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The influence of white lupin seeds in diets supplemented with fats of animal or plant origin on the fatty acid composition of broiler tissues*

A. Mieczkowska and S. Smulikowska[1]

The Kielanowski Institute of Animal Physiology and Nutrition,
Polish Academy of Sciences
05-110 Jabłonna, Poland

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ABSTRACT

Two experiments were conducted, each with 80 broiler chickens allocated to four groups of 20 birds. All diets were wheat-based and isoproteinous. In Experiment 1, the diets were prepared with or without 300 g of white lupin cv. Bardo per kg; either soya oil (diets S and SL) or tallow (diets T and TL) was added to equalize crude fat content. In Experiment 2, diets were prepared with or without 200 g lupin/kg and were supplemented either with lard (diets L and LL) or rapeseed oil (diets R and RL) to be isoenergetic. In Experiment 1, starter diets were fed between days 8 and 36, from 22 to 28 days a balance trial was performed on 8 birds from each group. In Experiment 2, starter, grower and finisher diets were fed from days 10 to 46 of life. At the end of the experiment, 12 birds from each group were slaughtered and the fatty acid composition of lipids in breast muscles, hearts and abdominal fat pads was analysed by gas chromatography.

In Experiment 1, the fat digestibility in diet T was 0.60, in diet TL 0.78 ($P<0.05$), however, performance was lower in the TL group ($P<0.05$). In Experiment 2 the performance of chickens did not differ among groups. In spite of the large differences in fatty acid composition of diets, oleic acid dominated in the lipids deposited in the body of all chickens, except those fed diet S. Inclusion of lupin into diets caused an increase in the concentration of oleic and α-linolenic acids, while, with the exception of group SL, it did not significantly affect the concentration of linoleic acid in broiler tissue lipids. Due to this, the *n-6/n-3* PUFA ratio in broilers fed diets with lupin was lower than in the respective controls. White lupin seeds may be used as a source of α-linolenic acid in balanced chicken diets and may favourably modify the fatty acid composition of carcass lipids and thus the health attributes of broiler meat.

KEY WORDS: white lupin, broiler chickens, n-3 PUFA, tallow, lard, soya oil, rapeseed oil

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[1] Corresponding author: e-mail: s.smulikowska@ifzz.pan.pl

INTRODUCTION

A high dietary ratio of *n-6/n-3* polyunsaturated fatty acids (PUFA) may negatively affect many physiological functions of animals and humans and hinder the elongation of α-linolenic acid into its long-chain derivatives, crucial for normal metabolism (Leskanich and Noble, 1997; Simopoulos, 2000). A balanced intake of both *n-6* and *n-3* fatty acids (FA) is essential for human health. It has been suggested that, in the human diet, it is beneficial to increase the level of *n-3* PUFA to an overall consumption of *n-6* to *n-3* FA at a ratio below 6:1 (BNF, 1992) or even 4:1 (Simopoulos, 2000). The FA composition of avian lipids may be modified easily to match human nutrition guidelines by appropriate manipulation of the FA composition of the diet (Leskanich and Noble, 1997; Blanch et al., 2000; Crespo and Esteve-Garcia, 2001; Nguyen et al., 2003). The lipids of cereals commonly used in poultry diets contain little α-linolenic acid and much more linoleic acid; the ratio of n-6/n-3 PUFA is 12 in barley, 15 in wheat, 36 in oats, 52 in maize (Kamińska et al., 2001). In animal fats used to enhance the energy concentration of poultry diets, the total amount of PUFA is relatively low and the *n-6/n-3* PUFA ratio varies from 10 to 13 (Crespo and Esteve-Garcia, 2001). In both soya and rapeseed oils, which are commonly used in poultry diets, α-linolenic acid constitutes proportionally about 0.07-0.08 FA, but the *n-6/n-3* PUFA ratio is about 8 in the former and about 2 in the latter. Nguyen et al. (2003) reported that in a broiler diet, substitution of 40 g lard/kg by double zero rapeseed oil resulted in increased deposition of n-3 FA and a respective two-fold decrease in the *n-6/n-3* PUFA ratio in the edible parts of broilers.

