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The effect of feeding system on slaughter-carcass characteristics, meat quality, and fatty acid composition of lambs

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Abstract. In this study, we aimed to determine the slaughter-carcass characteristics, meat quality, and fatty acid composition in lambs raised under intensive and extensive conditions. The animal material consisted of 30 Norduz male lambs, with an average age of 171 days. The lambs were divided into two groups: concentrate-fed lambs (CO) and pasture-fed lambs (PS). The results showed that the CO lambs had heavier carcasses ($p < 0.001$), a higher dressing percentage ($p < 0.001$), and higher intramuscular fat ($p < 0.01$) than the PS lambs. It was determined that the longissimus thoracis muscle of the CO lambs had a lower ultimate pH and higher L^* and water-holding capacity than the PS lambs. In this study, intramuscular fat (longissimus thoracis, semimembranosus, triceps brachii), subcutaneous and tail fat samples were used to evaluate the effect of feeding system on fatty acid composition. The polyunsaturated fatty acid to saturated fatty acid ratio (PUFA / SFA) of intramuscular fat was found to be significantly higher in the CO group than in the PS lambs, while similar subcutaneous and tail fat results were found in both groups. Moreover, the PS lambs had a lower n6 / n3 ratio and higher percentage of omega-3 than the CO lambs in all tissues studied ($p < 0.05$). Overall, the CO lambs have heavier and fattier carcasses with better meat quality traits than the PS lambs. However, the effects of feeding system have varying results based on the fatty acid composition of different types of fat deposits.

1 Introduction

Carcass and meat quality are dependent on many factors and one of the most important environmental factors amongst these is the feeding system. Previous studies that predominantly compared pasture vs. grain feeding indicated that growth performance and carcass characteristics (Carrasco et al., 2009b; Ripoll et al., 2008), meat quality traits, such as color (Priolo et al., 2001; Ripoll et al., 2008), water-holding capacity (WHC) (Santos-Silva et al., 2002b), sensory characteristics (Duckett et al., 2013; Fisher et al., 2000), fatty acid (FA) profile (Karaca and Kor, 2015; Nuernberg et al., 2008), and oxidative stability (Popova, 2007), can also be affected by feeding systems. In general, pasture-fed lambs have leaner carcasses, lower dressing percentage, and more beneficial FAs, whereas concentrate-fed lambs have higher growth rates, better carcass conformation, a less problematic ultimate pH, and a higher n6 / n3 ratio (Wood et al., 2008; Zervas and Tsiplakou, 2011).

Although ruminal biohydrogenation is the main factor in modifying dietary unsaturated fatty acids, the n-3 FA content differences between pasture and concentrate, in particular, make the feeding system important. The quantity and structure of FA intake modulates the metabolism, physiology, and immune response in humans, and, therefore, changes in the FA intake affect the risk of developing some chronic diseases, particularly cardiovascular diseases. Thus, increasing n-3 FA content is the common goal of the strategies to improve the lipid profile of meat (Bessa et al., 2015).

Pastures plays a very important role in small ruminant breeding and in extensive animal feeding, which is common practice in Turkey, where supplementation of lambs with commercial concentrate is limited. Norduz is a fat-tailed sheep breed native to the Eastern Anatolian province of Van, and meat quality and lipid contents have not been studied to date. The aim of the present study was to determine the effect of the feeding system on slaughter-carcass characteristics, meat quality, and FA profile of different types of fat deposits in Norduz lambs.

2 Materials and methods

2.1 Animals, diets, and experimental design

The study group consisted of 30, single-born, male Norduz lambs. The 30 lambs (age: 160–185 days; mean: 171 days; live weight: 35.01 ± 0.338 kg) were assigned to one of the two dietary regimes: 15 lambs grazed on pasture (PS) and 15 lambs were fed with concentrate ration in stall (CO). The grazing pasture, populated with multiple species of native plants, was located at 38°18′ N and 42°49′ E and 2460 m above sea level. The pasture has also been documented by Beyis (2009), who stated that 14.3 % *Poaceae* (grasses) and 13.4 % *Fabaceae* (legume) taxa contributed to the floristic composition, with 72.3 % taxa from other plant families, from which a hay harvest yielded 955 kg ha^{-1}. For the nutrient composition of the pasture, given in Table 1, the values determined by Karaca (2010) in the following year for the same pasture were used. Each lamb on the concentrate diet was fed with 200 g of alfalfa hay and ad libitum concentrate (barley 72.5 %, cotton seed pulp 24.0 %, calcium carbonate ($CaCO_3$) 2.4 %, salt (NaCl) 0.5 %, vitamin supplement 0.5 %, and mineral supplement 0.1 %). The chemical compositions of the diets of the lambs are given in Table 1.

Table 1. Chemical composition of concentrate and pasture hay.

Composition	Experimental diet	Pasture hay*
Crude protein (% DM)	14.71	10.44
Ether extract (% DM)	2.30	1.87
Ash (% DM)	9.42	7.26
ADF (% DM)	20.24	29.09
NDF (% DM)	38.56	50.47
Crude fiber	14.18	32.27
Metabolizable energy (MJ kg DM^{-1})	10.94	9.93
Fatty acid composition (fatty acids, %)		
C10:0	0.02	0.04
C12:0	0.13	0.65
C14:0	0.78	2.01
C14:1	0.09	0.30
C15:0	0.04	0.25
C15:1	0.40	0.23
C16:0	21.58	23.09
C16:1	0.37	0.88
C17:0	0.14	0.77
C18:0	2.75	3.91
C18:1	18.20	12.29
C18:2	46.93	15.73
C18:3	6.53	32.71
C20:0	0.11	0.26
C20:1	0.58	nd
Others	1.35	6.88

* by Karaca (2010); nd: not detected; DM: dry matter.

