

Effects of supplementary vegetable and animal fats on the slaughter values of fatteners, meat quality, and fatty acid profile in pigs

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ABSTRACT: The study was conducted on 32 hybrids of (Polish Large White × Danish Landrace) × Duroc breeds fed similar energy content feed, however differing in fat diet supplements. The animals were divided into four groups in which the following fat supplements were added to the feed: A – rapeseed and linseed oils, B – rapeseed and fish oils + swine fat, C – linseed and fish oils, D – rapeseed and linseed oils + lard. The carcass slaughter value was estimated and physicochemical and sensory traits of *longissimus lumborum* (LL) and *triceps brachii* (TB) muscles were determined. The content of fatty acids in the subcutaneous fat of the loin as well as in the raw LL and TB muscles was estimated as well. It was shown that there were no significant differences in the range of slaughter value traits and meat quality between the groups. However, it was found that different kinds of supplemented fat had a different effect on the content of the polyunsaturated fatty acids in the backfat and in the raw LL muscle. The lowest level of fatty acids characterized the group of pigs fed with supplements consisting of rapeseed and fish oils + lard. The highest values were detected among fatteners supplemented with linseed. The kind of supplemented fat affected the changes in the level of PUFA n-3 fatty acids, especially the linolenic acid C18:3 in backfat. The n-6/n-3 ratio in pigs fed with a greater share of linseed (C and D groups) was better (about 3) than in pigs which obtained a greater portion of rapeseed and fish oils (about 5.5). In both the muscles and fat of fatteners from groups B and C the DHA content was 2–3 times higher than in A and D groups. Higher EPA content was found in the TB muscle.

Keywords: pigs' feeding; oils; backfat; *triceps brachii*; *longissimus lumborum*

The relationships between the tissue composition of carcasses, their technological usefulness, and commercial value have been known for a long time (Branscheid et al., 1990). The most valuable component of a carcass is the meat and then the fat. The slaughter value of the carcass increases with the increase of the meat content. On the other hand, there are also positive relationships between the level of the intramuscular fat and meat juiciness, tenderness, and palatability. According to Wood et al. (1994, 2008), the content of the intramuscular fat in the range of 2–3% is the most favourable for the expected

sensory traits of meat. Too high amount of polyunsaturated fatty acids in the intramuscular and depot fat negatively affects technological traits and meat quality, especially the sensory traits. Polyunsaturated fatty acids characterize the greater susceptibility to oxidation processes, which influence taste, flavour, and colour. The supplementation of antioxidants, especially natural ones such as α -tocopherol, ascorbic acid, and β -carotene reduces the oxidative processes (Mitsumoto et al., 1991; Boler et al., 2009). In recent years, the interest of physicians, nutritionists, and epidemiologists in polyunsaturated acids from

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group n-3 has increased. The most significant of this group are eicosapentaenoic (EPA, C20:5) and docosahexaenoic (DHA, C20:6) acids. These acids can be accreted in animals' tissues directly from their feed or can be synthesized from α -linolenic acid which is a precursor of these fatty acids. The basic source of α -linolenic acid is vegetable oil (linseed, rapeseed). In full-fat flax seeds α -linolenic acid amounts to about 52% of the total of fatty acids, however in rapeseed oil it is 8.1%, in fish 1.2%, and in swine fat 0.8% (Barowicz and Kędzior, 2000; Ptasznik and Jerzewska, 2005; Makała and Kern-Jedrychowski, 2006).

Many authors described the positive effect of flax seeds as a supplement in pig feed on the increase of α -linolenic acid (C18:3 n-3) and on the decrease of the PUFA n-6/n-3 acids ratio (Barowicz and Kędzior, 2000; Nuernberg et al., 2005; Haak et al., 2008). Worse results in the modification of the fatty acids profile were stated in the case when olive oil (Nuernberg et al., 2005) or soybean oil (Benz et al., 2011) was used. According to Mitsumoto et al. (1991) and Leksanich et al. (1997), too high amount of polyunsaturated fatty acids in the intramuscular and depot fat affects the fat consistency (soft, sticky), worsens the taste, and also durability. For this reason, the supplementation of polyunsaturated fatty acids in feeding animals requires the use of antioxidants such as vitamin E. Vitamin E breaks the chain of free radical reactions in body cells, so the meat of such fed animals can be stored longer without oxidative fat changes (Barowicz and Kędzior, 2000).

The presented literature review concerning the use of supplements of various plant oils in pig nutrition did not give a full answer to what kind of supplement and in which dose must be used to obtain a raw product with high slaughter value and good quality of meat. Thus, the aim of the present study was to obtain dietetic meat by using fat supplements composed of different proportions of linseed, rapeseed, and fish oils and lard in the pigs' feeding. The studies included the slaughter value of carcasses, the physicochemical and sensory traits of meat, and also the profile of fatty acids.

MATERIAL AND METHODS

Animals and diets

Studies were conducted on 32 crossbred pigs, progeny of a Duroc boar and eight half-sisters (Polish

Large White \times Danish Landrace). The animals came from one boar and related mothers. The animals were maintained individually in pens equipped with automatic feeders and nipple drinkers, in the pigsty of the Institute of Animal Physiology and Nutrition in the Polish Academy of Sciences in Jabłonna near Warsaw, under the same thermo-neutral conditions: air temperature 18–20°C, humidity 60–70%, and the air speed 0.2–4 m/s.

The feeds were prepared from barley, maize, wheat, soybeans, rapeseed supplemented with premix containing vitamins, minerals, and crystalline amino acids. In each feed approximately 10% of the metabolic energy was replaced by a fat mixture (to the amount of 3.5%) containing fish oil, linseed or rapeseed, and lard. All mixtures were isoenergetic (13.5 MJ ME/kg) and iso-protein (133 g/kg digestible protein), the ratio of lysine to energy amounted to 0.55 g/MJ. Essential amino acids were balanced regarding the content of standardized ileal digestible (Degussa, 1999). The feeds differed in the concentration of omega-3 acid. The ingredients and chemical composition of the feeds, nutritive value, and metabolic energy content are shown in Table 1.