Polish varieties of sweet white lupin contain from 310 to 370 g crude protein/ kg, including 0.8 g methionine/16 g N and 4.9 g lysine/16 g N; on average 105 g crude fat/kg DM, from 0.7 to 0.9 g Mn/kg DM, from 450 to 800 mg total alkaloids/kg (Zduńczyk et al., 1996a; Wasilewko and Buraczewska, 1999) and from 350 to 420 non-starch polysaccharides (NSP)/ kg (Gdala and Buraczewska, 1996). While protein and fat from white lupin seeds are well digested (Alloui et al., 1994), its NSP, composed mainly from pectic polymers, are undigested by chickens (Carré et al., 1990).Until now, white lupins were neglected as a source of n-3 PUFA in poultry diets. The level and proportion of n-6/n-3 PUFA is similar, while the long-chain saturated (SFA) and monoenoic FA (MUFA), including erucic acid, may be higher in the crude fat of white lupin (Roth-Maier and Kirchgessner, 1993; Zduńczyk et al., l996b) than in rapeseed oil (Nguyen et al., 2003). It cannot be excluded, that the presence of lupin NSP in diet may affect digestibility of dietary fat. The composition of broiler lipids is a net effect of both dietary fatty acid profile and their digestibility. No information has been found in the literature on the effects of lupin seeds on FA composition of tissue lipids in broiler chickens.

The objective of the present study was to evaluate the influence of feeding diets containing white lupin seeds and different sources of supplementary fat on the FA profile of tissue lipids in broilers.

MATERIAL AND METHODS

Material and diets

Seeds of the white lupin (*Lupinus albus* L.) cultivar Bardo from the 1996 harvest, beef tallow, lard, commercial grade soya oil and rapeseed oil were used.

Two sets of diets based on wheat and soyabean meal, with a balanced level of protein and amino acids were prepared (Table 1). The diets differed in the level and source of added fat: in Experiment 1 either soya oil or tallow were used and the crude fat content of the diets was equalized; in Experiment 2, either double zero rapeseed oil or lard were used and the metabolizable energy content of diets was made similar. Diets were prepared with or without 300 g/kg (Experiment 1) or 200 g/kg (Experiment 2) of white lupin. In Experiment 1 only starter diets were used; in Experiment 2, starter, grower and finisher diets were prepared with the protein and amino acid contents adjusted to the requirements of chickens. Crude fat from lupin comprised 0.29 of total dietary fat in Experiment 1 and about 0.15 in the starter and finisher, and 0.165 in the grower diets in Experiment 2. All diets were cold pelleted on a CL-2 CPM Laboratory Pellet Mill.

Experimental procedure

In Experiment 1, 80 male ISA 215 broilers were used; in Experiment 2, 80 female Cobb 500 broilers were used. From the first day of life the birds were fed with a commercial starter diet without lupin. On day 8 (Experiment 1) or day 10 of age (Experiment 2) the birds were deprived of feed for 4 h, weighed and randomly allocated to four groups, 20 birds per group. The average initial body weight of chickens was 132 g in Experiment 1 and 212 g in Experiment 2. The birds were kept in individual cages, feed and water were supplied *ad libitum.* In Experiment 1 birds were fed experimental diets (Table 1) from days 8 to 36, in Experiment 2, they were fed starter diets from days 10 to 21, grower from days 22 to 35, and finisher diets (Table 1) from days 36 to 46. Feed intake and body weight of the chickens were recorded weekly. In Experiment 1 from 22 to 28 days, 8 birds from each group were fed the respective diets (Table 1) with 3 g Cr_2O_3/kg added on top prior to pelleting, and a balance trial was performed according to Bourdillon et al. (1990). On day 36 (Experiment 1)

