Effect of intensive fattening of lambs with forages on the fatty acid profile of intramuscular and subcutaneous fat

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ABSTRACT: The effect of forage and breed of lambs on the fatty acid profile of intramuscular fat in *m. longissimus lumborum* (*LL*) and depot fat (SCF) above this muscle was investigated. The study was carried out in two replications on 36 Koluda sheep (KS) and Ile de France×KS (IF×KS) ram-lambs fattened intensively to 32–37 kg of body weight. Lambs were fed *ad libitum* the same concentrate mixture and different roughage supplements: grass hay in group C (control), field forage fed in a sheep house in group F, and pasture grazing (4 h/day) in group P. In the case of LL fat, the composition of fatty acids was found to deteriorate in lambs receiving forages compared to lambs from group C. Lambs grazed on pasture (P) had a higher content of LL fat (2.31 and 1.90% in P and C, respectively; $P \leq 0.05$), a higher proportion of SFA (42.1 vs 39.6%; $P \leq 0.01$), a similar proportion of MUFA, and a lower proportion of PUFA (10.4 vs 12.5%; $P \leq 0.05$). With similar content of depot fat, changes in the FA composition of SCF fat were observed in F lambs compared to group C. Compared to C lambs, SCF of F and P lambs contained less SFA (5.16% vs 46.8; $P \leq 0.01$ and 49.3%) and more MUFA (41.8% vs 45.6; $P \leq 0.01$ and 43.6%), with a similar proportion of PUFA and higher CLA content in group P (by 17.8%). The crossing of KS with Ile de France meat rams did not result in any differences in LL fat content, with a generally unfavourable effect on FA composition and health quality parameters calculated on this basis. The present study showed an unfavourable effect of supplemental forage in intensive fattening of lambs on the fatty acid composition of intramuscular fat. However, both variants of forage use had a generally favourable effect on the lipid profile of subcutaneous fat.

Keywords: lambs; fatty acids; intramuscular fat; subcutaneous fat; breed; forages

In terms of health, red meat, which includes lamb, is considered to be a less desirable component of the human diet. It contains relatively high amounts of fat and cholesterol and is characterized by a comparatively less desirable fatty acid profile (unsaturated to saturated fatty acids – UFA:SFA ratio and polyunsaturated to saturated fatty acids – PUFA:SFA ratio), while the n-6:n-3 PUFA ratio, essential for the health quality of meat, usually exceeds the value of 4, which is considered optimal by nutritionists (Bartoň et al., 2007). On the other hand, however, meat fat (intramuscular, intermuscular and subcutaneous fat) is a concentrated source of energy and important bioactive components (e.g. as a carrier of vitamins A, D, E and K) and determines the culinary qualities of meat (flavour, juiciness and aroma) and texture parameters which are no less important to the consumer.

The fatty acid profile is one of the most important determinants of the health quality of meat and it is associated with many of its other components and physicochemical traits. In addition to nutrition, other important factors that modify the quality of lamb, including the lipid profile of fat (intramuscular fat and other depot fats such as subcutaneous or renal fat), are breed or breed origin of sheep, their sex and age (Wood et al., 2008). Breed of lambs determines the rate and amount of fat deposited in muscle tissue and other parts of the body. Depending on the location of adipose tissue in the carcass, fat may differ in fatty acid composition and response to the modification of methods used. It is known that intramuscular fat has a more beneficial lipid profile than subcutaneous and other depot fats (Bas and Morand-Fehr, 2000; Potkanski et al., 2002; Wood et al., 2008). Potkanski et al. (2002) found that feeding vegetable (linseed and rapeseed) oils to fattened lambs had a beneficial effect on the fatty acid profile of intramuscular and subcutaneous fat, but it had no impact on the fatty acid composition of renal fat.

Pasture grazing is the most natural management system for sheep as it provides them with the best welfare conditions while being inexpensive. However, as regards the preferences of some consumer groups, especially those from Europe, slaughter lambs fed extensively on pasture forage achieve poorer weight gains and are not fat enough (Font and Furnols et al., 2008). In the light of most studies (Rowe et al., 1999; Santos-Silva et al., 2002; Momani Shaker et al., 2003; Diaz et al., 2005), fattening of lambs with forages, in particular pasture grazing resulted in a beneficial fatty acid profile of their fat. It was characterized by a higher proportion of PUFA, including n-3 PUFA, α-linolenic C18:3 and EPA C20:5, which are very important for the health quality of meat. A similar effect was observed when hay rich in C18:3 was included in the diet of young cattle and lambs receiving concentrate mixtures (Scollan et al., 2001; Velasco et al., 2001; Nuernberg et al., 2005).