Nutrition

The animals were fed *semi ad libitum* (95% of *ad libitum* intake), and had continuous access to water from nipple drinkers. In the period of 25–60 kg of body weight (BW) the pigs were fed with the grower mixture (13.5 MJ ME and 7.4 g of lysine per 1 kg feed). When the pigs reached BW of 60 kg, they were allotted into 4 groups: A, B, C, and D ($n = 8$ per group) (Table 1). The individual groups of pigs were offered feeds with similar energy content and digestible protein content and also lysine, but different fat supplements, until they reached BW of about 105 kg (about 51 days of fattening). The content of fatty acids in the feeds of the studied groups was determined (Table 2).

Carcass measurements

The animals were slaughtered at the BW of about 105 kg, using the same slaughter technology (electrical stunning, bleeding in a hanging position, cooling by the single-degree method). In the hanging position, evaluations of meatiness using an

Table 1. Components, chemical composition, and nutritive value of compound feed (g/kg)

Traits	Diets ¹			
	A	B	C	D
Feed components (g/kg)				
Barley	360	360	360	360
Wheat	360	360	360	360
Corn	100	100	100	100
Rapeseed meal	40	40	40	40
Soyabean meal grain	80	80	80	80
Rapeseed oil	25	10	–	10
Linseed oil	10	–	25	23
Fish oil (cod liver oil)	–	20	10	–
Lard	–	5	–	2
Premix ²	25	25	25	25
Chemical composition (estimated) (g/kg)				
Dry matter	892	889	887	886
Ash	41	41	41	43
Organic matter	851	848	746	743
Crude protein	172	167	166	165
Ether extract	61	62	64	59
Crude fibre	40	43	41	43
Starch	460	453	440	450
Sugar	84	83	88	87
Nutritive value (estimated)				
Digestible crude protein (g/kg)	133	134	131	133
Standardized ileal digestible amino acids (g/kg)³				
Lysine		7.40		
Methionine		2.63		
Threonine		5.00		
Tryptophan		1.31		
Metabolizable energy (MJ/kg) ⁴	13.5	13.5	13.4	13.4

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²premix as 2.5% of the diet provided the required amount of micro- and macrominerals, essential amino acids, and vitamins (α -tocopherol 240 mg/kg of feed)

³according to Degussa (1999)

⁴calculated on the basis of digestible nutrient components, taking into account correction on the content of digestible protein, fat, starch, and sugar in organic matter

ultrasonic Ultra Fom 300 device (Carometec A/S, Herlev, Denmark) were performed on the warm, left half carcasses. Callipers were used for measuring the carcass fat thickness in the following points: backfat thickness on the back, i.e. over the last rib, backfat thickness over the beginning of the muscle *gluteus medius* (cross-section I), backfat thickness over the middle of the muscle *gluteus medius*

(cross-section II), backfat thickness over the end of the muscle *gluteus medius* (cross-section III).

Pork quality measurements

pH and electrical conductivity of muscles. In the muscle *longissimus lumborum* (LL) at the height

of the 1st–2nd lumbar basilar vertebra and also in the muscle *triceps brachii* (TP), pH measurements were carried out using the pH meter Radiometer PHM 80 Portable (Radiometer Analytical S.A. Villeurbanne, Cedex, France) with a composite Danish made electrode at 45 min (pH₄₅) and 24 h (pH₂₄) postmortem (ISO 2917, 2001). The electrical conductivity was measured 24 h postmortem in the muscle LL using the conductor LF-Star Model 340 (Mettler-Toledo, Greifensee, Switzerland).

Instrumental and subjective colour and marbling evaluation. The instrumental measurement of the colour was performed 24 h postmortem on the section of the muscle LL between the 1st–2nd basilar vertebra. Measurements were made using a Chroma Meter CR-400 camera (Konica Minolta Co. Ltd., Osaka, Japan) estimating L^* (lightness), a^* (redness), and b^* (yellowness). The subjective evaluation of the colour was conducted by a five-person team using a five-point model of colours, 1 point = the colour of pale pinkish grey to white, on the other hand, 5 points = dark purplish red (NPPC, 1991; Kauffman et al., 1992). The estimation of marbling in the same section of both studied muscles was conducted by using the standard five-point model of marbling (1 = devoid to practically devoid; 5 = moderately abundant or greater) (Kauffman et al., 1992; NPPC, 1999).

Drip loss, cooking and roast losses. About 100 g samples of the muscles LL and TB were placed in plastic bags and left at a temperature of 4°C for 48 h. Then the samples were weighed and from the difference of weights, the drip loss was calculated. Samples of the LL muscle of the thoracic part were weighed and heated in water to reach the internal temperature of 75°C in the middle of the meat sample. After cooling, the samples were weighed and from the difference of the weight, the percentage losses during the meat cooking were calculated. The weighed meat sample of TB was placed in an electric oven to reach the internal temperature of 80°C in the middle of the meat sample and then from the weight difference a calculation was made to find the loss from roasting (Honikel, 1997).

Water, intramuscular fat, and total protein content. The water content was determined according to ISO 1442 (2000). It was transferred to the cell weight of about a 3 g sample of minced meat (prepared according to ISO 3100 (1999)), weighed, and dried at a temperature of 105°C to obtain a constant weight. The water content in percentages was calculated from weight difference

of the sample before and after drying. The content of the intramuscular fat was determined according to ISO 1444 (2000). The dried, weighed sample was placed in an extracted thimble and fatty substances were extracted with petroleum ether using the automatic extraction system SOXTherm from the Gerhardt Laboratory System (Königswinter, Germany). The fat content was calculated from the difference of the samples weight before and after extraction. The total protein content was determined according to the Polish Standard Method PN-75/A-04018 (2002) using the method of the Kjeldtec System 1002 Distilling Unit.

