Research Regarding Fatty Acid Profile and Health Lipid Indices in the Lambs Meat of Employing Feed Supplemented with Different Vegetable Oils

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Enhancing healthy fatty acids (FA) in lamb tissues is a important research issue in meat science. The present study examined the effects of feeding-protected lipid supplements rich in linoleic acid or linolenic acid on the lipid composition of muscle and adipose tissues of lambs. Thirty, 10-week-old Tsigai breed ram lambs were assigned to one of three experimental diets (forage/concentrate ratio 40:60): no oil Ca soap (C-Control), with 4% sunflower oil Ca soap (SO-high in 18:2n-6), with 4% camelina oil Ca soap (CO-high in 18:3n-3). The diet high in α-linolenic acid (CO diet) produced the highest levels of n-3 FAs: 18:3n-3 (ALA), 20:5n-3 (EPA) and 22:6n-3 (DHA) intramuscular fat. In addition, the animals fed with the diet CO have intramuscular fat the lowest n-6/n-3 ratio, atherogenic (AI) and thrombogenic index (TI). In the intramuscular fat of the animals fed with the diet high in linoleic acid (SO diet), conjugated linoleic acid (CLA) isomers and trans 18:1 reached their highest concentrations. The results of this study indicated that linoleic acid was more effective in enhancing contents of CLA in muscle and adipose tissue than linolenic acid, which contributes to the enrichment of n-3 FA lamb meat. Feeding camelina oil Ca soap has been shown to be the most effective dietary management to improve health lipid indices (n-6/n-3 ratio, AI, TI) in lambs' meat.

Keywords: Atherogenic index, n-3 FA, CLA, Calcium soap, Lamb meat

Several factors influence the functional lipid components (n-3 FA and CLA) content of lamb meat, such as breed, sex, seasonal variation, type of muscle, production practices; however, diet plays the most important role. Enhancing the beneficial effects of animal products can be achieved through diet manipulation, such as the use of diets supplemented with plant oils with high purities of linoleic (C18:2n-6, LA), linolenic (C18:3n-3, ALA) or oleic (C18:1n-9) acids to improve the concentration of n-3 FA and CLA in lamb tissues [1]. These dietary practices can increase n-3 FA and CLA concentrations up to 3-fold [2]. Moreover, 18:1 *t*11 (vaccenic acid, VA) is the precursor of C18:2 *c*9,*t*11 (rumenic acid, RA) which is the major CLA isomer in animals and humans and therefore it might be considered as a fatty acid with beneficial properties [3].

The increase in 18:3n-3, as a percentage of total FA in muscle, will generally be higher when animals are fed a linolenic acid-rich source (fish oil, linseed) [4]. In the last years, there is a growing interest for new sources of vegetable oils with high content of unsaturated fatty acids [5-8]. Camelina oil is one of the few plant sources providing ample amounts of linolenic acid [9, 10] and could be an important source of 18:3n-3 for animal nutrition and also increase 18:3n-3 and its fatty acids metabolites (EPA and DHA) in meats [11].

Many researchers have found higher CLA content in muscle lipids by supplementing with different oils [12]. Supplementation with linoleic acid-rich oil or oilseeds such as safflower or sunflower in the diet of ruminants appears to be more effective method for obtaining increased CLA content in muscle [13]. The inclusion of sunflower oil in the diets of finishing cattle increased the CLA content of the beef by 75% when cattle were fed 6% sunflower oil. A more substantial increase in the CLA concentration was found when sunflower oil was added to both the growing and finishing diet of beef cattle [14]. Ruminant meats have more favorable ratios of n-6/n-3 than pork. In a survey of meat purchased in supermarkets, the percentage of 18:3n-3 and CLA in lamb was double than in beef [2].

The aim of this study was to determine the effects of feeding-protected lipid supplements rich in unsaturated FAs (linoleic or linolenic acid) on the lipid composition of muscle and adipose tissues and animal performance in lambs. In the current experiment was chased to improve fatty acid profile by increasing the level of functional lipid components (n-3 FA and CLA) in lamb meat and to reduce SFA content and the n-6/n-3 ratio.

Experimental part

Materials and metods

Thirty 10-week-old Tsigai breed ram lambs were randomly allocated to one of three experimental diets (forage/concentrate ratio 40:60) (n=10): 1) no oil Ca soap (C-control), 2) with 4% sunflower oil Ca soap (SO-high in 18:2n-6), 3) with 4% camelina oil Ca soap (CO-high in 18:3n-3). Calcium soap (Cs) were prepared in our laboratory, using sodium hydroxide and 20% calcium chloride solution via the precipitation method as described by Alexander et al [15]. The calcium soap formed was washed with tap water and was air dried in a dark room and stored at subzero temperature until used for feeding through inclusion in concentrated mixture. The ingredient and chemical composition of the diets are present in table 1. The alfalfa hay was grounded and mixed with the other ingredients. Was the diet pelleted. The energy value of the diets was 10.8 ME (MJ/kg DM) in the control group and 11.5 ME (MJ/kg DM) in experimental groups (table 1). The ME was estimated in according by NRC (National Research Council) [16]. Animals were housed individually with free access to diet and water.