The use of intensive indoor feeding of lambs based on concentrate mixtures fed *ad libitum* results in a high slaughter and culinary value, but it often makes carcass excessively fat, leads to an undesirable increase in the proportion of SFA in fat, and increases n-6/n-3 PUFA beyond recommended values. According to Nuernberg et al. (2005), this state of affairs is caused by the dominance of C18:2n-6 (precursor of n-6 PUFA) in the diet of ruminants receiving a high proportion of cereal grains and seeds of other cultivated plants. For extensive pasture management of sheep, the most popular methods that bring desirable results are additional feeding of concentrates to slaughter lambs on pasture or finishing indoors on concentrates only (Aurousseau et al., 2007).

Based on the above observations, we tested the hypothesis that during intensive fattening of lambs to high weight standards, based on complete concentrate mixture fed *ad libitum*, the addition of forage may favourably modify the fatty acid profile of intramuscular and depot fat. The aim of this study was to determine the effect of indoor feeding of forages and limited pasture grazing on fatty acid composition and the associated health quality parameters of intramuscular (IMF) and subcutaneous (SCF) fat with regard to the breed of lambs.

MATERIAL AND METHODS

Animals and feeding

The study was carried out with ram-lambs of 18 Koluda sheep (OK) and 18 F_1 sheep obtained from Ile de France meat-type rams (IF×OK). There were two replications of fattening (first in 2007, second in 2008), each with 18 lambs, which were assigned, based on the analogue principle, to 3 feeding groups with 6 lambs per group (3 OK and 3 IF×OK). Lambs were fattened in groups from weaning at about 8 weeks of age to 32–37 kg of body weight. All the groups received the same concentrate mixture *ad libitum* (for components see Table 1) and different roughage supplements. Group C (control) received grass hay, group F received field forage indoors (about 50% of rye and 50% of grasses – fescue and ryegrass), and group P was grazed on pasture (natural herbage with a predominance of grasses) for 4 h/day. About 80 to 90 g of roughage (DM basis) per kg of concentrate mixture was supplemented in groups C and F. The amount of concentrate mixture was recorded daily in all groups of lambs, as was hay in group C and forage in group F. Unconsumed feed was weighed twice weekly. The intake of pasture forage by lambs from group P was estimated based on the difference in paddock herbage mass from 4 randomly chosen squares (0.25 m^2) before and after grazing. The content of chemical components and the composition of fatty acids in feeds consumed by the

Table 1. Composition of concentrate mixture, daily consumption, nutritive value and chemical composition of feeds consumed by lambs

	Feeding group					
	C		F		P	
	2007	2008	2007	2008	2007	2008
Ingredient composition of concentrate mixture (g/100 g)						
Ground barley	25					
Ground wheat	25.5					
Dried forage	10					
Dried sugar beet pulp	18					
Rapeseed meal	20					
Mineral mixture	0.5					
Premix C	1					
Daily consumption (kg/animal)						
Concentrate mixture	1.246	1.342	1.256	1.304	1.304	1.312
Grass hay	0.118	0.074	–	–	–	–
Field forage	–	–	0.613	0.428	–	–
Pasture forage	–	–	–	–	0.631	0.559
Daily consumption of dry matter (kg/animal)	1.209	1.267	1.250	1.253	1.309	1.291
Nutritive value of feeds consumed per day						
UFV	1.19	1.23	1.21	1.20	1.27	1.26
PDIE (g)	134.7	139.4	136.9	136.0	143.0	142.3
PDIN (g)	139.9	145.4	142.8	142.2	149.1	147.9
Feed composition (g/100 g DM)						
Crude protein	14.04	13.30	14.60	13.30	14.07	12.83
Crude fat	5.08	3.66	5.50	4.28	4.91	4.20
Fibre	11.69	11.73	12.32	11.80	11.91	11.74
N-free extractives	62.73	64.06	61.17	63.78	63.41	64.21
Crude ash	6.46	7.25	6.41	6.84	5.70	7.02

C – control (concentrate mixture + hay); F – concentrate mixture + field forage; P – concentrate mixture + pasture grazing
UFV – feed units for meat production
PDIE – protein digested in small intestine according to feed energy available in rumen
PDIN – protein digested in small intestine according to nitrogen available in rumen

lambs were determined using medium compound feeds, which were made from samples collected at 7-day intervals (6 series per replication).

The lambs were fattened and slaughtered at the Experimental Station Koluda Wielka of the National Research Institute of Animal Production. The mean body weight of lambs in feeding groups at the start and at the end of fattening was similar (21.5 and 35.5 kg, respectively), with daily gains of 393, 357 and 347 g in groups C, F and P, respectively. Slaughter and separation of loins (saddle) from left half-carcass were performed in accordance with the method of the National Research Institute of Animal Production (Nawara et al., 1963).