TABLE 1

Composition and nutrient contents of experimental diets[a], g kg^{-1}

Ingredients	Experiment 1 Starter				Experiment 2											
					Starter				Grower				Finisher			
	S	SL	T	TL	L	LL	R	RL	L	LL	R	RL	L	LL	R	RL
Wheat	632.8	515.6	632.8	515.6	537.7	439.9	535.8	437.9	572.3	477.7	571.2	473.7	612.8	517.3	610.8	516.3
Soyabean meal	253	93	253	93	349	236	350	237	314	200	314	201	276	162	277	162
White lupin	-	300	-	300	-	200	-	200	-	200	-	200	-	200	-	200
Tallow	-	-	75	52	-	-	-	-	-	-	-	-	-	-	-	-
Soya oil	75	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lard	-	-	-	-	75	85	-	-	77	86	-	-	75	84	-	-
Rapeseed oil	-	-	-	-	-	-	76	86	-	-	78	88	-	-	76	85
L-Lys (78%)	1.8	2.0	1.8	2.0	1.4	1.7	1.3	1.7	-	0.1	-	0.1	-	-	-	-
DL-Met (98%)	1.4	1.4	1.4	1.4	0.9	1.4	0.9	1.4	0.7	1.2	0.8	1.2	0.2	0.7	0.2	0.7
Constants[b]	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
Analyzed																
CP (N × 6.25)	197	199	197	199	211	210	212	211	202	201	202	201	192	191	192	191
crude fat	89	87	89	87	91	114	92	115	93	101	82	103	91	113	92	114
ME, MJ/kg $^{-1}$ [c]	12.64	11.18	11.78	11.03	12.53	12.43	12.53	12.43	12.73	12.63	12.73	12.64	12.88	12.77	12.87	12.77

[a] major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin

[b] in it: limestone 14 , dicalcium phosphate 13 , NaCl 3, mineral-vitamin premix 5 (in starter and grower diets with antibiotic growth promoter and anticoccidial), Avizyme 1300 1

[c] Experiment 1 - determined, Experiment 2 - calculated

or 46 (Experiment 2), 12 birds of each group were slaughtered. The left breast muscle (*M. pectoralis major)* without intramuscular fat, heart with adjoining fat and both abdominal fat pads were immediately excised. Within each group 3 samples of each tissue, each pooled from 4 birds, were prepared and stored at -18°C for later analysis.

Chemical analysis

The chemical composition of lupin seeds and excreta was determined according to AOAC (1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) fractions in lupin seeds were assayed with Fibertec System M (Tecator) according to Van Soest and Wine (1967) and Van Soest (1973). NDF was assayed without sodium sulphite, both NDF and ADF were assayed with the use of α-amylase, the values were expressed without residual ash. In balance diets and excreta, crude fat was determined by diethyl ether extraction following acidification with 4 M HCl, gross energy content was determined with the use of a Parr adiabatic oxygen bomb calorimeter (KL-11), Cr_2O_3 was analysed spectrophotometrically following wet ashing according to Hinsberg et al. (1953). Faecal N in excreta was determined according to Ekman et al. (1949).

Oil from lupin seeds and diets was extracted by diethyl ether. Tissues were homogenized and one gram of sample was extracted with chloroform-methanol (2:1 v/v) according to Folch et al. (1957). The fatty acid composition in extracts was determined as described by Rotenberg and Andersen (1980) and Paterson and Amado (1997). The fatty acid methyl esters were separated and quantified using a gas chromatography apparatus (Hewlett-Packard, model 5890 series II), equipped with an on-column injector (HP 6890), a 30 m × 0.32 mm internal diameter, 0.25 μm film thickness capillary column (HP-225), and a flame ionization detector. Helium was used as the carrier gas. Temperature and other conditions were chosen to separate FA of 10-24 in chain length. The analyses were performed in triplicate. A HP ChemStation computer program was used for chromatogram integration and quantification of the fatty acids; all FA values were expressed as weight percentage of total fatty acids.

Calculations and statistical analysis

Performance was calculated for the period from 8 to 28 days of life in Experiment 1, and 10 to 44 days in Experiment 2. In Experiment 1 the coefficient of total tract apparent digestibility (CTTAD) of protein and fat and the metabolizable energy (AME_N) of diets were calculated relative to the content of Cr_2O_3 in diets and excreta. AME_N values were corrected to zero nitrogen

balance using 34.39 kJ/g N retained. Data within experiments were subjected to two-way analysis of variance (ANOVA) generated by Statgraphics® ver. 5.1. In each experiment two single degree of freedom contrasts between groups were estimated to test the hypothesis whether inclusion of lupin in the diets containing different supplementary fats had a significant effect on the fatty acid composition of the evaluated tissues.

