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Fatty acid composition of meat from typical lamb production systems of Spain, United Kingdom, Germany and Uruguay

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Abstract

The fatty acid composition of commercial lambs from different production systems of Spain, Germany, United Kingdom and of two types of Uruguayan lambs (heavy and light) was studied. Concentrate fed lambs, as Spanish lambs, displayed the highest proportions of linoleic acid (C18:2), while Uruguayan lambs, reared under extensive grazing conditions, showed the highest proportions of linolenic acid (C18:3), due to the great concentration of this fatty acid in grass. German and British lambs, which were fed grass and concentrate, displayed intermediate proportions of linolenic acid (C18:3). Heavy Uruguayan lambs had higher intramuscular fat content (5.92%) than German (4.25%) and British (4.32%) lambs, and this content was twofold higher than light lambs (Spanish (2.41%) and light Uruguayan (3.05%)). Heavy Uruguayan, German and British lambs had a low polyunsaturated/saturated (P/S) ratio due to their high saturated fatty acid (SFA) content and proportion. Principal component analysis was performed to study the relationship between fatty acids. Spanish lambs were clearly separated from the other types and were situated close to the proportions of short chain and $n-6$ fatty acids and $n-6/n-3$ ratio in the data plot for fatty acid proportions. Light Uruguayan lambs were located close to long chain fatty acids, and heavy Uruguayan and British lambs were placed near the antithrombotic potential (ATT), stearic acid (C18:0), SFA and conjugated linoleic acid (CLA) proportions. German lambs were located between Spanish lambs and the other types.

Keywords: Fatty acids; Lamb; Meat origin; Production system

1. Introduction

World-wide we have to note the emergence of countries in South America as entrants into the European Union market and these countries are able to produce cheap and good quality meat. Lamb production systems are different among countries of South America and Europe. The production system represents the combined effects of breed, weight, feeding, sex, age and husbandry, all of which can contribute to variations in meat fatty acid composition. Results of numerous studies confirm that fatty acid composition can be influenced by individual factors such as diet (Díaz et al., 2002), breed (Robelin, 1986), age/weight (Rhee, 2000) and level of fatness (Nürnberg, Wegner, & Ender, 1998). Thus, grain

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diets result in high concentrations of $n-6$ polyunsaturated fatty acids (PUFA), while grass diets increase muscle concentrations of $n-3$ PUFA (Enser et al., 1998). The effect of breed may be important but it is difficult to assess the real contribution of genetics to differences in fatty acid composition. Effects attributed to breed are often due to the degree of fatness, live weight, slaughter age or the production system (Sañudo et al., 2000). The fatty acid composition of meat may also be influenced by changes in age and fatness. Thus the proportion of PUFA in muscle decreases while the deposition of intramuscular neutral lipids increases with animal age (Link, Bray, Cassens, & Kauffman, 1970). Variations in fat content have an effect on fatty acid composition, independent of species or breed and dietary factors. The content of SFA and monounsaturated fatty acids (MUFA) increases faster with the fatness level than the content of PUFA (De Smet, Raes, & Demeyer, 2004).

Fatty acid composition influences the nutritive value and the organoleptic characteristics of meat. In relation to the nutritive value, consumption of SFA has been associated with increased plasma cholesterol and plasma low density lipoprotein (LDL) levels, linked to a major risk of coronary heart disease; on the other hand, consumption of $n-3$ PUFA is inversely associated with the incidence of this disease (Grundy, 1987). Conjugated linoleic acid (CLA) has been linked with important beneficial effects such as anticarcinogenic properties, beneficial actions on body composition (reducing body fat) and on the immune function (Williams, 2000). In regard to organoleptic characteristics, Fisher et al. (2000) found that flavour intensity is positively correlated with linolenic acid (C18:3) and negatively with linoleic acid (C18:2). In addition, fatty acid composition can affect meat lipid oxidation (Gatellier, Hamelin, Durand, & Renerre, 2001).

The purpose of this study was to assess the extent of natural dissimilarity in the fatty acid composition of meat from commercial lambs typical of the production systems in several countries of the European Union, such as Spain, Germany and United Kingdom and one country of South America, namely Uruguay.