Sensory evaluation. The sensory evaluation of the cooked LL muscle and the roasted TB muscle was carried out by a five-person trained team that tested the sensory sensitivity (ISO 8586-1, 1996; ISO 5496, 1997; ISO 3972, 1998). A five-point scale was used to evaluate flavour, juiciness, tenderness, and palatability (NPPC, 1991; ISO 4121, 1998). The flavour and palatability scale: 1 = very unacceptable; 5 = very acceptable. The juiciness scale: 1 = very dry; 5 = very juicy. The tenderness scale: 1 = very tough; 5 = very tender.

Warner-Bratzler shear force. From the cooked LL muscle and roasted TB muscle, cylindrical samples with a diameter of 2.54 cm were cut off. The shear force was measured by the Warner-Bratzler apparatus.

Lipid analysis. The profile of the fatty acids was determined in the following tissues: dorsal backfat, intramuscular fat of the raw LL muscle, and also intramuscular fat of the raw TB muscle. Esters of fatty acids of the tested fats were prepared according to ISO 5509 (1996). The determination of the composition of fatty acids was conducted by gas chromatography using a HP 6890 apparatus (Agilent Technologies Inc., Santa Clara, USA) equipped with a flame-ionizing detector and a high-polar column BPX 70 (length 60 m, film thickness 0.25 µm, internal diameter 0.22 mm). The analysis was carried out in the programmed temperature and time. The content of the tested fatty acids was expressed as g/100 g of the total of all fatty acids in the sample.

Statistical analysis

The results were analyzed statistically using the One-Way Analysis of Variance. The significance of differences between the studied groups of pigs was determined using Tukey's test.

RESULTS AND DISCUSSION

Estimation results of the carcass slaughter value

The characteristic traits of the slaughter value of the examined carcasses of three-race hybrids (Polish Large White × Danish Landrace) × Duroc are shown in Table 3. The examined groups of animals (A–D) were fed the same composition of feed components, while the individual groups varied in the fat supplements added to the feed (Table 1). The presented data show that feeding with fat supplements caused no significant differences between the groups in a range of studied slaughter traits. The average carcass weight was similar (82.54–84.3 kg), however the meatiness of carcasses varied (54.82–57.3%). It was also shown that the carcasses of the compared groups did not differ significantly regarding the backfat thickness measured at four locations on the carcass (17.9–20.4 mm) and also after slaughter yield (79–80.3%). Other authors (Jaturasitha et al.,

2009) have also shown that pigs fed with tuna oil supplements exhibited no significant differences in the slaughter yield, meatiness, and also the backfat thickness compared to the control group. Similarly, Mas et al. (2011) in pigs of Landrace × Large White breed fed soybean seeds with a supplement of the oleic acid Greedy-Grass OLIVA stated no significant differences in meatiness and backfat thickness in comparison to the control group. Also Casa et al. (2010) in the hybrids of pigs (Landrace × Yorkshire) × Duroc, which were given a diet supplemented with α -linolenic acid, noted a similar result as concerns the slaughter yield of carcasses, meat quality, ham and loin yields as in the control group. Moreover, the similar meatiness and backfat thickness (20.02 mm on the average) as in the presented study were recorded in pig carcasses of the Landrace breed and its crossbreeds with Yorkshire and Duroc pigs (Koćwin-Podsiadła et al., 2004). Contrarily, Sabbioni et al. (2002) in crossbreeds of the Duroc × Large White × Landrace pigs obtained by about 10% lower meatiness (47.4%) and thicker backfat

Table 2. Fatty acids concentration of the diets (g/kg)

Fatty acids	Diets ¹			
	A	B	C	D
Σ SFA	7.56	9.59	9.51	9.32
C14:0	0.05	0.50	0.42	0.15
C16:0	5.87	7.24	6.99	6.86
C18:0	1.04	1.31	1.63	1.77
Σ MUFA	17.42	16.74	15.14	15.12
C16:1	0.08	0.78	0.63	0.22
C18:1	16.65	14.00	12.23	14.04
Σ PUFA	24.71	23.63	28.68	27.95
LA C18:2 n-6	19.58	19.58	18.22	19.31
ALA C18:3 n-3	5.13	2.30	8.98	8.51
EPA	0.00	0.70	0.59	0.03
DPA	0.00	0.12	0.09	0.03
DHA	0.00	0.93	0.76	0.15
AA C20:4	0.00	0.01	0.00	0.00
Σ PUFA/ Σ SFA ²	3.27	2.46	3.01	3.00
C18:2n-6/C18:3n-3 ³	3.82	8.53	2.03	2.27
Σ PUFA n-3/ Σ PUFA n-6 ⁴	3.82	4.84	1.75	2.22

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²ratio of total polyunsaturated fatty acids (PUFA) to saturated fatty acids (SFA)

³proportion of linoleic acid to α -linolenic acid

⁴ratio of total polyunsaturated fatty acids n-6 to n-3

Table 3. Effect of oil diet inclusion on carcass characteristics ($n = 8$)

Carcass characteristics	Diets ¹				SEM	Significance
	A	B	C	D		
Live weight (kg)	105.10	103.90	104.18	104.19	2.38	ns
Hot carcass weight (kg)	84.3	82.54	83.59	83.02	2.10	ns
Meat content in carcass (%)	57.30	56.94	54.82	56.41	1.82	ns
Backfat thickness (mm)						
cross-section I	21.25	21.12	24.12	22.0	3.41	ns
cross-section II	13.88	13.75	16.63	14.38	2.59	ns
cross-section III	22.75	23.13	23.25	24.0	3.59	ns
over last rib	13.87	13.75	17.75	15.5	3.61	ns
Backfat thickness (mm) (means from 4 measurements)	17.94	17.93	20.43	18.97	3.29	ns
Dressing percentage (%)	80.3	79.45	80.29	79.44	1.49	ns

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard
ns = nonsignificant difference

(30.6 mm on the average) from three measurements on the carcass. This diversity in comparison to the results of the present work may be caused by different nutritive and environmental conditions. Mucha and Różycki (2004) showed that with age, the backfat accumulates much faster in the capitular and caudal parts than in the region of the last ribs.