2.2 Sampling procedures and instrumental analyses

All lambs were slaughtered after 12 h of fasting at the end of the fattening period of 84 days. After slaughter, the carcasses were stored at 4 °C for 24 h. The jointing of carcasses was based on the method given by Colomer-Rocher et al. (1987). The longissimus thoracis (LT) muscle (6th–13th ribs) was removed from the left side of the carcass at 24 h postmortem and used for color, water-holding capacity, proximate and FA analyses. In addition to this, the semimembranosus (SM) and triceps brachii (TB) muscles, tail fat (TF), and subcutaneous (SC) fat samples were removed from each carcass for FA profile determination.

Carcass pH was measured at 45 min post-slaughter (pH_{45}) and at 24 h post-slaughter (pH_{24}) using a digital pH meter (Hanna HI 99163N, Hanna instruments, Romania) equipped with a penetrating electrode and thermometer. The pH was directly measured on the LT muscle between the 12th and 13th thoracic vertebrae. In order to determine meat color, each sample had five measurements, from the fat-free areas, using a Lovibond RT-300 portable spectrophotometer (The Tintometer Limited, UK) (CIELAB-Illuminant $D_{65}/10°$) at 24 h post-slaughter. The measurements were performed on a freshly cut surface of 2.5 cm thick LT (12th–13th ribs) after allowing the muscle surface to bloom in the chiller for 45 min. Water-holding capacity (WHC) was determined according to Wierbicki and Deatherage (1958), where a 0.5 g sample of muscle tissue was placed on filter paper and pressed at 500 psi min^{-1} between two plexiglass plates. The results were expressed as the percentage of free water.

Longissimus muscle samples were vacuum-packed and frozen to −18 °C for use in chemical analysis. The samples were then thawed overnight, preceding the start of the analysis, and minced and homogenized. The nutrient content was analyzed according to AOAC (2000) by homogenizing the samples and measuring dry matter, ash, fat, and protein content (moisture: 950.46; ash: 920.153; fat: 960.39 (determined using ether extraction); protein: 928.08 (determined using the Kjeldahl method)). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents of feed samples were determined according to Van Soest and Robertson (1979).

Fatty acid analysis was performed on samples that had been stored at −18 °C for 1 month and then allowed to

thaw overnight at 4 °C. Fat samples that were used included SC (from above the 6th–12th chop) and TF, and intramuscular fat taken from the LT, SM, and TB muscle samples. Muscle (25 g) or fat (2 g) were homogenized with chloroform–methanol (2 : 1, v/v), and total lipids were extracted according to the procedure described by Folch et al. (1957); methylation was performed as described previously by Basturk et al. (2007). FA composition was determined by gas chromatography (Agilent 6890 N, Agilent Technology, USA) equipped with a flame ionization detector and a polar capillary column (DB-23, Agilent Technology, USA; 60 m × 0.25 mm I.D., 0.25 µm). Helium was used as the carrier gas (1.5 mL min^{-1}). The oven temperature was programmed at 120 °C for 5 min, increased to 240 °C at a rate of 15 °C min^{-1} and held at 240 °C for 20 min. FA methyl esters were identified by matching their retention times with those of their relative standards (Supelco 37 component FAME Mix, Sigma-Aldrich Co., USA). Moreover, the fatty acid composition of feed samples was determined according to the official EEC (1991) method (2568/91).

2.3 Indices and sums calculations

The saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) were calculated with the following Eqs. (1–3):

$$\begin{aligned}\text{SFA} =& \text{C10:0} + \text{C12:0} + \text{C14:0} + \text{C15:0} + \text{C16:0} \\ &+ \text{C17:0} + \text{C18:0} + \text{C20:0},\end{aligned} \quad (1)$$

$$\begin{aligned}\text{MUFA} =& \text{C14:1} + \text{C15:1} + \text{C16:1} + \text{C17:1} \\ &+ \text{C18:1n-9} + \text{C20:1},\end{aligned} \quad (2)$$

$$\text{PUFA} = \text{C18:2n-6} + \text{C18:3n-6}(\gamma) + \text{C18:3n-3}(\alpha). \quad (3)$$

The desirable fatty acids (DFAs) were calculating according to Huerta-Leidenz et al. (1991) with the following Eq. (4):

$$\text{DFA} = \text{Total unsaturated fatty acids (TUFA)} + \text{C18:0}. \quad (4)$$

Activities of desaturase activity indices were calculated according to Juárez et al. (2008) with the following Eqs. (5) and (6):

$$\Delta 9\text{DS(C16)} = 100 \times \left[\text{C16:1}/(\text{C16:0} + \text{C16:1})\right], \quad (5)$$

$$\Delta 9\text{DS(C18)} = 100 \times \left[\text{C18:1}/(\text{C18:0} + \text{C18:1})\right]. \quad (6)$$