RESULTS

The seeds of white lupin var. Bardo used in the experiments contained (in g/kg DM): crude protein, 324; crude fat, 96; crude fibre, 174; crude ash, 47; ADF, 269; NDF, 317. In lupin FA (Table 2) dominated MUFA (in it 1.88 g erucic acid per 100 g FA) followed by PUFA (the *n-6/n-3* PUFA ratio was 2) and SFA (in it: 3.33 g of C22:0 and 0.58 g of C24:0 per 100 g FA). The FA composition of supplementary fats differed greatly (data not shown), what strongly influenced the FA composition of the respective diets (Table 2). The diets based on tallow (T) and lard (L) contained more SFA and less PUFA than the diets with plant oils. The diet with soya oil (S) contained from 2 to 5 times more linoleic acid than other diets. The *n-6/n-3* PUFA ratio was highest in the diet L, followed by S, T, and lowest in the diet with rapeseed oil (R). The crude fat of lupin made up 0.29 of dietary lipids in Experiment 1 and about 0.15 in Experiment 2, however, it modified the relative FA concentration in diets. In the SL diet total MUFA increased and total PUFA decreased in comparison with the S diet; in the TL diet total SFA decreased and total MUFA and PUFA increased in comparison with the T diet. Due to lupin inclusion, in all diets the *n-6/n-3* PUFA ratio decreased in comparison with the respective control diets (Table 2).

The CTTAD of crude fat and CTTAD of crude protein in groups SL, S and TL were similar, while in group T it was significantly lower ($P<0.05$) than in remaining groups (Table 3). The CTTAD of crude fibre was from 2 to 1%. The metabolizable energy value of both diets with lupin (SL and TL) was significantly lower than the respective control diets (Table 3).

Chickens in the TL group had worse FCR and lower BWG ($P<0.05$) than in the remaining groups (Table 4). In Experiment 2, due to the higher level of added fat, the energy value of diets with lupin (LL and RL) was similar as in the respective control (L and R) diets (Table 1) and the performance of chickens in lupin-fed groups equaled that of the respective controls (Table 4).

TABLE 2

Major fatty acid composition of white lupin cv Bardo and of dietary lipids[a,b], in % wt wt $^{-1}$ of total fatty acids

Fatty acid	White lupin seeds	Dietary lipids - Experiment 1				Dietary lipids - Experiment 2			
		S	SL	T	TL	L	LL	R	RL
C14:0	0.12	-	0.08	1.86	1.26	1.08	0.94	0.06	0.07
C16:0	6.01	9.12	8.24	21.23	16.16	22.37	20.33	5.35	5.11
C16:1	0.22	0.09	0.16	0.98	0.79	1.92	1.72	0.19	0.20
C17:0	-	0.10	-	1.57	1.06	0.38	0.35	0.14	0.08
C18:0	1.62	4.38	3.69	28.49	19.42	15.38	14.30	2.02	2.01
C18:1	53.80	24.15	34.46	26.35	35.92	38.62	43.03	53.30	54.61
C18:2*n-6*	16.72	51.77	40.92	9.95	11.30	14.57	12.13	24.76	20.94
C18:3*n-3*	8.35	5.72	6.15	1.75	3.45	1.50	2.08	8.88	8.47
C20:0	1.06	0.47	0.74	0.53	0.74	0.29	0.44	0.68	0.76
C20:1	5.27	0.40	2.15	0.24	2.09	0.94	1.74	1.98	2.59
C22:0	3.33	0.56	1.61	0.23	1.38	-	0.73	0.44	0.99
C22:1	1.88	-	0.81	-	0.86	-	0.46	1.50	1.71
C24:0	0.58	-	0.42	-	0.41	-	0.35	-	0.40
Total SFA	12.71	14.63	14.78	54.50	40.85	39.50	37.44	8.69	9.42
Total MUFA	61.17	24.64	37.58	28.17	40.11	41.83	47.28	57.09	59.44
Total PUFA	23.35	57.70	47.37	11.92	15.11	16.70	14.86	33.79	29.58
n-6/n-3 PUFA	2.0	8.7	6.5	5.1	3.3	9.2	5.7	2.8	2.5

[a] major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin

[b] in Experiment 2 fat was extracted from starter, grower and finisher diets pooled in the ratio according to the average intake (2.8 : 4.7 : 2.5, respectively)

TABLE 3

Digestibility trial, Experiment 1

Group	Apparent digestibility, %			ME MJ/kg DM
	crude protein	crude fat	crude fibre	
S	91.1[b]	80.8[b]	2.7	14.36[c]
SL	90.5[ab]	80.6[b]	1.6	12.71[ab]
T	89.8[a]	60.4[a]	4.5	13.39[b]
TL	91.2[b]	78.5[b]	5.3	12.53[a]
Pooled SEM	0.4	1.8	1.8	0.21

major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin
[a,b] means within a column with no common superscripts are significantly different at P≤0.05

