

## The effect of breed on fatty acid composition of subcutaneous adipose tissues in fat-tailed sheep under identical feeding conditions

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### Abstract

A study was conducted to evaluate the fatty acid (FA) profile of subcutaneous adipose tissue and tailfat of two fat-tailed sheep breeds under identical feeding conditions. Twelve male lambs from two breeds, Sanjabi (n = 6), weighing 23.3 ± 0.48 kg, and Mehraban (n = 6), weighing 26.1 ± 2.14 kg, were used in this investigation. All animals were weighed and slaughtered at the end of a 90-day fattening period and FA composition of subcutaneous adipose tissue and tailfat was determined. Significant breed differences in total FA, total polyunsaturated fatty acid (PUFA) and n-6PUFA contents were observed in the subcutaneous adipose tissue, but not in the tailfat. Breed differences were observed in the conjugated linoleic acid (CLA) content of subcutaneous adipose tissue, with higher levels in Sanjabi than in Mehraban lambs. Linoleic and α-linolenic acid of subcutaneous adipose were significantly higher in the Sanjabi breed than in the Mehraban breed. Thus, adipose tissue from fat-tailed Sanjabi lamb has a higher proportion of health-promoting linoleic and α-linolenic acids, unsaturated fatty acids (UFA) and CLA, suggesting that the Sanjabi breed could be used for producing healthier lamb products.

**Keywords:** Fatty acid profile, Iranian sheep breeds, Mehraban lamb, Sanjabi lamb

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### Introduction

Fatty acids (FA) or lipids are a class of bio-compounds that play a significant role in cellular function and health. Fats are an important part of a balanced diet for human beings and are essential for the digestion of the fat-soluble vitamins A, D, E and K. Human beings, like all vertebrates and most animals, display an absolute dietary requirement for linoleic (C18:2n-6) and α-linolenic acid (C18:3n-3). Both linoleic acid and α-linolenic acid are polyunsaturated and serve as precursors for other important compounds, for instance, α-linolenic acid is the precursor for long-chain n-3 polyunsaturated fatty acid (PUFA) such as docosahexaenoic acid (DHA). Likewise, linoleic acid is the parent FA in n-6 PUFA (Ruxton *et al.*, 2004).

Bulliyya (2000) pointed out that many of today's common health problems and pathologies throughout the world can be related to changes in fat intake worldwide. According to Healy *et al.* (2000), these FAs are incorporated into all lipid membrane tissues, that is, all the immune system tissues and cells, through the consumption of n-3PUFA (Maroufyan *et al.*, 2012). Skin function and normal growth are maintained because of C18:3n-3 (Fu & Sinclair 2000). However, the physiological importance of n-6PUFA for humans has been confirmed for example, mammalian skin function, growth and reproduction are affected by a C18:2n-6 deficiency (Burr, 1973; Holman, 1977; Hansen & Jensen, 1985). According to Wahle *et al.* (2004) and Kelley *et al.* (2010), a group of geometric and positional isomers of linoleic acid are referred to as conjugated linoleic acid (CLA) (C18:2n-6), in which the double bonds are joined together. Research showed that CLA possesses anti-adipogenic, anti-atherogenic, anti-carcinogenic, anti-inflammatory and anti-diabetogenic properties. Kelley *et al.* (2010) pointed out that one of the richest natural sources of CLA isomers, especially rumenic acid (cis-9 trans-11 CLA), is ruminant fats. There is evidence to suggest that the CLA content in ruminant adipose tissues varies. Danc *et al.* (2009) reported differences in the CLA content of subcutaneous adipose tissue of beef cattle breeds. Wachira *et al.* (2002) also reported differences in the FA content of subcutaneous adipose tissues of the Suffolk, Soay and Friesland sheep breeds.

The Sanjabi and Mehraban are Iranian fat-tailed sheep breeds. They are well adapted to cold environmental conditions and are reared mainly for meat. Although this sheep's tailfat is available in Iran, it cannot be used effectively in the food or confectionery industry. Furthermore, little research has been done on the FA composition of the tailfat of sheep. There is also limited information on the FA composition of their subcutaneous adipose tissues. Therefore, the aim of the present study was to measure the FA profile of the tailfat and subcutaneous adipose tissues in Sanjabi and Mehraban sheep maintained under identical feeding conditions.

## Materials and Methods

The experiment was carried out at the Experimental Farm of the School of Agriculture, Razi University, Kermanshah, Iran. Two fat-tailed sheep breeds, the Sanjabi and Mehraban, were used.