2.4 Statistical analyses

One-way analysis of variance was performed using the Minitab 13.0 software program. Except for FAs, data were analyzed according to the following Eq. (7):

$$y_{ij} = \mu + a_i + e_{ij}. \quad (7)$$

The FA composition of different anatomical regions, in both PS and CO groups, was examined using the Eq. (8):

$$y_{ijk} = \mu + a_i + b_j + (ab)_{ij} + e_{ijk}, \quad (8)$$

where y_{ijk} is the value of the examined characteristic for the kth animal in the jth anatomical region from the ith feeding system; μ is the overall mean; a_i is the fixed effect of feeding system (a_i: concentrate or pasture); b_j is the fixed effect of anatomical region (j: SC, TF, LT, SM, and TB); $(ab)_{ij}$ is the interaction of the effects; and e_{ijk} is the random error. The principal component analysis was performed using the multivariate subsection of Minitab 13.0.

3 Results and discussion

3.1 Slaughter-carcass traits and meat quality

The results of slaughter traits for lambs raised under different feeding systems are given in Table 2. It was determined that the CO group had a higher slaughter and carcass weight than the PS group at the end of the fattening period. The dressing percentages were found to be lower in the PS lambs rather than the CO lambs. It has been frequently reported (Karaca and Kor, 2015; Priolo et al., 2002) that pasture-fed lambs have lower dressing percentages than concentrate-fed lambs, and this is thought to be related to the differences in the gastrointestinal content and fattening level of the feeding groups. Papi et al. (2011) reported that lambs fed low-energy and high-fiber diets had a higher digestive system content than those fed high-energy diets. The CO lambs had significantly higher omental–mesenteric fat (226.3 vs. 118.49 g; $p < 0.05$) and kidney-knob and channel fat (175.0 vs. 114.4 g; $p < 0.05$) than the PS lambs (data not shown in the table), whereas the percentages of fat recorded at the slaughter and cold carcass weights were found to be similar between the two groups (Table 2). The weights of the non-carcass parts, such as feet, which correlate with poor body growth, were greater in the PS lambs than the CO lambs and are consistent with those reported by Moron-Fuenmayor and Clavero (1999).

Meat quality traits of CO and PS lambs are presented in Table 3. Although $\text{pH}_{45\,\text{min}}$ results were similar between groups, PS lambs had significantly higher $\text{pH}_{24\,\text{h}}$ than CO lambs. The ultimate high pH in PS lambs can be related to higher muscle activity and a low-energy diet in these lambs compared to CO lambs. Some studies have also shown that increases in metabolic energy of the diet result in parallel increases in the muscle glycogen content (Immonen et al., 2000). Further results (Duckett et al., 2013; Karaca and Kor, 2015) also support the abovementioned findings, and the ultimate pH was higher in the lambs fed on pasture than lambs fed with a high-energy diet. However, it was reported by different researchers that the different feeding systems had limited effects, particularly on pH, as well as on the WHC

Table 2. Means for slaughter and carcass traits of concentrate (CO) and pasture lambs (PS).

	CO ($n = 15$)	PS ($n = 13$)	p
Slaughter weight (kg)	54.82 ± 0.438	40.70 ± 0.444	< 0.001
Hot carcass (kg)	27.18 ± 0.318	17.91 ± 0.447	< 0.001
Dressing percentage (%)	49.57 ± 0.363	43.97 ± 0.779	< 0.001
Proportions in slaughter weight (%)			
Head	5.61 ± 0.099	5.87 ± 0.193	0.197
Four feet	2.03 ± 0.035	2.34 ± 0.024	< 0.001
Skin	12.62 ± 0.258	12.15 ± 0.322	0.259
Omental–mesenteric fat	0.38 ± 0.077	0.29 ± 0.032	0.336
Heart–lung–liver	4.02 ± 0.058	4.07 ± 0.079	0.576
Spleen	0.24 ± 0.016	0.28 ± 0.040	0.324
Cold carcass (kg)	26.68 ± 0.304	17.55 ± 0.434	< 0.001
Chilling loss (%)	1.85 ± 0.217	2.00 ± 0.216	0.638
Proportions in cold carcass (%)			
Testes	1.56 ± 0.103	1.57 ± 0.158	0.971
Kidneys	0.52 ± 0.016	0.64 ± 0.024	< 0.001
Kidney-knob channel fat	0.65 ± 0.069	0.65 ± 0.071	0.985
Tail fat	16.04 ± 0.941	13.15 ± 0.728	0.037
Left half carcass (kg)	11.12 ± 0.183	7.86 ± 0.110	< 0.001
Proportions in left half carcass (%)			
Foreleg	17.72 ± 0.217	19.35 ± 0.329	< 0.001
Hind leg	33.11 ± 0.549	34.41 ± 0.401	0.098
Neck	8.60 ± 0.374	8.13 ± 0.479	0.448
Flank	13.29 ± 0.443	12.67 ± 0.422	0.347
Back loin	20.88 ± 0.735	19.62 ± 0.601	0.233
Shoulder	5.98 ± 0.263	5.79 ± 0.280	0.635
Commercial categories (%)			
First quality	59.99 ± 0.693	59.83 ± 0.849	0.887
Second quality	17.72 ± 0.217	19.35 ± 0.329	< 0.001
Third quality	21.90 ± 0.554	20.82 ± 0.679	0.228

First quality: hind leg, back loin and shoulder; second quality: foreleg; third quality: neck and flank.