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Variable	Tratamente[1]		
	C	SO	CO
Ingredients (% of DM)			
Alfalfa hay	40.0	40.0	40.0
Maize grain	29.0	23.5	23.5
Triticale grain	15.0	15.0	15.0
Soybean meal	14.5	16.0	16.0
Sunflower oil Ca soap	-	4.0	-
Camelina oil Ca soap	-	-	4.0
Mineral mixture	1.0	1.0	1.0
Vitamin supplement	0.5	0.5	0.5
Chemical composition (% of DM)			
CP (Crude protein)	16.6	16.4	16.4
NDF (Neutral Detergent Fiber)	33.17	34.02	34.02
ADF (Acid Detergent Fiber)	18.34	18.60	18.60
EE (Ether extract)	2.38	5.12	5.23
ME (MJ/kg DM)[2]	10.8	11.5	11.5
Fatty acid composition (% of FAME[3])			
C14:0	0.31	0.10	0.14
C16:0	13.84	7.11	6.07
C18:0	4.92	4.54	2.11
C18:1 n-9*c*	16.30	14.83	34.57
C18:2 n-6	56.12	67.20	46.19
C18:3 n-3	3.41	3.88	7.64

Table 1
INGREDIENTS AND CHEMICAL COMPOSITION OF LAMB DIETS

[1]C - control: diet without oil Ca soap; SO - diet supplemented with sunflower oil Ca soap (high in 18:2n-6); CO - diet supplemented with camelina oil Ca soap (high in 18:3n-3).

[2]Metabolizable energy, calculated using NRC (National Research Council, 2007) [16].

[3]Fatty acid methyl esters.

Measurement, sampling and analysis

The experiment lasted for 110 days, between May and August. Animal weights and feed samples were obtained at 10 day intervals. Animal handling followed the recommendations of European Council Directive 2010/63/EU [17] for protection of animals used for experimental and other scientific purposes.

At the end of the experiment feed and water were withdrawn, and after 1 h the lamb was weighed, stunned, bled, skinned, eviscerated and chilled at 4°C for 24 h and then weighed. Killing-out percentage was calculated as cold carcass weight expressed as percent of slaughter body weight [1]. At 24-h post-mortem from each carcass (left half carcass), 150-200 g meat samples were taken from loin muscle (LD - *longissimus dorsi*) and subcutaneous fat, between the 9th -10th ribs. Adipose tissue samples from subcutaneous and intramuscular depot were packed well and frozen at -20°C until analysis for FA composition. The rib-eye area was determined in the cross-section of the *longissimus* muscle obtained between the 12th and 13th thoracic vertebra, using a planimeter Koizumi, Type KP-27 [18].

Samples of the diet were stored at 4°C. Contents of dry matter, crude protein and ether extract in the diet were determined according to AOAC [19]. The NDF (Neutral Detergent Fiber) and ADF (Acid Detergent Fiber) content was estimated by the method of Van Soest et al. [20]. Feed samples were vacuum packed and frozen at –20°C until analysis of the fatty acid composition. The fatty acid composition of fats from feeds was determined according to procedures developed by Kramer et al. [21] and Copolovici et al. [22].

The samples of subcutaneous and intramuscular depot were homogenized in chloroform/methanol (2:1, v/v) solution according to the procedure of Folch et al [23] to extract the fat. Methylation of the lipids was conducted by following the method of Lepage and Roy [24] prior to injecting into the gas chromatograph (Varian CP-3380, Inc. Scientific Instruments, Palo Alto, CA, USA) equipped with a flame ionization detector and Chrompac CP-Sil 88 column (100 m, 0.25 mm, 0.2 μm film thickness, Varian, Inc. Scientific Instruments, Palo Alto, CA, USA). The injector and detector temperature was maintained at 250°C. The initial column temperature was 175°C (held for 30 min), and then increased by 15°C/min to 220°C (held for 40 min). Helium was used as the carrier gas at a constant flow of 1.0 mL/min. The identification of fatty acid peaks was made by comparison of retention times with the ones obtained for fatty acid methyl ester (FAME) standard mixtures acquired from Un-Check-Prep Inc. (Elysian, MN, USA) and from Supelco Inc. (Bellefonte, PA, USA) [25]. Additional standards of individual CLA isomers (C18:2 *c*9,*t*11, C18:2 *t*10,*c*12) were purchased from Matreya Inc. USA. Fatty acid composition was expressed as percentage of total FAMEs on basis of total mass.