Lambs were born from oestrus-synchronized ewes that were maintained under similar conditions and that received a similar diet containing lucerne hay, maize grain, soybean meal, wheat bran, salt and mineral premix. The forage/concentrate ratio was 60/40 and formulated according to NRC (2001) recommendations. Prior to initiation of the growth study, the lambs were maintained with their dams and had access to concentrate, lucerne hay and water until weaning at 90 days of age. After weaning, 12 male lambs from the two breeds, namely Sanjabi ( $n = 6$ ), weighing  $23.33 \pm 0.48$  kg, and Mehraban ( $n = 6$ ), weighing  $26.10 \pm 2.14$  kg, were selected for the experiment. The lambs were drenched against parasites and housed individually in metal-framed pens (2 m  $\times$  1 m), with slatted flooring 0.5 metre above the ground. All lambs received a similar pelleted diet and had access to water ad libitum during the fattening period of three months. The forage/concentrate ratio in the pelleted diet was 30/70, formulated according to NRC (1985). The diet consisted of 30% lucerne hay, 28% barley, 25% maize, 8% soybean meal, 5% wheat bran, 2.5% molasses, 0.5% dicalcium phosphate, 0.5% vitamin/mineral premix and 0.5% salt. Chemical composition and the FA profile of the pelleted diet are presented in Table 1. Lambs were weighed at monthly intervals and at the end of the fattening period after a 14 h fasting (with access to water), and slaughtered. Three grams subcutaneous fat were taken from between the eighth and ninth ribs of the carcass and from tailfat, and frozen at  $-20$  °C, pending FA analysis.

Samples of the diet (500 g) were collected every 7 d and stored at 4 °C. Feed refusals for each lamb were weighed daily and stored at 4 °C until analysed for dry matter (DM). Feed samples were dried at 60 °C for 48 h to determine the DM content, ground to pass a 1 mm screen, and analysed for crude protein (CP), ether extract (EE), ash, organic matter (OM), neutral detergent fibre (NDF) and acid detergent fibre (ADF) according to standard AOAC methods (AOAC, 1990). Crude protein (CP, total nitrogen  $\times$  6.25) was determined by method number 990.03 of the AOAC (1990). Neutral detergent fibre and ADF were determined according to Van Soest *et al.* (1991).

Total FAs were extracted from the feed and fat, using the method of Folch *et al.* (1957) with some modifications by Rajion *et al.* (1985) as described by Ebrahimi *et al.* (2012), using chloroform : methanol (2 : 1 v/v) containing butylated hydroxyl toluene to prevent oxidation during sample preparation. One gram of the experimental diet and 0.5 g tissue were homogenized in 40 mL chloroform : methanol (2 : 1 v/v) using an Ultra-Turrax T5 FU homogenizer (IKA Analysentechnik GmbH, Heidolph, Viertrieb, Germany) in a 50-mL stoppered ground-glass extraction tubes. Transmethylation of the extracted FAs to their fatty acid methyl esters (FAME) was carried out using 0.66N KOH in methanol and 14% methanol boron trifluoride (BF<sub>3</sub>) (Sigma Chemical) according to the methods by AOAC (2007), as described by Ebrahimi *et al.* (2012). The FAME were separated by gas chromatography (Agilent 7890A), using a Supelco SP 2560 capillary column of 100 m  $\times$  0.25 mm ID  $\times$  0.2  $\mu$ m film thickness (Supelco, Bellefonte, PA, USA). One microlitre was injected by an auto sampler (Agilent Auto Analyzer 7683 B series, Agilent Technologies, Santa Clara, Calif, USA) into the chromatograph, equipped with a split/splitless injector and a flame ionization detector. The carrier gas was nitrogen at a flow rate of 1.2 mL/min. The split ratio was 1 : 20 after injection of 1  $\mu$ L of the FAME. The injector temperature was programmed at 250 °C, and the detector temperature was 270 °C. The column temperature programme ran at 150 °C for 2 min, warmed to 158 °C at 1 °C/min, held for 28 min, warmed to 220 °C at 1 °C/min, and then held for 20 min to achieve satisfactory separation (Ebrahimi *et al.*, 2013). The peaks of samples were identified, and concentrations calculated based on the retention time and peak area of known standards (Sigma Chemical). The FA concentrations are expressed as percentage of identified FAs in each sample.

All data were analysed using the GLM procedures of SAS (SAS, 2003). The following model was used:

$$Y_{ij} = \mu + D_i + S_j + e_{ij}$$

where  $Y_{ij}$  represents an observation;  $\mu$  is the overall mean;  $D_i$  is the effect of the breed ( $i =$  Mehraban, Sanjabi);  $S_j$  is the animal effect and  $e_{ij}$  is the residual error. Least significant difference comparison

procedures were used for mean separation in the presence of a significant F-statistic. All statistical tests were conducted at 95% confidence level.

