Effect of dietary linseed supplementation on the performance, meat quality, and fatty acid profile of pigs

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ABSTRACT: The effect of a dietary linseed (*Linum usitatissimum* L.) supplement on the traits of fattening, carcass value, physical and chemical characteristics of meat quality, and the fatty acid composition of pig meat was evaluated. Seventy-two hybrids (Czech Large White $_{(paternal)}$ × (Czech Large White $_{(maternal)}$ × Czech Landrace)) were divided into four treatments according to diet (0 and 150 g/kg linseed) and sex (barrows and gilts). A significantly (P = 0.050) higher feed conversion value was ascertained in barrows fed with linseed compared with the other three groups. Most of the physical and chemical characteristics of the carcasses were not significantly influenced by dietary linseed addition or sex. The linseed supplement significantly (P < 0.001) increased the polyunsaturated fatty acid (PUFA) content and PUFA/SFA (saturated fatty acid) ratio, especially through increasing the n-3 PUFA content, and decreased the monounsaturated fatty acid (MUFA) content, the MUFA/PUFA, MUFA/SFA, and n-6/n-3 PUFA ratios and the thrombogenic index. Supplementation of the diet with linseed modified the fatty acid composition and improved fatty acid ratios in both sexes, without any negative effect on performance, carcass value or physical and chemical indicators of pig meat quality.

Keywords: pork meat; *Linum usitatissimum*; fattening; carcass value; physical and chemical characteristics; fatty acid composition

Pig meat is the most frequently consumed meat, but it is also a source of saturated fatty acids, which have negative effects on human health. SFAs are associated with cardiovascular diseases, especially in developed countries. Therefore, according to recommendations (Department of Health, 1994), the PUFA/SFA ratio should be higher than 0.4, and the n-6/n-3 PUFA ratio should be 4–5 or less. The fatty acid composition of animal products reflects both tissue fatty acid biosynthesis and the fatty acid composition of ingested lipids. This relationship is stronger in monogastrics than in ruminants, where dietary fatty acids are hydrogenated in the rumen (Kouba and Mourot, 2011). Linoleic (18:2, n-6) and α-linolenic (18:3, n-3) PUFAs cannot be synthesized by porcine organism, in contrast to SFA and MUFAs. Therefore, their content depends on the lipid composition of the diet. Flachowsky et al. (2008) showed strong correlations between the intake and concentration of polyunsaturated fatty acids in backfat (r = 0.85). In addition, linoleic and α-linolenic acids are dietary precursors of the longer chain (C20-22) fatty acids of the n-6 and n-3 series. The fatty acid profile of meat can be easily modified through feeding, thereby improving the quality of pork for the consumer and meeting nutritionists' recommendation (Mourot and Lebret, 2009).

Linseed is an effective feed for increasing the n-3 PUFA content of pig meat and can improve the n-6/n-3 PUFA ratio (Rentfrow et al., 2003). Inclusion of linseed in pig diets may improve the nutritional value of pork without deleteriously affecting organoleptic characteristics, oxidation

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or colour stability (Matthews et al., 2000; Riley et al., 2000; Kouba et al., 2003; Corino et al., 2008) and enhance the levels of n-3 fatty acids, which have a potentially positive health effect in humans. Additionally, Wood et al. (2004) showed that adverse effects on meat quality defined in terms of shelf life (lipid and myoglobin oxidation) and flavour only occur when the concentrations of α-linolenic acid approach 3% of neutral lipids or phospholipids.

Linseed is fed in various forms and doses. Lower doses of linseed were examined by Matthews et al. (2000) (50 g of whole linseed per kg), Riley et al. (2000) (10, 20, and 30 g of linseed per kg), Kouba et al. (2003) (60 g of whole crushed linseed per kg) or Corino et al. (2008) (50 g of extruded linseed per kg). Higher doses of linseed were mentioned in studies of Juárez et al. (2009) (150 g of co-extruded flaxseed per kg) or Bečková and Václavková (2010) (134 g of ground linseed per kg). Based on results of Juárez et al. (2009) and other studies revealing that pigs can be fed up to 15% linseed without affecting performance, there was examined a dose of 150 g of crushed linseed per kg in gilts and barrows.