Table 3. Means for meat quality traits of concentrate (CO) and pasture lambs (PS).

	CO ($n = 15$)	PS ($n = 13$)	p
$pH_{45\,min}$	6.42 ± 0.044	6.44 ± 0.047	0.778
$pH_{24\,h}$	5.94 ± 0.061	6.15 ± 0.020	0.002
L^*	38.07 ± 0.315	34.53 ± 0.685	< 0.001
a^*	21.53 ± 0.365	20.36 ± 0.653	0.107
b^*	6.71 ± 0.320	5.33 ± 0.390	0.012
C^*	22.57 ± 0.415	21.06 ± 0.717	0.063
h°	17.24 ± 0.646	14.56 ± 0.680	0.011
WHC (percentage of free water)	34.91 ± 1.616	37.39 ± 0.962	0.250
Nutrient matter (%)			
Moisture	74.98 ± 0.219	78.54 ± 0.271	< 0.001
Protein	20.97 ± 0.274	18.92 ± 0.308	< 0.001
(% DM)	83.86 ± 0.961	88.18 ± 0.745	0.004
Ether extract	3.16 ± 0.324	1.68 ± 0.208	0.002
(% DM)	12.58 ± 1.238	7.80 ± 0.949	0.010
Ash	0.87 ± 0.022	0.84 ± 0.021	0.445
(% DM)	3.50 ± 0.092	3.96 ± 0.116	0.005

DM: dry matter; L^*: lightness, a^*: redness, b^*: yellowness, C^*: chroma, h°: hue angle.

and tenderness of the meat (Diaz et al., 2002; Sanudo et al., 2007).

The ultimate pH of meat has a determining role in the meat color, and high ultimate pH results in a darker color compared to a lower pH (Sanudo et al., 2007). Comparable to these reports, PS lambs in our study, with a high ultimate pH, had lower luminosity (L^*) ($p < 0.001$) compared to CO lambs. Similar to our findings, research has shown that the meat color in PS lambs is darker than that in CO lambs (Diaz et al., 2002; Karaca and Kor, 2015; Priolo et al., 2002). In addition, Minchin et al. (2009) reported that the brighter appearance of meat from cows fed with high-energy diets can be due to the changes caused in reflectance values by increased fat deposition. However, Priolo et al. (2001) reported that the meat color was darker in pasture-fed lambs, even in conditions where fat deposition was high, when compared to concentrate-fed lambs.

Another important consideration in the pasture-fed lambs is the redness of meat or the a^* value. It was reported that the a^* value was higher in pasture-fed lambs than in concentrate-fed lambs (Carrasco et al., 2009a; Ripoll et al., 2008). The high a^* value is associated with raised pigmentation depending on increased muscle activity and live weight of the lambs (Ripoll et al., 2008; Sanudo et al., 2007; Carrasco et al., 2009a). In our study, no significant difference with respect to the a^* value could be found between the CO and PS lambs. Thus, it can be suggested that increases in the a^* values due to high slaughter weight of CO lambs may lead to similar results in these groups. In addition to this, meat yellowness (b^*) and saturation (h°) values were significantly higher in CO lambs than in PS lambs ($p < 0.05$) (Table 3). The high ultimate pH of PS lambs had a negative effect on meat color parameters and plays an important role in the variance between b^* and h° values.

It was determined that the percentage of free water was lower and WHC was better in the CO lambs than in the PS lambs (Table 3). Santos-Silva et al. (2002b) reported similar results. However, Diaz et al. (2002) found no difference in WHC in concentrate- and pasture-fed lambs. It is also known that in meats with a higher ultimate pH, the WHC increases (Sanudo et al., 2007). However, in our study, the PS lambs had a higher ultimate pH than the CO lambs, which had a lower WHC. It seems that the higher fat deposition recorded in the CO group affected the results of WHC.

The production system was also found to have an important effect on the nutritional content of the meat in the present study (Table 3). The moisture content in meat was found to be higher in PS lambs than in CO lambs ($p < 0.001$), while the protein and fat content was higher in CO lambs. It should be noted that the dry matter content also varied between the groups due to differences in the moisture content of the nutrients. When these results were evaluated on the basis of dry matter (DM %), protein and ash were found to be higher in

Table 4. Least square means for percentage of fatty acids in depot fat (subcutaneous (SC) and tail fat (TF)) of concentrate (CO) and pasture lambs (PS).