2. Materials and methods

Five groups of 20 lambs from Spain, United Kingdom, Germany and heavy and light lambs from Uruguay were used in the present study. Lambs were slaughtered at the usual commercial weights, representing the typical production systems of each country. Spanish lambs were entire male of Rasa Aragonesa breed, reared under intensive husbandry conditions, and fed concentrates and cereal straw ad libitum until slaughter at less than 3 months of age. The carcass weight was 10.2 ± 0.6 kg. British lambs were commercial crossbred castrated males, mainly reared on a grass-based system using strategic concentrate supplementation. The carcass weight was 22.8 ± 1.7 kg. German lambs were commercial entire males from crossbreeds between Suffolk or Schwarzköpfe × Merino Landschaf, reared on grass supplemented with concentrate. The carcass weight was 23.2 ± 3.6 kg and animals were slaughtered at 4–6 months of age. Uruguayan lambs were castrated male Corriedales raised under extensive improved-grazing conditions. Light lambs were slaughtered at 3–4 months of age at a carcass weight of 11.1 ± 1.4 kg, whereas heavy lambs were slaughtered at 12–13 months of age at a carcass weight of 19.4 ± 2.2 kg.

The *m. longissimus dorsi* was dissected 24 h after slaughter and samples were obtained in order to determine the composition of fatty acids in the muscle from the level of T1 (first thoracic vertebra) to T6 (sixth thoracic vertebra) of the left side. The muscle samples were vacuum-packed and frozen at −25 °C. Intramuscular fat was extracted from the muscle according to the Hanson and Olley (1963) method. Methyl esters were formed according to the method of Morrison and Smith (1964), using 14% boric trifluoride in methanol. Nonadecanoic acid (19:0) was added prior to saponification as an internal standard. Chromatographic analysis of methyl esters was performed using a Perkin–Elmer gas chromatograph (Perkin–Elmer, USA) equipped with a split-splitness injector and a flame ionisation detector (FID), using a fused silica capillary column (0.32 mm internal diameter and 30 m long). The mobile phase consisted of helium C-50 at a flow of 9 psig. Fatty acids were identified using Sigma reference standards and quantified using the internal standard. Data regarding fatty acid composition were expressed in percentage by weight of total identified fatty acids and data concerning fatty acid content were expressed in mg per 100 grams of muscle.

2.1. Statistical analyses

The data were analysed using one-way analysis of variance with the GLM procedure of the Statistical Analysis System package (SAS, 1996) according to the model:

$$y_{ij} = \mu + X_{i(1\ldots5)} + \varepsilon_{j(i)},$$

where y_{ij} is the fatty acid, μ is the population mean, X_i is the effect of lamb type (Spanish, German, British and heavy and light Uruguayan) and $\varepsilon_{j(i)}$ is the experimental error. Differences between least square means were determined using the Student Newman–Keuls test.

In order to summarise the relative differences amongst samples in relation to their overall fatty acid profiles, and to determine the contribution of individual

fatty acids to these differences two principal component analysis (PCA) were carried out on the data, one using the proportion and the other using the content (mg/100 g muscle) of the different fatty acids. PCA analyses were performed using the PRINCOMP procedure of the SAS package (SAS, 1996). The variables for PCA were standardised to a mean of zero and a variance of one.

3. Results

Least square means of fatty acid composition (fatty acid percentage by weight of total fatty acids) are shown in Table 1. The major saturated fatty acids were palmitic (C16:0) and stearic (C18:0) fatty acids. The proportion of palmitic acid (C16:0) was significantly higher in Uruguayan lambs, whereas lambs from the United Kingdom had the highest proportion of stearic acid (C18:0). Since Spanish lambs' muscle contained the lowest proportions of palmitic (C16:0) and stearic (C18:0) fatty acids, these lambs presented the lowest proportion of SFA. Except for light Uruguayan lambs that displayed the lowest proportion of oleic acid (C18:1), proportions of this fatty acid were similar among lambs of different origins and production systems.

Proportions of $n-3$ PUFA, such as linolenic acid (C18:3) and eicosapentaenoic acid (C20:5), were significantly higher in the intramuscular fat of lambs fed grass under extensive conditions (mainly Uruguayan lambs) compared with those reared intensively on concentrates (Spanish lambs). However, proportions of $n-6$ PUFA, such as linoleic acid (C18:2) and arachidonic acid (C20:4), were higher in Spanish lambs than in those of other origins. The CLA isomer *cis-9*, *trans-11 C18:2* was detected in the samples of all the countries. This isomer represented only 0.40% of total fatty acids in Spanish lambs, while other lambs diplayed more than twice this proportion (0.94% and 0.79% in heavy and light Uruguayan lambs, 0.97% in German and 1.05 % in British lambs).