It can be assumed that feeding linseed, which is rich in α-linolenic acid, causes increasing n-3 tissue PUFA level and decreasing the atherogenic and thrombogenic index of pig meat. Physical and chemical characteristics are supposedly influenced, too. Presumably, gilts and barrows will react differently on linseed addition due to different ability to store fat in the body on the basis of sex hormones. Barrows have a higher proportion of intramuscular fat compared to boars and gilts. The fatty acid composition of backfat and intramuscular fat showed much smaller differences between sexes than between fat supplements to the diets (Flachowsky et al., 2008). There are only a few studies dealing with the interaction of dietary linseed supplement and sex in pigs. Therefore, the objectives of this study were to determine the effect of the addition of linseed to the diet of pigs of different sexes (barrows and gilts) on the characteristics of quantitative and qualitative indicators of carcass value and the profile of fatty acids in the loin and to improve the nutritional value and fatty acid ratios of pig meat. Moreover, the effect of linseed addition with simultaneous increase of energy value of mixed feed and sex on fattening indicators was evaluated.

MATERIAL AND METHODS

Animals and diet

The experiment was performed at the pig breeding test station at Ploskov near Lány. A total of 72 (final crossbreeds of Czech Large White $_{(paternal)}$ × (Czech Large White $_{(maternal)}$ × Czech Landrace)) 69-day-old gilts and barrows with an average live weight of 28.7 kg were included in the experiment. The placing and housing of the pigs was carried out in pairs, but both genders were separated. The pigs were fed with a complete feed mixture (CFM) containing three components (wheat, barley, and soybean meal) and premix. The diet was mixed separately for each group. Both sexes were divided into two groups according to linseed addition (*Linum usitatissimum* L.). The control group did not receive the crushed linseed supplement, and pigs from the experimental group were fed a diet enriched with linseed (150 g/kg). The nutrient composition of the CFM is shown in Table 1. Transition of the CFM from A1 to A2 and CDP (A1, A2, CDP are types of mixed feeds fed to pigs with average live weights of 28–35 kg, 35.1–60 kg, and 60.1–110 kg, respectively) was realized continuously during the test. The pigs were fed *ad libitum*. Each pig was weighed monthly, and the feed intake per pen was measured daily. The average daily weight gain, feed intake, and feed conversion were calculated from the observed values. At the end of the experiment, the pigs were slaughtered in a commercial abattoir using electrical stunning at an average live weight of 110 kg. The transport lasted about 1 h.

Carcass value

To assess quantitative and qualitative carcass value traits, carcass measurements were carried out according to Scheper and Scholz (1985) 24 h post-mortem. Forty pigs were chosen on the basis of average live weight. The carcasses of 40 pigs (20 barrows and 20 gilts) were weighed, and the right half was measured. From the quantitative carcass value characteristics, the lean meat percentage and main meat parts percentage were evaluated. The loin, ham, neck, and shoulder were dissected from the carcass into meat with bone and fat cover with skin.

Qualitative carcass value characteristics were assessed at the cut between the 13th and 14th rib

Table 1. Ingredients and nutrient composition of the diets

Ingredient (g/kg)	Control group			Experimental group		
	A1	A2	CDP	A1	A2	CDP
Wheat	400.0	445.5	465.0	281.0	307.4	320.0
Barley	383.0	394.9	400.0	400.0	400.0	400.0
Soybean meal	182.0	124.6	100.0	137.0	111.1	100.0
Premix[1]	35.0	35.0	35.0	32.0	31.5	30.0
Crushed linseed[2]	–	–	–	150.0	150.0	150.0
Calculated nutrient composition						
Dry matter	881.50	880.10	879.60	885.40	884.70	884.30
Mep by calculation (MJ/kg)	12.71	12.67	12.64	13.40	13.40	13.41
Fat	1.91	1.94	1.95	5.81	5.82	5.83
Crude protein	182.74	162.10	153.20	181.30	172.10	168.10
Crude fibre	36.99	36.20	35.86	42.15	41.70	41.54
Lysine	11.32	9.78	9.12	10.59	9.85	9.42
Lysine/Mep	0.89	0.77	0.72	0.79	0.74	0.70
Threonine	6.87	6.00	5.62	6.83	6.43	6.24
Calcium	8.68	8.57	8.52	8.22	8.06	7.70
Available phosphorus	1.90	1.83	1.79	1.75	1.71	1.66
Sodium	2.02	2.01	2.01	1.89	1.87	1.80
Retinol (IU)	14.40	14.40	14.40	13.17	12.97	12.36
Calciferol (IU)	2.31	2.31	2.31	2.11	2.01	1.98
α-tocopherol (mg/kg)	145.52	144.30	144.61	132.23	130.63	125.34
Thiamine (mg/kg)	6.25	6.38	6.44	6.27	6.30	6.24
Riboflavin (mg/kg)	6.93	6.82	6.78	6.66	6.54	6.29
Pantothenic acid (mg/kg)	21.43	21.17	21.06	19.94	19.65	19.06
Choline (mg/kg)	1654.60	1555.50	1513.00	1695.40	1643.60	1605.70

