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Lipid profile of intramuscular fat in lamb meat

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Lipid profile of intramuscular fat (IMF) from *semitendinosus* muscle of lambs was examined in relation to the intensity of fattening system, animals' final body weight and sex. Conducted were two repeations of fattening (2 x 32 lambs) each based on intensive (IN, 16 lambs) *vs.* semi-intensive (SIN, 16 lambs) feeding system, continued up to lower *vs*. higher slaughter weight, and with reference to sex. Owing to a higher content of C18:0 and polyunsaturated fatty acids (PUFA) the IMF of IN lambs showed more favourable lipid profile than that of SIN animals. More favourable FA profile was recorded of the IMF from the lambs fattened to lower weight categories in comparison to those fattened to higher categories of weight (higher PUFA content). When fattening the rams to higher body weight than the ewes, it was found that their IMF was distinguished by more favourable parameters of health quality (more C18:0 and PUFA). The system of fattening, final weight category and sex did not differentiate CLA and cholesterol content of the IMF examined. The IMF had distinctly more favourable fatty acid profile as compared to the non-tissue depot fats, *i.e.* external and intermuscular. In the studies on the improvement of health quality of meat, the optimization of the participation of the particular types of fat tissue in culinary cuts of the carcass should be considered.

KEY WORDS: cholesterol / CLA / fattening / fatty acid profile / intramuscular fat / lamb / meat

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Animal production science is faced with the serious challenges and explanations of the conditions and mechanisms, shaping the health quality of food products of animal origin, and development of natural methods for their modification, being favourable from the consumer's point of view.

The rumen bacteria are able to transform directly the alpha linoleic acid into stearic and palmitic acids [Boles *et al*. 2005]. With this specificity, the dietary contributions rich in polyunsaturated fatty acids (PUFA) largely influence the content of linolenic acid of ruminant meats [Wachira *et al*. 2002, Meane *et al*. 2002]. In fact, the introduction of linseed into the diet of growing lambs significantly increased C18:3 level of meat [Normand *et al*. 2007]. In the same way, Nurnberg *et al.* [1998] found that the oilseed rape cake supply leads to increase the content of C18:3 and their long-chain counterparts in the muscle of lamb with proportions multiplied by 2.4 for C18:3, 3.5 for C20:5 and 1.8 for C22:5. Geay *et al*. [2002] reported that the carcasses of lambs raised on the pasture presented a higher percentage of C18:3 in their muscles compared to those with diets containing concentrates.

Physiological diversity of processes of depositing the particular types of fat tissues in animal organism and their other life functions cause that the so-called reserve fats (external and intermuscular fat) differ distinctly in the composition of fatty acids from the intramuscular fat. Significant differences in the composition and different location of the mentioned fat tissues in meat cause that they have a different meaning for culinary and dietetic quality of the meat. Quantitative proportions of the particular types of fat tissues in the body of animals and lipid profile are subject to big changes with time (age and physiological state of animals, season of the year, *etc*.) as well as in relation to genetic and numerous environmental factors. Due to the differences in lipid composition and functional role of intramuscular fat as compared to the main reserve fats of animal carcasses, situated outside the muscular tissue, the discussion of the results of the conducted studies in separate research papers has been considered as justified.

In this paper the results of the research on lipid profile of intramuscular fat of the lambs are presented, as obtained on the same animals and resulting from the same experimental design as described by Borys *et al.* [2011].

Material and methods

The lambs were maintained and their carcasses prepared at the Experiment Station Kołuda Wielka of the National Research Institute of Animal Production, Cracov, while the determination of fatty acid profile was carried out at the Meat and Fat Research Institute in Warsaw.

The animal material consisted of 64 crossbred lambs, coming from commercial crossing of Suffolk rams with prolific Merinofin Mf-40 ewes. Fattening of lambs started after weaning, at their mean age of 8 weeks. Management and feeding of the lambs followed the system earlier employed by Borys *et al.* [2011] .

During fattening, the lambs were fed according to the standards of the National Research Institute of Animal Production [Osikowski *et al.* 1998]. The restricted feeding system was employed: one meal a day for 6 week-days without a meal on Sunday. The lambs were kept in pens with the slot floor and constant access to water and salt licks.

The IN lambs were fed *ad libitum* the full-ration diet (+ 100 g hay per each kg of the mixture offered). SIN animals were fed using standardized feeding based on roughages and mixture of concentrate.