Least square means of intramuscular fat percentage and fatty acid contents (mg of fatty acids per 100 g of muscle) are given in Table 2. Spanish and light Uruguayan lambs had the lowest intramuscular fat percentage (2.41% and 3.05%, respectively), while the highest value (5.92 %) was observed in heavy Uruguayan lambs. The sum of myristic acid (C14:0) and palmitic acid (C16:0) was 2.4 times greater in heavy Uruguayan lambs than in Spanish ones, and 2.2 times greater than in light Uruguayan lambs. The content of stearic acid (C18:0) was 675 mg per 100 g muscle in heavy Uruguayan lambs, while it was 282 mg and 208 mg per 100 g muscle in light Uruguayan and Spanish lambs, respectively. Lambs from Germany and United Kingdom showed intermediate amounts of stearic acid (C18:0). Amounts

Table 1
Fatty acid composition of *m. longissimus dorsi* in percentage by weight of total identified fatty acids of lambs from typical production systems of several countries

	Spain	Germany	United Kingdom	Uruguay light	Uruguay heavy	SEM	Sign.
C10:0	0.24^{a}	0.23^{a}	0.16^{b}	0.22^{a}	0.22^{a}	0.06	***
C12:0	0.42^{a}	0.30^{b}	0.16^{c}	0.27^{b}	0.12^{c}	0.12	***
C14:0	3.77^{a}	3.62^{a}	2.36^{b}	3.60^{a}	2.55^{b}	0.87	***
C14:1	0.15^{a}	0.12^{b}	0.06^{c}	0.11^{b}	0.07^{c}	0.05	***
C15:0	0.47^{a}	0.49^{a}	0.43^{a}	0.41^{a}	0.32^{b}	0.10	***
C16:0	22.58^{b}	23.65^{ab}	23.43^{b}	24.73^{a}	24.66^{a}	1.52	***
C16:1	1.81^{a}	1.39^{b}	1.32^{b}	1.42^{b}	1.44^{b}	0.28	***
C17:0	1.31^{a}	1.04^{b}	1.10^{b}	1.07^{b}	1.02^{b}	0.19	***
C17:1	0.98^{a}	0.64^{c}	0.75^{b}	0.56^{c}	0.59^{c}	0.14	***
C18:0	12.56^{d}	18.79^{ab}	19.78^{a}	16.62^{c}	17.49^{bc}	2.08	***
C18:1	39.63^{a}	39.05^{a}	40.51^{a}	35.81^{b}	40.56^{a}	2.58	***
C18:2$n-6$	9.48^{a}	5.45^{b}	3.92^{c}	6.01^{b}	4.18^{c}	1.41	***
C18:3$n-3$	0.56^{c}	1.48^{b}	1.62^{b}	3.37^{a}	3.19^{a}	0.59	***
CLA	0.40^{c}	0.97^{ab}	1.05^{a}	0.79^{b}	0.94^{ab}	0.31	***
C20:0	0.09^{ab}	0.10^{a}	0.09^{ab}	0.11^{a}	0.07^{b}	0.03	***
C20:3$n-6$	0.28^{a}	0.14^{cd}	0.17^{c}	0.22^{b}	0.10^{d}	0.07	***
C20:4$n-6$	3.99^{a}	1.22^{c}	1.13^{c}	1.94^{b}	0.86^{c}	0.77	***
C20:5$n-3$	0.34^{c}	0.51^{c}	0.94^{b}	1.29^{a}	0.86^{b}	0.35	***
C22:5$n-3$	0.68^{b}	0.58^{b}	0.81^{b}	1.14^{a}	0.60^{b}	0.28	***
C22:6$n-3$	0.24^{ab}	0.21^{b}	0.22^{b}	0.31^{a}	0.17^{b}	0.10	***
SFA	41.44^{b}	48.23^{a}	47.51^{a}	47.04^{a}	46.44^{a}	2.35	***
MUFA	42.58^{a}	41.21^{a}	42.64^{a}	37.90^{b}	42.66^{a}	2.68	***
PUFA	15.58^{a}	9.60^{b}	8.80^{b}	14.27^{a}	9.96^{b}	2.83	***

^{a,b,c,d} Least square means in the same row with different superscript letters are different ($P < 0.05$); CLA: isomer *cis-9*, *trans-11* C18:2; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.
*** $P < 0.001$.

Table 2
Fatty acid composition of *m. longissimus dorsi* in mg per 100 g of muscle of lambs from typical production systems several countries