Table 2. Fatty acid content in the fatty acid pool of dietary fat and their daily consumption by lambs

	Feeding group					
	C		F		P	
	2007	2008	2007	2008	2007	2008
Content of fat (g/100 g)						
C 14:0	0.61	0.38	0.57	0.39	0.58	0.44
C 16:0	16.37	16.48	16.04	16.08	15.55	16.89
C 16:1	0.85	1.06	1.07	0.65	1.16	0.72
C 18:0	2.09	1.47	1.98	1.33	2.00	1.52
C 18:1 c9	24.65	23.12	24.07	19.99	23.58	20.08
C 18:1 c11	4.73	4.73	4.66	3.96	4.54	3.96
C 18:2	37.60	41.37	37.04	42.21	36.42	41.36
C 18:3	7.94	9.03	9.53	12.43	10.42	12.43
C 20:0	0.43	0.39	0.41	0.38	0.45	0.35
C 20:1	0.80	0.66	0.73	0.64	0.88	0.63
SFA	19.91	19.14	19.45	18.67	19.03	19.61
UFA	76.90	80.24	77.42	80.14	77.35	79.51
incl.: MUFA	31.36	29.84	30.85	25.49	30.51	25.72
PUFA	45.54	50.40	46.57	54.65	46.84	53.79
Daily consumption[a] (g/animal)						
C 14:0	0.36	0.17	0.37	0.20	0.36	0.23
C 16:0	9.61	7.31	10.54	8.24	9.55	8.75
C 16:1	0.50	0.47	0.70	0.33	0.71	0.37
C 18:0	1.23	0.65	1.30	0.68	1.23	0.79
C 18:1 c9	14.47	10.26	15.82	10.25	14.49	10.41
C 18:1 c11	2.78	2.10	3.06	2.03	2.79	2.05
C 18:2	22.08	18.35	24.34	21.64	22.38	21.44
C 18:3	4.66	4.01	6.26	6.37	6.40	6.44
C 20:0	0.25	0.17	0.27	0.19	0.28	0.18
C 20:1	0.47	0.29	0.48	0.33	0.54	0.33
SFA	11.69	8.49	12.78	9.57	11.69	10.16
UFA	45.15	35.59	50.88	41.09	47.53	41.21
incl.: MUFA	18.41	13.24	20.28	13.07	18.75	13.33
PUFA	26.74	22.36	30.61	28.02	28.78	27.88

SFA – Σ C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0; MUFA – Σ C14:1, C16:1 C17:1, C18:1, C20:1; PUFA – Σ C18:2 and C18:3; UFA = MUFA + PUFA

[a]daily consumption of dry matter × fat content × fatty acid content × 0.956 (Weihrauch et al., 1976)

Sampling

Samples of *m. longissimus lumborum* (*LL*) and the overlying SCF were taken for chemical analysis. A part of fresh *LL* was assayed for intramuscular fat content (IMF) using the method of Soxhlet according to the Polish Standard PN-73/A-82111. Thickness of subcutaneous fat was measured at

the thickest area over the ribs, at the cross-section behind the last rib. The other *LL* and SCF fragments were vacuum packed and frozen at –20°C until analysis of the fatty acid composition.

Analyses

The nutritive value of the compound feeds (Table 1) was calculated based on tabular values from IZ PIB-INRA (2009) standards. The basic chemical composition of compound feeds was determined using standard methods. The fatty acid composition of fats from compound feeds was determined according to procedures developed by Kramer et al. (1997) with modifications of Borys et al. (1999). Fat from feeds was extracted with a mixture of chloroform/methanol (2:1). A gas chromatograph (Agilent Technologies, model 6890N) with a flame-ionization detector and a BPX70 capillary column (60 m × 0.22 mm × 25 μm) were used.

After thawing, ground *LL* and SCF samples (100 mg) were extracted according to a modified version of the method described by Folch et al. (1957). Fatty acids were esterified according to AOAC procedure (1995). Separation and quantitative determination of individual fatty acids were performed using a TRACE GC ULTRA gas chromatograph equipped with a SUPELCOWAX 10 column (30 m × 0.25 mm × 0.25 μm) with helium as the carrier gas (flow rate 7.5 ml/min).

The results were analysed statistically (STATISTICA 8.0, 2008) by a three-way analysis of variance (feeding method, breed, year), using the orthogonal model with first-degree interactions. Duncan's test was used to compare the differences at a significance level $P = 0.05$ and $P = 0.01$. For health quality parameters of the analysed fat the index of atherogenicity (IA) and the Δ9 – desaturase index (Σ Δ9 index) were calculated (Ulbricht and Southgate, 1991; Korniluk et al., 2008).

RESULTS AND DISCUSSION

Feed and nutrient consumption

With the use of the same concentrate mixture given *ad libitum* (Table 1) in all groups of lambs and different roughage supplements, mean daily consumption of the mixture was similar in the groups. Clear differences were found in daily consumption of roughage, which was used to improve the ration structure and to modify the health quality of meat. In the control group (C), lambs consumed 60% more hay during the first year of fattening compared to the second, with 7.2% lower consumption of concentrate mixture. These differences could be due to differences in hay quality between the first and second year of the study. Also in the groups supplemented with forage, considerable differences were observed between both groups and years. With a similar consumption of field (group F) and pasture forage (group P) in the first year, the consumption of field forage (group F) in the second year was much lower than in group F in the first year (by 30.2%) and compared to the consumption of pasture forage in group P in the second year (by 23.4%). In group F, the much lower consumption of forage in the second year was paralleled by 3.8% higher consumption of concentrate mixture.