Calculations and statistical analysis

The atherogenic index (AI) was calculated according to Chilliard et al. [26] as follows: AI = (C12:0 + 4 x C14:0 + C16:0)/(MUFA + PUFA), whereas the thrombogenic index (TI) was calculated in accordance with Ulbricht and Southgate [27] using the formula: TI = (C14:0 + C16:0 + C18:0)/(0.5 x MUFA + 0.5 x n-6 PUFA + 3 x n-3 PUFA + n-3/n-6 PUFA).

The obtained data were subjected to variance analysis by using the General Linear Models procedure of SAS, Version 9.1 (SAS Institute, Cary, NC, USA) [28]. Multiple comparisons among means were done with the Duncan test. The level of significance was established at $P < 0.05$.

Results and discussions

Experimental diets

The crude protein content met the lambs' requirements [16]. Linoleic acid (C18:2n-6) was the most abundant fatty acid in the diets (46.19 - 67.20% of total fatty acids), followed by oleic acid (C18:1n-9), palmitic acid (C16:0) and linolenic acid (C18:3n-3). The C18:2n-6 in the SO diets was higher than the C and CO diets. The feed of the CO group contained approximately 2 times higher linolenic acid (C18:3n-3) than control and SO diet (table 1). Similar aspects of the fatty acid composition in diets were observed

Variable	Tratament[1]			SEM	p-values
	C	SO	CO		
Performances					
Initial BW, kg	15.60	15.87	15.21	0.32	0.17
Final BW, kg	39.36[b]	41.87[a]	40.50[a]	0.76	<0.05
DMI, kg/day	1.603	1.609	1.612	0.04	0.19
ADG, g/day	216.05[b]	236.35[a]	225.41[a]	6.54	<0.05
FCR (DMI/ADG)	7.42[a]	7.11[b]	7.05[b]	0.21	<0.05
Carcass characteristics					
Killing out percentage	46.76	47.62	47.07	0.20	0.54
LM area, cm^2	14.51	14.74	14.72	0.24	0.48
Tissular composition (%):					
- muscle	57.31	56.58	56.73	0.21	0.50
- fat	22.80	23.34	23.08	0.86	0.43
- bone	18.15	18.42	18.36	0.46	0.30
- others	1.71	1.57	1.82	0.05	0.85

Table 2
EFFECT OF DIETS CONTAINING DIFFERENT VEGETABLE OILS ON THE PERFORMANCE AND CARCASS CHARACTERISTICS OF LAMBS

[1]C - control: diet without oil Ca soap; SO - diet supplemented with sunflower oil Ca soap (high in 18:2n-6); CO - diet supplemented with camelina oil Ca soap (high in 18:3n-3). SEM - standard error of the mean; BW - body weight; ADG - average daily gain; FCR - feed conversion ratio; DMI - dry matter intake; LM - Longissimus dorsi muscle.

[a,b] – Means within the same row with different letters differ significantly according to Duncan's tests (p>0.05).

by Ebrahimi et al. [29], when the kids' diet was supplemented with flax and sunflower oils.

Feed intake, animal performance, and carcass traits

Mean values of feed intake and animal performance are shown in table 2.

The initial weight, final weight, daily feed intake and feed conversion ratio did not differ between control and SO or CO treatment groups (P >0.05). Feeding of the oil Ca soap supplemented diet slightly increased average daily gain and therefore, the feed conversion ratio (FCR) was slightly lower for the lambs fed CO and SO (7.05 and 7.11, respectively) than for the control lambs (7.42). There were no significant effects of SO or CO as compared to control diet on killing-out percentage, rib-eye area and tissue composition of carcass (P >0.05) (table 2). Similarly, Bolte et al. [30] in lambs and Hristov et al. [31] in cattle found no effect of high-oleate or high-linoleate safflower seeds on growth of carcass. On the other hand, Bessa et al. [32] observed greater proportion of intramuscular fat and less proportion of muscle when lambs were fed with 10% soybean oil. This tendency of reduction of muscle mass ratio in the structure of the carcass as a result of diet supplementation with sunflower oil Ca soaps or camelina oil Ca soaps has been observed in our study as well, but the differences were not significant, probably due to the smaller quantity of fat in the diet.

Fatty acid composition and health lipid indices of muscle and subcutaneous fat

Results of FA composition in loin muscle and subcutaneous fat are presented in table 3 and 4, respectively.