	Spain	Germany	United Kingdom	Uruguay light	Uruguay heavy	SEM	Sign.
G%	2.41^{c}	4.25^{b}	4.32^{b}	3.05^{c}	5.92^{a}	1.72	***
C10:0	4.07^{c}	6.68^{b}	3.77^{c}	3.86^{c}	8.75^{a}	2.73	***
C12:0	7.16^{ab}	8.71^{a}	3.77^{c}	4.86^{bc}	4.70^{bc}	3.38	***
C14:0	65.17^{b}	104.57^{a}	57.29^{b}	64.55^{b}	102.74^{a}	38.27	***
C14:1	2.70^{ab}	3.44^{a}	1.71^{b}	2.08^{ab}	3.18^{ab}	1.80	*
C15:0	8.01^{cd}	14.09^{a}	10.37^{bc}	7.09^{d}	12.24^{ab}	4.19	***
C16:0	378.26^{d}	673.46^{b}	574.30^{bc}	423.39^{cd}	984.49^{a}	244.80	***
C16:1	30.94^{b}	39.80^{b}	32.39^{b}	25.11^{b}	58.79^{a}	18.62	***
C17:0	21.84^{cd}	30.03^{b}	26.87^{bc}	18.46^{d}	39.66^{a}	10.43	***
C17:1	16.49^{b}	18.36^{ab}	18.22^{ab}	9.60^{c}	22.86^{a}	6.39	***
C18:0	208.48^{c}	532.09^{b}	490.00^{b}	282.17^{c}	675.27^{a}	151.51	***
C18:1	664.04^{c}	1105.47^{b}	1003.48^{b}	619.50^{c}	1613.47^{a}	394.68	***
C18:2*n* − *6*	154.56^{a}	152.34^{a}	91.43^{b}	94.42^{b}	158.01^{a}	36.89	***
C18:3*n* − 3	9.72^{c}	42.06^{b}	39.62^{b}	53.99^{b}	125.54^{a}	26.57	***
CLA	6.89^{c}	27.65^{b}	26.34^{b}	13.65^{c}	38.95^{a}	15.64	***
C20:0	1.53^{c}	2.94^{a}	2.09^{bc}	1.85^{c}	2.61^{ab}	0.83	***
C20:3*n* − 6	4.47	4.00	3.87	3.43	3.74	1.37	NS
C20:4*n* − *6*	63.18^{a}	33.88^{b}	25.57^{b}	28.06^{b}	31.23^{b}	12.29	***
C20:5*n* − 3	5.71^{d}	14.46^{c}	21.88^{b}	18.86^{b}	32.17^{a}	6.40	***
C22:5*n* − 3	11.09^{c}	16.15^{b}	18.83^{b}	16.98^{b}	22.19^{a}	4.52	***
C22:6*n* − 3	4.10^{b}	5.86^{a}	5.28^{ab}	4.48^{ab}	6.15^{a}	2.00	**
SFA	694.52^{c}	1372.56^{b}	1168.47^{b}	806.23^{c}	1830.45^{a}	431.86	***
MUFA	714.17^{c}	1167.07^{b}	1055.79^{b}	656.29^{c}	1698.30^{a}	418.36	***
PUFA	252.83^{bc}	268.75^{b}	206.48^{c}	220.23^{bc}	379.03^{a}	72.75	***

^{a,b,c,d} Least square means in the same row with different superscript letters are different ($P < 0.05$); *G*%: intramuscular fat proportion; CLA: isomer *cis-9*, *trans-11* C18:2; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.
NS: non-significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

of the major fatty acid, oleic acid (C18:1), were 2.4 times higher in heavy Uruguayan lambs than in Spanish and light Uruguayan ones and 1.5 times higher than in German and British lambs. With regards to $n-3$ PUFA, heavy Uruguayan lambs had 13 times more linolenic acid (C18:3), the major $n-3$ PUFA, than Spanish ones, but only 3, 3.2 and 2.3 times more, respectively, than German, British and light Uruguayan lambs.

CLA fatty acid content decreased in the following order: heavy Uruguayan (39 mg/100 g muscle) > German and British (28 and 26 mg/100 g muscle, respectively) > light Uruguayan (14 mg/100 g muscle) > Spanish (7 mg/100 g muscle) lambs. Despite the fact that the Spanish lambs had less intramuscular fat, their arachidonic acid (C20:4) levels were significantly higher than those of the other lambs studied.

The fatty acid ratios, related to healthy nutrition, are shown in Table 3. The P/S (PUFA/SFA) ratio decreased in the following order: Spanish > light Uruguayan > heavy Uruguayan, German and British lambs. Spanish and light Uruguayan lambs displayed the highest P/S2 (PUFA/(SFA-C18:0)) ratio, due to Spanish lambs having the lowest percentage of SFA and both types displaying the highest percentages of PUFA. Stearic acid (C18:0) has not been included to calculate P/S2 ratio, since this fatty acid is not hypercholesterolaemic (Choi, Enser, Wood, & Scollan, 2000). The $n-6/n-3$ fatty acid ratio in Spanish lambs was very high (8.42) in

Table 3
Ratios of fatty acids related to human health in intramuscular fat of lambs from typical production systems from several countries