**Table 1** Chemical composition (% of dry matter, DM) and fatty acid (FA) profile (% of total identified fatty acids) in the experimental diet

Dietary chemical composition	g/kg DM	Fatty acids	% of total identified FA
Dry matter	911	C10:0	0.06
Organic matter	910	C12:0	0.38
Crude protein	153.4	C14:0	0.53
Ether extract	23.0	C15:0	0.46
Neutral detergent fibre	328.7	C16:0	19.45
Acid detergent fibre	186.7	C16:1	0.69
		C18:0	5.95
		C18:1n-9	20.68
		C18:2n-6	44.57
		C18:3n-6	0.78
		C18:3n-3	6.44
		Total SFA	26.84
		Total UFA	73.16
		Total MUFA	21.37
		Total n-3PUFA	6.44
		Total n-6PUFA	44.57
		Total PUFA	51.02
		n-6: n-3 ratio	6.92

SFA: saturated FAs; MUFA: monounsaturated FAs; PUFA: polyunsaturated FAs.

Total SFA = sum of C14:0+C15:0+C16:0+C18:0;

Total UFA = sum of C16:1+C18:1n-9+C18:2n-6+C18:3n-6+C18:3n-3;

Total MUFA = sum of C16:1+C18:1n-9;

Total n-3PUFA = sum of C18:3n-3;

Total n-6 PUFA = sum of C18:2n-6;

Total PUFA = sum of C18:3n-3+ C18:2n-6;

n-6: n-3 ratio = sum total n-6PUFA; sum of total n-3PUFA.

## Results and Discussion

The FA composition of subcutaneous adipose tissue and tailfat is expressed as a percentage of total identified FAs (Tables 2 and 3). The average daily feed (g) consumed by the Sanjabi and Mehraban breeds was  $1192.6 \pm 56.57$  g and  $1338.8 \pm 58.98$  g, respectively, and was not significantly different between breeds ( $P < 0.05$ ). Breed affected the FA composition of subcutaneous adipose tissue significantly. Differences in the FA composition of fat have been observed between sheep breeds (Sanudo *et al.*, 2000) and beef cattle breeds (Laborde *et al.*, 2001; Dance *et al.*, 2009). However, results from these studies are confounded because the two breeds were from different regions and kept under different management and feeding conditions, contrary to the present study where the two breeds were under identical management and feeding conditions. To the researchers' knowledge, no information is available on the FA profiles of the Sanjabi and Mehraban sheep breeds and how they compare. The synthesis and metabolism of FAs in the ruminant animal could be affected by genetic and microbial activities in the rumen. Saatchi *et al.* (2013) demonstrated that the heritability of FAs varies with chain length. FAs with a chain length of >18 carbons (with the exception of C24:0) had lower heritabilities (0.06 to 0.24) than FAs with shorter chains (0.08 to 0.57).

**Table 2** Fatty acid (FA) composition (% total identified fatty acids) (mean  $\pm$  SE; n = 6) in subcutaneous adipose tissue of two fat-tailed sheep breeds, Mehraban and Sanjabi