	SC		TF		*p*		
	CO	PS	CO	PS	Feeding system (FS)	Anatomical location (AL)	FS × AL
C10:0	0.30 ± 0.063	0.22 ± 0.078	0.33 ± 0.063	0.45 ± 0.078	0.800	0.078	0.196
C12:0	0.16 ± 0.027	0.18 ± 0.034	0.25 ± 0.027	0.29 ± 0.034	0.384	0.004	0.812
C14:0	3.29 ± 0.187	3.03 ± 0.230	3.72 ± 0.187	3.90 ± 0.230	0.839	0.003	0.304
C14:1	2.75 ± 0.165	1.67 ± 0.202	2.81 ± 0.165	2.53 ± 0.202	0.001	0.016	0.037
C15:0	1.88 ± 0.090	1.07 ± 0.110	1.86 ± 0.090	1.43 ± 0.110	< 0.001	0.105	0.063
C15:1	1.19 ± 0.099	0.66 ± 0.121	1.11 ± 0.099	1.31 ± 0.121	0.143	0.013	0.002
C16:0	24.42 ± 0.584	20.77 ± 0.716	22.81 ± 0.584	18.06 ± 0.716	< 0.001	0.002	0.407
C16:1	5.24 ± 0.231	3.58 ± 0.283	5.86 ± 0.231	5.27 ± 0.283	< 0.001	< 0.001	0.044
C17:0	3.52 ± 0.157	2.74 ± 0.193	2.79 ± 0.157	2.55 ± 0.193	0.006	0.012	0.125
C17:1	2.51 ± 0.174	1.53 ± 0.214	2.92 ± 0.174	2.80 ± 0.214	0.007	< 0.001	0.032
C18:0	12.78 ± 0.673	21.21 ± 0.825	8.88 ± 0.673	11.25 ± 0.825	< 0.001	< 0.001	< 0.001
C18:1n9*	35.60 ± 0.581	35.90 ± 0.711	38.95 ± 0.581	40.89 ± 0.711	0.092	< 0.001	0.214
C18:2n6*	4.44 ± 0.209	3.59 ± 0.256	4.89 ± 0.209	4.68 ± 0.256	0.029	0.002	0.175
C18:3n6 (γ)	0.12 ± 0.018	0.17 ± 0.022	0.09 ± 0.018	0.19 ± 0.022	0.001	0.826	0.197
C18:3n3 (α)	0.68 ± 0.074	1.64 ± 0.091	0.98 ± 0.074	1.63 ± 0.091	< 0.001	0.077	0.074
C20:0	0.39 ± 0.059	0.65 ± 0.072	0.51 ± 0.059	0.67 ± 0.072	0.003	0.300	0.450
C20:1	0.64 ± 0.073	1.33 ± 0.090	1.16 ± 0.073	2.04 ± 0.090	< 0.001	< 0.001	0.250
Sums							
SFA	46.79 ± 0.998	49.90 ± 1.223	41.19 ± 0.998	38.63 ± 1.223	0.806	< 0.001	0.014
MUFA	47.95 ± 0.855	44.69 ± 1.047	52.83 ± 0.855	54.86 ± 1.047	0.520	< 0.001	0.008
PUFA	5.25 ± 0.250	5.40 ± 0.306	5.97 ± 0.250	6.51 ± 0.306	0.224	0.002	0.485
DFA	66.00 ± 0.678	71.31 ± 0.830	67.70 ± 0.678	72.63 ± 0.830	< 0.001	0.053	0.805
Indexes							
Δ9DS(C16)	17.68 ± 0.889	14.75 ± 1.089	20.55 ± 0.889	22.80 ± 1.089	0.731	< 0.001	0.012
Δ9DS(C18)	73.67 ± 1.090	63.02 ± 1.335	81.51 ± 1.090	78.44 ± 1.335	< 0.001	< 0.001	0.003
Ratios							
PUFA / SFA	0.11 ± 0.008	0.10 ± 0.010	0.14 ± 0.008	0.17 ± 0.010	0.272	< 0.001	0.121
n6 / n3	7.82 ± 0.414	2.35 ± 0.507	5.09 ± 0.414	3.00 ± 0.507	< 0.001	0.030	0.001

* Sum of the cis and trans isomers. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Δ9DS(18): Δ9-desaturase (C18) index; Δ9DS(16): Δ9-desaturase (C16) index.

the PS lambs. In similar studies, it was determined that the moisture content was higher in the pasture-fed lambs than in the concentrate-fed lambs, while the fat content was lower (Karaca and Kor, 2015; Rowe et al., 1999).

3.2 FA composition of adipose tissue

In ruminants, most dietary unsaturated FAs are hydrolyzed and then form saturated FAs, and this process varies significantly depending on the biohydrogenation activity (Wood et al., 2008; Zervas and Tsiplakou, 2011). Comparing the effects of the feeding system in terms of the percentages of C16:0 and C18:0 FA in depot fats, it can be observed that the percentage of C16:0 was higher in the CO lambs, whereas the percentage of C18:0 was higher in the PS lambs (Table 4). In terms of the intramuscular fat in CO and PS lambs, the percentage of C18:0 was found to be higher in the PS lambs (Table 5). Similar results were also obtained in some previous studies (Diaz et al., 2002; Guler et al., 2011; Rowe et al., 1999). The amount of C12:0, C14:0, and C16:0 found in meat is important due to the hypercholesterolemic effects, which may increase the risk of atherosclerosis and thus have adverse effects on human health (Zock et al., 1994). The amount of C18:0, which is one of the primary FAs in ruminant meats, depends on the biohydrogenation of unsaturated C18 FAs. The biohydrogenation activity of polyionic FAs decreased due to the concentrate diet reducing rumen pH levels and the time spent by the concentrate in the rumen when compared to that of forage (Jenkins et al., 2008; Wood et al., 2008; Diaz et al., 2002). However, it was reported that there were similarities in the percentages of C16:0 and C18:0 in

Table 5. Least square means for percentage of fatty acids in intramuscular fat (longissimus thoracis, LT; semimembranosus, SM; triceps brachii, TB) of concentrate (CO) and pasture lambs (PS).