	Spain	Germany	United Kingdom	Uruguay light	Uruguay heavy	SEM	Sign.
P/S	0.38^{a}	0.20^{c}	0.19^{c}	0.31^{b}	0.21^{c}	0.08	***
P/S2	0.55^{a}	0.33^{b}	0.32^{b}	0.48^{a}	0.34^{b}	0.12	***
n − 6/*n* − 3	8.42^{a}	2.47^{b}	1.54^{bc}	1.36^{bc}	1.07^{c}	1.51	***
C18:2/C18:3	19.68^{a}	3.75^{b}	2.91^{b}	1.85^{b}	1.34^{b}	3.66	***
ATT	0.17^{e}	0.55^{d}	1.05^{b}	0.80^{c}	1.19^{a}	0.19	***

^{a,b,c,d,e} Least square means in the same row with different superscript letters are different ($P < 0.05$); P/S: PUFA/SFA; P/S2: PUFA/(SFA − C18:0); *n* − 6/*n* − 3: (C18:2 + C20:3 + C20:4)/(C18:3 + C20:5 + C22:5 + C22:6); ATT: (C20:3+C20:5)/C20:4.
*** $P < 0.001$.

comparison with the other lambs (<2.50). Spanish lambs, with low ATT ((C20:3 + C20:5)/C20:4) values, showed an unfavourable ATT, whereas heavy Uruguayan lambs displayed the most favourable ATT value.

The results of the PCA of the fatty acid proportions are shown in Fig. 1. The first five PC explain 86% of the total variation in fatty acid composition. The first PC (PC1) explained 35% of the total variability in fatty acid composition. This component was mainly characterised by linoleic acid (C18:2) and arachidonic acid (C20:4) proportions on the right side and ATT and stearic acid (C18:0) proportion on the left side (Fig. 1(a)); these variables were located far from the origin of PC1. The second PC (PC2) explained 21.5% of the variability and was defined by the long chain fatty acid proportions (docosapentaenoic acid (C22:5), docosahexaenoic acid (C22:6) and eicosapentaenoic acid (C20:5)) and in the opposite direction by MUFA proportion. The PC3 explained 15.8% of the variability, the PC4 8.1% and the PC5 5.3%. The projection of the fatty acid proportions in the plane defined by the first two PCs of the five types studied is shown in Fig. 1(b). Spanish lambs were clearly differentiated from the other lamb types and were located on the right side of the figure, where lauric (C12:0), myristic (C14:0), myristoleic (C14:1), pentadecanoic (C15:0), palmitoleic (C16:1), heptadecanoic (C17:0), heptadecenoic (C17:1), linoleic (C18:2) and arachidonic (C20:4) fatty acid proportions and the $n-6/n-3$ ratio lay. Light Uruguayan lambs

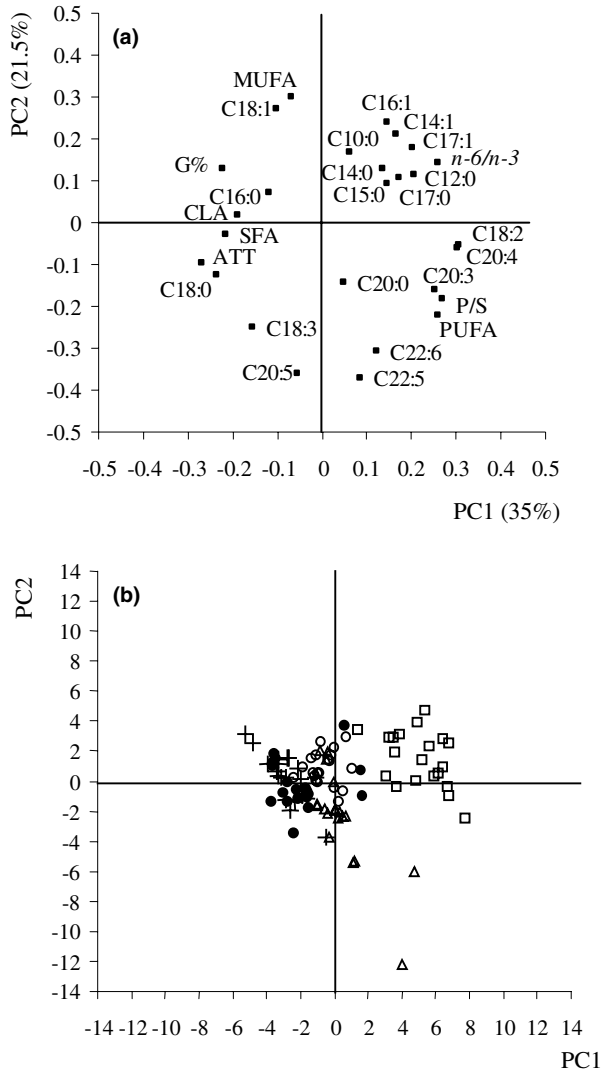

Fig. 1. (a) Projection of fatty acid proportions, ratios (P/S, $n-6/n-3$, ATT) and intramuscular fat proportion (G%) in the plane defined by two principal components. (b) Projection of the variables of the five lamb groups studied in the plane defined by two principal components: ○, German; □, Spanish; ●, British + heavy Uruguayan; △, light Uruguayan.