Quality traits of *longissimus lumborum* and *triceps brachii* muscles

Results of the quality traits of the LL muscle were shown in Table 4 and those on TB in Table 5. The pH values of both muscles obtained 45 min after slaughter confirmed the correct run of the process of glycolysis in the muscular tissue. Also, results of the pH measurements 24 h after slaughter are correct and among others point to proper treatment before slaughter. The obtained results of pH and the electrical conductivity confirmed that in the studied population, there were no deviations in the meat quality between the types PSE and DFD (Kauffman et al., 1993; Fischer, 2001; Homsí and Francisco, 2003). The degree of the tissular acidification is strictly related to the colour and drip loss. Relatively lower drip losses were reported in TB (1.98–2.54%) and higher in LL (3.82–5.15%) muscular tissue. Homsí and Francisco (2003) also mentioned similar values of drip loss for both the

muscles. There were no statistically significant differences in the range of pH values, lightness of the colour, and size of the drip loss between the studied groups. It indicates that these parameters were not influenced by oil supplements in the diet. Also, in the studies of other authors, in the LL muscle of pigs fed a diet either with or without oil supplements (e.g. linseed or olive oil), no differences were noted in the values of pH₄₅, the drip loss, and colour defined subjectively using a Minolta apparatus (Lauridsen et al., 2005; Nuernberg et al., 2005; Jaturasitha et al., 2009; Mas et al., 2011). The loss during cooking of the LL muscle was higher in group C (29.71%) in comparison to other groups (25.09–27.28%). It can be associated with the higher water content and lower fat level in the muscles of these pigs.

Interesting studies were conducted by Moeller et al. (2010) who analyzed the loss of meat weight in dependence on the temperature of the heat treatment ranging 62.8–79.4°C. These authors stated lower weight losses at lower temperatures and larger at higher temperatures (24.6% and 28.2%, respectively). Among the studied groups, the highest fat content in the LL muscle was recorded in the carcasses of group B (2.62%) and the lowest in those of group C (1.44%). Similarly, the highest level of intramuscular fat in the TB muscle exhibited group B carcasses – 2.31% and the lowest those of group C – 1.61%. Other authors of works on pig feeding with fat supplements in the diet have also noted no statistically significant differences in the

Table 4. Effect of oil diet inclusion on traits of raw *longissimus lumborum* muscle

Traits	Diets ¹				SEM	Significance
	A	B	C	D		
pH ₄₅	6.13	6.22	6.32	6.28	0.24	ns
pH ₂₄	5.57	5.55	5.86	5.75	0.26	ns
EC ₂₄ ²	6.16	5.56	5.97	4.90	0.23	ns
<i>L</i> * (lightness)	50.17	49.34	50.14	49.34	2.82	ns
<i>a</i> * (redness)	5.68	5.59	5.66	5.84	1.00	ns
<i>b</i> * (yellowness)	2.03	2.13	1.64	2.37	1.15	ns
Drip loss (%)	3.92	5.15	4.77	4.58	2.01	ns
Cooking loss (%)	25.09 ^a	27.28 ^a	29.71 ^b	27.08 ^a	2.82	*
Colour evaluation (score) ³	2.20	2.16	2.16	2.41	0.28	ns
Marbling (score) ⁴	2.17	2.44	2.65	2.33	0.62	ns
Moisture content (%)	73.10 ^a	72.65 ^a	74.49 ^b	74.02 ^a	1.18	*
Fat content (%) ⁵	2.10	2.62	1.44	1.96	0.96	ns
Protein content (%)	23.70	23.63	22.97	22.91	0.96	ns

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²electrical conductivity

³colour scale (1–5): 1 = pale pinkish gray to white, 5 = dark purplish red (NPPC, 1991)

⁴marbling scale (1–5): 1 = devoid to practically devoid, 5 = moderately abundant or greater (NPPC – Kaufman, 1992)

⁵intramuscular fat content

^{a,b}different letters within a row indicate significant differences, ns = nonsignificant difference, **P* ≤ 0.05

intermuscular fat of the LL muscle between the control and experimental groups (Jaturasitha et al., 2009). However, these differences were noted be-

tween sex – higher muscular fatness was observed in barrows than in gilts (Nuernberg et al., 2005; Mas et al., 2011). In our study the protein level in

Table 5. Effect of oil diet inclusion on traits of raw *triceps brachii* muscle

Traits	Diets ¹				SEM	Significance
	A	B	C	D		
pH ₂₄	5.75	5.82	5.72	5.67	0.18	ns
<i>L</i> * (lightness)	44.89	43.93	43.43	43.93	1.78	ns
<i>a</i> * (redness)	11.05	12.01	12.07	11.08	1.60	ns
<i>b</i> * (yellowness)	2.15	2.88	2.30	3.16	1.12	ns
Drip loss (%)	1.98	2.74	2.75	2.54	1.31	ns
Colour evaluation (score) ²	2.16	2.52	2.18	2.24	0.53	ns
Roast loss (%)	33.78	37.55	32.63	34.38	4.18	ns
Marbling (score) ³	3.62	3.27	3.30	3.61	0.23	ns
Moisture content (%)	75.3	74.2	75.6	75.49	0.90	ns
Fat content (%)	2.10	2.32	1.61	2.28	0.80	ns
Protein content (%)	21.5	22.4	21.64	21.11	0.95	ns

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²colour scale (1–5): 1 = pale pinkish gray to white, 5 = dark purplish red (NPPC, 1991)

³marbling scale (1–5): 1 = devoid to practically devoid, 5 = moderately abundant or greater (NPPC – Kaufman, 1992)

ns = nonsignificant difference

both muscles did not differ significantly between the groups. Moreover, in both muscles the protein level was relatively balanced (22.91–23.70% and 21.1–22.4% in the LL and TB muscles, respectively).