The nutritive value of medium compound feeds consumed per day by lambs from groups C and F was very similar, and in group P it was higher, by 4.0% for UFV (feed units for meat production) and by 4.1% for PDIE (protein digested in small intestine according to feed energy available in rumen) and PDIN (protein digested in small intestine according to feed nitrogen available in rumen) (Table 1). In the feeding groups compared, the consumption of basic feed ingredients was similar except the consumption of fat in the groups fed forage. Compared to group C, daily consumption of fat per dietary dry matter was 11.9% higher in group F and 4.1% higher in group P.

Marked differences in the fatty acid composition of fats from compound feeds consumed by the lambs from different groups occurred only for the content of linolenic acid C18:3, especially in the second year (Table 2). More of this acid was found in fat from forage feeds F and P compared to C, on average by 2.50 and 2.94 percentage units (p.u.), respectively. Overall, compared to C feeds, the fat from forage feeds contained more PUFA (50.46 vs. 47.97% on average), less total monounsaturated acids (MUFA) (28.14 vs 30.60%), and a similar level of SFA. In the second year of fattening, the fat from all compound feeds contained more PUFA than in the first year, and the differences in forage groups were much higher than in group C. These differences were most likely due to variation in the fatty acid profile of the feed ingredients, in particular forages, which were a part of the feeds in the first and second year of the study.

Differences in the fat content of compound feeds and in the fatty acid composition of their fat caused that lambs from the forage-fed groups consumed more PUFA than lambs from group C receiving hay (Table 2). On average for both years, differences in PUFA consumption between experimental groups F and P and group C were 19.4 and 15.4%, respectively, including 13.8 and 8.4% for C18:2 and as much as 45.7 and 48.3% for C18:3. The generally lower consumption of fatty acids by lambs in the second year of fattening is also worth noting, with larger differences in MUFA, the consumption of which was on average 31.0% lower than in the first year.

The lower fat content of dry matter in C feed compared to forage feeds is supported by Jankowska-Huflejt and Wrobel (2008), who studied the chemical composition and nutritive value of forages and hay and found that in terms of dry matter, pasture forage contained 25.7% more crude fat compared to hay (39.6 vs 31.5 g/kg DM; means from a total of 100 samples). Meanwhile, clear differences in the content of linolenic acid C18:3 are supported by the observations of Matthes et al. (1996), who found that fat from grass forage contained twice as much C18:3 acid compared to fat from hay and concentrate mixture.

Intramuscular fat (IMF)

Out of the analysed factors, only the grazing of fattened lambs on pasture caused marked differences in the level of fat in muscle tissue (Table 3). The muscles of P lambs contained 21.6% more fat compared to C lambs ($P \leq 0.05$) and 15.5% more fat than F lambs ($P \leq 0.10$). On average in both years, lambs from the breed groups (B) compared had a similar IMF content, but in the first and second year (Y) differences in the marbling of muscles from KS and IF×KS lambs were pronounced (27 and 37%, respectively) and inverse, which caused a statistically significant B×Y interaction ($P \leq 0.01$).

The intramuscular fat content of lamb meat depends on both the feeding method and the breed of lambs, and the effect of these factors can be modified in different ways (Kedzior, 2005). In general, the IMF content of the analysed lambs was in the range of optimum values for lamb meat (1.5 to 2.5%). Similar values for intensively fattened lambs of different breeds and crossbreds were obtained by Borys and Borys (2001), Ciuryk and Kaczor (2001) and Grzeskowiak et al. (2003). The available literature reports inconsistent data concerning the effect of forage (pasture) feeding on the fat content of lamb meat. Most studies compared extensive pasture management with intensive indoor fattening or supplementation of concentrates to pasture-fattened lambs. No studies are available to discuss the present results of intensive fattening using supplemental forage to improve the ration structure or dietetic quality of meat. The overwhelming majority of studies and review papers take the view that meat fatness (both IMF and SCF) is lower when fattening is based on pasture compared to concentrate feeding (Sanudo et al., 1998; Rowe et al., 1999; Kedzior, 2005). One study showed that the muscle tissue of Weisse Alpenschaf lambs fattened extensively on pasture contained more fat than that of lambs of the same breed fattened intensively indoors (Dufey and Wirz, 1995).

Both groups of forage-fattened lambs were characterized by a general deterioration in the fatty acid composition of intramuscular fat in relation to group C (Table 3). With similar types of changes in the fatty acid profile of IMF from F and P lambs, statistically significant differences in relation to group C were found for pastured lambs. The fat of P lambs contained more SFA (by 2.54 p.u.; $P \leq 0.01$) and less PUFA (by 2.06 p.u.; $P \leq 0.01$), with a similar MUFA percentage. Compared to C lambs, the fat of P lambs had a significantly higher proportion of C14:0, C16:0 and C16:1 and less C20:4 and C20:5.