Fatty acids	Mehraban	Sanjabi	P-value
C10:0	0.40 $\pm$ 0.06	0.52 $\pm$ 0.10	0.325
C12:0	0.24 $\pm$ 0.03	0.18 $\pm$ 0.03	0.198
C14:0	5.17 $\pm$ 0.32	4.12 $\pm$ 0.37	0.039
C14:1	0.95 $\pm$ 0.04	0.93 $\pm$ 0.12	0.883
C15:0	1.33 $\pm$ 0.10	1.52 $\pm$ 0.31	0.589
C16:0	28.9 $\pm$ 0.83	26.6 $\pm$ 0.58	0.031
C16:1	3.62 $\pm$ 0.23	3.14 $\pm$ 0.26	0.250
C17:0	0.43 $\pm$ 0.05	0.49 $\pm$ 0.13	0.717
C17:1	3.97 $\pm$ 0.20	4.62 $\pm$ 0.50	0.331
C18:0	8.96 $\pm$ 0.47	9.22 $\pm$ 0.70	0.798
C18:1n-9	37.9 $\pm$ 1.45	37.8 $\pm$ 0.86	0.975
C18:1t-11	3.40 $\pm$ 0.33	4.18 $\pm$ 0.64	0.375
C18:2n-6	3.02 $\pm$ 0.13	4.52 $\pm$ 0.39	0.012
C18:3n-6	0.15 $\pm$ 0.05	0.30 $\pm$ 0.09	0.178
c-9 t-11CLA	0.73 $\pm$ 0.06	1.15 $\pm$ 0.18	0.052
c-12 t-10CLA	0.28 $\pm$ 0.06	0.22 $\pm$ 0.04	0.325
C18:3n-3	0.35 $\pm$ 0.02	0.59 $\pm$ 0.05	0.009
C20:4n-6	0.14 $\pm$ 0.01	0.17 $\pm$ 0.02	0.068
C20:5n-3	0.28 $\pm$ 0.08	0.36 $\pm$ 0.10	0.533
C22:5n-3	0.27 $\pm$ 0.07	0.26 $\pm$ 0.09	0.928
C22:6n-3	0.29 $\pm$ 0.10	0.23 $\pm$ 0.01	0.754
Total SFA	45.4 $\pm$ 1.07	42.7 $\pm$ 0.82	0.068
Total UFA	54.6 $\pm$ 1.07	57.3 $\pm$ 0.82	0.068
Total MUFA	49.8 $\pm$ 1.11	50.7 $\pm$ 0.66	0.531
Total n-3 PUFA	1.20 $\pm$ 0.20	1.45 $\pm$ 0.20	0.443
Total n-6 PUFA	3.16 $\pm$ 1.11	4.69 $\pm$ 0.40	0.011
Total PUFA	4.35 $\pm$ 0.30	6.14 $\pm$ 0.56	0.016
Total trans FA	3.40 $\pm$ 0.33	4.18 $\pm$ 0.64	0.374
Total CLA	1.00 $\pm$ 0.08	1.37 $\pm$ 0.19	0.117
n-6 : n-3 ratio	2.98 $\pm$ 0.47	3.71 $\pm$ 0.38	0.311
UFA: SFA ratio	1.21 $\pm$ 0.05	1.35 $\pm$ 0.04	0.070
PUFA: SFA ratio	0.10 $\pm$ 0.01	0.14 $\pm$ 0.01	0.007

SE: standard error; CLA: conjugated linoleic acid; UFA: unsaturated fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids. Total SFA = sum of C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0; Total UFA = sum of C14:1 + C16:1 + C17:1 + C18:1n-9 + C18:2 + C18:3n-6 + C18:3n-3 + C20:4 + C20:5n-3 + C22:5n-3 + C22:6n-3; Total MUFA = sum of C14:1 + C16:1 + C17:1 + C18:1n-9; Total n-3 PUFA = sum of C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3; Total n-6 PUFA = sum of C18:2n-6 + C18:3n-6 + C20:4n-6; Total PUFA = sum of C18:2n-6 + C18:3n-6 + C18:3n-3 + C20:4n-6 + C20:5n-3 + C22:5n-3 + C22:6n-3; Total trans fatty acid = sum of C18:1t-11; Total CLA = sum c-9 t-11CLA + c-12 t-10CLA; n-6: n-3 ratio = total n-6 PUFA; total n-3 PUFA.

Palmitic acid (C16:0), stearic acid (C18:0) and myristic acid (C14:0) were the major SFAs in the subcutaneous adipose tissue and tailfat of the two breeds. The levels of C16:0 (28.9% vs. 26.6%) and C14:0

(5.17% vs. 4.12%) in the subcutaneous adipose tissue of the Mehraban were significantly ( $P < 0.05$ ) higher than in the Sanjabi. Similar breed differences have been reported by Wachira *et al.* (2002), who found that myristic acid concentration was significantly higher in the subcutaneous adipose tissue of Friesland and Soay, compared with Suffolk lambs. The levels of stearic acid in the Sanjabi and Mehraban breed were 8.96% and 9.22% in the present study, which are lower than those of Wachira *et al.* (2002), who reported values of 14.7% - 18.7% for three lamb breeds that were fed a control diet.

The concentrations of palmitic acid (26.5% vs. 25.7%), stearic acid (11.01% vs. 7.11%) and myristic acid (4.31% vs. 4.28%) of tailfat in the Sanjabi and Mehraban breeds were not significantly different ( $P > 0.05$ ). The C18:0 values (7.11 - 11.01) of tailfat in the current study were similar to values reported by Nuernberg *et al.* (2008) for Skudde lambs (9.40 - 11.96 g/100 g), but lower than those of ewes of the Han (9.92 - 14.57 g/100 g) (Peng *et al.*, 2010) and Damara (13% of total FAs) (Alvice *et al.*, 2013), suggesting a breed effect. Similar concentrations of palmitic acid (27.47%) and myristic acid (6.70%) were observed by Alipanah & Kashan (2011) for tailfat of other Iranian sheep breeds. Alvice *et al.* (2013) recently reported lower concentrations (16.5% and 2%) for palmitic and myristic acid, respectively, in the tailfat of the Damara breed. The levels of C15:0 (1.58% vs. 0.87%) and C17:0 (0.70% vs. 0.38%) in the tailfat of Sanjabi lambs were significantly ( $P < 0.05$ ) higher than in that of Mehraban lambs.