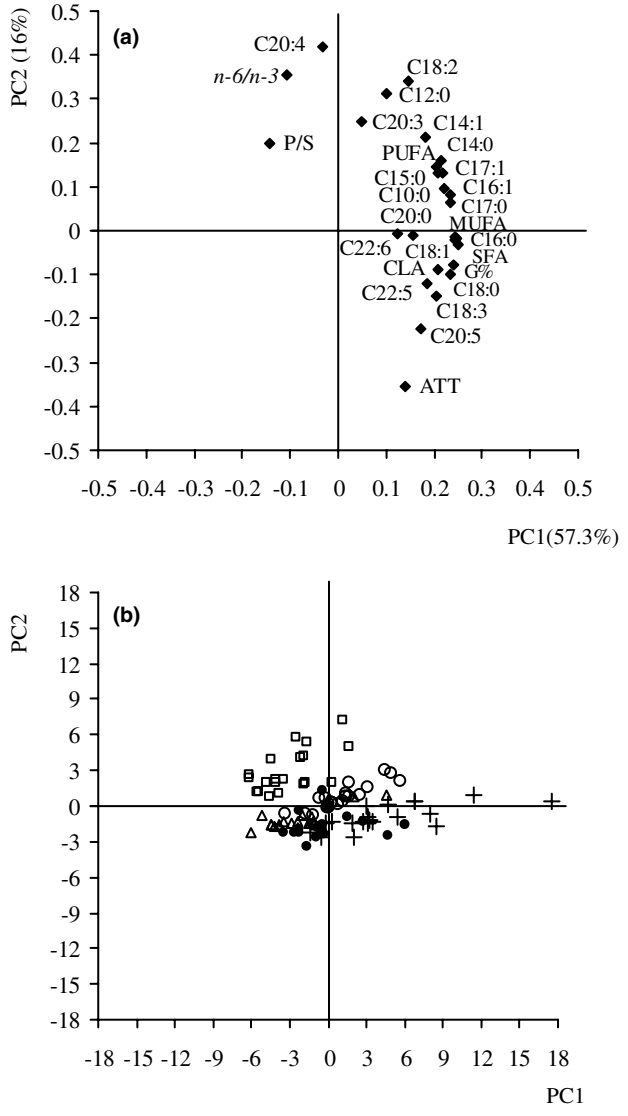

Fig. 2. (a) Projection of fatty acid content (mg/100 g muscle), ratios (P/S, $n-6/n-3$, ATT) and intramuscular fat proportion (G%) in the plane defined by two principal components. (b) Projection of the variables of the five lamb groups studied in the plane defined by two principal components: ○, German; □, Spanish; ●, British + heavy Uruguayan; △, light Uruguayan.

were located where arachidic acid (C20:0) and long chain fatty acid proportions (eicosapentaenoic acid (C20:5), docosapentaenoic acid (C22:5) and docosahexaenoic acid (C22:6)) lay. Heavy Uruguayan and British lambs were placed on the left side of the graph where ATT, stearic acid (C18:0), SFA and CLA proportions lay. German lambs were located between the types mentioned above. The results of the PCA of fatty acid content are presented in Fig. 2. The first five components explained 90% of the variability in fatty acid content, PC1 explained 57.3% and PC2 16.0%. PC1 was characterised by intramuscular fat proportion, palmitic acid (C16:0), oleic acid (C18:1), SFA content and MUFA content; these variables were placed far from the origin of PC1 (Fig. 2(a)). PC2 was defined by arachidonic acid (C20:4), the $n-6/n-3$ ratio, ATT and linoleic acid (C18:2). The PC3 explained 8.2% of the variability, the PC4 4.6% and the PC5 3.7%. The projection of the fatty acid content data in the plane defined by the two first PCs of the five lamb types studied is shown in Fig. 2(b). Spanish lambs were clearly differentiated from the other lamb types and were located on the left side of the figure, where arachidonic acid (C20:4), $n-6/n-3$ and P/S ratios lay. Heavy Uruguayan lambs were located on the right side of the graph where intramuscular fat proportion and the major fatty acids (palmitic (C16:0), stearic (C18:0) and oleic (C18:1) fatty acids) lay.