A1 = mixed feed fed to pigs with average live weight of 28–35 kg, A2 = mixed feed fed to pigs with average live weight of 35.1–60 kg, CDP = mixed feed fed to pigs with average live weight of 60.1–110 kg

[1]1 kg of vitamin-mineral premix provided: retinol 400 000 IU, cholecalciferol 66 000 IU, α-tocopherol 3600 mg, menadione 100 mg, thiamine 60 mg, riboflavin 150 mg, niacin 800 mg, Ca pantothenate 375 mg, vitamin B_6 100 mg, vitamin B_{12} 1 mg, choline Cl 15 000 mg, folic acid 15 mg, Fe 3500 mg as $FeSO_4 \cdot H_2O$, Zn 3600 mg as ZnO, Mn 3100 mg as MnO, Cu 330 mg as $CuSO_4 \cdot 5H_2O$, I 75 mg as $Ca(IO_3)_2$, Co 15 mg as $2CoCO_3 \cdot 3Co(OH)_2 \cdot H_2O$, Se 13 mg as Na_2SeO_3, 6-phytase (EC 3.1.3.26) 25 000 FTU, Ca 220 g, P 20 g, Na 50 g, Mg 10 g, lysine 85 g, methionine 15 g, threonine 15 g

[2]content of selected fatty acids (in % of total determined fatty acids): oleic acid 20.51, linoleic acid 15.34, α-linolenic acid 52.25, SFA 10.17, MUFA 21.78, n-6 PUFA 15.55, n-3 PUFA 52.50; fat content 27.53%

in the loin (*musculus longissimus lumborum et thoracis*; MLLT). The pH_{45} value was measured using a pH meter (pH 330i/set) equipped with pH-electrode (Sen Tix Sp) (both WTW GmbH, Weilheim, Germany) 45 min post-mortem, and electrical conductivity (conductometer/pigmeter, Czech Technical University in Prague, Czech Republic) was determined 50 min post-mortem (EC_{50}). Meat colour values (L^* = lightness, a^* = redness, b^* = yellowness) (CM-2500d spectrophotometer; Minolta, Osaka, Japan), the shear force value (Instron 3342; Instron, Norwood, USA), and drip loss were measured 24 h post-mortem according to method of Rasmussen and Andersson (1996). The samples were stored at 5°C for 24 h.

Representative MLLT samples were taken from the right half-carcass, stored in plastic bags at –80°C for 3 weeks as maximum, homogenized, and subjected

to chemical analyses. The contents of water (from the difference of the sample weight before and after drying with sea sand), intramuscular fat (IMF) (via gravimetric determination following extraction with petrolether in solvent extractor (SER 148; VELP Scientifica, Usmate, Italy)), crude protein (amino nitrogen determined according to the Kjeldahl method (KjelFlex K-360; Büchi, Flavil, Switzerland)), and ash (via burning the sample at 550°C until organic substances were burnt (Ht40AL oven; LAC, Rajhrad, Czech Republic)) were determined.

Fatty acid analysis

Fatty acid methyl esters were determined following extraction of total lipids according to Folch et al. (1957). Methanolysis was performed by applying the catalytic effect of potassium hydroxide and extraction of acids in the form of methyl esters in heptane. The contents of isolated methyl esters were determined using a gas chromatograph Master GC (Dani Instruments S.p.A., Cologno Monzese, Italy) equipped with a flame ionization detector and a column with polyethylene glycol as the stationary phase (FameWax; 30 m × 0.32 mm × 0.25 μm). Helium was used as the carrier gas, with a flow rate of 5 ml/min and a split ratio of 1 : 9. The obtained records were analyzed using Clarity software, Version 5.2 and quantified on the basis of known retention times from a standard Food Industry FAME Mix (Restek Co., Bellefonte, USA). The atherogenic index (AI) was calculated according to Chilliard et al. (2003) as follows:

$$AI = (C12:0 + 4 \times C14:0 + C16:0)/(MUFA + PUFA)$$

whereas the thrombogenic index (TI) was calculated in accordance with Ulbricht and Southgate (1991) using the formula

$$TI = (C14:0 + C16:0 + C18:0)/(0.5 \times MUFA + 0.5 \times n\text{-}6\ PUFA + 3 \times n\text{-}3\ PUFA + n\text{-}3/n\text{-}6\ PUFA)$$

The fatty acid analysis was carried out in the Department of Animal Husbandry, Czech University of Life Sciences Prague.