As for the fatty acid composition, the intramuscular fat of F lambs differed more markedly in relation to P lambs than C lambs. No significant differences were found in the percentage of analysed fatty acids in IMF between groups F and C, with significant differences between groups F and P in the content of C14:0, C16:0, C17:1 and C22:5 (Table 3).

Health quality parameters of muscle tissue, calculated from the fatty acid composition of IMF (Table 5), were the most favourable for lambs from group C, followed by F lambs supplemented with field forage, and pastured lambs (P). In the IMF of F and P lambs in relation to C lambs, statistically significant differences or clear tendencies were observed for poorer UFA:SFA (by 5.0 and 10.5%), PUFA:SFA (by 13.5 and 21.1%) and DFA:OFA ratios (hypocholesterolaemic to hypercholesterolaemic fatty acids) (by 6.1 and 12.5%, respectively), with an unfavourably lower content of n-3 PUFA (by 8.2 and 14.2%) and a higher index of atherogenicity (IA) (by 6.4 and 15.6%, respectively). Compared to

Table 3. Fat content and fatty acid composition of the fatty acid pool in intramuscular fat; (%)

Trait	Nutrition (N)			Breed (B)		Effect of year (Y)	SEM
	C	F	P	KS	IF×KS		
n	12	12	12	18	18		
Fat (g/100 g)[2]	1.90[a]	2.00[α]	2.31[aα]	2.05	2.09	NS	0.086
SFA[2]	39.56[A]	40.70[α]	42.10[Aα]	39.89[A]	41.68[A]	*	0.431
Incl.: C14:0[4]	2.00[A]	2.13[B]	2.49[AB]	2.09[a]	2.32[a]	**	0.085
C16:0[3]	22.02[Aα]	22.91[aα]	24.00[Aa]	22.44[A]	23.52[A]	NS	0.267
C17:0	0.92	1.01	0.98	0.98	0.96	**	0.023
C18:0	13.95	13.93	13.86	13.66	14.17	NS	0.201
UFA[1]	59.34[A]	58.10[a]	56.61[Aa]	58.85[A]	57.18[A]	*	0.450
Others	1.1	1.2	1.29	1,26	1.14	NS	0.056
MUFA	46.88	47.00	46.21	46.58	46.81	NS	0.376
Incl.: C16:1	2.12[a]	2.22	2.32[a]	2.15[a]	2.29[a]	**	0.037
C17:1[3]	0.67[b]	0.73[ab]	0.66[a]	0.68	0.69	NS	0.028
C18:1c	43.83	43.79	42.98	43.49	43.58	NS	0.364
PUFA[4.5]	12.46[a]	11.11	10.40[a]	12.27[a]	10.37[a]	*	0.442
Incl.: C18:2[4.5]	6.48	5.83	5.76	6.40[a]	5.65[a]	NS	0.222
C18:3	0.53	0.53	0.54	0.56[α]	0.51[α]	NS	0.016
C20:4[4]	3.34[A]	2.91[α]	2.47[Aα]	3.28[A]	2.53[A]	*	0.147
C22:5[4]	0.59[A]	0.50[a]	0.46[Aa]	0.58[A]	0.46[A]	NS	0.024

KS – Koluda sheep, IF×KS – F_1 sheep from Ile de France × KS; SEM – standard error of the mean, values in the same row and section with the same index are significantly different: $^{AA}P \leq 0.01$; $^{aa,bb}P \leq 0.05$; $^{\alpha\alpha}P \leq 0.10$; effect of year: NS – not significant; $^{**}P \leq 0.01$, $^{*}P \leq 0.05$; significant interactions: [1]N × B and [2]B × Y at $P \leq 0.01$; [3]N × B and [4]N × Y and [5]B × Y at $P \leq 0.05$
SFA – ∑ C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0 and C24:0; UFA = MUFA + PUFA, MUFA – ∑ C14:1, C16:1, C17:1, C18:1c, C20:1 and C24:1; PUFA – ∑ C18:2, CLA, C18:3, C20:2, C20:3, C20:4, C20:5, C22:4, C22:5 and C22:6

group C, Δ9-desaturase index in group P decreased by 3.3% ($P \leq 0.05$). However, both forage-supplemented groups showed a favourable tendency towards a narrower n-6:n-3 PUFA ratio, by 4.4% in group F and by 5.3% in group P.

The feeding system had no significant effect on CLA (conjugated diene of linoleic acid) percentage in the pool of IMF fatty acids. However, with the higher content of intramuscular fat in pastured lambs, the absolute value of this component in the muscles of P lambs was significantly higher (by 31% on average) than in groups C and F.