Composition and nutritive value of full-ration diet in IN and SIN animals were described by Borys *et al*. [2008]. Slaughtering of lambs, dissection of the right carcass-side into cuts and detailed dissection of the leg were carried out according to the National Research Institute of Animal Production [Nawara *et al*. 1963]. Fatty acid profile (including CLA content within the frames of the second repeation) and cholesterol content were determined in the intramuscular fat (IMF), extracted from *m. semitendinosus*.

Cholesterol content was determined using gas chromatograph HEWLETT PACKARD 5890 sII with flame-ionization detector, on HP-1 column, 25 m x 0.20 mm x 0.11 μm. The respective determinations of fatty acid profile were performed according to Kramer *et al*. [1997], with modifications introduced by Borys *et al.* [1999]. Gas chromatograph by HEWLETT PACKARD model 6890 with flame-ionization detector and Rtx-2330 column 105 m x 0.25 mm x 0.20 μm was used.

Statistical analysis of the results was carried out using Statistica 8.0 package with the application of ANOVA procedure in orthogonal four-factor system: fattening system, weight standard, sex and repeation. Interactions of the first degree were considered.

Results and discussion

The fattening system affected significantly the content of single fatty acids as well as values of part of the parameters of health quality of intramuscular fat (Tab. 1, 2 and 3). IMF of the IN comparing to SIN lambs, contained significantly less C18:0, and more C17:0. Regarding unsaturated acids IMF of IN group contained more C18:1c9, C18:1c11 and C18:3 than IMF of SIN group. In total, IMF from IN as compared to that from SIN lambs contained significantly less saturated (SFA) and more unsaturated (UFA) fatty acids. As related to this, it had more favourable UFA : SFA ratio (by 9.6% higher, $P \leq 0.01$), with higher content of monounsaturated fatty acids – MUFA (by 22.4%, $P \leq 0.01$) as well as of PUFA (by 11.7%, ns). Owing to this, the tendency occurred to favourably higher PUFA : SFA ratio (by 7.9%, ns) in the IMF of IN lambs. In the IN, as compared to SIN fattening, the favourable tendency to higher content of acids n-3 (by 14.3%, ns) as well as significant lowering of thrombosis risk index (IT) by 10.1% ($P \leq 0.001$) was also identified. On the other hand, the system of fattening did not differentiate more distinctly the n-6 : n-3 ratio and CLA and cholesterol content in the IMF examined.

Table. 1. Fatty acids content of intramuscular fat of *semitendinosus* muscle in lambs (g/100g)

Item	SFA	C14:0	C16:0	C17:0	C18:0
Fattening system					
IN	41.64	3.36	22.06	2.17	12.87
SIN	43.85	3.46	22.42	1.95	14.85
Weight category					
L	42.09	3.36	21.87	1.96	13.74
H	43.39	3.46	22.61	2.16	13.98
Sex					
rams	42.31	3.28	21.48	2.09	14.28
ewes	43.18	3.54	22.93	2.04	13.44
Significance of differences between					
fattening systems (F)	xx	ns	ns	xx	xxx
weight categories (W)	ns	ns	xx	ns	ns
sexes (S)	ns	ns	xx	ns	xx
repeations (R)	ns	ns	ns	ns	xx
Interaction	ns	ns	ns	ns	WxR^{xx}
SEM	0.278	0.117	0.197	0.041	0.246

Fattening system: IN – intensive, SIN – semi-intensive; Weight category: L – low, H – high.
SEM – standard error of the mean, xxx – P≤0,001, xx – P≤0.01, x – P≤0.05; ns – not significant. SFA = Σ C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0.

Body weight category of the lambs differentiated the content of most of the analysed fatty acids of the examined fat distinctly. In the IMF of H lambs there were more SA (C16:0 and C17:0) and MUFA (C17:1 and C18:1c9). The mentioned differences were partially significant – Table 1 and 2. On the other hand, the fat of the lambs fattened to lower weight categories (L) contained significantly more vaccenic acid C18c11 and PUFA: C18;2, C18;3 and C20:4, being very favourable from the health point of view. In total, however, the body weight category of the lambs did not differentiate significantly the total content and SFA : UFA ratio, with the tendency of more favourable parameters in L lambs. Univocal differentiation of the content of individual PUFA has been reflected in significantly higher PUFA content and higher PUFA : SFA ratio in the fat of L lambs – the respective differences in relation of H lambs reached 23.7% (P≤0.001) and 27.1% (P≤0.01). The fat of L lambs had also higher MUFA and n-3 content and higher value of the ratio of the hypo- and hypercholesterolemic acids – DFA : OFA (OFA = SFA-C18:0) and lower index of thrombosis risk (IT), being more favourable from the health point of view. On the other hand, any effect of weight category of the lambs on CLA and cholesterol content was not identified.

