18.58	2.73	7.88	25.69	27.43	0.20
	70 g/kg	32	2.69	0.32	17.19	2.34	7.64	24.37	30.22	0.21
PSEM			0.058	0.015	0.113	0.056	0.065	0.172	0.163	0.003
Effects	tissue (T)		***	***	*	***	***	***	**	NS
	oil (O)		NS	NS	*	NS	NS	***	***	***
	level of oil (LO)		**	***	***	***	**	***	***	NS
	T × O		NS	NS	NS	NS	NS	NS	NS	NS
	T × LO		NS	NS	NS	NS	NS	NS	NS	NS
	O × LO		NS	NS	NS	NS	*	NS	***	***
	T × O × LO		NS	NS	NS	NS	NS	NS	NS	NS

[1]hexane/2-propanol extract

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS = non significant

Table 2b. The effect of tissue, oil and level of oil on the fatty acid pattern in meat – ANOVA

Factor		*n*	18:3n-3	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	7.45	0.26	0.23	4.16	0.87	1.02	1.71	1.48	5.70
	thigh meat	64	7.38	0.27	0.09	2.11	0.52	0.45	0.69	0.39	7.52
Oil	Atalante	64	13.07	0.26	0.30	2.29	1.15	0.36	1.77	1.10	1.59
	Lola	64	1.77	0.27	0.03	3.98	0.23	1.11	0.63	0.77	11.63
Level of oil	10 g/kg	32	3.01	0.33	0.07	3.50	0.52	0.76	1.02	0.91	5.83
	30 g/kg	32	6.31	0.28	0.14	3.04	0.64	0.69	1.12	1.03	5.89
	50 g/kg	32	9.10	0.23	0.21	3.32	0.84	0.85	1.46	1.06	6.54
	70 g/kg	32	11.24	0.21	0.22	2.68	0.77	0.64	1.20	0.73	8.18
PSEM			0.123	0.004	0.007	0.082	0.022	0.021	0.031	0.048	0.058
Effects	tissue (T)		NS	*	***	***	***	***	***	***	***
	oil (O)		***	NS	***	***	***	***	***	***	***
	level of oil (LO)		***	***	***	**	***	**	***	NS	***
	T × O		NS	NS	***	***	***	***	***	**	***
	T × LO		NS	NS	**	NS	*	NS	*	NS	NS
	O × LO		***	NS	***	NS	***	***	***	NS	***
	T × O × LO		NS	NS	**	NS	*	NS	**	NS	NS