Subcutaneous adipose tissue of Sanjabi contained less saturated fatty acids (SFA) (42.7% of total FAs) and more unsaturated fatty acids (UFA) (57.3%) compared with the Mehraban (45.4% and 54.6%, respectively). This resulted in a slightly higher UFA : SFA ratio for subcutaneous adipose (1.35) of the Sanjabi compared with the Mehraban (1.21). The high concentration of C18:2n-6 and C18:3n-3, and the low concentration of palmitic acid (C16:0) and myristic acid (C14:0) in subcutaneous adipose of the Sanjabi was responsible for these differences. The *de novo* FA synthesis in ruminants is limited primarily to 14, 16 and 18 carbon FAs. Since the heritability of these FAs is higher than that of long-chain FAs, the differences in the content of palmitic acid (C16:0) and myristic acid (C14:0) of the adipose tissue between the Sanjabi and Mehraban breeds might be attributed to genetic differences.

Based on the present study, tailfat from the two breeds contained 42% SFA and 58% UFA, consistent with results of Alipanah & Kashan (2011), who reported that average percentages of the sheep tailfat were between 39.4% and 65.4% for SFA and between 32.2% and 60.8% for UFA.

Oleic acid (C18:1n-9) was the major monounsaturated fatty acid (MUFA), which contributed to more than 90% of the total MUFA in both subcutaneous adipose tissue and tailfat of the two breeds (Tables 2 and 3). The concentrations of C14:1, C16:1 and C17:1 in subcutaneous adipose were the reason for the major differences in FA composition between the breeds, and were significantly higher in the Sanjabi than the Mehraban.

The levels of the major contributors of n-6PUFA, namely C18:2n-6 (4.52% vs. 3.02%) in Sanjabi lambs, were significantly higher than in the Mehraban ( $P < 0.05$ ). However, the levels of C18:2n-6, C18:3n-6, C20:4n-6 and total n-6PUFA in the tailfat were not significantly different between the breeds. The levels of C20:5n-3, C22:5n-3, C22:6n-3 and total n-3PUFA were not significantly different between the breeds, either, but C18:3n-3 in the subcutaneous adipose tissue of the Sanjabi breed was higher ( $P < 0.05$ ) than in the Mehraban. Nfor *et al.* (2014) reported similar results on cattle muscle. He recorded that the Gudali breed contained higher concentrations of C18:3n-3 in their muscles compared to the White Fulani. The levels of individual n-3PUFA and total n-3PUFA in the tailfat were not significantly different between the breeds.

Subcutaneous adipose tissue of the Sanjabi contained a higher total PUFA (6.14% vs. 4.35%) concentration and PUFA : SFA ratio (0.14 vs. 0.10) than the Mehraban. The high concentrations of C18:2n-6 and C18:3n-3, and consequently, the slightly higher content of C20:4n-6 in the subcutaneous adipose of the Sanjabi, were responsible for this significant difference. The high content of n-6 PUFA in Sanjabi is largely owing to the high content of linoleic acid of subcutaneous adipose tissue. However, the higher content of C18:2n-6 might be the driving force for the synthesis of C20:4n-6 in this breed. These findings on the n-6PUFA content of Sanjabi subcutaneous adipose are similar to those reported by Fisher *et al.* (2000) for Soay lambs, which, when compared with the Suffolk, had higher concentrations of n-6PUFA in their semimembranosus muscle. This could be owing to the low concentration of total lipids in muscle and a higher ratio of phospholipids to total lipids. The similar quantities of the long chain n-3PUFA in the muscles of the two breeds indicated similar quantities of phospholipids in their muscles and a similar metabolism of C18:3n-3 to produce these FAs.

The PUFA : SFA ratio of the tailfat was similar to that in the adipose tissue of the two breeds. The PUFA : SFA ratio in the Sanjabi and Mehraban breeds is consistent with the results of Alipanah & Kashan, (2011), who reported values of between 0.069% and 0.195% for sheep breeds.

The levels of the C18:1t-11 (3.40% - 4.18%) and c-12 t-10 CLA (0.22% - 0.28%) of subcutaneous adipose tissue were not significantly different ( $P > 0.05$ ) between the breeds, but c-9 t-11 CLA levels (0.73% - 1.15%) in the subcutaneous adipose tissue of Sanjabi were higher ( $P < 0.05$ ) than in the Mehraban. The

levels of C18:1t-11 (3.41% - 3.84%) and c-9 t-11 CLA (1.18% - 1.50%) and c-12 t-10 CLA (0.15% - 0.17%) in the tailfat were not significantly different between the breeds.