4. Discussion

The production system represents the combined effects of breed, weight, diet, sex, age and husbandry, all of which may affect meat fatty acid composition. Despite the fact that the fatty acid composition of ruminant meat is less affected by diet due to ruminal modifications, in this study lamb meat has reflected differences in the composition of dietary lipids. Lambs fed concentrate under intensive production conditions, as the Spanish lambs, presented the highest proportions of linoleic acid (C18:2) and lowest proportions of stearic acid (C18:0). In addition, Díaz et al. (2002) found that lambs fed concentrate showed a lower percentage of stearic acid (C18:0) and higher proportions of linoleic acid (C18:2) than lambs reared at pasture, as linoleic acid (C18:2) is the major polyunsaturated fatty acid present in the cereal-based concentrates consumed by these lambs (Sañudo et al., 2000). Moreover, a concentrate-based diet increases available soluble carbohydrates, resulting in lower ruminoreticular pH, which decreases hydrogenase activity, producing less conversion of linoleic acid (C18:2) to stearic acid (C18:0) (Tove & Matrone, 1962). Both fatty acids were important components of PC1, although they had opposite signs (Fig. 1(a)). Besides, linoleic acid (C18:2) was negatively correlated with oleic acid (C18:1), since they were in this loading plot, separated by 180°. These results agree with Jeffcoat and James (1984), who reported that linoleic acid (C18:2) is the most potent inhibitor of the enzyme Δ9-desaturase, responsible for oleic acid (C18:1) synthesis.

Uruguayan lambs had the highest $n-3$ PUFA intake, and thus the highest proportion of linolenic acid (C18:3), as they consumed grass, which has more linolenic acid (C18:3) than concentrate. German and British lambs had intermediate proportions, since they consumed grass supplemented with concentrates. The higher concentration of linolenic acid (C18:3) found in grass-fed animals agrees with the results of other authors (Díaz et al., 2002; Enser et al., 1998; Nürnberg et al., 1998; Rowe, Macedo, Visentainer, Souza, & Matsushita, 1999). An increase in linolenic acid (C18:3) levels is considered beneficial to human health, although increasing the risk of PUFA peroxidation (Gatellier et al., 2001).

Animals exclusively fed concentrate (e.g., Spanish lambs) presented the lowest proportion of CLA while grass-fed lambs (mainly British, German and heavy Uruguayan lambs) had higher proportions. Aurousseau, Bauchart, Calichon, Micol, and Priolo (2004) reported that proportions of *9-cis*, *11-trans 18:2* in muscle triglycerides ranged between 0.34% and 0.77% in concentrate fed lambs and between 0.67% and 1.86% in grass-fed lambs, whereas the *9-cis*, *11-trans 18:2* proportions in phospholipids were lower than in triglycerides. French et al. (2000) reported a linear increase in CLA concentrations (g/100 g of fatty acids methyl esters) as dietary concentrate proportions decreased. In that study dietary intakes of linoleic acid (C18:2) were similar across all the diets. In our study, British and German lambs consumed grass and concentrate and also displayed high proportions of CLA. These findings could be due to high levels of linoleic acid (C18:2) in the concentrates. According to several authors the CLA in ruminant fats can be increased with diets rich in linoleic acid (C18:2) (Ivan et al., 2001; Madron et al., 2002) or rich in linolenic acid (C18:3) sources (Raes, De Smet, & Demeyer, 2004).

The proportion of arachidonic acid (C20:4) was more than two times higher in Spanish lambs than in the other types (Table 1), which agrees with results of Sañudo et al. (2000) in a study of Spanish and British lambs. Arachidonic acid (C20:4) was positively correlated with linoleic acid (C18:2) (Fig. 1(a)), since C18.2 in the diet is a precursor of arachidonic acid (C20:4) (Kinsella, 1991) and both fatty acids were situated on the right side, close to Spanish type (Figs. 1(a) and (b)).

Slaughter weight and age also affect fatty acid composition. The effect of age on fatty acid profiles is related to body fatness (Nürnberg et al., 1996). According to Huerta-Leindez et al. (1996), the state of fatness, and therefore the amount of fat deposited, affects fatty acid composition. Our study clearly corroborates this

finding, as Uruguayan lambs reared under the same production system but slaughtered at different weights displayed different levels of fatness and therefore different fatty acid compositions. In this regard, light Uruguayan lambs showed higher proportions of myristic acid (C14:0) and PUFA, while heavy lambs showed higher proportions of oleic acid (C18:1) and MUFA. Similar findings have been reported by other authors, including Díaz et al. (2002), who found that lambs slaughtered at a lower weight (24 vs. 28 kg) displayed a higher percentage of myristic acid (C14:0). On the other hand, Jackson and Winkler (1970) noted that monounsaturation of fat depots increased with fatness, due to the enhanced activity of Δ9 desaturase, responsible for the synthesis of oleic acid (C18:1) from stearic acid (C18:0). In this regard, Wood and Enser (1997) found that levels of oleic acid (C18:1) in sheep increased, while those of stearic acid (C18:0) decreased, as fatness increased. Moreover, Nürnberg et al. (1996) reported a negative relationship between concentrations of carcass fat and PUFA proportions in lambs. According to these authors, the proportion of SFA in muscle increased with age, while that of PUFA decreased.