	LT		SM		TB		*P*		
	CO	PS	CO	PS	CO	PS	Feeding system (FS)	Anatomical location (AL)	FS × AL
Fat (%)	3.22 ± 0.283	1.68 ± 0.335	3.03 ± 0.305	2.13 ± 0.432	3.60 ± 0.305	2.87 ± 0.353	< 0.001	0.044	0.411
C10:0	1.18 ± 0.320	0.20 ± 0.378	1.13 ± 0.332	0.88 ± 0.488	1.17 ± 0.332	1.09 ± 0.399	0.164	0.458	0.419
C12:0	0.11 ± 0.037	0.19 ± 0.044	0.16 ± 0.039	0.34 ± 0.057	0.17 ± 0.039	0.31 ± 0.047	0.001	0.038	0.550
C14:0	2.03 ± 0.237	2.76 ± 0.280	2.16 ± 0.246	2.61 ± 0.362	2.97 ± 0.246	2.95 ± 0.295	0.096	0.066	0.365
C14:1	0.40 ± 0.109	0.41 ± 0.130	0.30 ± 0.114	0.87 ± 0.167	0.56 ± 0.114	0.91 ± 0.137	0.005	0.033	0.100
C15:0	0.35 ± 0.062	0.63 ± 0.073	0.40 ± 0.064	0.44 ± 0.095	0.57 ± 0.064	0.69 ± 0.077	0.019	0.023	0.261
C15:1	0.15 ± 0.032	0.23 ± 0.038	0.13 ± 0.033	0.21 ± 0.049	0.24 ± 0.033	0.34 ± 0.040	0.010	0.007	0.926
C16:0	20.48 ± 0.553	19.95 ± 0.655	17.73 ± 0.574	18.78 ± 0.845	19.80 ± 0.574	19.36 ± 0.690	0.960	0.017	0.438
C16:1	1.71 ± 0.177	2.05 ± 0.209	2.06 ± 0.183	1.37 ± 0.270	2.38 ± 0.183	1.92 ± 0.221	0118	0.128	0.038
C17:0	1.29 ± 0.138	1.92 ± 0.163	1.63 ± 0.143	2.39 ± 0.211	1.28 ± 0.143	2.57 ± 0.172	< 0.001	0.035	0.095
C17:1	0.51 ± 0.081	0.75 ± 0.096	0.67 ± 0.084	0.89 ± 0.124	0.71 ± 0.084	0.70 ± 0.101	0.060	0.337	0.368
C18:0	22.05 ± 0.905	25.40 ± 1.071	20.63 ± 0.939	26.83 ± 1.383	19.42 ± 0.939	25.50 ± 1.129	< 0.001	0.387	0.302
C18:1n9*	37.50 ± 0.802	35.87 ± 0.949	39.46 ± 0.832	30.34 ± 1.225	38.74 ± 0.832	31.15 ± 0.998	< 0.001	0.092	< 0.001
C18:2n6*	7.18 ± 0.401	5.83 ± 0.475	8.32 ± 0.417	5.48 ± 0.614	7.40 ± 0.417	5.88 ± 0.501	< 0.001	0.714	0.267
C18:3n6(γ)	0.72 ± 0.129	0.16 ± 0.153	0.61 ± 0.134	0.94 ± 0.197	0.64 ± 0.134	0.57 ± 0.161	0.422	0.100	0.020
C18:3n3(α)	2.39 ± 0.261	1.99 ± 0.308	2.91 ± 0.270	5.19 ± 0.398	2.02 ± 0.270	3.88 ± 0.325	< 0.001	< 0.031	< 0.001
C20:0	0.57 ± 0.123	0.71 ± 0.146	0.64 ± 0.128	1.08 ± 0.189	0.54 ± 0.128	0.81 ± 0.154	0.023	0.310	0.606
C20:1	1.29 ± 0.214	0.88 ± 0.253	0.98 ± 0.222	1.29 ± 0.327	1.30 ± 0.222	1.30 ± 0.267	0.885	0.659	0.369
Sums									
SFA	48.10 ± 1.028	51.79 ± 1.216	44.51 ± 1.066	53.38 ± 1.570	45.97 ± 1.066	53.32 ± 1.282	< 0.001	0.719	0.095
MUFA	41.59 ± 0.855	40.21 ± 1.011	43.63 ± 0.887	35.00 ± 1.306	43.95 ± 0.887	36.34 ± 1.066	< 0.001	0.308	0.001
PUFA	10.30 ± 0.550	7.99 ± 0.651	11.86 ± 0.571	11.62 ± 0.840	10.07 ± 0.571	10.33 ± 0.686	0.158	0.001	0.098
DFA	73.95 ± 0.713	73.60 ± 0.843	76.12 ± 0.740	73.45 ± 1.089	73.46 ± 0.740	72.18 ± 0.889	0.043	0.089	0.407
Indexes									
Δ9DS(C16)	7.64 ± 0.681	9.21 ± 0.806	10.36 ± 0.707	6.42 ± 1.040	10.74 ± 0.707	8.85 ± 0.849	0.036	0.138	0.004
Δ9DS(C18)	63.00 ± 1.306	58.57 ± 1.546	65.75 ± 1.356	53.16 ± 1.995	66.72 ± 1.356	54.98 ± 1.629	< 0.001	0.628	0.015
Ratios									
PUFA / SFA	0.22 ± 0.015	0.15 ± 0.018	0.26 ± 0.016	0.21 ± 0.024	0.22 ± 0.016	0.19 ± 0.019	0.003	0.019	0.545
n6 / n3	3.88 ± 0.357	3.34 ± 0.423	3.24 ± 0.371	1.31 ± 0.546	4.34 ± 0.371	1.87 ± 0.446	< 0.001	0.012	0.054

* Sum of the cis and trans isomers. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Δ9DS(18): Δ9-desaturase (C18) index; Δ9DS(16): Δ9-desaturase (C16) index.

