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Diversification of feeding systems for light lambs: sensory characteristics and chemical composition of meat

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Abstract

Forty-eight light lambs were used to study the effect of feeding systems on the sensory quality and chemical composition of their meat. Animals were divided into four batches as follows: GR: lambs with dams continuously on pasture until slaughter; GR+S: like GR, but the lambs had free access to concentrate; DRL-GRE: lambs in drylot and ewes with rationed grazing; DRL: lambs in drylot with dams indoors. DRL-GRE and DRL lambs were weaned at age 45 days. All lambs were slaughtered on reaching 22-24 kg live weight. Sensory attributes were not affected by the feeding system; grazing systems would therefore be a good alternative to indoor feeding systems. Meat from grazing lambs (GR and GR+S) presented the lowest values of C18:2 n-6/C18:3 n-3 and n-6/n-3, DRL-GRE lambs yielded intermediate values and DRL lambs the highest values. Ewes' diet during lactation affects the fatty acid composition of the meat of light lambs. The feeding system affected the relationships between the meat's sensory characteristics and chemical properties. Discriminant analysis using fatty acid composition was able to distinguish between lambs from each feeding system, and could therefore be used as a tool for traceability.

Additional key words: grazing; indoors; meat quality; relationships; traceability.

Resumen

Diversificación de los sistemas de producción de corderos ligeros: características sensoriales y composición química de la carne

Se utilizaron 48 corderos para estudiar el efecto del sistema de producción sobre la calidad sensorial y la composición química de la carne. Los animales se distribuyeron en 4 lotes: GR, los corderos permanecieron con sus madres en pastoreo hasta sacrificio; GR+S, como el anterior pero los corderos tenían acceso a concentrado; DRL-GRE, los corderos se alimentaron con cebo y madres en pastoreo; DRL, corderos y madres permanentemente estabulados, con cebo. Los lotes DRL-GRE y DRL se destetaron a los 45 días de edad. Todos los corderos se sacrificaron al alcanzar los 22-24 kg de peso vivo. El sistema de producción no afectó las características sensoriales de la carne. Por lo tanto, los sistemas de pastoreo podrían ser una buena alternativa a los sistemas de estabulación. La carne de los corderos en pastoreo (GR y GR+S) presentó los valores más bajos de C18:2 n-6/C18:3 n-3 y n-6/n-3, presentando valores intermedios los del sistema DRL-GRE y los valores más bajos los del sistema DRL. La dieta de las ovejas durante la lactación afectó a la composición en ácidos grasos de la carne de los corderos. El sistema de producción afectó a las correlaciones entre las variables sensoriales y la composición química de la carne. Un análisis discriminante basado en el perfil de ácidos grasos fue capaz de distinguir entre los sistemas de producción y por consiguiente, podría utilizarse como herramienta de trazabilidad.

Palabras clave adicionales: calidad de la carne; correlaciones; estabulación; pastoreo; trazabilidad.

Introduction

In European Mediterranean countries, lambs are traditionally reared with their dams in indoor conditions until they are weaned (at approx. 45 days) and then fattened with concentrate until slaughter, at around 20-24 kg live weight. Consumers are used to this kind of meat and consider it a high-quality product (Sañudo *et al.,* 1998). Nowadays, the recent increases in cereal prices have constrained this production system, making

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Abbreviations used: DRL (drylot); DRL-GRE (drylot lambs with grazing restricted ewes); GR (grazing system); GR+S (grazing plus concentrate to lambs); MUFA (monounsaturated fatty acids); PCA (principal component analysis); PUFA (polyunsaturated fatty acids; SFA (saturated fatty acids).

many farms unprofitable. New approaches are needed to solve these problems. Grazing to produce lambs can support meat production in a more socially acceptable way than an intensive concentrate-based system.