Statistical analyses

The results of the experiment were evaluated using the General Linear Models procedure of SAS

Table 2. Effects of diet and sex on fattening and carcass characteristics (mean ± SD)

Item	Control group		Experimental group		Significance		
	barrows (n = 11)	gilts (n = 13)	barrows (n = 9)	gilts (n = 7)	diet	sex	diet × sex
Live weight (kg)	114.1 ± 3.37	112.8 ± 6.01	117.9 ± 9.10	112.2 ± 9.61	ns	ns	ns
Daily gain (g/day)	1034 ± 55.53	988 ± 61.25	1029 ± 77.27	990 ± 97.62	ns	ns	ns
Feed consumption (kg/day)	2.49 ± 0.23	2.27 ± 0.19	2.66 ± 0.29	2.26 ± 0.24	ns	< 0.001	ns
A1 (kg/day)	1.66 ± 0.27	1.71 ± 0.15	1.51 ± 0.32	1.63 ± 0.06	ns	ns	ns
A2 (kg/day)	2.17 ± 0.29	2.03 ± 0.28	2.20 ± 0.24	1.89 ± 0.15	ns	0.012	ns
CDP (kg/day)	2.99 ± 0.32	2.61 ± 0.23	3.36 ± 0.56	2.72 ± 0.40	ns	< 0.001	ns
Feed : gain ratio (kg/kg)	2.45^{b} ± 0.16	2.35^{b} ± 0.19	2.69^{a} ± 0.07	2.39^{b} ± 0.12	0.002	< 0.001	0.050
A1 (kg/kg)	1.84^{b} ± 0.18	1.79^{b} ± 0.14	2.33^{a} ± 0.58	1.62^{b} ± 0.30	ns	0.001	0.003
A2 (kg/kg)	2.08 ± 0.28	2.13 ± 0.21	2.10 ± 0.13	2.07 ± 0.20	ns	ns	ns
CDP (kg/kg)	2.91 ± 0.18	2.68 ± 0.25	3.20 ± 0.19	2.85 ± 0.20	0.002	< 0.001	ns
Lean meat (%)	55.01 ± 1.66	58.62 ± 1.23	54.87 ± 2.79	58.24 ± 2.11	ns	< 0.001	ns
Main meat parts (meat + bone) (%)	50.98 ± 1.63	53.82 ± 1.54	52.07 ± 2.00	51. 41 ± 6.99	ns	ns	ns
Main meat parts (fat cover + skin) (%)	14.68 ± 1.54	12.01 ± 1.11	14.28 ± 1.90	14.44 ± 7.00	ns	ns	ns

SD = standard deviation, A1 = mixed feed fed to pigs with average live weight of 28–35 kg, A2 = mixed feed fed to pigs with average live weight of 35.1–60 kg, CDP = mixed feed fed to pigs with average live weight of 60.1–110 kg, ns = nonsignificant

(Statistical Analysis System, Version 6.04, 2001). Testing of significant differences was carried out according to the following mathematical-statistical two-ways analysis model:

$$Y_{ij} = \mu + d_i + s_j + (ds)_{ij} + e_{ij}$$

where:
Y_{ij} = value of the trait
μ = overall mean
d_i = effect of diet (i = 1, 2)
s_j = effect of sex (j = 1, 2)
$(ds)_{ij}$ = combined effect of diet and sex
e_{ij} = random residual

RESULTS

The effects of dietary linseed and sex on the selected fattening and carcass value characteristics are shown in Table 2. The live weight of the pigs, average daily gain, and main meat parts were not significantly influenced by linseed addition or sex. Linseed supplementation in the diet increased feed conversion (P = 0.050) in barrows. The feed conversion rate in barrows from the experimental group was 2.69 kg/kg, in contrast to that of gilts from both the experimental (2.39 kg/kg) and control (2.35 kg/kg) groups. The gilts exhibited statistically significantly lower feed consumption (P < 0.001) and a higher lean meat percentage (P < 0.001) compared to the barrows.