For specifications see Table 2a

Table 3. The fatty acid pattern in meat – Duncan's test

Oil	Tissue	Level of oil in the diet (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	1.05^{a}	0.70^{b}	22.56^{a}	3.92^{b}	8.81^{b}	33.21^{c}	17.16^{a}	0.16^{b}	4.32^{a}
		30	8	1.32^{a}	0.66^{b}	20.17^{a}	3.66^{b}	7.65^{a}	29.28^{b}	18.01^{ab}	0.13^{ab}	11.26^{b}
		50	8	1.03^{a}	0.64^{b}	17.94^{a}	2.46^{a}	8.15^{ab}	24.63^{a}	18.22^{ab}	0.12^{ab}	16.27^{c}
		70	8	1.28^{a}	0.45^{a}	16.32^{a}	1.89^{a}	8.19^{ab}	22.77^{a}	19.75^{b}	0.12^{ab}	20.99^{d}
	thigh meat	10	8	3.22^{a}	0.39^{b}	22.60^{d}	5.06^{c}	7.54^{a}	35.41^{d}	19.15^{a}	0.19^{b}	4.90^{a}
		30	8	4.05^{b}	0.29^{ab}	20.62^{c}	4.47^{c}	6.93^{a}	33.23^{c}	19.18^{a}	0.16^{a}	10.87^{b}
		50	8	3.83^{ab}	0.25^{ab}	19.12^{b}	3.62^{b}	7.24^{a}	29.46^{b}	19.48^{a}	0.14^{a}	15.93^{c}
		70	8	3.76^{ab}	0.20^{a}	17.21^{a}	2.76^{a}	7.65^{a}	26.73^{a}	20.67^{a}	0.14^{a}	19.98^{d}
Lola	breast meat	10	8	0.98^{a}	0.74^{ab}	22.52^{c}	3.97^{b}	8.78^{b}	30.87^{c}	21.63^{a}	0.22^{ab}	1.21^{a}
		30	8	1.23^{a}	0.64^{bc}	21.00^{b}	3.51^{b}	8.51^{ab}	26.69^{b}	27.80^{b}	0.26^{bc}	1.38^{a}
		50	8	1.11^{a}	0.51^{cd}	18.31^{a}	1.99^{a}	8.43^{ab}	22.20^{a}	35.61^{c}	0.27^{cd}	2.18^{a}
		70	8	1.39^{a}	0.42^{d}	17.36^{a}	1.93^{a}	7.82^{a}	22.38^{a}	40.22^{d}	0.30^{d}	1.98^{a}
	thigh meat	10	8	3.20^{a}	0.40^{a}	22.49^{b}	5.16^{b}	7.72^{a}	35.10^{c}	22.79^{a}	0.23^{ab}	1.62^{a}
		30	8	4.21^{b}	0.30^{a}	21.93^{b}	4.55^{b}	7.23^{a}	31.36^{b}	28.52^{b}	0.24^{bc}	1.74^{a}
		50	8	3.99^{b}	0.24^{a}	18.93^{a}	2.84^{a}	7.70^{a}	26.48^{a}	36.43^{c}	0.27^{cd}	2.04^{a}
		70	8	4.33^{b}	0.21^{a}	17.86^{a}	2.77^{a}	6.92^{a}	25.62^{a}	40.23^{d}	0.30^{d}	1.99^{a}
				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	0.34^{c}	3.75^{b}	0.17^{a}	0.89^{a}	0.75^{b}	1.78^{a}	1.48^{a}	2.65^{b}	
		30	8	0.28^{b}	2.58^{a}	0.35^{b}	1.26^{b}	0.47^{a}	2.21^{b}	2.03^{a}	1.27^{ab}	
		50	8	0.19^{a}	3.08^{ab}	0.57^{c}	1.91^{c}	0.43^{a}	3.35^{c}	2.05^{a}	0.94^{a}	
		70	8	0.18^{a}	2.50^{a}	0.57^{c}	1.75^{c}	0.31^{a}	2.65^{d}	1.55^{a}	0.85^{a}	
	thigh meat	10	8	0.34^{b}	2.12^{a}	0.08^{ab}	0.59^{a}	0.37^{a}	0.82^{a}	0.42^{a}	3.26^{b}	
		30	8	0.27^{a}	1.48^{a}	0.14^{bc}	0.81^{ab}	0.20^{a}	0.96^{ab}	0.39^{a}	1.61^{a}	
		50	8	0.24^{a}	1.41^{a}	0.21^{cd}	0.98^{b}	0.17^{a}	1.23^{b}	0.52^{a}	1.13^{a}	
		70	8	0.24^{a}	1.39^{a}	0.28^{d}	1.02^{b}	0.16^{a}	1.18^{ab}	0.39^{a}	1.01^{a}	
Lola	breast meat	10	8	0.32^{b}	5.52^{b}	0.05^{a}	0.38^{a}	1.33^{a}	1.11^{b}	1.35^{b}	7.31^{a}	
		30	8	0.29^{b}	5.73^{b}	0.05^{a}	0.26^{a}	1.53^{a}	0.99^{ab}	1.36^{b}	8.99^{b}	
		50	8	0.23^{a}	5.78^{b}	0.07^{a}	0.32^{a}	1.94^{b}	0.90^{ab}	1.27^{ab}	9.94^{b}	
		70	8	0.22^{a}	4.35^{a}	0.04^{a}	0.17^{a}	1.39^{a}	0.68^{a}	0.75^{a}	13.63^{c}	
	thigh meat	10	8	0.32^{b}	2.59^{a}	0.01^{a}	0.20^{a}	0.60^{a}	0.38^{a}	0.41^{a}	10.09^{a}	
		30	8	0.30^{b}	2.35^{a}	0.00^{a}	0.23^{a}	0.57^{a}	0.32^{a}	0.34^{a}	11.70^{b}	
		50	8	0.27^{ab}	3.03^{a}	0.01^{a}	0.14^{a}	0.87^{b}	0.36^{a}	0.40^{a}	14.14^{c}	
		70	8	0.22^{a}	2.50^{a}	0.00^{a}	0.15^{a}	0.68^{ab}	0.30^{a}	0.24^{a}	17.22^{d}	