TABLE 4

Effect of lupin and dietary fat source on growth performance

Group	BWG g	Feed intake g	FCR, g feed/g BWG	Live BW at slaughter, g
Experiment 1	8-28 days of life (n = 12)			36 day
S	1062[ab]	1632	1.54[a]	1697
SL	1151[b]	1829	1.59[a]	1667
T	1076[ab]	1708	1.59[a]	1686
TL	959[a]	1660	1.79[b]	1563
Pooled SEM	52	74	0.05	55
Experiment 2	10-44 days of life (n = 20)			46 day
L	2011	3848	1.88	2429[ab]
LL	2097	3889	1.86	2457[b]
R	2087	3933	1.89	2428[ab]
RL	2004	3710	1.90	2341[a]
Pooled SEM	55	92	0.06	38

major sources of dietary fat: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin
[a,b] within experiment means within a column with no common superscripts are significantly different at P≤0.05

The FA composition of lipids in different broiler tissues was shown in Tables 5, 6 and 7. Oleic acid was the predominant fatty acid in all of the evaluated tissues in all groups, except the group fed S diet. Inclusion of lupin into the diet caused a significant increase of oleic acid and total MUFA concentration and decrease of total SFA in abdominal fat and heart lipids (P<0.01 or 0.001), while the effect was negligible in breast muscle. Linoleic acid dominated in the lipids of birds fed the S diet, inclusion of lupin into the SL diet caused a significant decrease in the concentration of this acid in abdominal fat and heart (P<0.001) and in breast (P<0.05) lipids. The concentration of long-chain *n-3* PUFA in breast muscle was slightly lower in groups fed diets based on animal fats than in groups fed diets

TABLE 5

Major fatty acid composition of broiler breast muscle (*M. pectoralis major*) lipids, (% wt wt $^{-1}$ of total fatty acids)

Treatments[a]	C16:0	C18:0	C18:1	C18:2*n-6*	C20:4*n-6*	C18:3*n-3*	C22:5*n-3*	C22:6*n-3*	Total SFA	Total MUFA	Total PUFA*n-6*	Total PUFA*n-3*	*n-6/n-3* PUFA
Experiment 1													
S	19.45	10.31	23.86	28.11	4.64	2.23	0.96	0.64	30.08	25.55	34.49	3.84	9.0
SL	17.22	8.99	30.75	26.14	3.66	2.89	0.73	0.63	26.52	32.94	30.40	4.36	7.0
T	20.33	10.39	38.08	11.85	2.80	0.49	0.51	0.52	32.08	42.43	15.47	1.51	10.2
TL	20.10	11.38	38.99	11.25	2.96	1.01	0.71	0.99	32.76	42.55	14.89	3.17	4.7
Pooled SEM	0.56	0.66	1.47	0.75	0.55	0.19	0.10	0.11	0.95	1.72	1.03	0.20	0.2
Main effects													
soya oil vs tallow	**	NS	***	***	NS	***	*	NS	**	***	***	***	*
control vs lupin	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	**	***
interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	***
S vs SL	*	NS	*	*	NS	NS	NS	NS	*	**	**	NS	*
T vs TL	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	***
Experiment 2													
L	16.89	8.59	41.02	12.62	2.92	2.12	0.55	0.66	26.65	44.87	16.54	3.20	6.2
LL	16.70	9.77	38.66	11.85	4.33	1.65	0.96	1.64	27.04	41.79	17.74	4.39	4.1
R	12.91	7.35	42.05	15.25	3.55	3.40	1.40	1.48	20.91	44.45	19.84	6.82	2.9
RL	10.46	6.65	45.87	15.46	3.06	4.26	1.32	1.63	17.99	48.40	19.47	7.61	2.6
Pooled SEM	0.87	0.57	0.79	0.32	0.46	0.29	0.19	0.31	1.27	0.91	0.73	0.54	0.8
Main effects													
lard vs rapeseed oil	**	**	**	***	NS	**	*	NS	**	**	**	**	*
control vs lupin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
interaction	NS	NS	**	NS	NS	*	NS	NS	NS	**	NS	NS	NS
L vs LL	NS	NS	NS	NS	NS	NS	NS	**	*	NS	NS	NS	*
R vs RL	*	NS	*	NS	NS	*	NS	NS	**	NS	NS	NS	NS