The results concerning the qualitative characteristics of the loin of the carcass assessed using physical and chemical methods are presented in Table 3. Linseed addition in mixed pig feed did not influence the evaluated values. A significant difference (P = 0.025) was detected between barrows and gilts regarding the redness (a^*) value. A combined effect of diet and sex was observed in the ash content (P = 0.031). The lowest value was ascertained in barrows from experimental group. According to the measured pH_{45} values, it can be stated that quality deviation was not found. The EC_{50} value in barrows from the experimental treatment group nonsignificantly fell down within the category indicating defects tending towards PSE meat. The barrows and gilts from the control group exhibited a nonsignificantly lighter colour and higher tenderness of the loin compared to barrows and gilts from the experimental group. The drip loss was nonsignificantly lower in both sexes fed with the diet enriched with linseed.

The fatty acid profile in the loin is shown in Table 4. There is an evident statistically significant effect of dietary linseed regarding increasing the contents of linoleic acid, α-linolenic acid, eicosapentaenoic acid, henecosanoic acid, the total PUFAs and n-3 PUFAs, and the PUFA/SFA ratio. The

Table 3. Effects of diet and sex on physical and chemical characteristics of MLLT in pigs (mean ± SD)

Item	Control group		Experimental group		Significance		
	barrows (n = 11)	gilts (n = 13)	barrows (n = 9)	gilts (n = 7)	diet	sex	diet × sex
pH_{45} value	6.08 ± 0.29	6.18 ± 0.22	6.18 ± 0.24	5.98 ± 0.26	ns	ns	ns
EC_{50} (mS)	3.83 ± 0.56	3.85 ± 0.69	4.50 ± 1.12	3.93 ± 1.21	ns	ns	ns
Colour: lightness (L^*)	53.89 ± 5.35	51.45 ± 1.93	50.13 ± 4.76	49.89 ± 4.33	ns	ns	ns
redness (a^*)	–0.15 ± 0.75	–0.97 ± 0.95	0.09 ± 1.66	–0.75 ± 0.95	ns	0.025	ns
yellowness (b^*)	10.38 ± 2.20	9.13 ± 1.46	9.11 ± 1.85	8.72 ± 2.00	ns	ns	ns
Shear force (N)	39.37 ± 4.26	42.79 ± 6.21	45.45 ± 9.70	46.86 ± 11.97	ns	ns	ns
Drip loss (%)	7.98 ± 2.66	7.82 ± 2.38	7.17 ± 2.32	6.80 ± 2.73	ns	ns	ns
Water (%)	73.50 ± 0.83	73.85 ± 0.81	74.26 ± 1.33	73.52 ± 0.67	ns	ns	ns
IMF (%)	1.89 ± 0.45	1.64 ± 0.88	1.88 ± 0.58	1.79 ± 0.42	ns	ns	ns
Crude protein (%)	22.99 ± 0.43	22.92 ± 0.64	22.77 ± 1.39	23.29 ± 0.62	ns	ns	ns
Ash (%)	1.21^a ± 0.10	1.21^a ± 0.10	1.12^b ± 0.06	1.25^a ± 0.07	ns	ns	0.031

MLLT = *musculus longissimus lumborum et thoracis*, SD = standard deviation, pH_{45} = pH value 45 min post-mortem, EC_{50} = electrical conductivity value 50 min post-mortem, IMF = intramuscular fat, ns = nonsignificant

Table 4. Effects of diet and sex on the fatty acid composition of MLLT in pigs (mean ± SD)