[1]hexane/2-propanol extract; [a,b,c,d]means with different superscripts differ significantly $P < 0.05$

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

X – level of linseed oil in the diet (%)	Y – content (% of all FA) in meat[1]			$Y = a + bX + cX^2$						
				a	b	c	r	P	$X_{extr.}$	$Y_{extr.}$
A1–A7	C14:0	BM	0.61 ± 0.041	0.77	–0.0389*	–	0.382	> 0.05	–	–
		TM	0.29 ± 0.016	0.41	–0.0300**	–	0.736	> 0.05	–	–
L1–L7		BM	0.58 ± 0.044	0.80	–0.0550**	–	0.499	> 0.05	–	–
		TM	0.29 ± 0.017	0.41	–0.0309**	–	0.718	> 0.05	–	–
A1–A7	C16:0	BM	19.25 ± 0.465	23.44	–1.0476**	–	0.905	> 0.05	–	–
		TM	19.89 ± 0.431	23.42	–0.8839**	–	0.823	> 0.05	–	–
L1–L7		BM	19.80 ± 0.427	23.43	–0.9079**	–	0.854	> 0.05	–	–
		TM	20.30 ± 0.406	23.68	–0.8446**	–	0.836	> 0.05	–	–
A1–A7	C18:0	BM	8.20 ± 0.142	9.30	–0.667	0.074831	0.424	< 0.05	4.46	7.81
		TM	7.34 ± 0.149	7.22	0.0309	–	0.083	> 0.05	–	–
L1–L7		BM	8.39 ± 0.137	8.98	–0.1475*	–	0.433	> 0.05	–	–
		TM	7.39 ± 0.127	7.77	–0.0959	–	0.303	> 0.05	–	–
A1–A7	C16:1	BM	2.98 ± 0.178	4.43	–0.3634**	–	0.820	> 0.05	–	–
		TM	3.98 ± 0.181	5.53	–0.3886**	–	0.862	> 0.05	–	–
L1–L7		BM	2.85 ± 0.201	4.38	–0.3821**	–	0.764	> 0.05	–	–
		TM	3.83 ± 0.224	5.61	–0.4443**	–	0.798	> 0.05	–	–
A1–A7	C18:1n-9	BM	27.47 ± 0.822	34.67	–1.7986**	–	0.879	> 0.05	–	–
		TM	31.21 ± 0.685	37.17	–1.4905**	–	0.874	> 0.05	–	–
L1–L7		BM	25.53 ± 0.699	34.52	–3.678	0.272467	0.905	< 0.01	6.75	22.11
		TM	29.64 ± 0.758	38.28	–3.102	0.179595	0.899	< 0.05	8.64	24.88
A1–A7	C20:1	BM	0.25 ± 0.014	0.36	–0.0288**	–	0.812	> 0.05	–	–
		TM	0.27 ± 0.010	0.38	–0.053	0.004548	0.737	< 0.05	5.77	0.23
L1–L7		BM	0.27 ± 0.011	0.34	–0.0193**	–	0.690	> 0.05	–	–
		TM	0.28 ± 0.012	0.35	–0.0165**	–	0.539	> 0.05	–	–
A1–A7	C18:2n-6	BM	18.29 ± 0.271**	16.69	0.3987**	–	0.592	> 0.05	–	–
		TM	19.62 ± 0.354**	18.65	0.2424	–	0.275	> 0.05	–	–
L1–L7		BM	31.31 ± 1.325	18.60	3.1786**	–	0.963	> 0.05	–	–
		TM	31.99 ± 1.266	19.94	3.0119**	–	0.956	> 0.05	–	–
A1–A7	C18:3n-6	BM	0.14 ± 0.004**	0.18	–0.020	0.001640	0.763	< 0.05	6.19	0.12
		TM	0.16 ± 0.005**	0.22	–0.028	0.002339	0.760	< 0.05	5.95	0.14
L1–L7		BM	0.26 ± 0.009	0.21	0.0122**	–	0.530	> 0.05	–	–
		TM	0.26 ± 0.009	0.22	0.0111**	–	0.482	> 0.05	–	–