[a] major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin
NS - non significant, * P<0.05; ** P<0.01; *** P<0.001

TABLE 6

Major fatty acid composition of broiler heart lipids, in % wt wt $^{-1}$ of total fatty acids

Treatments[a]	C 16:0	C18:0	C 18:1	C 18:2*n-6*	C 20:4*n-6*	C 18:3*n-3*	C 22:1	C 22:5*n-3*	C 22:6*n-3*	Total SFA	Total MUFA	Total PUFA *n-6*	Total PUFA *n-3*	*n-6/n-3* PUFA
Experiment 1														
S	16.20	7.34	29.93	33.66	1.95	3.73	nd	0.16	0.10	24.08	32.88	35.61	4.05	8.8
SL	14.46	6.81	36.17	29.94	1.38	4.15	0.14	0.13	0.09	21.87	39.38	30.93	4.38	7.5
T	20.30	9.33	46.47	9.89	1.31	0.71	nd	nd	nd	31.35	52.11	11.19	0.71	15.9
TL	17.65	9.35	47.74	10.59	1.37	1.67	0.15	0.11	0.06	28.47	52.90	11.96	1.94	6.1
Pooled SEM	0.41	0.38	0.77	0.4	0.43	0.06	-	0.04	0.03	0.35	0.89	0.69	0.06	0.3
Main effects														
soya oil vs tallow	***	**	***	***	NS	***	-	-	-	***	***	***	***	*
control vs lupin	**	*	**	**	NS	***	-	-	-	***	**	*	***	***
interaction	NS	NS	*	***	NS	**	-	-	-	NS	*	**	***	***
S vs SL	**	NS	***	***	NS	**	-	NS	NS	**	**	**	**	*
T vs TL	**	NS	NS	NS	NS	***	-	-	-	**	NS	NS	***	***
Experiment 2														
L	21.11	7.84	45.48	12.32	1.87	0.95	nd	0.11	nd	29.99	50.34	14.19	1.11	12.9
LL	19.30	7.90	46.60	12.10	1.87	1.36	0.18	0.11	0.06	28.40	51.40	14.30	1.63	8.8
R	12.98	6.25	47.68	17.43	2.55	3.73	0.14	0.26	0.17	19.90	51.02	20.03	4.31	4.7
RL	10.16	5.22	51.13	17.82	2.11	4.64	0.21	0.21	0.20	16.15	54.40	20.24	5.16	3.9
Pooled SEM	0.21	0.24	0.50	0.29	0.33	0.09	-	0.02	0.04	0.25	0.52	0.56	0.07	0.5
Main effects														
lard vs rapeseed oil	***	***	**	**	NS	***	-	**	-	***	*	***	***	***
control vs lupin	***	NS	**	NS	NS	***	-	NS	-	***	**	NS	***	**
interaction	*	NS	NS	NS	NS	*	-	NS	-	**	NS	NS	*	*
L vs LL	**	NS	NS	NS	NS	**	-	NS	-	NS	NS	NS	**	***
R vs RL	**	*	**	NS	NS	***	-	NS	NS	**	NS	NS	***	NS

[a] major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin
nd - not detected; NS - non significant, * P<0.05; ** P<0.01; *** P<0.001

TABLE 7

Major fatty acid composition of broiler abdominal fat lipids, in % wt wt^{-1} of total fatty acids