Sex of the lambs differentiated quite distinctly, and in some cases significantly (Tab. 2 and 3) the content of individual fatty acids as well as the health parameters, being calculated on the ground of the acids mentioned. In general, the IMF of the

Table. 2. Fatty acids content of the intramuscular fat of *semitendinosus* muscle in lambs (g/100g)

Item	UFA	MUFA	C16:1	C17:1	C18:1T	C18:1c9	C18:1c11	PUFA	C18:2	C18:3	C20:4	C22:5
Fattening system												
IN	57.52	46.14	2.71	0.97	2.11	36.44	1.97	11.38	6.62	0.64	2.26	0.58
SIN	55.23	45.04	2.62	0.78	1.94	35.57	1.60	10.19	5.61	0.44	2.22	0.59
Weight category												
L	57.02	45.10	2.67	0.82	2.02	35.12	1.86	11.92	6.65	0.58	2.57	0.66
H	55.73	46.09	2.66	0.93	2.03	36.89	1.71	9.64	5.57	0.50	1.91	0.51
Sex												
rams	56.79	44.51	2.49	0.86	1.94	35.47	1.83	12.28	6.98	0.57	2.66	0.66
ewes	55.96	46.67	2.84	0.90	2.11	36.53	1.73	9.29	5.24	0.51	1.82	0.51
Significance of differences between:												
fattening systems (F)	xx	xx	ns	xxx	ns	x	xxx	ns	x	x	ns	ns
weight categories (W)	ns	xxx	ns	ns	ns	xxx	xx	xxx	xx	x	xx	xx
sexes (S)	ns	xx	ns	ns	ns	ns	xx	X	xx	ns	ns	ns
repeations (R)	nNs	xx	xx	x	ns	x	ns	ns	ns	xxx	ns	ns
Interaction			SxR^{xx}						WxS^{x}	FxR^{xxx}	SxR^{x}	
SEM	0.283	0.320	0.040	0.025	0.082	0.269	0.039	0.431	0.239	0.024	0.125	0.028

Abbreviations, P levels and significance of differences are given at the bottom of Table 1.

Table. 3. Components and health parameters of intramuscular fat of *semitendinosus* muscle in lambs

Item	n-3 g/100g	CLA g/100g	Cholesterol g/100g	UFA:SFA	PUFA:SFA	DFA:OFA	n-6:n-3	IT
Fattening system								
IN	1.74	0.26	0.062	1.386	0.277	2.471	5.287	0.671
SIN	1.52	0.27	0.064	1.265	0.235	2.439	5.407	0.746
Weight category								
L	1.81	0.27	0.062	1.359	0.286	2.524	5.226	0.690
H	1.45	0.25	0.063	1.292	0.225	2.386	5.467	0.729
Sex								
rams	1.76	0.25	0.065	1.353	0.269	2.567	5.785	0.697
ewes	1.50	0.27	0.061	1.298	0.216	2.343	4.909	0.719
Significance of differences between:								
fattening systems (F)	ns	ns	ns	xx	ns	ns	ns	xxx
weight categories (W)	xx	ns	ns	ns	xx	xx	ns	ns
sexes (S)	ns	ns	ns	ns	xx	xx	x	ns
repeations (R)	xx	ns	xx	ns	ns	x	xxx	ns
Interaction							WxS^x	
SEM	0.069	0.013	1.022	0.015	0.012	0.041	0.118	0.008

Abbreviations, P levels and significance of differences are given at the bottom of Tables 1 and 2.
n-3 = Σ C18:3; C22:5; C22:6, n-6 = Σ C18:2; C20:2; C22:4; CLA – conjugated linoleic acid
DFA = UFA + C18:0; OFA = SFA – C18:0;
IT (index of thrombogenicity) = Σ C14:0, C16:0, C18:0 / Σ MUFA + n-3 + n-6 + (n-3:n-6) – Ulbricht and Southgate [1991].

rams was characterized by the more favourable FA profile comparing to ewes. It contained significantly less C16:0 and more C18:0 and C18:2 (by 6.3%, 6.2% and 33.2%, respectively, $P \leq 0.01$), with distinctly lower content of the remaining PUFA: C18:3, C120:4 and C22:5 as compared to the ewes – by 11.8%, 46.2 and 29.4%, respectively, ns).