In the current study, the addition of vegetable oils to the concentrate caused a significant decrease in the proportion of C16:0 in both intramuscular and subcutaneous fat, probably due to a reduction of the *novo* synthesis of palmitic acid [1].

The highest values of total monounsaturated fatty acid (MUFA) were found in the CO diet. The values of total MUFA in our study were similar to those reported by Diaz et al. [33] on the LD fatty acid contents of Spanish and Uruguayan lambs fed concentrate (38.37-41.17%).

The dietary treatment did not significantly increase the proportion of PUFA, but rather it modified its composition. The SO diet contained more linoleic acid (C18:2n-6) than the CO and control diets, due to the high level of C18:2n-6 in the calcium soap of sunflower oil that was added to the diet. This difference is not reflected in the level of C18:2n-6 or of its metabolite (C20:4n-6) in intramuscular and subcutaneous fat. This result is in agreement with other authors, who observed that incorporation of C18:2n-6 in muscle was not influenced by the supplementation of the diet with vegetable oils [1, 34]. This suggests that

Intramuscular fat	Tratament[1]			SEM	p-values
	C	SO	CO		
C12:0	0.47	0.45	0.46	0.01	0.23
C14:0	3.43	3.06	3.07	0.05	0.08
C16:0	24.62[c]	23.47[b]	21.48[a]	0.20	<0.01
C18:0	17.57	17.69	16.86	0.18	0.06
C18:1 n-9	35.80[ab]	34.46[a]	37.43[b]	0.64	<0.001
C18:1 *trans*	2.57[a]	5.12[c]	3.74[b]	0.23	<0.001
C18:2 n-6 (LA)	8.92	8.31	9.07	0.17	0.78
CLA *cis*-9, *trans*-11 (RA)	1.21[a]	1.96[c]	1.64[b]	0.06	<0.001
CLA *trans*-10, *cis*-12	0.09[a]	0.18[c]	0.14[b]	0.01	<0.01
Total CLA	1.30[a]	2.14[c]	1.78[b]	0.18	<0.001
C18:3 n-3 (ALA)	0.67[a]	0.84[a]	1.83[b]	0.07	<0.01
C20:4 n-6	1.14	1.12	0.87	0.11	0.31
C20:5 n-3 (EPA)	0.33[a]	0.39[ab]	0.44[b]	0.02	<0.05
C22:5 n-3 (DPA)	0.09	0.11	0.11	0.01	0.78
C22:6 n-3 (DHA)	0.70[a]	0.86[ab]	1.03[b]	0.09	<0.05
Others FA	2.39	2.08	1.83	0.17	0.56
SFA	46.09[b]	44.67[ab]	41.87[a]	0.21	<0.01

Table 3
EFFECT OF DIETS CONTAINING DIFFERENT VEGETABLE OILS ON THE FATTY ACID COMPOSITION (% OF FAME) OF INTRAMUSCULAR FAT IN LAMBS

MUFA	38.37[a]	39.48[ab]	41.17[b]	0.40	<0.01
PUFA n-3[2]	1.79[a]	2.20[b]	3.41[c]	0.08	<0.001
PUFA n-6[3]	10.06	9.43	9.94	0.42	0.80
Total PUFA	13.15[a]	13.77[a]	15.13[b]	0.38	<0.01
PUFA : SFA ratio	0.28[a]	0.31[ab]	0.36[b]	0.02	<0.05
n-6/n-3 FA	5.62[c]	4.28[b]	2.91[a]	0.16	<0.001
HFA[4]	28.52[b]	26.98[b]	25.01[a]	0.22	<0.01
Atherogenic index (AI)	0.75[b]	0.68[ab]	0.61[a]	0.02	<0.01
Thrombogenic index (TI)	1.53[b]	1.41[b]	1.15[a]	0.03	<0.01

[1]C - control: diet without oil Ca soap; SO - diet supplemented with sunflower oil Ca soap (high in 18:2n-6); CO - diet supplemented with camelina oil Ca soap (high in 18:3n-3).

SEM - standard error of the mean; FAME - fatty acid methyl esters; CLA - conjugated linoleic acids; SFA – saturated fatty acid; MUFA – monounsaturated fatty acid; PUFA – polyunsaturated acid; FA – fatty acid.

[2][C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3].

[3][C18:2n-6 + C20:4n-6].

[4]HFA (hypercholesterolaemic FA) - C12:0 + C14:0 + C16:0.

[a,b,c] – Means within the same row with different letters differ significantly according to Duncan's tests (p Â0.05).

biohydrogenation of linoleic acid may be very effective in the rumen [34].

As was expected, lambs fed CO diet had a greater proportion ($P < 0.001$) of linolenic acid (C18:3n-3) in meat, compared with lambs fed C and SO diet due to the high level of C18:3n-3 in the calcium soap of camelina oil that was added to the diet.