Treatments[1]	C 16:0	C 18:0	C 18:1	C 18:2*n-6*	C 20:4*n-6*	C 18:3*n-3*	Total SFA	Total MUFA	Total PUFA*n-6*	Total PUFA*n-3*	*n-6 / n-3* PUFA
Experiment 1											
S	17.74	5.39	30.94	35.22	0.19	4.47	23.66	34.28	35.41	4.47	7.9
SL	15.30	5.12	36.66	30.35	0.19	4.60	20.88	40.12	30.54	4.79	6.4
T	22.32	7.87	48.29	8.25	nd	0.70	32.19	54.78	8.25	0.70	11.8
TL	20.52	7.64	49.81	8.71	nd	1.67	29.88	55.84	8.71	1.69	5.2
Pooled SEM	0.31	0.12	0.28	0.51	0.02	0.07	0.37	0.33	0.52	0.07	0.1
Main effects											
soya oil vs tallow	***	***	***	***	-	***	***	***	***	***	***
control vs lupin	**	NS	***	**	-	***	**	***	**	***	***
interaction	NS	NS	***	***	-	***	NS	***	***	***	***
S vs SL	***	NS	***	***	NS	NS	**	***	***	**	***
T vs TL	**	NS	**	NS	NS	***	**	*	NS	***	***
Experiment 2											
L	21.02	7.14	49.51	12.11	0.20	1.38	29.21	54.25	12.50	1.38	9.1
LL	20.15	7.53	50.55	11.52	0.20	1.56	28.81	55.27	11.94	1.56	7.7
R	12.66	4.44	53.52	17.40	0.18	5.00	17.68	56.79	17.70	5.07	3.5
RL	10.32	3.97	55.35	17.59	0.20	5.65	14.99	58.73	17.93	5.73	3.1
Pooled SEM	0.23	0.12	0.15	0.16	0.01	0.07	0.28	0.19	0.16	0.07	0.8
Main effects											
lard vs rapeseed oil	***	***	***	***	NS	***	***	***	***	***	***
control vs lupin	***	NS	***	NS	NS	**	**	***	NS	**	***
interaction	*	**	*	*	NS	**	**	*	*	**	***
L vs LL	*	*	**	NS	NS	*	NS	*	NS	NS	***
R vs RL	**	*	**	NS	NS	***	**	**	NS	***	*

[1] major dietary fat sources: S - soya oil; SL - S and lupin; T - tallow; TL - T and lupin; L - lard; LL - L and lupin; R - rapeseed oil; RL - R and lupin
nd - not detected, NS - non significant, * P<0.05; ** P<0.01; *** P<0.001

based on plant oils, and increased slightly after inclusion of lupin, but only the difference in the content of C22:6*n-3* in L vs LL group was significant ($P<0.01$; Table 5). Inclusion of lupin into diets increased the concentration of α-linolenic acid (more in abdominal fat and heart than in breast lipids), while, with the exception of the SL group, did not significantly affect the concentration of linoleic acid. Due to this the *n-6/n-5* PUFA ratio in groups fed the SL, TL, and LL diets decreased ($P<0.05$-0.001) in comparison with respective controls (Tables 5, 6 and 7). Long-chain saturated FA of 22 and 24 carbon units were not detected in measurable amounts in any of the analysed tissues, probably due to the very low dietary content and poor digestibility of SFA in broiler chickens. Erucic acid was not detected in measurable amounts in breast muscle or in abdominal fat, however minute amounts (0.14-0.21 of FA) were detected in the heart lipids of broilers fed diets with both, lupin and rapeseed oil (Tables 5, 6 and 7).

DISCUSSION

The seeds of white lupin used in the study had less protein but more fat and fibre than the same cultivar from the 1992 harvest year analysed by Alloui et al. (1994). Its FA composition (Table 2) agrees well with the range reported in the literature for white lupins (Roth-Maier and Kirchgessner, 1993; Zduńczyk et al., 1996b) and was similar to the FA composition of double zero rapeseed oil (Nguyen et al., 2003). In both, the ratio of *n-6/n-3* PUFA was about 2, however, lupin fat had a higher content of SFA and MUFA with chains equal to or longer than 20 carbon units than the rapeseed oil.

The results of the balance study indicated, that the CTTAD of white lupin protein is not lower than soyabean meal protein, and CTTAD of white lupin fat is comparable to soya oil and higher than tallow. In our previous report it was shown, that white lupin NSP did not induce high viscosity of digesta in broilers (Mieczkowska et al., 2004). However, the lupin diets ought to be supplemented with more fat to compensate for its lower ME. The results of the Experiment 2 agree well with conclusions of Roth-Maier and Kirchgessner (1993) and Alloui et al. (1994), that moderate amounts of white lupin may be safely used in balanced broiler diets.

In spite of the large differences in FA composition of diets, MUFA, followed by SFA, dominated in the fat deposited in the body of all chickens with the exception of the group fed diet with soya oil. Data are in agreement with results of Ajuyah et al. (1991), Skrivan et al. (2000) and Crespo and Esteve-Garcia (2001) and indicate, that total SFA and MUFA contents in the lipids of broiler body depends more on *de novo* synthesis, than on dietary lipid intake. Inclusion

of lupin into the diet caused a significant increase of oleic acid and total MUFA concentration and decrease of total SFA in abdominal fat and heart lipids. High concentration of MUFA in poultry products may be beneficial to human health, as diets rich in MUFA increase the resistance of plasma LDL lipoproteins to oxidative modifications, which lowers their atherogenicity (Bonanome et al., 1992).