Table 4. to be continued

X – level of linseed oil in the diet (%)	Y – content (% of all FA) in meat[1]			$Y = a + bX + cX^2$						
				a	b	c	r	P	$X_{extr.}$	$Y_{extr.}$
A1–A7	C20:4n-6	BM	2.97 ± 0.175**	3.63	−0.1630*	–	0.374	> 0.05	–	–
		TM	1.60 ± 0.081**	2.48	−0.427	0.039305	0.654	< 0.05	5.43	1.32
L1–L7		BM	5.35 ± 0.264	6.04	−0.1741	–	0.265	> 0.05	–	–
		TM	2.62 ± 0.117	2.53	0.0204	–	0.070	> 0.05	–	–
A1–A7	C22:4n-6	BM	0.49 ± 0.037**	0.76	−0.0677**	–	0.741	> 0.05	–	–
		TM	0.23 ± 0.017**	0.47	−0.112	0.009703	0.890	< 0.01	5.78	0.15
L1–L7		BM	1.55 ± 0.084	0.91	0.404	−0.046714	0.425	< 0.05	4.32	1.79
		TM	0.68 ± 0.035	0.57	0.0270	–	0.308	> 0.05	–	–
A1–A7	C18:3n-3	BM	13.21 ± 1.166**	2.20	2.7518**	–	0.948	> 0.05	–	–
		TM	12.92 ± 1.053**	2.86	2.5157**	–	0.959	> 0.05	–	–
L1–L7		BM	1.69 ± 0.118	1.07	0.1552**	–	0.528	> 0.05	–	–
		TM	1.85 ± 0.055	1.56	0.0705**	–	0.511	> 0.05	–	–
A1–A7	C20:3n-3	BM	0.41 ± 0.038**	0.13	0.0718**	–	0.757	> 0.05	–	–
		TM	0.18 ± 0.015**	0.05	0.0339**	–	0.876	> 0.05	–	–
L1–L7		BM	0.05 ± 0.005	0.06	−0.0009	–	0.072	> 0.05	–	–
		TM	0.01 ± 0.002	0.01	0.0003	–	0.048	> 0.05	–	–
A1–A7	C20:5n-3	BM	1.45 ± 0.098**	0.81	0.1613**	–	0.662	> 0.05	–	–
		TM	0.85 ± 0.045**	0.56	0.0736**	–	0.662	> 0.05	–	–
L1–L7		BM	0.28 ± 0.029	0.40	−0.0286*	–	0.390	> 0.05	–	–
		TM	0.18 ± 0.028	0.23	−0.0115	–	0.166	> 0.05	–	–
A1–A7	C22:5n-3	BM	2.50 ± 0.146**	0.97	0.754	−0.070735	0.624	< 0.05	5.33	2.98
		TM	1.05 ± 0.046**	0.78	0.0671**	–	0.581	> 0.05	–	–
L1–L7		BM	0.92 ± 0.051	1.19	−0.0677**	–	0.538	> 0.05	–	–
		TM	0.34 ± 0.014	0.38	−0.0100	–	0.283	> 0.05	–	–
A1–A7	C22:6n-3	BM	1.78 ± 0.150**	1.73	0.0124	–	0.033	> 0.05	–	–
		TM	0.43 ± 0.023*	0.42	0.0022	–	0.038	> 0.05	–	–
L1–L7		BM	1.18 ± 0.116	1.56	−0.0948	–	0.327	> 0.05	–	–
		TM	0.35 ± 0.030	0.43	−0.0218	–	0.297	> 0.05	–	–