The camelina oil Ca soaps in the diet improved total n-3 FA content from 1.79% to 3.41% in intramuscular fat, and from 0.64% to 1.90% in subcutaneous fat, due to a significant increase in muscle and subcutaneous fat C18:3n-3, C20:5n-3 and C22:6n-3 FA (table 3 and 4). As noted in other studies, some of the dietary C18:3n-3 escapes hydrogenation in the rumen and is subsequently metabolized to C20:5n-3 and C22:6n-3 FA, which are found in ruminant tissues (cell membranes) [35]. The dietary replacement of sunflower oil Ca soaps with camelina oil Ca soaps did not significantly increase the C20:5n-3 and C22:6n-3 FA in lamb meats. The synthesis of C20:5n-3 and C22:6n-3 FA from dietary CO (rich in 18-3n-3) seems to be limited, and thus the vegetable oils are not the best fatty acids source to ruminant diets when the objective is to increase C20:5n-3 and C22:6n-3 FA in meat.

High-concentrate diets are associated with high levels of C18:1 *trans*-10 in lamb meat [1, 32]. Because in the current experiment the chromatographic peaks corresponding to *trans*-10 and *trans*-11 C18:1 isomers

Table 4
EFFECT OF DIETS CONTAINING DIFFERENT VEGETABLE OILS ON THE FATTY ACID COMPOSITION (% OF FAME) OF SUBCUTANEOUS FAT IN LAMBS

Subcutaneous fat	Tratament[1]			SEM	p-values
	C	SO	CO		
C12:0	0.73	0.71	0.77	0.07	0.52
C14:0	4.01	3.66	3.51	0.43	0.24
C16:0	25.39[b]	24.18[ab]	23.07[a]	1.09	<0.05
C18:0	22.06	21.61	20.90	0.77	0.54
C18:1 n-9	32.74[ab]	31.06[a]	33.54[b]	0.85	<0.05
C18:1 *trans*	4.83[a]	7.59[c]	6.08[b]	0.22	<0.001
C18:2 n-6 (LA)	6.12	6.29	5.98	0.30	0.13
CLA *cis*-9, *trans*-11 (RA)	0.82[a]	1.36[c]	1.18[b]	0.05	<0.01
CLA *trans*-10, *cis*-12	0.06[a]	0.11[c]	0.09[b]	0.02	<0.01
Total CLA	0.88[a]	1.47[c]	1.27[b]	0.04	<0.01
C18:3 n-3 (ALA)	0.51[a]	0.70[b]	1.58[c]	0.03	<0.001
C20:4 n-6	0.46	0.51	0.41	0.12	0.55
C20:5 n-3 (EPA)	0.04[a]	0.05[a]	0.07[b]	0.01	<0.05
C22:5 n-3 (DPA)	0.03[a]	0.03[a]	0.05[b]	0.02	<0.05
C22:6 n-3 (DHA)	0.06[a]	0.10[b]	0.19[c]	0.02	<0.01
Others FA	2.14	2.03	2.57	0.18	0.15
SFA	52.19[b]	50.16[ab]	48.25[a]	0.94	<0.01
MUFA	37.57	38.65	39.62	0.88	0.34
PUFA n-3[2]	0.64[a]	0.89[b]	1.90[c]	0.08	<0.001
PUFA n-6[3]	6.58	6.80	6.39	0.36	0.12
Total PUFA	8.10[a]	9.16[b]	9.56[b]	0.67	<0.05
PUFA : SFA ratio	0.15[a]	0.18[b]	0.20[c]	0.02	<0.05
n-6/n-3 FA	10.28[c]	7.64[b]	3.36[a]	0.68	<0.001
HFA[4]	30.13[b]	28.55[a]	27.35[a]	0.76	<0.01
Atherogenic index (AI)	0.92[c]	0.83[ab]	0.77[a]	0.07	<0.05
Thrombogenic index (TI)	2.14[c]	1.94[b]	1.64[a]	0.11	<0.01

[1]C - control: diet without oil Ca soap; SO - diet supplemented with sunflower oil Ca soap (high in 18:2n-6); CO - diet supplemented with camelina oil Ca soap (high in 18:3n-3).

SEM - standard error of the mean; FAME - fatty acid methyl esters; CLA - conjugated linoleic acids; SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated acid; FA - fatty acid.

[2][C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3].

[3][C18:2n-6 + C20:4n-6].

[4]HFA (hypercholesterolaemic FA) = C12:0 + C14:0 + C16:0.