The PUFA concentration and the ratio of *n-6/n-3*PUFA in all tissues depends to a great extent on their dietary supply, as chickens cannot synthesize *de novo* FA of *n-6* and *n-3* families (Leskanich and Noble, 1997; Crespo and Esteve-Garcia, 2001). In the present study concentration of PUFA longer than 18 carbon units in lipids of abdominal fat and heart was negligible, in many cases below the threshold of detection. It confirms the findings of earlier research (Crespo and Esteve-Garcia, 2001) that long-chain PUFA are preferentially incorporated into phospholipids of muscle lipids.

In the present study sources of added fat as well as the presence of lupin in diets had a stronger effect on fatty acid composition of abdominal fat and heart than on breast lipids. Long-chain saturated FA of C22 and C24 as well as erucic acid were not detected in measurable amounts in analysed tissues, with exception of the last one in the heart of broilers fed diets with both, lupin and rapeseed oil. Due to inclusion of lupin into diet the *n-6/n-3* PUFA ratio in broiler tissues decreased in comparison with respective controls. A balanced intake of both *n-6* and *n-3* FA is essential for the health of humans. The use of white lupin seeds in poultry feeds may lead to improvement of the dietetic value of poultry meat.

CONCLUSIONS

Moderate levels of white lupin may be used as a source of α-linolenic acid in balanced broiler diets. Lupin-containing diets may positively modify the fatty acid composition of broiler chicken tissues and health attributes of broiler meat.

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STRESZCZENIE

Wpływ nasion łubinu białego w dietach uzupełnionych tłuszczami zwierzęcymi lub roślinnymi na skład kwasów tłuszczowych w tkankach brojlerów

Przeprowadzono dwa doświadczenia, każde na 80 kurczętach brojlerach podzielonych na 4 grupy po 20 ptaków, umieszczonych w indywidualnych klatkach. W obrębie doświadczeń przygotowano diety pszenne, izobiałkowe. W doświadczeniu 1 diety przygotowano bez lub z udziałem 300 g łubinu białego odmiany Bardo/kg, a olej sojowy (diety S i SL) lub łój wołowy (diety T i TL) były użyte dla wyrównania zawartości tłuszczu. W doświadczeniu 2 diety przygotowano bez lub z udziałem 200 g łubinu białego/kg, a olej rzepakowy (diety R i RL) lub smalec (diety L i LL) były użyte do wyrównania zawartości energii metabolicznej w dietach. W doświadczeniu 1 diety podawano od 8 do 36 dnia życia, między 22-28 dniem u 8 ptaków z grupy oznaczono strawność składników pokarmowych. W doświadczeniu 2 diety starter, grower i finiszer podawano od 10 do 46 dnia życia. Po zakończeniu doświadczeń ubito po 12 ptaków z grupy i oznaczono skład kwasów tłuszczowych w mięśniu piersiowym, sercu i tłuszczu brzusznym.

W doświadczeniu 1 strawność tłuszczu diety T wynosiła 60%, diety TL 78% ($P<0,05$), jednak wyniki odchowu były gorsze w grupie TL ($P<0,05$). W doświadczeniu 2 wyniki odchowu nie różniły się między grupami. Mimo dużego zróżnicowania składu kwasów tłuszczowych w dietach, w lipidach ciała wszystkich grup, z wyjątkiem grupy S, dominował kwas oleinowy. We wszystkich grupach włączenie łubinu do diet spowodowało zwiększenie udziału kwasów oleinowego i α-linolenowego, a w grupie SL jednoczesne zmniejszenie udziału kwasu linolowego, co powodowało obniżenie proporcji *n-6/n-3* PUFA w lipidach ciała w porównaniu z odpowiednimi grupami żywionymi dietami bez łubinu.

Nasiona łubinu białego mogą stanowić źródło kwasu α-linolenowego w zbilansowanych dietach dla kurcząt i w korzystny sposób modyfikować skład kwasów tłuszczowych tuszek, a tym samym właściwości funkcjonalne mięsa brojlerów.