In respect of health parameters, the IMF from the rams occurred more valuable than that of the ewes. First of all, it contained significantly more PUFA (by 32.2%, $P \leq 0.05$) what was reflected in favourably higher PUFA : SFA ratio (by 24.6%, $P \leq 0.05$) and higher content of n-3 acids (by 17.3%, ns). Owing to significantly higher content of stearic acid (C18:0), the fat of the rams showed also more favourable DFA : OFA ratio (by 9.6%, $P \leq 0.01$).

In the IMF from the ewes, the significantly higher MUFA content was, however, recorded as compared to that of the rams (by 4.9%) and favourably lower n-6 : n-3 acids ratio (by 17.8%). On the other hand, any distinct differences in both CLA and cholesterol content as related to lambs'sex were not identified.

The repeation of fattening differentiated the content of many individual fatty acids significantly as well as the health-promoting parameters based on them. Significant differences were also recorded between the effects of the main variation sources (feeding, weight category and sex of the lambs) on the content of individual FA within the frames of the repeations of fattening.

Fatty acid profile

In general, the differences in the IMF composition between the IN and SIN lambs were similar to those revealed for the reserve fats, as being discussed by Borys *et al*. [2011] and reflected in more favourable parameters of health quality of the discussed fat and by this, also muscular tissue (meat) of the IN *vs.* SIN lambs.

Simultaneously, differentiation of the IMF in this respect was, however, less distinct than of the depot fats. The system of fattening differentiated univocally the content of stearic acid C18:0 (being significantly lower in case of IN than SIN) and of C17:0, C17:1, C18:1t, C18:1c11, C18:2 and C18:3 (higher in IN than in SIN lambs) in all the types of fat examined. On the other hand, any more distinct effect of the fattening system on the content of PUFA C20:4 and C22:5, being important from the health quality point of view was not recorded, but the content of both mentioned acids was decisively higher in the IMF as compared to external and intermuscular fats [Borys *et al*. 2008]; the mean content of C20:4 was equal to 2.30 *vs.* 0.14 and 0.17 g/100 g fat, respectively, and of C22:5 which amounted to 0.63 *vs.* 0.12 g/100 g fat, respectively.

Similarly as in case of depot fats, the IN fattening of lambs affected favourably the most of the analysed parameters of health quality of the IMF, the content of n-3 acids, UFA: SFA and PUFA: SFA ratio and lowering the IT index. It should be mentioned that values of all analysed health-promoting parameters, based on the FA

composition, were decisively more favourable for IMF fat as compared to the similar (in this respect) external and intermuscular fats [Borys *et al*. 2008]. The content of n-3 acids was higher by 184.4%, UFA : SFA ratio – by 30.0%, PUFA : SFA ratio – by 232.1% and DFA : OFA – by 19.5% higher. On the other hand, the IT value was favourably higher by 19.6% in the intermuscular fat.

Discussion of the results obtained during the studies on the effect of fattening system on FA profile of depot fats in the lamb carcass conducted earlier by Borys *et al.* [2011] also refers to the intermuscular fat in the present part of the study. Also, in case of intermuscular fat, there were results of studies by Bas and Morand-Fehr [2000], Enser [2000] and Kraus *et al*. [2001] revealing that the increased share of roughages in the rations for fattening lambs resulted in the increase of saturation of depot and tissue fats of the lambs as compared to feeding based on cereals and dried forage crops.

As opposed to the non-tissue depot fats being discussed by Borys *et al*. [2011], in case of IMF the body live weight category of the lambs differentiated more distinctly a fatty acid profile and the health-promoting parameters, based on the mentioned acids. The FA profile of IMF in lambs fattened to the lower live weight was more favourable in respect of health. It resulted, first of all, from the significantly higher content of PUFA and remained in accordance with the results of the earlier own studies [Borys and Borys 1975] as well as those by Nurnberg *et al*. [1988], Radzik-Rant *et al*. [1999] Kosulwat *et al*. [2003] and Santos-Silva *et al*. [2003].

The effect of sex of the lambs on fatty acid profile for IMF was similar to that reported for other examined depot fats [Borys *et al*. 2011].

Fat of the rams was distinguished by more favourable parameters of health quality as compared to the ewe fat. First of all, this resulted from the higher content of stearic acid C18:0 and all PUFA and was reflected in distinctly more favourable parameters of the rams' meat – higher content of n-3 acids, higher PUFA : SFA and DFA : OFA ratio and more favourable, lower n-6 : n-3 ratio.