X – level of linseed oil in the diet (%)	*Y* – content (% of all FA) in meat[1]			$Y = a + bX + cX^2$						
				a	*b*	*c*	*r*	*P*	$X_{extr.}$	$Y_{extr.}$
A1–A7	Σ SFA	BM	28.13 ± 0.525	32.69	−1.1405**	–	0.872	> 0.05	–	–
		TM	27.48 ± 0.487	30.98	−0.8756**	–	0.722	> 0.05	–	–
L1–L7		BM	28.76 ± 0.509	33.20	−1.1104**	–	0.875	> 0.05	–	–
		TM	27.98 ± 0.459	31.86	−0.9715**	–	0.850	> 0.05	–	–
A1–A7	Σ MUFA	BM	30.74 ± 0.990	39.47	−2.1831**	–	0.886	> 0.05	–	–
		TM	35.39 ± 0.853	42.93	−1.8834**	–	0.887	> 0.05	–	–
L1–L7		BM	28.65 ± 0.880	39.53	−4.286	0.298280	0.901	< 0.01	7.18	24.13
		TM	33.75 ± 0.964	42.26	−2.1265**	–	0.886	> 0.05	–	–
A1–A7	Σ PUFA	BM	40.73 ± 1.403	27.71	3.2545**	–	0.932	> 0.05	–	–
		TM	36.95 ± 1.231	26.05	2.7259**	–	0.889	> 0.05	–	–
L1–L7		BM	42.20 ± 1.242	26.63	5.964	0.394506	0.936	< 0.01	7.56	49.17
		TM	38.10 ± 1.313	26.11	2.9959**	–	0.917	> 0.05	–	–
A1–A7	Σ n-6 PUFA	BM	21.86 ± 0.327**	21.24	0.1558	–	0.191	> 0.05	–	–
		TM	21.69 ± 0.369**	21.40	0.0702	–	0.076	> 0.05	–	–
L1–L7		BM	38.17 ± 1.234	23.16	5.446	−0.322842	0.951	< 0.01	8.43	46.13
		TM	35.42 ± 1.295	23.45	2.9907**	–	0.928	> 0.05	–	–
A1–A7	Σ n-3 PUFA	BM	18.86 ± 1.311**	3.28	5.420	0.290216	0.963	< 0.01	9.34	28.59
		TM	15.27 ± 1.118**	4.64	2.6557**	–	0.954	> 0.05	–	–
L1–L7		BM	4.04 ± 0.172	4.26	−0.0559	–	0.130	> 0.05	–	–
		TM	2.68 ± 0.073	2.66	0.0052	–	0.028	> 0.05	–	–
A1–A7	n-6/n-3 PUFA	BM	1.43 ± 0.136**	3.46	−0.932	0.080860	0.942	< 0.01	5.76	0.77
		TM	1.75 ± 0.165**	4.24	−1.119	0.094755	0.970	< 0.01	5.91	0.93
L1–L7		BM	9.97 ± 0.567	5.99	0.9952**	–	0.704	> 0.05	–	–
		TM	13.29 ± 0.578	8.52	1.1913**	–	0.828	> 0.05	–	–

[1]mean ± standard error of the mean; BM = breast meat; TM = thigh meat

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

[a b,c]parameters of equation; significance of the difference between A and L and of linear regression coefficient *b* *$P < 0.05$; **$P < 0.01$

r = correlation coefficients; *P* = significance of the deviation from linearity; X_{extr}, Y_{extr} = parameters of extreme values

SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids

energy and consumption of energy per unit weight gain (Zelenka et al., 2006), the content of lipids in the meat of chickens receiving various fat levels in the diet was not different. The only exception was their decreased content in TM of chickens receiving the dose of 10 g of oils per kg of feed mixture.