[a,b,c] – Means within the same row with different letters differ significantly according to Duncan's tests (p > 0.05).

could not be differentiated, the peak has been interpreted as C18:1 *trans*, according to Manso et al [1]. In animals, C18:2 *c*9,*t*11 can be produced endogenously from vaccenic acid (C18:1 *trans*-11), whereas the C18:1 *trans*-10 isomer cannot be bioconverted to C18:2 *c*9,*t*11 [35]. In this study did not separate the C18:1 *trans*-11 and C18:1 *trans*-10 isomers, therefore the levels of C18:2 *c*9,*t*11 contributed by vaccenic acid endogenously with the SO and CO diets cannot be explained using the present data. In the current study, CLA *t*10,*c*12 as well as C18:1 *trans* increased in intramuscular and subcutaneous fat of animals receiving SO diet, compared of CO diet. Similarly to the results observed in the current experiment Bessa et al. [32] using sunflower oil in a study carried out with lambs, observed an increase in CLA *t*10,*c*12 in response to soybean oil supplementation to high-concentrate diets. Although C18:1 *trans*-11 seems to play a more important role than the *trans*-10 isomer in modulating plasma lipid and lipoprotein metabolism, C18:2 *c*9,*t*11 and CLA *t*10,*c*12 have potential beneficial effects for human health [36].

Feeding SO increased the concentration of C18:2 *c*9,*t*11 in meat (SO Ã CO Ã C). The results of this study indicated that linoleic acid (SO diet) was more effective in enhancing contents of C18:2 *c*9,*t*11 in intramuscular and subcutaneous fat than linolenic acid (CO diet). The present data confirmed an earlier observation that has reported increased contents of 18:3n-3 and total n-3 long chain PUFA and decreased concentrations of C18:1 *trans* and CLA *c*9,*t*11 in the intramuscular fat of the lambs, when sunflower oil was replaced by linseed oil or camelina oil or canola oil as the fat supplement in the diet [13, 37].

The other important aspect of nutritional value of food is the n-6/n-3 ratio, which should be no larger than 4 [27]. The current study the n-3 FA percentage increased due to the higher linolenic acid content and additionally the n-6 FA group was not influenced by calcium soap of vegetable oils in SO and CO groups. These changes resulted that the n-6/n-3 ratio being significantly lower in CO samples (3.36-2.91), followed by SO (7.64-4.28), than that of the control lambs (10.28-5.62). In the present study, the n-6/n-3 ratio was more beneficial in intramuscular fat of lambs compared of subcutaneous fat. It can be considered a beneficial property for human nutrition [36]. However, this value is higher for control and SO samples than the recommendation of nutritionists [27]. In the present study, a significant decrease in the atherogenic (AI) and thrombogenic index (TI) was found in response to camelina oil Ca soap supplementation in intramuscular and subcutaneous fat. Intramuscular fat for SO diet showed only a tendency to have lower AI and TI, which could probably be related to the numeric changes in saturated and monounsaturated fatty acids, which did not reach the required significance level to be statistically different. On the other hand, subcutaneous fat seems to be more responsive to changes in the dietary fatty acid supply or changes in rumen metabolism than intramuscular fat, thus AI and TI registered significantly lower values in the SO diet compared to the control group; however, these values were higher than in the CO diet.

Conclusions

The inclusion of 4% sunflower oil Ca soap or camelina oil Ca soap in the concentrate for young fattening lambs increases de proportion of CLA in intramuscular and subcutaneous fatty acid without affecting feed intake, animal performance and carcass characteristics. Supplementation with camelina oil Ca soap increases n-3 FA and lowered n-6/n-3 ratio in the meat, while supplementation with sunflower oil Ca soap only depressed the n-6/n-3 ratio. Feeding camelina oil Ca soap has been shown to be the most effective dietary management to improve health lipid indices in lambs' meat.

References

1.MANSO, T., BODAS, R., CASTRO, T., JIMENO, V., MANTECÓN, A.R., Animal performance and fatty acid composition of lambs fed with different vegetable oils, Meat Sci., **83**, no. 3, 2009, pp. 511-516.

2.WOOD, J.D., ENSER, M., FISHER, A.V., NUTE, G.R., SHEARD, P.R., RICHARDSON, R.I., HUGHES, S.I., WHITTINGTON F.M., Fat deposition, fatty acid composition and meat quality: A review, Meat Sci., **78**, no. 4, 2008, pp. 343-358.

3.GARCIA, P.T., CASAL, J.J., Effect of dietary plant lipids on conjugated linoleic acid (CLA) concentrations in beef and lamb meats, in Soybean-Bio-Active Compounds, El-Shemy H.A., Ed., InTech, Vienna, Austria, 2013, pp. 135-159.