The changes in the composition of fatty acids and the resultant deterioration of associated health quality parameters of muscle tissue from lambs receiving both forage supplementation variants were probably due to greater marbling of muscles and the associated higher saturation of fatty acids (Wood et al., 2008). One of the reasons for the higher deposition of fat in *LL* muscle of F and P lambs compared to C lambs could be the higher consumption of fat in the dry matter of feeds (Table 1). However, this does not completely explain the differences in IMF content, because differences in the consumption of this component between lambs from group F and C were more than twice larger than those between group P and C.

The breed also caused differences in the fatty acid composition of intramuscular fat and the analysed health quality parameters of muscle tissue (Tables 3 and 5). The fat of IF×KS lambs had a less favourable composition of fatty acids compared

Table 4. External fatness of carcass and fatty acid composition of the fatty acid pool in subcutaneous fat; (%)

Trait	Nutrition (N)			Breed (B)		Effect of year (Y)	SEM
	C	F	P	KS	IF×KS		
Fat layer over the ribs (mm)	4.02	3.96	4.00	3.77	4.21	NS	0.258
SFA	$51.63^{A\beta}$	$46.76^{A\alpha}$	$49.33^{\alpha\beta}$	50.26^{α}	48.22^{α}	NS	0.650
Incl.: C14:0 [4]	3.81	3.11	3.77	3.84^{α}	3.29^{α}	NS	0.181
C15:0	0.71	0.84	0.78	0.84^{α}	0.72^{α}	**	0.037
C16:0[4]	23.85^{α}	$22.52^{A\alpha}$	24.56^{A}	23.64	23.64	NS	0.333
C17:0[3.4]	2.00^{A}	2.43^{Aa}	2.09^{a}	2.18	2.17	*	0.072
C18:0	20.55^{ab}	17.32^{a}	17.43^{b}	19.03	17.84	**	0.626
UFA	$46.05^{A\alpha}$	49.86^{A}	48.16^{α}	46.87^{a}	49.18^{a}	NS	0.552
Others	2.32	3.38	2.51	2.87	2.6	NS	0.074
MUFA	41.81^{A}	$45.55^{A\alpha}$	43.56^{α}	42.53^{a}	44.74^{a}	NS	0.552
Incl.: C16:1	2.40^{ab}	2.85^{a}	2.84^{b}	2.52^{a}	2.88^{a}	**	0.903
C17:1	$0.78^{A\alpha}$	1.13^{A}	0.97^{α}	0.93	0.99	**	0.060
C18:1 c	38.22^{A}	41.17^{Aa}	39.35^{a}	38.67^{a}	40.48^{a}	*	0.464
PUFA[5]	4.25	4.31	4.60	4.34	4.43	*	0.119
Incl.: C18:2[2]	3.23	3.26	3.49	3.26	3.39	NS	0.096
C18:3[5]	0.56	0.58	0.58	0.58	0.56	NS	0.018

values in the same row and section with the same index are significantly different: $^{AA}P \leq 0.01$; $^{aa}P \leq 0.05$; $^{\alpha\alpha,\beta\beta}P \leq 0.10$; effect of year: $^{**}P \leq 0.01$, $^{*}P \leq 0.05$; NS – not significant; significant interactions: [2]B × Y at $P \leq 0.01$; [3]N × B and [4]N × Y and [5]B × Y at $P \leq 0.05$

SFA – Σ C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0 and C20:0; UFA = MUFA + PUFA, MUFA – Σ C14:1, C15:1, C16:1, C17:1, C18:1T, C18:1C and C20:1; PUFA – Σ C18:2, C18:3, C20:2, C20:3, C20:4, C20:5, C22:4, C22:5 and C22:6

to the milk-prolific line of Koluda sheep (KS) as it contained significantly more SFA (by 1.79 p.u.; $P \leq 0.01$) and less PUFA (by 1.90 p.u.; $P \leq 0.05$), with a similar percentage of MUFA. Fat from IF×KS lambs contained significantly more C14:0, C16:0 and C17:1 and less C18:2, C20:4 and C22:5 than the fat from KS lambs. In general, most of the analysed health quality parameters of meat, based on the fatty acid profile of IMF, followed a more favourable pattern in KS lambs than in IF×KS rams. Compared to IF×KS lambs, the muscle tissue of KS lambs had higher UFA:SFA, PUFA:SFA and DFA:OFA ratios and a higher n-3 PUFA content (by 8.3, 25.2 and 7.6%, and by 0.24 p.u.), with a favourably lower index of atherogenicity (IA) (by 7.0%; $P \leq 0.01$). The breed of lambs did not cause any significant differences in n-6:n-3 PUFA, CLA content and Δ9-desaturase index.

In the available literature, there are no consistent data to show the direct effect of sheep breed on the fatty acid composition of their meat. A marked deterioration in the lipid profile of intramuscular fat from Ile de France ram-lambs compared to Suffolk, Finnsheep, East Friesian and in particular Texel was reported by Borys and Borys (2002) for animals fattened intensively to 40–45 kg of final body weight, but this was due to the highest marbling in Ile de France lambs. However, the differences found in the profile of fatty acids depending on the breed of lambs cannot be linked directly to the IMF content, which was similar in both breed groups (Table 3).