Weight losses during roasting of the TB muscle were rather diverse between the groups, but insignificantly. Lower thermal weight losses were recorded in the muscles of group C (32.63%) and higher in group B (37.55%).

Sensoric quality of the *longissimus lumborum* and *triceps brachii* muscles

Results of the sensory evaluation of the cooked muscle LL and roasted muscle TB and shear force of the studied groups are presented in Table 6. Both muscles obtained high results for flavour, juiciness, tenderness, and palatability (4.3–4.4 points on an average). These balanced results of the estimation were confirmed by statistical analysis, which showed no significant differences among the sensory properties of the muscles in the studied groups. Perhaps this positive evaluation of sensory meat traits was caused by supplementing the diet with vitamin E. It is known that this antioxidant influences the stability of oxidative fat, which is connected with taste and flavour (Migdał et al., 2008). Nuernberg et al. (2005) also

found no differences in the sensory evaluation of the grilled LL muscle coming from pigs fed a diet supplemented with linseed and olive oils. Calkins and Hodgen (2007) claim that about 50 substances contribute to creating meat flavour. Moreover, the authors think that aroma is created and developed not only during meat preparation, but also at the stage of animals' feeding and meat treatment after slaughter (ripening conditions).

Positive relationships have been known between intramuscular fat in meat and its juiciness, tenderness, and palatability. According to Wood et al. (1994), the 2–3% intramuscular fat content is the most favourable as concerns expected sensory traits of meat. Wood et al. (2004) showed a positive correlation between meat taste and the content of saturated and monounsaturated fatty acids and a negative correlation in comparison to unsaturated fatty acids. Moreover, the optimal level of intramuscular fat, pH, and also temperature during meat treatment affects its fragility (Moeller et al., 2010). In our study, measurements of the muscle shear force turned out to be rather differentiated but the differences between the groups were not confirmed statistically. The shear force of the cooked LL muscle was in the range of 86.8–103.8 N, while in the TB muscle it made 103.2–126.8 N. Also Jatunasitha et al. (2009) and Mas et al. (2011) reported similar shear force values of the meat in control

Table 5. Effect of oil diet inclusion on traits of raw *triceps brachii* muscle

Traits	Diets ¹				SEM	Significance
	A	B	C	D		
pH ₂₄	5.75	5.82	5.72	5.67	0.18	ns
L*(lightness)	44.89	43.93	43.43	43.93	1.78	ns
a* (redness)	11.05	12.01	12.07	11.08	1.60	ns
b* (yellowness)	2.15	2.88	2.30	3.16	1.12	ns
Drip loss (%)	1.98	2.74	2.75	2.54	1.31	ns
Colour evaluation (score) ²	2.16	2.52	2.18	2.24	0.53	ns
Roast loss (%)	33.78	37.55	32.63	34.38	4.18	ns
Marbling (score) ³	3.62	3.27	3.30	3.61	0.23	ns
Moisture content (%)	75.3	74.2	75.6	75.49	0.90	ns
Fat content (%)	2.10	2.32	1.61	2.28	0.80	ns
Protein content (%)	21.5	22.4	21.64	21.11	0.95	ns

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²colour scale (1–5): 1 = pale pinkish gray to white, 5 = dark purplish red (NPPC, 1991)

³marbling scale (1–5): 1 = devoid to practically devoid, 5 = moderately abundant or greater (NPPC – Kaufman, 1992)

ns = nonsignificant difference

Table 6. Sensory traits of the *longissimus lumborum* (LL) and *triceps brachii* (TB) muscles (points)

Traits	Diets ¹				SEM	Significance
	A	B	C	D		
Traits of cooked LL muscle						
Flavour ²	4.34	4.29	4.43	4.41	0.22	ns
Juiciness ³	4.50	4.43	4.36	4.19	0.23	ns
Tenderness ⁴	4.31	4.30	4.29	4.28	0.17	ns
Taste ²	4.45	4.29	4.36	4.36	0.14	ns
Overall examination traits	4.40	4.33	4.36	4.31	0.18	ns
Shear force (N)	86.83	93.4	103.8	90.72	25.6	ns
Traits of roasted TB muscle						
Flavour	4.53	4.57	4.53	4.41	0.19	ns
Juiciness	4.30	4.10	4.34	4.31	0.26	ns
Tenderness	4.5	4.37	4.32	4.32	0.18	ns
Taste	4.56	4.39	4.45	4.48	0.17	ns
Overall examination traits	4.47	4.36	4.41	4.38	0.20	ns
Shear force (N)	103.27	126.8	109.8	107.47	32.08	ns

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²scale: 1 = very unacceptable, 5 = very acceptable

³scale: 1 = very dry, 5 = very juicy

⁴scale: 1 = very tough, 5 = very tender

ns = nonsignificant difference

and experimental pigs fed a diet supplemented with Greedy Grass OLIVA (soybeans and oleic acid).

Fatty acids composition (%) of backfat lipids

The content of fatty acids in the dorsal backfat of the studied nutrition groups was presented in Table 7. The level of the saturated fatty acids (SFA) in the backfat of tested fatteners was roughly similar (35.7–37.9%) but the content of monounsaturated fatty acids (MUFA) differed among animals. The pigs of groups B and C had significantly ($P < 0.01$) more palmitoleic acid (C16:1) (1.74 and 1.56 g/100 g, respectively) and eicosenoic acid (C20:1) (1.7 and 1.44 g/100 g, respectively) compared to the remaining groups. However, the pigs of groups A and B had more oleic acid (C18:1) (37.47 and 36.94 g/100 g, respectively) in comparison to other animals. The significantly smaller total share of polyunsaturated fatty acids (PUFA), including PUFA n-3 was noted in group B (20.85 and 3.05 g/100 g, respectively). For this reason, the n-6 : n-3 ratio in this group was less profitable (5.57) in comparison to groups C and D (3.11 on the average). However, the values