On the other hand, a growing number of consumers require safe, healthy, lean meat, with consistent quality when eaten and clear information on production systems, especially animal feeding and management. The chemical composition of the meat can be partially modified by animal feeding (Santos-Silva *et al.*, 2002a; Demirel *et al.*, 2006; Scollan *et al.*, 2006; Joy *et al.*, 2008a; Carrasco *et al.,* 2009). It is well known that fatty acid composition can be manipulated by feeding strategies (Enser *et al.*, 1998; Rowe *et al.*, 1999; Wood *et al.*, 2008), even in ruminants and despite rumen biohydrogenation processes. Some research in this direction has been conducted and it has been observed that forage diets increase the content of n-3 polyunsaturated fatty acids (n-3 PUFA) and reduce the content of saturated fatty acids (SFA) in the meat, the opposite of what occurs with concentrate diets (Valvo *et al.*, 2005; Atti *et al.*, 2006; Scerra *et al.*, 2007; Joy *et al.*, 2008a). Moreover, supplementing grazing with concentrate leads to a relatively high concentration of n-6 PUFA and a low level of n-3 PUFA, the n-6/n-3 ratio higher than in forage-fed diets (Santos-Silva *et al.*, 2002b). Concerning quality when eaten, the fatty acid (FA) profile can affect the organoleptic characteristics of the meat, especially flavour (Wood and Enser, 1997), although the literature on this is not conclusive. Finally, with reference to traceability, efforts have been made recently to trace feeding systems in herbivores in order to implement food safety (Prache *et al.*, 2005; Ripoll *et al.*, 2008) and the FA profile can act as a tracer of animal diet (Santos-Silva *et al.*, 2002b; Aurousseau *et al.*, 2007a, b). Hence the aim of this study was to assess the effect of the increasing intensification gradient according to the use of concentrates on the relationships between some sensory characteristics and the chemical composition of the meat of light lambs, and to evaluate the usefulness of the fatty acid profile in tracing the lamb feeding system.

Material and methods

Animal management

Forty-eight *Churra Tensina* single male lambs (live weight at birth 3.6 ± 0.08 kg) were selected from the experimental flock of the La Garcipollera Research Station (945 m asl, north-eastern Spain). After birth, ewe-lamb pairs were allocated at random to four treatments (n = 12), taking into account the lambing date and the lamb's live weight at birth. The treatments were:

— *Grazing* (GR): Lambs and ewes were continuously stocked on permanent pasture. No concentrate was available to dams or lambs. Ewes suckled their lambs and the lambs grazed until transport and subsequent slaughter.

— *Grazing with supplement for lambs* (GR+S): The same management as GR, but these lambs received concentrate *ad libitum* in lamb creep feeders until slaughter.

— *Drylot lambs with grazing ewes* (DRL-GRE): Lambs remained indoors and fed on concentrate while ewes grazed for eight hours a day (8 a.m. to 4 p.m.). Thereafter, ewes received a supplement of 0.5 kg fresh barley meal per day [119 g raw protein (RP), 248 g neutral detergent fibre (NDF), as dry matter]. This system aimed to correspond to the management system commonly used in the region. Lambs were weaned when 45 days old.

— *Drylot* (DRL): Lambs and ewes were kept in confinement at all times. Ewes had free access to dry unifeed (110 g RP, 681 g NDF, as dry matter) and lambs had concentrate *ad libitum.* Lambs were weaned when 45 days old.

Throughout the trial, GR+S, DRL-GRE and DRL lambs had free access to concentrate (185 g and 175 g RP, 190 g and 212 g NDF respectively, as dry matter, the first month and subsequently). In both drylot treatments, DRL-GRE and DRL, ewes and lambs had *ad libitum* barley straw (37 g RP, 807 g NDF, as dry matter). Ewes were removed from the experiment after weaning. All the animals were supplied with fresh water and vitamin/mineral supplement *ad libitum*.

Pasture characteristics were broadly described in Álvarez-Rodríguez *et al.* (2007). Briefly, the botanical composition was 68% grass and 20% leguminous. The stocking rate was 24 ewes ha^{-1} (0.5 ha $paddock^{-1}$). Herbage mass and quality were non-limiting throughout the experiment, with a mean sward height ranging from 8.4 to 12.7 cm, RP between 179 and 215 g and NDF content between 490 and 524 g, as dry matter, depending on the grazing pressure exerted by each treatment. For further details see Carrasco *et al.* (2009).