The comments for the results concerning the effect of sex of the lambs on the FA profile of the IMF are the same as for results obtained for non-tissue depot fats given by Borys *et al*. [2011].

Distinct differences in fatty acid composition and decisively more favourable health-promoting properties of IMF as compared to the depot and intermuscular fat refer to meat of the sheep as well as of other farm animals and are in accordance with review papers and textbooks [Bas and Morand-Fehr 2000, Wood *et al*. 2003, Kędzior 2005] and in other studies on the lambs [e.g. Bodkowski *et al*. 1999, Borys *et al*. 2007].

CLA

None of the considered variation factors directly differentiated CLA content of IMF. In the literature available, there are limited data on factors affecting the content and possibilities of modifying CLA concentration of the sheep products. The main

process of CLA synthesis in ruminants includes bacterial isomerization of linoleic acid in the rumen [Demirel *et al*. 2001, Reklewska and Bernatowicz 2002]. It may result that the intensity of the discussed processes and the rate of CLA incorporation in the tissues of the fattened lambs is affected, first of all, by the nutritive factors (the system of fattening) and the degree of development of function of their forestomachs (in this case, weight category related to the age of lambs at the moment of slaughter).

The IMF contained considerably less CLA than both examined non-tissue depot fats – by 0.26 vs. 0.45 g/100g of fat, respectively. The concentration of CLA, being by 42.2% lower in the IMF as compared to the depot fats is an evidence of physiological differentiation of the rate of incorporation the discussed component in different tissues of the fattened lambs. CLA content of the compared fats was found on a similar level as in earlier own studies, in case of intensive feeding of the lambs up to the approximate weight categories (Borys *et al.* 2007); 100 g of IMF contained 0.21 g of CLA and of external and intermuscular fat – 0.35 g, on average. In own studies the CLA content of IMF of the lambs was found considerably lower than that recorded by Patkowska-Sokoła *et al*. [2000] and Radzik-Rant [2005] – equal to 1.23 and 0.58 g /100 g fat, respectively. A high variation in CLA content of meat of ruminants, including lambs, is caused mainly by physiological and nutritional factors [Schmid *et al*. 2006].

Cholesterol

No statistically significant effect was found of any of the main variation factors on cholesterol content of the IMF examined. Significant differences between the repeated fattenings indicate the effect of other environmental factors on the level of the discussed components, being not considered in the present studies.

Other studies concerning the effect of the factors, covered with the experiment, on the cholesterol level in lamb meat gave the divergent results in many cases, what was discussed in details by Borys *et al.* [2011].

Attention should be paid to wide differences in cholesterol content between all types of lamb fat considered in this study. The least cholesterol was found in IMF (0.063 g/100 g on the average) which is important from the meat's health quality point of view. External fat had by 28.6% more cholesterol (0.081 g/100 g on the average), and the most of it contained intermuscular fat – 0.107 g/100 g – *i.e.* by 69.8% more compared to IMF [Borys *et al.* 2011].

Similar differentiation was reported in the earlier study by Przegalińska-Gorączkowska and Borys [2004] in which cholesterol content of lamb IMF, external and intermuscular fats amounted to 0.064, 0.076 and 0.113 g/100 g, respectively. According to Barowicz and Janik [1998] most of the studies on this area indicated a significant differentiation in cholesterol content in relation to the type of tissue : fat ratio. On the other hand, Solomon [1991] did not reveal any univocal difference in the cholesterol content of fat from different fat locations in the ram lambs body.

It is concluded that intramuscular fat of intensively fattened lambs had, mainly owing to higher content of stearic acid and PUFA. More favourable fatty acid profile than that of lambs semi-intensively fattened. Generally, more favourable FA profile of intermuscular fat of lambs fattened to lower (20-30 kg) in comparison to higher (30-40 kg) live weight was found owing to higher content of PUFA. In spite of fattening rams to higher body weight (by 5 kg) in comparison to ewes, their intramuscular fat was distinguished by more favourable parameters of health quality, mainly due to higher content of stearic acid and PUFA. The compared systems of fattening, slaughter weight category and sex of the lambs did not affect significantly the CLA and cholesterol content of the intramuscular fat. The results of part one [Borys *et al.* 2011] and part two (this study) of the present research revealed FA profile of intramuscular fat as being more favourable from the health quality point of view than those of both non-tissue depot fats examined – external and intramuscular fat. It constitutes the significant premise for orientation of the further studies towards improvement of health properties of the meat, including mutton *via* optimization of the share of particular types of fat tissue in the carcass and its culinary elements.

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