of these coefficients are not high in comparison to the studies of other authors. Wajda et al. (2004) and Nuernberg et al. (2005) reported the PUFA n-6/n-3 ratio amounting to 7–10 in the backfat of pigs whose diet was supplemented with olive oil, soya oil or flax seeds (APC-Premix). Based on our results it can be assumed that a profitable ratio of PUFA n-6/n-3 acids in the backfat of pigs of groups C and D resulted from the doubled supplement of the linseed oil in the diet compared to other animals. Barowicz and Kędzior (2000) mentioned that full-fat flax seeds are the richest source of α -linolenic acid (C18:3, n-3) attaining here to 52–58% of the total fatty acids. In the organism of mammals the α -linolenic acid is the precursor of the long-chained polyunsaturated fatty acids EPA and DHA, which are essential for the proper development and maintenance of human health.

The Polish Institute of Meat and Fat conducted an experiment in which two groups of pigs were for 60 days on diets supplemented with a preparation from linseed oil (Leenlife E – 5 and 7.5% respectively). In the backfat of both groups the PUFA n-6/n-3 ratio amounted to 1.7, whereas in the control group it was 5.56 (Grześkowiak

Table 7. Fatty acids composition (g/100 g FAME) of backfat lipids

Fatty acid	Diets ¹				SEM	Significance
	A	B	C	D		
C10:0	0.1	0.1	0.1	0.1	0.00	ns
C12:0	0.1	0.1	0.1	0.1	0.00	ns
C14:0	1.0	1.12	1.05	1.02	0.06	ns
C15:0	0.1	0.1	0.1	0.1	0.00	ns
C16:0	20.41	21.60	20.69	20.71	0.91	ns
C16:1	1.39 ^X	1.74 ^Y	1.56 ^Z	1.32 ^X	0.12	**
C17:0	0.25	0.30	0.30	0.29	0.06	ns
C17:1	0.21	0.22	0.24	0.22	0.05	ns
C18:0	13.59	14.35	13.91	14.37	0.83	ns
C18:1	37.47 ^x	36.94 ^{xy}	35.64 ^y	34.87 ^y	1.35	*
C18:2 n-6	18.29	16.59	17.15	18.06	1.34	ns
C18:3 n-3	3.36 ^X	2.00 ^Y	4.81 ^Z	5.52 ^Q	0.33	**
C20:0	0.27	0.25	0.21	0.21	0.04	ns
C20:1	1.25 ^X	1.7 ^Y	1.44 ^{ZX}	0.99 ^Q	0.15	**
C20:2 n-6	0.99	0.85	0.81	0.81	0.11	ns
C20:3 n-6	0.1	0.1	0.1	0.1	0.00	ns
C20:4 n-6	0.19	0.17	0.14	0.14	0.04	ns
C20:5 n-3 EPA	0.12 ^x	0.19 ^y	0.17 ^y	0.10 ^x	0.03	*
C22:4 n-6	0.10	0.10	0.10	0.10	0.00	ns
C22:5 n-3 DPA	0.15 ^X	0.41 ^Y	0.34 ^Y	0.16 ^X	0.06	**
C22:6 n-3 DHA	0.12 ^X	0.45 ^Y	0.31 ^Y	0.10 ^X	0.04	**
ΣSFA ²	35.75	37.9	36.39	36.87	0.38	ns
ΣMUFA ³	40.32 ^x	40.60 ^x	38.87 ^{xy}	37.41 ^y	0.18	*
ΣPUFA ⁴	23.32 ^X	20.85 ^Y	23.89 ^X	25.04 ^X	0.28	**
PUFA n-3	3.66 ^{Xx}	3.05 ^{xy}	5.64 ^Y	5.89 ^Y	0.12	**
PUFA n-6	18.67	16.95	17.44	18.34	0.29	ns
OFA ⁵	21.41	22.72	21.74	21.73	0.50	ns
UFA ⁶	63.65 ^x	61.45 ^y	62.76 ^{xy}	62.45 ^y	0.55	ns
DFA ⁷	77.24	75.80	76.67	76.82	0.56	ns
UFA/SFA	1.78	1.62	1.72	1.69	0.30	ns
PUFA n-6/PUFA n-3	5.11 ^X	5.57 ^Y	3.11 ^Z	3.11 ^Z		**

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²all saturated fatty acids

³all monounsaturated fatty acids

⁴all polyunsaturated fatty acids

⁵dietary fatty acids having undesirable hypercholesterolemic effect in humans (C14:0 + C16:0)

⁶ΣPUFA + MUFA

⁷dietary fatty acids having desirable neutral or hypocholesterolemic effect in humans (UFA + C18:0)

^{x-z}different letters within a row indicate significant differences $P \leq 0.01$ ($*P < 0.05$)

^{x-z}different letters within a row indicate significant differences $P \leq 0.05$ ($**P < 0.01$)

ns = nonsignificant difference

Table 8. Fatty acids composition (g/100 g FAME) of intramuscular fat in raw *longissimus lumborum* muscle