**Table 3** Fatty acid (FA) composition (% total identified fatty acids) (mean  $\pm$  SE; n = 6) in the tailfat of two fat-tailed sheep breeds, Mehraban and Sanjabi

Fatty acids	Mehraban	Sanjabi	P-value
C10:0	0.41 $\pm$ 0.03	0.42 $\pm$ 0.04	0.917
C12:0	0.22 $\pm$ 0.03	0.20 $\pm$ 0.01	0.471
C14:0	4.31 $\pm$ 0.41	4.28 $\pm$ 0.15	0.947
C14:1	0.76 $\pm$ 0.15	1.12 $\pm$ 0.04	0.044
C15:0	0.87 $\pm$ 0.14	1.58 $\pm$ 0.14	0.004
C16:0	26.5 $\pm$ 0.95	25.7 $\pm$ 0.57	0.495
C16:1	3.04 $\pm$ 0.46	4.24 $\pm$ 0.44	0.07
C17:0	0.38 $\pm$ 0.03	0.70 $\pm$ 0.12	0.01
C17:1	3.39 $\pm$ 0.37	5.39 $\pm$ 0.36	0.007
C18:0	11.01 $\pm$ 1.72	7.11 $\pm$ 1.02	0.069
C18:1n-9	40.01 $\pm$ 1.22	39.16 $\pm$ 1.24	0.606
C18:1t-11	3.41 $\pm$ 0.38	3.84 $\pm$ 0.39	0.505
C18:2n-6	3.93 $\pm$ 0.40	4.35 $\pm$ 0.23	0.381
C18:3n-6	0.35 $\pm$ 0.07	0.35 $\pm$ 0.06	0.954
c-9 t-11CLA	1.18 $\pm$ 0.22	1.50 $\pm$ 0.14	0.249
c-12 t-10CLA	0.17 $\pm$ 0.08	0.15 $\pm$ 0.01	0.786
C18:3n-3	0.53 $\pm$ 0.07	0.59 $\pm$ 0.05	0.502
C20:4n-6	0.21 $\pm$ 0.04	0.18 $\pm$ 0.01	0.477
C20:5n-3	0.24 $\pm$ 0.09	0.29 $\pm$ 0.08	0.713
C22:5n-3	0.14 $\pm$ 0.04	0.25 $\pm$ 0.11	0.279
C22:6n-3	0.13 $\pm$ 0.02	0.12 $\pm$ 0.02	0.873
Total SFA	43.7 $\pm$ 1.99	40.0 $\pm$ 1.24	0.136
Total UFA	56.3 $\pm$ 1.99	60.0 $\pm$ 1.24	0.136
Total MUFA	50.6 $\pm$ 1.94	53.8 $\pm$ 1.17	0.188
Total n-3 PUFA	1.04 $\pm$ 0.15	1.25 $\pm$ 0.16	0.318
Total n-6 PUFA	4.14 $\pm$ 0.44	4.52 $\pm$ 0.23	0.454
Total PUFA	5.18 $\pm$ 0.50	5.77 $\pm$ 0.32	0.335
Total trans FA	3.41 $\pm$ 0.38	3.84 $\pm$ 0.39	0.505
Total CLA	1.35 $\pm$ 0.24	1.64 $\pm$ 0.14	0.306
n-6 : n-3 ratio	4.19 $\pm$ 0.43	3.75 $\pm$ 0.35	0.43
UFA: SFA ratio	1.31 $\pm$ 0.10	1.51 $\pm$ 0.08	0.148
PUFA: SFA ratio	0.12 $\pm$ 0.01	0.15 $\pm$ 0.01	0.147

SE: standard error; CLA: conjugated linoleic acid; UFA: unsaturated FAs; SFA: saturated FAs; MUFA: monounsaturated FAs; PUFA: polyunsaturated FAs.  
 Total SFA = sum of C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0;  
 Total UFA = sum of C14:1 + C16:1 + C17:1 + C18:1n-9 + C18:2n-6 + C18:3n-3 + C20:4n-6 + C20:5n-3 + C22:5n-3 + C22:6n-3; Total MUFA = sum of C14:1 + C16:1 + C17:1 + C18:1n-9;  
 Total n-3 PUFA = sum of C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3;  
 Total n-6 PUFA = sum of C18:2n-6 + C18:3n-6 + C20:4n-6;  
 Total PUFA = C18:2n-6 + C18:3n-6 + C18:3n-3 + C20:4n-6 + C20:5n-3 + C22:5n-3 + C22:6n-3;  
 Total trans FA = sum of C18:1t-11;  
 Total CLA = sum c-9 t-11CLA c-9 t-11 + c-12 t-10CLA;  
 n-6: n-3 ratio = total n-6 PUFA; total n-3 PUFA.