When Lopez-Ferrer et al. (1999) supplemented 8.2% of linseed oil into the diet, the proportions of long-chain (C20–22) n-3 PUFA of total FA in BM and TM were 4.32% and 1.91%, respectively. In our experiment, however, these proportions were exceeded already at 1.0% of oil A in the diet. The relative proportion of DHA was independent of the level of oil in the diet.

The ratio of n-6 to n-3 PUFA ranged from 0.9 to 13.6 and from 1.0 to 17.2 in BM and TM, respectively. In our experiment it was found out that at the dose of 30 g A/kg the ratio of n-6/n-3 in BM was 1.3 while Barteczko and Borowiec (2001) reported the ratio 3.1 in chicks fed 34 g of linseed oil containing high amounts of LNA; using the same doses of oil with the predominating content of LA we found the ratio 9.0 while the aforementioned authors reported about 24.3. The ratio found out in our experiment with 30 g of oil A in 1 kg of feed fits well with the ratio 1.35, which was published by Nguyen et al. (2003), who used the same amount of linseed oil.

The mean values of FA percentages of all FA in the meat are presented in Table 4. Dependences of the above values (Y) upon the level of linseed oil in the diet (X) in the range from 1 to 7% 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 the reduction was significant, parameters a, b and c of parabola equation were presented in Table 4. When the deviation from linearity was insignificant, parameters a and b of linear regression were presented in this table. Regarding the fact that the composition was rather different, calculations were carried out separately for each type of oil.

The relative proportions of total SFA and MUFA in meat decreased and those of total PUFA increased significantly ($P < 0.01$) in dependence on the increasing level of linseed oils in the diet (Table 4). Lopez-Ferrer et al. (2001) also found out that increasing dietary levels of LNA resulted in an increase in the contents of individual long-chain n-3 FA in the fat of TM; in our experiment, however, this observation for DHA was not corroborated. Our results reinforce the theory that broiler chickens show a limited capacity to desaturate and elongate LNA (Chanmugam et al., 1992).

When feeding oil A, a significant ($P < 0.01$) increase in the proportion of LA in BM was observed, but the increase in TM was not significant ($P > 0.05$). The proportion of the other n-6 fatty acids significantly decreased and that of all determined n-3 fatty acids with the exception of DHA increased with the increasing level of oil in the diet. Similarly, Valavan et al. (2006) reported that the proportion of DHA either in BM or in TM was not significantly different at levels of 1, 2 or 3% of dietary linseed oil.

When feeding oil L with a low content of LNA, its increasing content in the diet increased the relative proportion of LA as well as its elongation to γ-linolenic acid; however, the proportions of AA and ADA did not change significantly ($P > 0.05$). The proportion of LNA increased in both BM and TM. The proportion of its n-3 metabolites decreased but this downturn was significant only in the case of EPA and clupanodonic acid in BM.

An increase in the level of oil L in the diet by 1% caused that the n-6/n-3 ratio of PUFA extended by 1.00 and 1.19 units in BM and TM, respectively. The dependences of the n-6/n-3 ratio on the level of oil A were not linear, they were expressed more precisely ($P < 0.01$) by parabola equations

$$Y_{BM} = 3.46 - 0.932X + 0.080860X^2;\ r = 0.942$$

$$Y_{TM} = 4.24 - 1.119X + 0.094755X^2;\ r = 0.970$$

Convex parabolas achieved minima at 5.8 and 5.9% levels of oil in the feed mixture for BM and TM, respectively. The supply of 70 g oil per kg of the diet was too high for a further narrowing of the n-6/n-3 ratio.

It can be concluded that by means of the inclusion of linseed oil with a high content of LNA into the feed mixture it would be possible to produce poultry meat with an arbitrary n-6/n-3 PUFA ratio as a functional food.

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Received: 2007–02–22
Accepted after correction: 2007–04–17

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