Fatty acid	Diets ¹				SEM	Significance
	A	B	C	D		
C10:0	0.1	0.1	0.1	0.1	0.0	ns
C12:0	0.1	0.1	0.1	0.1	0.0	ns
C14:0	1.09	1.22	1.1	1.19	0.10	ns
C16:0	22.9	23.89	22.96	23.62	0.98	ns
C16:1	2.39 ^x	2.71 ^y	2.34 ^x	2.45 ^{xy}	0.25	
C17:0	0.2	0.2	0.2	0.19	0.0	ns
C17:1	0.17	0.2	0.19	0.17	0.04	ns
C18:0	13.19	14.01	13.75	14.32	0.92	ns
C18:1	39.87 ^{xy}	41.01 ^x	39.52 ^y	40.22 ^{xy}	2.24	
C18:2 n-6	13.22	10.72	12.05	10.95	2.17	ns
C18:3 n-3	1.51 ^X	0.90 ^Y	2.04 ^Z	2.17 ^Z	0.24	
C20:0	0.19	0.20	0.20	0.20	0.01	ns
C20:1	0.97 ^{xy}	1.06 ^x	1.04 ^{xy}	0.9 ^y	0.10	
C20:2 n-6	0.49 ^x	0.40 ^y	0.44 ^{xy}	0.40 ^y	0.06	
C20:3 n-6	0.27	0.22	0.26	0.20	0.07	ns
C20:4 n-6	1.75	1.16	1.32	1.15	0.51	ns
C20:5 n-3 EPA	0.30 ^x	0.41 ^{xy}	0.62 ^y	0.32 ^x	0.15	
C22:4 n-6	0.22 ^x	0.11 ^y	0.11 ^y	0.12 ^y	0.04	
C22:5 n-3 DPA	0.55	0.45	0.61	0.46	0.14	ns
C22:6 n-3 DHA	0.21 ^x	0.51 ^y	0.52 ^y	0.19 ^x	0.09	
ΣSFA ²	37.76	39.72	38.41	39.72	0.52	ns
UFA ³	61.95	59.88	61.07	59.72	0.40	ns
ΣMUFA ⁴	43.41	44.98	43.08	43.75	0.64	ns
ΣPUFA ⁵	18.53	14.9	17.99	15.97	0.17	ns
PUFA n-3	2.57 ^X	2.27 ^X	3.8 ^Y	3.15 ^Y	0.15	
PUFA n-6	15.47	12.22	13.75	12.42	1.18	ns
DFA ⁶	75.14	73.89	74.82	74.04	1.30	ns
OFA ⁷	23.99	25.11	24.06	24.81	0.59	ns
UFA/SFA	1.61	1.51	1.59	1.50	0.29	ns
PUFA n-6/PUFA n-3	6.01 ^X	5.38 ^Y	3.60 ^Z	3.95 ^Z		

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²all saturated fatty acids

³ΣPUFA + MUFA

⁴all monounsaturated fatty acids

⁵all polyunsaturated fatty acids

⁶dietary fatty acids having desirable neutral or hypocholesterolemic effect in humans (UFA + C18:0)

⁷dietary fatty acids having undesirable hypercholesterolemic effect in humans (C14:0 + C16:0)

^{x-z}different letters within a row indicate significant differences ($P \leq 0.01$)

^{x-z}different letters within a row indicate significant differences ($P \leq 0.05$)

ns = nonsignificant difference

Table 9. Fatty acids composition (g/100 g FAME) of intramuscular fat in raw *triceps brachii* muscle

Fatty acid	Diets ¹				SEM	Significance
	A	B	C	D		
C10:0	0.1	0.1	0.1	0.1	0.00	ns
C12:0	0.1	0.1	0.1	0.1	0.00	ns
C14:0	0.92	0.92	1.02	1.02	0.08	ns
C15:0	0.1	0.1	0.1	0.1	0.00	ns
C16:0	21.45	21.9	21.4	21.92	0.85	ns
C16:1	2.02	2.21	2.05	2.09	0.24	ns
C17:0	0.21	0.24	0.29	0.22	0.04	ns
C17:1	0.17	0.20	0.20	0.19	0.05	ns
C18:0	13.21	13.46	13.3	13.72	0.60	ns
C18:1	36.58	36.76	35.56	37.78	0.82	ns
C18:2 n-6	17.21	16.1	16.45	14.72	1.90	ns
C18:3 n-3	2.03 ^X	1.14 ^Y	2.77 ^Z	3.16 ^{XZ}	0.32	
C20:0	0.15	0.12	0.10	0.11	0.04	ns
C20:1	0.86 ^X	1.02 ^Y	0.95 ^{XY}	0.84 ^X	0.07	
C20:2 n-6	0.62 ^X	0.51 ^Y	0.52 ^Y	0.55 ^Y	0.08	
C20:3 n-6	0.32 ^X	0.34 ^X	0.27 ^Y	0.24 ^Y	0.05	
C20:4 n-6	1.99 ^X	1.97 ^X	1.76 ^{XY}	1.30 ^Y	0.35	
C20:5 n-3 EPA	0.36 ^X	0.72 ^Y	0.91 ^{Zz}	0.36 ^X	0.12	
C22:4 n-6	0.26 ^X	0.17 ^Y	0.16 ^Y	0.16 ^Y	0.04	
C22:5 n-3 DPA	0.59 ^X	0.77 ^Y	0.84 ^Y	0.56 ^Y	0.07	
C22:6 n-3 DHA	0.24 ^X	0.77 ^Y	0.72 ^Y	0.23 ^X	0.11	
ΣSFA ²	36.19	36.94	36.36	37.25	0.40	ns
UFA ³	63.28	62.71	63.10	62.2	0.35	ns
ΣMUFA ⁴	39.65	40.20	38.67	40.9	0.29	ns
ΣPUFA ⁵	23.64	22.51	24.42	21.3	0.34	ns
PUFA n-3	3.22 ^X	3.41 ^X	5.25 ^Y	4.32 ^Z	0.15	
PUFA n-6	19.78 ^X	18.59 ^Y	18.65 ^Y	16.42 ^Z	0.48	
DFA ⁶	76.49	76.17	76.4	75.92	0.47	ns
OFA ⁷	22.37	22.82	22.37	22.94	0.48	ns
UFA/SFA	1.75	1.70	1.73	1.67	0.27	ns
PUFA n-6/PUFA n-3	6.12 ^X	5.45 ^X	3.57 ^Y	3.81 ^Y		

¹diets: A = 2.5% rapeseed oil and 1% linseed oil, B = 1% rapeseed oil, 2% fish oil + 0.5% lard, C = 2.5% linseed oil and 1% fish oil, D = 2.3% linseed oil, 1% rapeseed oil + 0.2% lard