SC and TF (Nuernberg et al., 2008; Velasco et al., 2001) and intramuscular fats (Cividini et al., 2014; Popova, 2007) from pasture and concentrate lambs. In the present study, no significant difference in the percentage of saturated FAs (SFA) in depot fats was determined. However, the percentage of the SFA in intramuscular fats was higher in PS lambs than in CO lambs ($p < 0.001$).

The percentages of some of the monounsaturated fatty acids (MUFAs) in depot fats, such as C14:1, C16:1, and C17:1, was found to be higher in CO lambs than in PS lambs (Table 4). Regarding intramuscular fats, CO lambs were found to have a higher C18:1n9 level than PS lambs (Table 5). These results may be associated with the differences in dietary FA profile and rumen biohydrogenation activity. In a concentrate-based diet, the percentage of the C18:2n6 is quite high compared to that in pasture (Table 1). There is also an observed increase in the synthesis of oleic acid from stearic acid, depending on an increasing level of Sterol-CoA desaturase (Δ9 desaturation) enzyme activity combined with an increased fat deposition (Velasco et al., 2001; Cividini et al., 2014). The Δ9 desaturation (C18) index, both in depot and intramuscular fats, was found to be higher in CO lambs than in PS lambs ($p < 0.001$; Tables 4 and 5). In similar studies, the C16:1 and/or C18:1 content was high in the concentrate-fed lambs (Cividini et al., 2014; Fisher et al., 2000; Santos-Silva et al., 2002a; Nuernberg et al., 2008), but these results were not found to be significant in other studies (Diaz et al., 2002; Popova, 2007). Moreover, the effect of feeding system on C16:1, C18:1n9 and C18:3n3 varied depending on muscle type, and significant interactions were present for these FAs ($p < 0.001$). The percentages of C18:1n9 and C18:3n3 were similar in CO and PS lambs for LT, while PS lambs had a lower percentage of C18:1n9 and a higher percentage of C18:3n3 than CO lambs for SM and TB (Table 5). The differences in muscle type in terms of activity and low intramuscular fat deposition in these muscles might cause LT to have different profile for these fatty acids than SM and TB in PS lambs. Hence, Moreno et al. (2006) suggested that low intramuscular fat deposition could alter the FA profile of calves fed on pasture and concentrate. In

addition to this, Rogowski et al. (2013) reported that increasing Δ9-desaturase activity of muscle increases triglyceride PUFA content.

The results obtained in this study were similar to those of previous studies (Diaz et al., 2002; Popova, 2007; Rowe et al., 1999), and the percentage of linoleic acid (LA, C18:2n6) was found to be higher in depot and intramuscular fats of CO lambs than of PS lambs, whereas alpha-linolenic acid (ALA, C18:3n3) levels were higher in the PS lambs except for in LT (Tables 4 and 5). ALA is elongated and desaturated into longer-chain omega-3 FAs, such as C20:5n3 (EPA) and C22:6n-3 (DHA), and therefore, the availability of ALA is highly important (Bessa et al., 2015). In general terms, the effect of the feeding system on polyunsaturated FAs (PUFA) in tissues can be associated with the high amount of LA found in concentrate feed and of ALA in pasture (Table 1).

The results of the principal component analysis (PCA) are presented in Fig. 1a. The first component (PC1) explained 52.7 % of the total variation. SC and TF were located on the opposite side of PC1 and were clearly separated from each other. It can be seen that SFA and SC were located on the left side of the PC1 and were associated with each other, whereas PUFA, MUFA, Δ9 DS 16/18, n6, and TF were located on the right side. The results confirmed the differences between TF and SC and were in agreement with Table 4. The second component (PC2) explained 27.3 % of variability and was characterized by CO, PS, and n3. CO was located on the opposite side of PS and n3, in PC2, and the relationship between PS and n3 FAs can be clearly seen. This relationship is in agreement with results reported by other researchers (Fisher et al., 2000; Özcan et al., 2015).

The results of PCA analysis in intramuscular FA composition were presented in Fig. 1b. PC1 and PC2 explained 41.7 and 21.1 % of the total variation, respectively. Unlike fat depots, PS was associated with SFA and located on the left side of the first component, opposite to CO, which was related to MUFA and Δ9 DS 16/18 on the right side of the PC1, in the intramuscular fat. PC2 was characterized by n3 and PUFA and closer to SM than LT and TB, which were located opposite to PC2.