Fatty acid (%)		Control group		Experimental group		Significance		
		barrows (n = 11)	gilts (n = 13)	barrows (n = 9)	gilts (n = 7)	diet	sex	diet × sex
Butyric	C4:0	0.01 ± 0.02	0.01 ± 0.04	0.04 ± 0.11	0.04 ± 0.07	ns	ns	ns
Caprylic	C8:0	0.03 ± 0.05	0.01 ± 0.02	0.06 ± 0.10	0.04 ± 0.07	ns	ns	ns
Capric	C10:0	0.31 ± 0.07	0.30 ± 0.10	0.32 ± 0.14	0.28 ± 0.17	ns	ns	ns
Lauric	C12:0	0.22 ± 0.06	0.14 ± 0.09	0.25 ± 0.12	0.22 ± 0.12	ns	ns	ns
Myristic	C14:0	2.73 ± 0.33	2.32 ± 0.49	2.57 ± 0.39	2.60 ± 0.46	ns	ns	ns
Myristoleic	C14:1-9*c*	0.06 ± 0.07	0.09 ± 0.12	0.06 ± 0.10	0.04 ± 0.07	ns	ns	ns
Pentadecanoic	C15:0	0.06 ± 0.07	0.03 ± 0.04	0.03 ± 0.05	0.04 ± 0.07	ns	ns	ns
Palmitic	C16:0	30.46 ± 1.95	29.04 ± 1.48	27.65 ± 1.78	27.70 ± 1.88	0.001	ns	ns
Palmitoleic	C16:1-9*c*	6.83 ± 1.16	6.04 ± 0.90	4.59 ± 0.87	4.52 ± 1.15	< 0.001	ns	ns
Margaric	C17:0	0.22 ± 0.08	0.22 ± 0.09	0.14 ± 0.12	0.17 ± 0.08	0.025	ns	ns
Heptadecenoic	C17:1-10*c*	0.42 ± 0.11	0.46 ± 0.14	0.28 ± 0.14	0.29 ± 0.18	0.002	ns	ns
Stearic	C18:0	8.25 ± 0.73	8.88 ± 1.31	8.80 ± 0.67	8.66 ± 0.93	ns	ns	ns
Oleic	C18:1-9*c*	34.07 ± 2.20	34.34 ± 1.85	29.97 ± 3.00	29.48 ± 1.90	< 0.001	ns	ns
Linoleic	C18:2-9,12*c*	10.40 ± 2.12	11.64 ± 2.08	12.86 ± 3.03	13.53 ± 2.24	0.010	ns	ns
γ-Linolenic	C18:3-6,9,12*c*	0.12 ± 0.08	0.16 ± 0.08	0.04 ± 0.06	0.03 ± 0.05	< 0.001	ns	ns
α-Linolenic	C18:3-9,12,15*c*	1.35 ± 2.17	0.83 ± 0.25	7.31 ± 1.05	6.88 ± 2.82	< 0.001	ns	ns
Arachidic	C20:0	0.10 ± 0.08	0.10 ± 0.11	0.07 ± 0.12	0.06 ± 0.11	ns	ns	ns
Eicosenoic	C20:1-11*c*	0.39 ± 0.08	0.39 ± 0.11	0.26 ± 0.17	0.29 ± 0.07	0.002	ns	ns
Eicosadienic	C20:2-11,14*c*	0.03 ± 0.05	0.13 ± 0.18	0.13 ± 0.12	0.11 ± 0.11	ns	ns	ns
Eicosatrienoic	C20:3-8,11,14*c*	0.31 ± 0.10	0.40 ± 0.17	0.22 ± 0.14	0.35 ± 0.14	ns	0.023	ns
Arachidonic	C20:4-5,8,11,14*c*	3.03 ± 0.82	4.15 ± 1.29	1.97 ± 0.65	2.50 ± 0.77	< 0.001	0.007	ns
Eicosapentaenoic	C20:5-5,8,11,14,17*c*	0.09 ± 0.22	0.02 ± 0.04	0.63 ± 0.20	0.55 ± 0.27	< 0.001	ns	ns
Henecosanoic	C21:0	0.39 ± 0.65	0.19 ± 0.12	1.70 ± 0.56	1.57 ± 0.76	< 0.001	ns	ns
SFA		42.81 ± 1.97	41.25 ± 1.36	41.64 ± 2.13	41.42 ± 1.99	ns	ns	ns
MUFA		41.81 ± 3.00	41.38 ± 2.44	35.20 ± 3.63	34.63 ± 2.83	< 0.001	ns	ns
PUFA		15.36 ± 4.37	17.34 ± 3.42	23.16 ± 4.52	23.94 ± 4.45	< 0.001	ns	ns
n-6 PUFA		13.55 ± 2.52	15.95 ± 3.33	14.87 ± 3.66	16.05 ± 2.24	ns	ns	ns
n-3 PUFA		1.44 ± 2.39	0.85 ± 0.25	7.94 ± 1.17	7.43 ± 3.05	< 0.001	ns	ns
n-6/n-3 PUFA		17.38 ± 6.68	19.99 ± 6.84	1.87 ± 0.35	3.92 ± 5.20	< 0.001	ns	ns
MUFA/PUFA		2.91 ± 0.78	2.53 ± 0.82	1.60 ± 0.45	1.53 ± 0.52	< 0.001	ns	ns
MUFA/SFA		0.98 ± 0.06	1.00 ± 0.05	0.85 ± 0.09	0.84 ± 0.05	< 0.001	ns	ns
PUFA/SFA		0.36 ±0.12	0.42 ± 0.09	0.56 ± 0.13	0.58 ± 0.13	< 0.001	ns	ns
Atherogenic index		0.73 ± 0.07	0.66 ± 0.07	0.66 ± 0.08	0.66 ± 0.08	ns	ns	ns
Thrombogenic index		1.33 ± 0.23	1.28 ± 0.07	0.80 ± 0.11	0.85 ± 0.28	< 0.001	ns	ns