The year of fattening caused significant differences in the percentage of some fatty acids and in the majority of analysed health quality parameters of meat (Tables 3 and 5). There were relatively many

Table 5. Health quality parameters of *LL* and subcutaneous fat based on the FA profile

Trait	Nutrition (N)			Breed (B)		Effect of year (Y)	SEM
	C	F	P	KS	IF×KS		
***LL* fat**							
UFA:SFA[1]	$1.510^{A\beta}$	$1.434^{\alpha\beta}$	$1.352^{A\alpha}$	1.489^{A}	1.375^{A}	*	0.026
PUFA:SFA[4.5]	$0.318^{A\alpha}$	0.275^{α}	0.251^{A}	0.313^{A}	0.250^{A}	*	0.078
DFA:OFA[3]	2.877^{Ab}	2.701^{ab}	2.517^{Aa}	2.797^{A}	2.600^{A}	**	0.048
PUFA n-3 (%)[5.6]	1.34	1.23	1.15	1.36^{A}	1.12^{A}	NS	0.050
PUFA n-6:n-3	8.255	7.890	7.818	7.826	8.149	**	0.191
CLA; (%) FA	0.44	0.43	0.48	0.47	0.43	**	0.020
– mg/100 g tissue	8.37a	8.40^{b}	10.97^{ab}	9.26	9.23	*	0.518
IA[1.4]	0.409^{Aa}	0.435^{Ba}	0.473^{AB}	0.423^{A}	0.455^{A}	**	0.009
Σ Δ9 index[1]	0.548^{a}	0.542	0.530^{a}	0.545	0.534	NS	0.004
Subcutaneous fat							
UFA:SFA	$0.900^{A\beta}$	$1.072^{A\alpha}$	$0.986^{\alpha\beta}$	0.943^{a}	1.029^{a}	NS	0.023
PUFA:SFA[2]	0.083	0.093	0.094	0.087	0.093	NS	0.003
DFA:OFA	2.159	2.301	2.098	2.144	2.229	*	0.053
PUFA n-3 (%)[7]	0.39	0.41	0.43	0.41	0.41	NS	0.014
PUFA n-6:n-3	$8.968^{A\beta}$	$8.447^{A\alpha}$	$8.540^{\alpha\beta}$	8.528	8.776	**	0.174
CLA (%)	0.45	0.47	0.53	0.49	0.48	*	0.026
IA	0.613^{a}	0.522^{ab}	0.604^{b}	0.602	0.557	NS	0.016
Σ Δ9 index	$0.460^{A\alpha}$	0.508^{Aa}	$0.481^{a\alpha}$	0.472^{a}	0.494^{a}	NS	0.006

values in the same row and section with the same index are significantly different: $^{AA,BB}P \leq 0.01$, $^{aa,bb}P \leq 0.05$, $^{\alpha\alpha,\beta\beta}P \leq 0.10$; effect of year: $^{**}P \leq 0.01$, $^{*}P \leq 0.05$; NS – not significant; significant interactions: [1]N × B and [2]B × Y at $P \leq 0.01$; [3]N × B, [4]N × Y and [5]B × Y at $P \leq 0.05$

DFA (hypocholesterolaemic fatty acids) = UFA + C18:0; OFA (hypercholesterolaemic fatty acids) = SFA – C18:0; PUFA n-6 – Σ C20:2, C20:4 and C22:4; [6] PUFA n-3 – Σ C18:3, C20:5, C22:5 and C22:6; [7] PUFA n-3 – C18:3, IA (index of atherogenicity) = (Σ C12:0, C14:0 and C16:0)/UFA, Σ Δ9 index = (Σ cis9: C14:1, C16:1 and C18:1)/(Σ cis9: C14:0, C14:1, C16:0, C16:1, C18:0 and C18:1)

different first-degree interactions showing the interaction of the analysed treatment factors for the analysed traits.

Subcutaneous fat (SCF)

With similar subcutaneous fat content of carcasses, measured over the ribs (4.0 mm on average), more pronounced changes in the fatty acid composition of this fat in comparison with the control group (C) were observed in lambs receiving field forage (F) compared to pastured lambs (P) (Table 4). SCF fat from F and P lambs compared to C lambs contained less SFA and more MUFA, with a similar PUFA content. Respective differences in SFA and MUFA content were 4.87 and 3.74 p.u. ($P \leq 0.01$) for F lambs, and 2.30 and 1.75 p.u. ($P \leq 0.10$) for P lambs. Similar differences were determined in the content of individual fatty acids except palmitic acid C16:0, which was most abundant in fat from P lambs, i.e. 2.04 p.u. more ($P \leq 0.01$) than in fat from F lambs.