Some of the total FAs found in depot and intramuscular fats and their ratios, which are used as criteria in healthy nutrition have been shown in Tables 4 and 5. Although there was no significant difference regarding the percentages of the SFA, MUFA, and PUFA in depot fats, both higher SFA ($p < 0.001$) and lower MUFA ($p < 0.001$) levels were found in the intramuscular fats of PS lambs than in that of CO lambs. Similar results were also reported in some previous studies (Diaz et al., 2002; Guler et al., 2011; Özcan et al., 2015; Popova, 2007). The British Department of Health (1994) has recommended the PUFA / SFA ratio to be above 0.45 and the n6 / n3 ratio to be below 4.00. Despite a similar PUFA / SFA ratio in depot fats for both groups (Table 4), the ratio was found to be higher in the intramuscular fats of CO lambs than in that of PS lambs ($p < 0.01$) (Table 5). Moreover, the n6 / n3 ratio in both depot and intramuscular fats was found to be lower in PS lambs than in CO lambs ($p < 0.001$) except for LT.

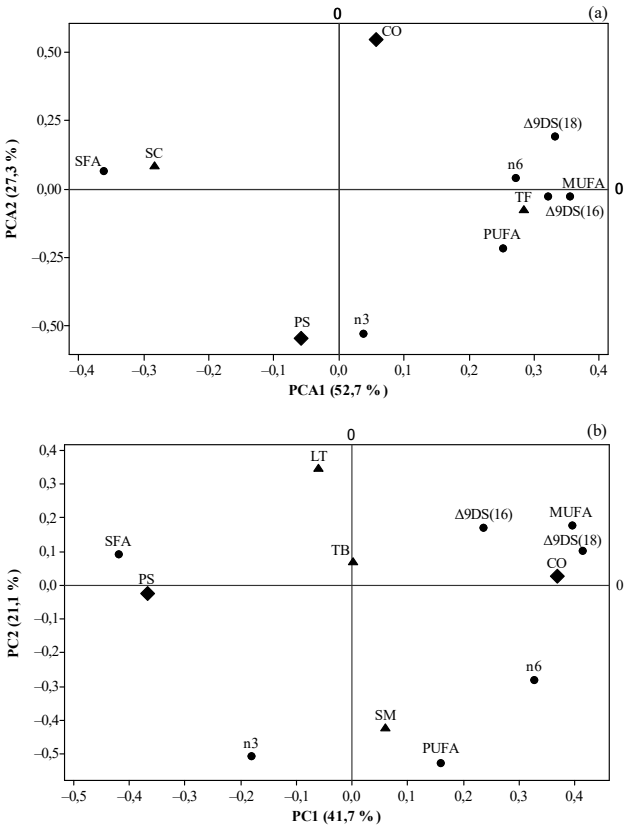

Figure 1. Principal component analysis for some fatty acid groups and indexes (●) of fat depots **(a)** and intramuscular fat **(b)** (▲) in different feeding systems (♦). CO: concentrate lambs; PS: pasture lambs; SC: subcutaneous; TF: tail fat; LT: longissimus thoracis; SM: semimembranosus; TB: triceps brachii; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Δ9DS(18): Δ9-desaturase (C18) index; Δ9DS(16): Δ9-desaturase (C16) index.

With the results associated with FA composition in SC and TF, it was determined that the percentage of the SFA was higher in SC, whereas MUFA and PUFA were determined to be higher ($p < 0.01$) in TF (Table 4). It must be noted that the effect of the feeding system on some FAs varies according to individual SC and TF and that interactions related to these FAs were found to be significant ($p < 0.05$). Despite the fact that the percentages of the C14:1, C15:1, C16:1, and C17:1 MUFA as well as Δ9 desaturation (C16) index in SC and TF of CO lambs showed similarities, the same FAs in the SC of PS lambs were found to be significantly lower when compared to the TF values ($p < 0.05$). In accordance with these results, Gallardo et al. (2014) reported that FA composition, in both SC and TF in lambs, varied according to pasture type. The researchers noted that the tissue-specific

response, depending on the pasture type, may be associated with gene and protein expression or lipogenic enzyme activity (stearoyl-CoA desaturase; SCD). Moreover, TF had a higher PUFA / SFA ratio than SC ($p < 0.001$), and the n6 / n3 ratio of TF was found to be lower than that of SC ($p < 0.05$). It can be suggested that TF has more beneficial FAs than SC.

Ruminants tend toward storing essential FAs in intramuscular fats instead of depot fats (Wood et al., 2008). Alpha-linoleic acid was found to be the most important source of diversity in intramuscular fats (SM > TB > LT; $p < 0.05$), and SM was the muscle tissue with the highest PUFA / SFA and lowest n6 / n3 ratios (Table 5). Similar results were reported by Coutinho et al. (2014), and SM and TB had higher PUFA / SFA ratios than LT.

4 Conclusions

The results of this study showed that the feeding system had an important effect in terms of the many characteristics examined. Compared to the lambs raised on pasture, more fattened carcasses with higher dressing percentages were obtained from the CO lambs. Moreover, it was determined that the feeding system significantly changed the major meat quality characteristics; the PS lambs had meat with a higher pH, darker color, and lower WHC than CO lambs. CO has better index values related with FAs, whereas the percentage of the ALA of PS was found to be higher than CO in all tissues. On the other hand, it must be noted that the effects of the feeding system have varying results based on different types of fat deposits.

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