With regards to total fatty acid content (mg/100 g muscle), heavy Uruguayan lambs, whose fat content was the highest, presented higher levels of the major fatty acids (oleic acid (C18:1), palmitic acid (C16:0) and stearic acid (C18:0)) than light lambs (Spanish and light Uruguayan). Thus, the PCA of the fatty acid content (Fig. 2(a)) showed a high and positive correlation between intramuscular fat proportion and SFA, stearic acid (C18:0), oleic acid (C18:1) and palmitic acid (C16:0) contents. These fatty acids were located on the right side, where heavy Uruguayan lambs lay (Fig. 2(b)). The contents of palmitic acid (C16:0) and stearic acid (C18:0) were higher in heavy Uruguayan lambs than in the other types. High levels of palmitic acid (C16:0) are responsible for increasing total plasma and LDL cholesterol concentrations, whereas stearic acid (C18:0) is not hypercholesterolaemic and does not increase total cholesterol or LDL cholesterol concentrations (Williams, 2000) and oleic acid (C18:1) helps to decrease them (Bonanome & Grundy, 1988). On the other hand, heavy Uruguayan lambs had the highest CLA content and Spanish and light Uruguayan lambs the lowest as a result of their differences in intramuscular fat proportion. This finding was according to Raes, De Smet, Balcaen, Claeys, and Demeyer (2003), who found that CLA content was positively related to total intramuscular fatty acid content. CLA is predominantly deposited in the triacylglycerols and as a result, a quantitatively higher CLA content is associated with a higher intramuscular fat content (Raes et al., 2004).

The higher intramuscular fat content was also associated with higher SFA and MUFA contents (heavy Uruguayan lambs), whereas the PUFA content remained in the same order across the lamb types. This is because the muscle phospholipid content is relatively constant and contains mainly PUFA, while the neutral lipids, primarily formed by SFA and MUFA, increase when intramuscular fat content rises (Sharma, Gandemer, & Goutefongea, 1987). SFA and MUFA levels increase faster than those of PUFA as fatness increases, leading to a reduction in the relative proportion of PUFA (Raes et al., 2004).

With respect to the fatty acid ratios in heavy Uruguayan, German and British lambs, the P/S ratio was low due to the high content and proportion of SFA related to their higher fat proportion. On the contrary, Spanish lambs displayed the highest ratio, which came closest to the nutritional recommendation of 0.45 (Department of Health, 1994). The P/S ratio in ruminants is affected by fat levels and much less by nutrition, as part of the dietary unsaturated fatty acids of these animals are hydrogenated in the rumen (Raes et al., 2004). Nevertheless, Enser et al. (1998) noted higher P/S ratios in animals fed concentrate, high in linoleic acid (C18:2), than in animals fed grass, with high concentration of stearic acid (C18:0). On the contrary, French et al. (2000) reported that a decrease in concentrate intake in a grass-based diet resulted in a linear increase in the P/S ratio in intramuscular fat.

The $n-6/n-3$ ratio is an index of the role played by fatty acids in human atherosclerosis (Sanders, 1988). The appropriate balance for $n-6/n-3$ recommended by Department of Health (1994) is 4. The inappropriate balance of $n-6$ and $n-3$ PUFA could contribute to a greater risk of coronary heart diseases (CHD) (Williams, 2000). In our study, intramuscular fat from concentrate-fed lambs (Spanish) had a more unfavourable $n-6/n-3$ PUFA ratio than that of grass-fed (Uruguayan lambs). According to other authors (Enser et al., 1998; French et al., 2000), these difference could be a consequence of the fatty acid composition of the diet, as linolenic acid (C18:3) is the major fatty acid in grass lipids while linoleic acid (C18:2) predominates in concentrates. In this regard, Raes et al. (2004) also affirmed that the $n-6/n-3$ ratio is highly influenced by the fatty acid composition of the diet.

In conclusion, the combined effects of diet, age, sex and breed produced differentiation in meat fatty acid profiles according to their origin. The differences were more evident in Spanish lambs, since they presented high levels of $n-6$ fatty acids and therefore a high $n-6/n-3$ ratio, due to the exclusively concentrate based diet. However lambs fed grass had high levels of $n-3$ fatty acids and low $n-6/n-3$ ratios. On the other hand, older and castrated lambs, such as heavy Uruguayan lambs, had the highest intramuscular fat and SFA levels.

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