Unlike intramuscular fat, depot fat of lambs from both groups receiving forage was characterized by more favourable health quality parameters compared to group C (Table 5). For most health quality

parameters analysed, the best results were obtained by lambs from group F, which, in several cases, were significantly better than those from group C and P. Statistically significant differences or clearly beneficial trends in both groups receiving forage were found for the UFA:SFA, PUFA:SFA and n-6: n-3 PUFA ratios. SCF fat from F lambs compared to C and P lambs had more beneficial indices of IA and Δ9-desaturase. Pastured lambs (P) tended to have a higher CLA content than C and F lambs, by 15.2% on average ($P \geq 0.01$).

The effect of forage feeding on the fatty acid profile of subcutaneous fat is supported by the results of other studies, in which pasture fattening was most often compared with concentrate feeding indoors (Sanudo et al., 1998; Bas and Morand-Fahr, 2000; Nuernberg et al., 2005). The greater changes in the composition of fatty acids in F than P lambs compared to control lambs were due to the fact that differences in fat consumption (with modified composition of FA, Table 2) between group F and C were much higher than between group P and C, on average by 11.9 and 4.1% in the first and second year, respectively (Table 1). In the light of our results, Jenkins and Lundy (2001) seemed justified in concluding that in ruminants the quality of food products (meat and milk) is dependent rather on the amount of fatty acids in dietary fat than on their percentage composition.

The varying effects of forage supplements used for lamb fattening on the lipid profile of intramuscular fat (generally unfavourable) and subcutaneous fat (favourable), observed in the present study, are not confirmed by the available literature. This could be due to different metabolism of fatty acid synthesis and deposition depending on the location of adipose tissue. This hypothesis was corroborated by Wood et al. (2008), who reported that ruminants show the preference of incorporation of metabolically important fatty acids into muscle tissue rather than to their storage in depot fats. The fact that subcutaneous fat was more susceptible to the analysed treatment factor than intramuscular fat was also observed in another study in which lambs received oil components, rapeseed cake and linseed (Borys et al., 2009). This is probably due to the fact that the fatty acid composition of intramuscular fat is, by its very nature, more favourable in terms of health compared to subcutaneous fat and thus less susceptible to health-promoting modifications by nutritional factors. The differences observed in the lipid profile of intramuscular and subcutaneous fat depending on the breed of lambs are difficult to interpret conclusively based on the analysed fatness parameters, intramuscular fat content and measurement of fat layer over the ribs. It can be assumed that the expression of the effect of breed factor on the analysed traits was largely modified by many interactions between breed, nutrition and replication of the experiment, which were particularly numerous for intramuscular fat.

Crossing of KS sheep with Ile de France rams had no significant effect on the degree of external fatness, with a tendency towards higher external fatness in the crossbreds (by 11.7%) (Table 4). Nonetheless, the pool of SCF fatty acids from IF×KS lambs showed a tendency towards a lower percentage of SFA compared to KS lambs (by 2.04 p.u.; $P \leq 0.10$), with a significantly higher content of MUFA (by 2.21 p.u.; $P \leq 0.05$) and a similar content of PUFA. In the group of saturated acids, the crossbreds showed a clear tendency towards a lower content of C14:0, C15:0 and C18:0 acids, with an unchanged level of palmitic acid C16:0. Out of MUFA acids, the content of dominant oleic acid C18:1 was significantly higher (by 1.81 p.u.; $P \leq 0.05$), with a 0.36 p.u. lower content of C16:1 ($P \leq 0.05$). Overall, the depot fat of crossbred lambs was characterized by more favourable health quality parameters compared to lambs of the milk-prolific line of Koluda sheep (Table 5). Significant differences between IF×KS and KS were found in the UFA:SFA ratio and in the Δ9-desaturase index (higher by 9.1 and 68.2%, respectively; $P \leq 0.05$), with favourable trends of the PUFA:SFA ratio (higher by 6.9%) and the index of atherogenicity (lower by 7.5%).

Replications of the experiment revealed significant differences in the percentage of some fatty acids in SCF fat and in the values of several health parameters. There were statistically significant first-degree interactions resulting mainly from changes in the response of lambs representing different feeding groups and different breeds to the conditions of experimental fattening in successive years. Relatively many interactions, with a three-factorial design of the experiment and rather small number of animals, make it difficult to evaluate the effects of the main treatment factor (feeding forage supplements to fattened lambs).

CONCLUSION

The present study found an unfavourable effect of forages added to the diets of intensively fattened

lambs and of the commercial crossbreeding scheme on the fatty acid composition of intramuscular fat, with a weaker effect of limited pasture grazing compared to field forage supplementation.

Both variants of forage use in lamb fattening had a positive effect on the lipid profile of subcutaneous fat, with more beneficial results obtained when field forage was used in the sheep house compared to limited grazing.

Crossing of the milk-prolific line of Koluda sheep with Ile de France meat-type rams had a negative effect on the fatty acid profile of intramuscular fat and a positive effect on depot fat.

The varying and partly surprising effects of both experimental factors, observed for the fats compared and in successive replications of fattening, should be validated by further research.

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