The concentration of c-9 t-11 CLA isomer in the Sanjabi subcutaneous adipose was twofold higher than in the Mehraban. Although the difference was not significant, the level of trans vaccenic acid (TVA) (C18:1t-11) was higher in the Sanjabi breed. TVA (C18:1t-11) is an important MUFA for *de novo* synthesis of CLA (c-9 t-11CLA), which is a potent anti-carcinogen that is synthesized in the subcutaneous adipose tissues (Bauman & Lock 2006). These results are consistent with the study of Schen *et al.* (2007), who reported tissue and breed-specific responses in terms of TVA and CLA in cattle fed either a pasture or a concentrate diet. Breed differences in CLA content were also reported by Danc *et al.* (2009), who demonstrated the highest c-9 t-11 CLA level in the subcutaneous adipose tissues of Longhorn cattle compared with Charolais cross, Belted Galloway and Shorthorn cattle.

## Conclusion

In the present study, differences between the sheep breeds in their FA profiles and c-9 t-11 CLA were observed in the adipose tissue, but not in the tailfat. Subcutaneous adipose tissue from Sanjabi lamb had a higher proportion of healthy linoleic and  $\alpha$ -linolenic acid, polyunsaturated FAs and cis-9 trans-11 CLA isomer. However, there were minimal differences in FA profiles of tailfat in the two breeds. It would be interesting to investigate ways to genetically or managerially manipulate the FA profile in fat-tailed breeds so that their product is more health promoting.

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## References

- Alipanah, M. & Kashan, N.E., 2011. Fatty acid composition of fat tail, visceral and meat fat of three Iranian sheep breeds. *J. Food. Agric. Environ.* 9, 416-418.
- AOAC, 1990. Official methods of analysis of the Association of Official Analytical Chemists (15<sup>th</sup> ed.). Association of Official Analytical Chemists, Washington D.C., USA.
- AOAC, 2007. Official methods of analysis of the Association of Official Analytical Chemists (18<sup>th</sup> ed.). Association of Official Analytical Chemists, Washington D.C., USA.
- Bauman, D.E. & Lock, A.L., 2006. Conjugated linoleic acid: biosynthesis and nutritional significance. In: *Advanced Dairy Chemistry, Volume 2: Lipids*. Springer, New York. pp. 93-136.
- Bulliyya, G., 2000. Key role of dietary fats in coronary heart disease under progressive urbanization and nutritional transition. *Pac. J. Clinic Nutr.* 9, 289-297.
- Burr, G.O., 1973. A new deficiency disease produced by the rigid exclusion of fat from the diet. *Nutr. Rev.* 31, 148-149.
- Dance, L.J.E., Matthews, K.R. & Doran, O., 2009. Effect of breed on fatty acid composition and stearoyl-CoA desaturase protein expression in the semimembranosus muscle and subcutaneous adipose tissue of cattle. *Livest. Sci.* 125, 291-297.
- Demirel, G., Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Wood, J.D. & Enser, M., 2004. Effects of dietary n-3 polyunsaturated fatty acids, breed and dietary vitamin E on the fatty acids of lamb muscle, liver and adipose tissue. *Br. J. Nutr.* 91, 551-565.
- Ebrahimi, M., Rajion, M.A., Goh, Y.M. & Sazili, A.Q., 2012. Impact of different inclusion levels of oil palm (*Elaeis guineensis* Jacq.) fronds on fatty acid profiles of goat muscles. *J. Anim. Physiol. Anim. Nutr.* 96, 962-969.
- Ebrahimi, M., Rajion, M.A., Goh, Y.M., Sazili, A.Q. & Schonewille, J.T., 2013. Effect of linseed oil dietary supplementation on fatty acid composition and gene expression in adipose tissue of growing goats. *Biomed. Res. Int.* 2013.
- Fisher, A.V., Enser, M., Richardson, R.I., Wood, J.D., Nute, G.R., Kurt, E., Sinclair, L.A. & Wilkinson, R.G., 2000. Fatty acid composition and eating quality of lamb types derived from four diverse breed x production systems. *Meat Sci.* 55, 141-147.
- Folch, J., Lees, M. & Sloane-Stanley, G.H., 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* 226, 497-509.
- Fu, Z. & Sinclair, A.J., 2000. Increased alpha-linolenic acid intake increases tissue alpha-linolenic acid content and apparent oxidation with little effect on tissue docosahexaenoic acid in the guinea pig. *Lipids* 35 (4), 395-400.