²all saturated fatty acids

³ΣPUFA + MUFA

⁴all monounsaturated acids

⁵all polyunsaturated fatty acids

⁶dietary fatty acids having desirable neutral or hypocholesterolemic effect in humans (UFA + C18:0)

⁷dietary fatty acids having undesirable hypercholesterolemic effect in humans (C14:0 + C16:0)

^{X-Z}different letters within a row indicate significant differences ($P \leq 0.01$)

^{x-z}different letters within a row indicate significant differences ($P \leq 0.05$)

ns = nonsignificant difference

et al., 2008). Benz et al. (2011) used in the diet a 5% supplement of soybean oil in a period of 25 to 82 days of the pigs' life. In the backfat of animals, the total content of PUFA acids increased from 17.2% (on day 26 of feeding) to 29.6% (on day 82). Koczanowski et al. (2004) determined the fatty acids contents in a variously thick backfat of Landrace × Polish Large White pigs with a body weight of 100 kg. The authors found out that with the increasing backfat thickness (from 12 to 16 mm), the participation of saturated fatty acids went up (from 37.7 to 40.4%), while the share of the polyunsaturated fatty acids decreased (from 16.1 to 12.9%). The authors showed that the backfat of gilts contained less saturated acids (by about 1.22%) and more polyunsaturated fatty acids (by about 1.59%) than the backfat of barrows.

Fatty acids composition (%) of intramuscular fat in the raw *longissimus lumborum* muscle

The level of fatty acids in the intramuscular fat of the raw LL muscle is shown in Table 8. There were no significant differences between the groups in the total content of saturated (SFA, 37.76–39.72 g/100 g), monounsaturated (MUFA, 43.08–44.98 g/100 g), and polyunsaturated (PUFA, 14.9–18.53 g/100 g) fatty acids. However, in groups C and D the PUFA n-6/n-3 ratios significantly lowered (3.60 and 3.95) in comparison with groups A and B (6.01 and 5.38), respectively. In our previous study in (Landrace × Large White) × (Hampshire × Duroc) crossbreeds, when 5% and 7.5% of a linseed oil preparation was added to the feed for 60 days, the ratio of n6/n3 fatty acids in LL muscle was low and amounted to 2.8 and 2.47, respectively (Grześkowiak et al., 2008). In the study by Haak et al. (2008), in the *longissimus thoracis* muscle of pigs fed a diet supplemented with flax seeds (linseed oil), fish oil, and also their mixtures, the ratio of PUFA n-6/n-3 fatty acids amounted to 5.23, 3.03, and 3.74, respectively. It should be noted that in the *longissimus dorsi* (LD) muscle of pigs from different breeds non-supplemented with fats, the ratio of PUFA n-6/n-3 fatty acids was higher and amounted to over 10 (Barowicz and Kędzior, 2000). According to experts of the International Society for the Study of Fatty Acids and Lipids, this ratio in the human diet should be lower than 4 and therefore it is recommended to increase the n-3 group fatty acids and to lower the n-6 group

fatty acids intake. Thus, in our study the feeding regimen of pigs from groups C and D fully met the mentioned standards. Significant differences in EPA and DHA concentration in different feeding schemes were observed. In the TB muscle of group B and group C, EPA concentration was respectively 2 and 3 times higher than in groups A and D. EPA level in the LL muscle was also higher in groups B and C reaching respectively 0.41 and 0.62 g/100 g whereas in groups A and D it was only 0.30 g/100 g. DHA level was also higher in groups B and C. In the LD muscle DHA concentration was more than twice higher than in other groups whereas in the TB muscle and fat it was over 3 times higher.

It could be assumed that the higher DHA and EPA concentrations in the muscles and fat by groups B and C might be caused by codfish liver oil added to the feed (group B – 20 g/kg, group C – 10 g/kg). This fact has been confirmed by a fatty acids profile found in the feed mixture. Guil-Guerrero et al. (2011) reported a relatively high EPA and DHA concentration in Atlantic codfish liver oil reaching 8.9 and 10.7 g/100 g, respectively.

Fatty acids composition (%) of intramuscular fat in the raw *triceps brachii* muscle

The composition of fatty acids in the raw TB muscle is shown in Table 9. There were no significant differences between the groups in the range of the total content of fatty acids of the SFA, MUFA, and PUFA groups. However, a higher (by 5–6 g/100 g) content of PUFA was detected in the raw TB muscle than in the raw LL muscle (Table 8). The contents of PUFA n-3 fatty acids differed significantly between groups, but as concerns the raw LL muscle, a higher content of these acids was detected in all groups of pigs (by 0.65, 1.14, 1.45, and 1.17 g/100 g in group A, B, C, and D, respectively). Simultaneously, a higher content of PUFA n-6 acids was noted in the raw TB compared to the raw LL muscle (by 4.3, 6.37, 4.9, and 4.0 g/100 g in group A, B, C, and D, respectively). It indicates that modifying the profile of fatty acids in the meat of the studied groups seems to be more profitable in the TB than in the LL muscle.

CONCLUSION

The pig feed supplementation with linseed, rapeseed, and fish oils and lard had no significant ef-

fect on the carcass value, physicochemical and sensory traits of meat. However, it was found that different kinds of supplemented fat had different effects on the content of the polyunsaturated fatty acids in backfat and in the raw *longissimus lumborum* muscle. The lowest level of fatty acids characterized the group of pigs fed with supplements of rapeseed, fish oil, and lard. Better results were achieved among fatteners supplemented with linseed. The kind of supplemented fat affected the level of PUFA n-3 fatty acids, especially of the linolenic acid C18:3, which in consequence led to the differentiation between the ratio of n-6 and n-3 acids in backfat. The n-6/n-3 ratio in pigs consuming a larger share of linseed (groups C and D) was better (about 3) than in pigs which obtained a larger portion of rapeseed and fish oils (about 5.5). The higher DHA and EPA concentration in muscles and fat in groups B and C might be caused by codfish liver oil added to the feed.

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