4.RIBEIRO, C., OLIVEIRA, D., JUCHEM, S., SILVA, T., ÉLEN SILVEIRA NALÉRIO, E., Fatty acid profile of meat and milk from small ruminants: a review. Rev. Bras. Zootecn., **40**, 2011, pp. 121-137.

5.ISOPENCU, G., MARFA, M., JIPA, I., STROESCU, M., STOICA GUZUN, A., CHIRA, N., POPESCU, M., Optimization of the Oil Extraction from Nigella sativa Seeds Using Response Surface Methodology, Rev. Chim. (Bucharest), **68**, no. 2, 2017, pp. 331-336.

6.DINU, M., UIVAROSI, V., POPESCU, M., RADULESCU, V., ARAMA, C., NICOLESCU, T.O., ANCUCEANU, R.V., Proximate Composition and Some Physico-chemical Properties of Abutilon theophrasti (velvetleaf) Seed Oil, Rev. Chim. (Bucharest), **61**, no. 1, 2010, pp. 50-54.

7.KONUSCAN, O., KONUSCAN, D.B., LEVAI, C.M., Rev. Chim. (Bucharest), **68**, no. 9, 2017, p. 2073

8.CHIRA, N.A., TODASCA, M.C., NICOLESCU, A., ROSU, A., NICOLAE, M., ROSCA, S.I., Evaluation of the Computational Methods for Determining Vegetable Oils Composition using 1 H-NMR Spectroscopy, Rev. Chim. (Bucharest), **62**, no. 1, 2011, pp. 42-46.

9.RAICIU, A.D., POPESCU, M., IVOPOL, G.C., BORDEI, N., ALEXANDRU, G., CRISAN, I., MANEA, S., DIMA, S.O., Therapeutic Applications of Vegetable Oils and GC-MS Evaluation of ù-3, ù-6 and ù-9 Amounts in Six Oleaginous Plants, Rev. Chim. (Bucharest), **67**, no. 12, 2016, pp. 2449-2453.

10. AVRAM, M., STROESCU, M., STOICA-GUZUN, A., FLOAREA, O., Optimization of the Oil Extraction from Camelina (Camelina sativa) Seeds Using Response Surface Methodology, Rev. Chim. (Bucharest), **66**, no. 3, 2015, pp. 417-421.

11. MIERLITA, D., Effects of part-time grazing and feeding management on the fatty acid composition and antioxidant capacity in the milk of Turcana ewes, J. Food Agric. Environ., **13**, no. 2, 2015, pp. 130-137.

12. NOCI, F., FRENCH, P., MONAHAN, F.J., MOLONEY, A.P., The fatty acid composition of muscle fat and subcutaneous adipose tissue of grazing heifers supplemented with plant oil-enriched concentrates, J. Anim. Sci., **85**, 2007, pp. 1062–1073.

13. JERÓNIMO, E., ALVES, S., PRATES, J., SANTOS-SILVA, J., BESSA, R., Effect of dietary replacement of sunflower oil with linseed oil on intramuscular fatty acids of lamb meat, Meat Sci., **83**, 2009, pp. 499–505.

14. MIR, P.S., MCALLISTER, T.A., ZAMAN, S., MORGAN JONES, S.D., HE, M.L., AALHUS, J.L., JEREMAIAH, L.E., GOONEWARDENE, L.A., WESELAKE, R.J., MIR, Z., Effect of dietary sunflower oil and vitamin E on beef cattle performance, carcass characteristics and meat quality, Can. J. Anim. Sci., **83**, 2003, pp. 53-66.

15. ALEXANDER, G., RAO, Z.P., PRASAD, J.R., Effect of supplementing sheep with sunflower acid oil or its calcium soap on nutrient utilization, Asian Austral. J. Anim., **15**, 2002, pp. 1288-1293.

16. NATIONAL RESEARCH COUNCIL, Nutrient requirements of small ruminants. N.R.C., Ottawa, Canada, 2007.

17.*** EUROPEAN COUNCIL DIRECTIVE 2010/63/EU, http://eur-lex.europa.eu/legal-content/EN/TXT/.

18. OSORIO, J., OSORIO, M., Producao de carne ovina: técnicas de avaliacao in vivo e nacarcaça. 2ed. Pelotas: Universidade Federal de Pelotas, 2005, pp. 45-62.