MLLT = *musculus longissimus lumborum et thoracis,* SD = standard deviation, *c* = *cis*, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, ns = nonsignificant

addition of linseed in the mixed feed decreased the contents of palmitic acid, palmitoleic acid, margaric acid, C17:1-10*c*, oleic acid, γ-linolenic acid, eicosenoic acid, and arachidonic acid and the total MUFAs, the n-6/n-3 PUFA, MUFA/PUFA, and MUFA/SFA ratios, and the thrombogenic index. A significant effect of sex was observed regarding the eicosatrienoic acid ($P = 0.023$) and arachidonic acid ($P = 0.007$) contents. No statistically significant interaction between the effects of diet and sex was found in the fatty acid profile.

DISCUSSION

The addition of linseed increased feed conversion. This fact was probably caused by higher energy value of the diet supplemented with linseed than by linseed itself. Other fattening characteristics were not influenced. Consistent with our results, Kouba et al. (2003), Corino et al. (2008), Flachowsky et al. (2008), Bečková and Václavková (2010), and Nurnberg et al. (2011) also did not find any significant effect of linseed feeding on fattening characteristics in pigs. Additionally, Matthews et al. (2000) showed that with the exception of a slight difference in feed intake, there was no effect of diet on production characteristics or carcass traits. As expected, in the present study, fattening parameters were influenced by sex rather than linseed addition to the diet. A lower feed conversion and feed intake were observed in gilts than in barrows. The gilts showed a lower feed intake and weight gain, resulting in a more favourable feed conversion ratio compared to the barrows (Van Oeckel et al., 1997).

There was also no significant effect of linseed feeding recorded in the quantitative carcass value characteristics. This finding is consistent with the results of Romans et al. (1995), Matthews et al. (2000), Kouba et al. (2003), and Corino et al. (2008), who also did not detect any significant effect of mixed feed enriched with linseed on quantitative carcass value indicators. However, Van Oeckel et al. (1997) reported that carcass quality in terms of the lean meat percentage was less favourable for the highest linseed level tested (10 g α-linolenic acid per kg of feed) compared to an intermediate level (7 g α-linolenic acid per kg of feed). Most of the physical and chemical parameters of meat quality were not affected by linseed addition or sex. Both Corino et al. (2008) and Nurnberg et al. (2011) found no significant effect of linseed on meat quality. Additionally, Van Oeckel et al. (1997) reported that meat quality, evaluated based on physical measurements (pH, light scattering, conductivity, colour, light reflection, tenderness, and water holding capacity), was not influenced to any significant extent by the fatty acid composition of the feed. Furthermore, Mas et al. (2010) found that among the observed physical characteristics of meat quality, only the yellowness value (b^*) ($P < 0.05$) was influenced by sex. The lean meat percentage and intramuscular fat content were not affected by linseed supplementation in a study by Bečková and Václavková (2010), whereas the pH value (1 h after slaughter) and drip loss were significantly influenced by the applied dietary treatment ($P < 0.01$). Higher pH value, drip loss, and susceptibility to PSE (pale, soft, exudative) meat were detected in the group fed linseed diet. Huang et al. (2008) observed no significant differences ($P > 0.05$) in terms of the average backfat thickness, lean meat percentage or loin muscle area, whereas the intramuscular fat content increased linearly ($P < 0.01$) as the time of feeding a linseed diet (linseed at the level of 10%) was prolonged.