- Hansen, H.S. & Jensen, B., 1985. Essential function of linoleic acid esterified in acylglucosylceramide and acylceramide in maintaining the epidermal water permeability barrier. Evidence from feeding studies with oleate, linoleate, arachidonate, columbinic acid, and  $\alpha$ -linolenate, *Biochim. Biophys. Acta* 84, 357-363.
- Healy, D.A., Wallace, F.A., Miles, E.A., Calder, P.C. & Newsholme, P., 2000. Effect of low-to-moderate amounts of dietary fish oil on neutrophil lipid composition and function. *Lipids* 35, 763-768.
- Holman, R.T., 1977. Essential fatty acids in human nutrition. In: *Function and Biosynthesis of Lipids*. Springer, New York. pp. 515-534.
- Kelley, N.S., Hubbard, N.E. & Erickson, K.L., 2010. Alteration of human body composition and tumorigenesis by isomers of conjugated linoleic acid. In: *Modern Dietary Fat Intakes in Disease Promotion*. Springer, New York. pp. 121-131.
- Laborde, F.L., Mandell, I.B., Tosh, J.J., Wilton, J.W. & Buchanan-Smith, J.G., 2001. Breed effects on growth performance, carcass characteristics, fatty acid composition, and palatability attributes in finishing steers. *J. Anim. Sci.* 79, 355-365.
- Maroufyan, E., Kasim, A., Ebrahimi, M., Loh, T.C., Hair-Bejo, M. & Soleimani, A.F., 2012. Dietary methionine and n-6:n-3 polyunsaturated fatty acid ratio reduce adverse effects of infectious bursal disease in broilers. *Poult. Sci.* 91, 2173-2182.
- NRC, 1985. Nutrient requirements of sheep. (6<sup>th</sup> ed.). National Academy Science, Washington, D.C., USA.
- NRC, 2001. Nutrient requirements of sheep. (7<sup>th</sup> ed.). National Academy Science, Washington DC, USA.
- Nuernberg, K., Fischer, A., Nuernberg, G., Ender, K. & Dannenberger, D., 2008. Meat quality and fatty acid composition of lipids in muscle and fatty tissue of Skudde lambs fed grass versus concentrate. *Small Rumin. Res.* 74, 279-283.
- Peng, Y.S., Brown, M.A., Wu, J.P. & Liu, Z., 2010. Different oilseed supplements alter fatty acid composition of different adipose tissues of adult ewes. *Meat Sci.* 85, 542-549.
- Rajion, M.A., McLean, J.G. & Cahill, R.N., 1985. Essential fatty acids in the fetal and newborn lamb. *Aust. J. Boil. Sci.* 38, 33-40.
- Ruxton, C.H.S., Reed, S.C., Simpson, M.J.A. & Millington, K.J., 2004. The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence. *J. Hum. Nutr. Diet.* 17, 449-459.
- Saatchi, M., Garrick, D.J., Tait, R.G., Mayes, M.S., Drewnoski, M., Schoonmaker, J., Diaz, C., Beitz, D.C. & Reecy, J.M., 2013. Genome-wide association and prediction of direct genomic breeding values for composition of fatty acids in Angus beef cattle. *BMC Genomics* 14, 730.
- Sanudo, C., Enser, M.E., Campo, M.M., Nute, G.R., Maria, G., Sierra, I. & Wood, J.D., 2000. Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain. *Meat Sci.* 54, 339-346.
- SAS, 2003. SAS User's Guide: Statistics, Version 9.1 edition. SAS Inst., Inc., Cary, NC, USA.
- Schen, X., Nuernberg, K., Nuernberg, G., Zhao, R., Scollan, N., Ender, K. & Dannenberger, D., 2007. Vaccenic acid and cis-9, trans-11 CLA in the rumen and different tissues of pasture- and concentrate-fed beef cattle. *Lipids* 42, 1093-1103.
- Susana, P., Alves, S.P., Bessa, R.J.B., Quaresma, M.A.G., Kilminster, K., Scanlon, T., Oldham, C., Milton, J., Greeff, J. & Almeida, A.M., 2013. Does the fat tailed Damara ovine breed have a distinct lipid metabolism leading to a high concentration of branched-chain fatty acids in tissues? *PLOS ONE* 8(10): e77313. doi:10.1371/journal.pone.0077313.
- Van Soest, P., Robertson, J.B. & Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74, 3583-3597.
- Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Enser, M., Wood, J.D. & Fisher, A.V., 2002. Effects of dietary fat source and breed on the carcass composition, n-3 polyunsaturated fatty acid and conjugated linoleic acid content of sheep meat and adipose tissue. *Br. J. Nutr.* 88, 697-709.
- Wahle, K.W., Heys, S.D. & Rotondo, D., 2004. Conjugated linoleic acids: are they beneficial or detrimental to health? *Prog. Lipid Res.* 43, 553-587.