19.*** AOAC, Official methods of analysis (17th ed.). Association of Official Analytical Chemists, Inc. Arlington, Virginia, USA, 2003.
20.VAN SOEST, P.J., ROBERTSON, J.B., LEWIS, B.A., Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition, J. Dairy Sci., **74**, 1991, pp. 3583-3597.
21.KRAMER, J.K., FELLNER, V., DUGAN, M.E., SAUER, F.D., MOSSOBA, M.M., YURAWECZ, M.P., Evaluating acid and base catalysts in the methylation of milk and rumen fatty acids with special emphasis on conjugated dienes and total trans fatty acids, Lipids, **32**, no. 11, 1997, pp. 1219-1228.
22.COPOLOVICI, D., BUNGAU, S., BOSCENCU, R., TIT, D.M., COPOLOVICI, L., The Fatty Acids Composition and Antioxidant Activity of Walnut Cold Press Oil, Rev. Chim. (Bucharest), **68**, no. 3, 2017, p. 507
23.FOLCH, J., LEES, M., STANLEY, G.H.S., A simple method for the isolation and purification of total lipides from animal tissues, J. Biol. Chem., **226**, 1957, pp. 497–509.
24.LEPAGE, G., ROY, C.C., Direct transesterification of all classes of lipid in a one-step reaction, J. Lipid Res., **27**, 1986, pp. 114-121.
25.HOVANET, M.V., DOCIU, N., DINU, M., ANCUCEANU, R., MOROSAN, E., OPREA, E., A Comparative Physico-chemical Analysis of Acer platanoides and Acer pseudoplatanus Seed Oils, Rev. Chim. (Bucharest), **66**, no. 7, 2015, pp. 987-991.
26. CHILLIARD, Y., FERLAY, A., ROUEL, J., LAMBERET, G., A review of nutritional and physiological factors affecting goat milk lipid synthesis and lipolysis, J. Dairy Sci., **86**, no. 5, 2003, pp. 1751-1770.
27. ULBRICHT, T.L., SOUTHGATE, D.A., Coronary heart disease: Seven dietary factors. Lancet, **338**, 1991, pp. 985-992.
28.*** SAS, Statistical analysis software, version 9.1.3. SAS Institute Inc., Cary, NC, USA, 2006.
29. EBRAHIMI, M., RAJION, M.A., GOH, Y.M., Effects of oils rich in linoleic and á-linolenic acids on fatty acid profile and gene expression in goat meat, Nutrients, **6**, 2014, pp. 3913-3928.
30.BOLTE, M.R., HESS, B.W., MEANS, W.J., MOSS, G.E., RULE D.C., Feeding lambs high-oleate or high-linoleate safflower seeds differentially influences carcass fatty acid composition, J. Anim. Sci., **80**, no. 3, 2002, pp. 609-616.
31.HRISTOV, A.N., KENNINGTON, L.R., MCGUIRE, M.A., HUNT, C.W., Effect of diets containing linoleic acid- or oleic acid-rich oils on ruminal fermentation and nutrient digestibility, and performance and fatty acid composition of adipose and muscle tissues of finishing cattle, J. Anim. Sci., **83**, 2005, pp. 1312–1321.
32.BESSA, R.J.B., PORTUGAL, P.V., MENDES, I.A., SANTOS-SILVA, J., Effect of lipid supplementation on growth performance, carcass and meat quality and fatty acid composition of intramuscular lipids of lambs fed dehydrated lucerne or concentrate, Livest. Prod. Sci., **96**, 2005, pp. 185-194.
33.DIAZ, M.T., ALVAREZ, I., DE LA FUENTE, J., SANUDO, C., CAMPO, M.M., OLIVER, M.A., FONT, M., FURNOLS, I., MONTOSSI, F., SAN JULIAN, R., NUTE, G.R., CANEQUE, V., Fatty acid composition of meat from typical lamb production systems of Spain, United Kingdom, Germany and Uruguay, Meat Sci., **71**, 2005, pp. 256-263.
34.ZSEDELY, E., KIRALY, A., SZABO, CS., NÉMETH, K., DOKA, O., SCHMIDT, J., Effect of dietary linseed oil soap on lamb meat, World Acad. Sci. Eng. Technol., **6**, 2012, pp. 229-232.
35 PONNAMPALAM, E.N., MANN, N.J., SINCLAIR, A.J., Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and *trans* fatty acids in Australian beef cuts: potential impact on human health, Asia Pac. J. Clin. Nutr., **15**, no. 1, 2006, pp. 21-29.
36 DELEANU, M., SANDA, G., STANCU, C., POPA, M., SIMA, A., Profiles of Fatty Acids and the Main Lipid Peroxidation Products of Human Atherogenic Low Density Lipoproteins, Rev. Chim. (Bucharest), **67**, no. 1, 2016, p. 8
37.MIERLITA, D., Effects of different sources of fat (calcium soap) on carcass quality and fatty acid profile of muscle and adipose tissues in lambs, Analele Univ. din Oradea, Fascicula: Ecotox. Zooteh. Teh. Ind. Alim., **XIVA**, 2015, pp. 363-372.

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