The present study confirmed findings previously published by Enser et al. (2000), Hoz et al. (2003), Kouba et al. (2003), Huang et al. (2008), and Guillevic et al. (2009) who showed that the main effect of dietary linseed addition is reflected in the fatty acid profile in the muscle of pigs. Palmitic and stearic acid are the dominant acids among the SFA (Miller et al., 1990; Juárez et al., 2009). Among the MUFA, oleic and palmitoleic acid were the most frequent. The same conclusion was reached by Woods and Fearon (2009). Bečková and Václavková (2010) reported higher contents of linoleic acid and α-linolenic acid in pigs fed a mixture enriched with linseed, while the effect of linseed in the feed had a negative effect on arachidonic acid. The decrease in arachidonic acid may be due to the competition between linoleic acid and α-linolenic acid for desaturation and elongation to arachidonic acid and eicosapentaenoic acid (Cherian and Sim, 1995). Linseed feeding increased content of linolenic acid at the expense of linoleic acid and increased the contents of eicosapentaenoic and arachidonic acids (Romans et al., 1995; Enser et al., 2000). The percentage of total SFA was not influenced by the diet, in contrast to the percentage of total MUFA and PUFA in the loin, where decreasing ($P < 0.001$)

and increasing ($P < 0.001$) effects of linseed were observed, respectively. Consistent with results of the present study, Bečková and Václavková (2010) found a decrease in MUFA content, and Matthews et al. (2000) detected an increase of n-3 PUFA and a decrease of the n-6/n-3 PUFA ratio (from 7.2 to 3.9%). The n-6/n-3 PUFA ratio decreased in both barrows and gilts due to the addition of linseed. Corino et al. (2008) also reported a significant ($P < 0.05$) reduction of the n-6/n-3 PUFA ratio in both the loin (from 12 to 4.5%) and backfat (from 11 to 3%). The n-6/n-3 PUFA ratio in the tenderloin was significantly influenced by dietary linseed, which was due to increases ($P < 0.05$) in n-3 PUFA (especially α-linolenic and arachidonic acids) and decreases in the C18:2n-6 and n-6 PUFA contents (D'Arrigo et al., 2002; Hoz et al., 2003). The MUFA/PUFA (from 3.41 to 2.79) and MUFA/SFA (from 1.29 to 1.14) ratios showed a decreasing trend, as found by Bečková and Václavková (2010). Nurnberg et al. (2011) also reported an increase in the PUFA/SFA ratio in a group given feed with added linseed. The higher content of eicosatrienoic acid and arachidonic acid in gilts in the present study is consistent with work of Alonso et al. (2009) which stated that female pigs had the most polyunsaturated intramuscular fat than castrated males. Conversely, Cordero et al. (2010) did not observe the effect of sex on intramuscular fatty acid profile.

Moreover, there were two indicators evaluated related to human health: the atherogenic and thrombogenic indexes, which reflect the probability of an increase in pathogenic phenomena, such as atheroma and thrombus formation. A significant reduction in the thrombogenic index ($P < 0.001$) after linseed feeding in both gilts and barrows was observed. An effect of linseed feeding regarding reducing the atherogenic and thrombogenic indexes has been reported in cow's milk (Caroprese et al., 2010), ewe's milk (Cieslak et al., 2010; Caroprese et al., 2011), and rabbit meat (Peiretti and Meineri, 2010). For example, Cieslak et al. (2010) showed reduction of the atherogenic index from 1.4 to 0.5 and thrombogenic index from 0.8 to 0.4.

CONCLUSION

Linseed addition in the diets of pigs had no negative effect on the characteristics of fattening and quantitative and qualitative parameters of carcass values in both barrows and gilts. The highest feed conversion value and the lowest ash content were observed in barrows fed with linseed. Linseed addition in the diet increased the PUFA content, n-3 PUFA content, and PUFA/SFA ratio and decreased the MUFA content, MUFA/PUFA, MUFA/SFA, and n-6/n-3 PUFA ratios and thrombogenic index. Linseed feeding has less detrimental effects concerning the atherosclerosis and coronary thrombosis risk associated with the consumption of pig meat. The linseed-containing diet radically approximated the n-6/n-3 PUFA (control vs. experimental groups; 17.38 and 19.99 vs. 1.87 and 3.92) and thrombogenic index (1.33 and 1.28 vs. 0.80 and 0.85) in meat of barrows and gilts to the values recommended by the WHO.

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