Slaughtering procedure

Lambs were weighed weekly until 76 ± 2.3; 62 ± 1.3, 65 ± 1.8, and 72 ± 2.5 days old for GR, GR+S, DRL-GRE and DRL respectively, when they reached 22-24 kg live weight. They were then transported to the experimental abattoir of the Research Institute in Zaragoza, which is located 180 km away from the farm. Transport was carried out according to EU animal welfare regulations. On arrival lambs were accommodated until slaughter, in line with their original treatment. There was no fasting period. Grazing lamb groups (GR and GR+S) received green forage and indoor lamb groups (DRL-GRE and DRL) were provided with the same concentrate as during the experimental period. Twenty hours after their arrival, lambs were weighed again and slaughtered according to EU laws. The procedures used complied with the guidelines of Council Directive 86/609/EEC (European Communities, 1986) on the protection of animals used for experimental and other scientific purposes. All carcasses were in classes B and C of the European carcass classification system for light lambs (9-12.5 kg, commercial category *Ternasco*). All carcasses were classified with O and R scores and fatness was between 2 and 3. The characteristics of the carcasses were described in Carrasco *et al.* (2009).

After 24 hours' refrigeration at 4°C, the tails were removed from the carcasses and the carcasses were split along their length. The *longissimus thoracis* et *lumborum* muscles were removed from the left half of the carcasses. The loin portion from the 6th to the 10th thoracic vertebra was taken for chemical analysis, and the loin portion from the 1st to the 6th lumbar vertebra was taken for the sensory analysis. All samples were vacuum-packed and frozen (–20°C) until analysis.

Sensory analysis

On the day of the panel test, samples were thawed inside their bags under cold running water until they reached an internal temperature of 17-19°C. After being opened, the loins were wrapped in aluminium foil and cooked on a heated double-plate grill (Sammic P8D-2, heated to 200°C) to an internal temperature of 70°C, monitored using an internal thermocouple (Jenway 2000). Every loin was then trimmed of any external connective tissue, cut into 2 × 2 cm samples, wrapped in individually-marked aluminium foil and stored in a warm cabinet at 50°C until they were tasted. Samples were served at random to a trained (ISO 8586-1, 1993) eight-member taste panel in individual booths, under red lighting to mask differences in meat colour. A comparative multi-sample test, with four samples each, was used to detect differences in taste attributes between treatments. The sensory variables analysed were the lamb's odour intensity, abnormal odour intensity, tenderness, juiciness, lamb flavour intensity, fat flavour intensity, abnormal flavour intensity and overall rating, using a structured 10-point scale on which 1 was the lowest score and 10 the highest score for the attribute in question.

Chemical composition of meat

Samples were thawed to 25°C and minced. Moisture (AOAC, 1999), intramuscular fat (AOCS, 2004) and raw protein (Dumas procedure; AOAC, 1999) were measured. Meat lipids were extracted from minced meat with chloroform-methanol and hydrolyzed with an alkali. Fatty acids (FAs) were converted to methyl esters, and fatty acid esters were obtained using a solution of 20% boron trifluoride in methanol (Rule, 1997). Analysis of fatty acid methyl esters was performed by gas chromatography (SP2330 30 m capillary column, Supelco, Tres Cantos, Madrid) and a flame ionisation detector with helium as the carrier gas at 1 mL min^{-1}. The oven temperature was programmed to increase from 150°C to 225°C at 7°C per minute. Injector and detector temperatures were both 250°C. Individual fatty acid content was expressed as a percentage of the total amount of fatty acids identified.

After ascertaining the proportion of fatty acids, SFA = C14:0 + C16:0 + C18:0 + C20:0, MUFA = C16:1 + C18:1, and PUFA = C18:2 n-6 + C18:3 n-3 + C20:4 + C20:5 + C22:6, and PUFA/MUFA, C18:2 n-6/C18:3 n-3 and n-6/n-3 series ratios were calculated.

Statistical analysis

Statistical analysis were performed using the SPSS 15.0 statistical package. A one-way ANOVA test was carried out using the General Linear Model, with the feeding system as a fixed effect. Differences between the means were determined using the Duncan multiple-range test, at significance level $\alpha = 0.05$.

Relationships between variables were calculated using Pearson coefficients, and graphically using principal component analysis (PCA), both for the pull of the data and for each of the feeding strategies studied. Finally, a canonical discriminant analysis was carried out on groups' feeding systems according to the fatty acid composition of the meat.

Results and discussion

Sensory analysis

The feeding system did not affect any of the meat's sensory characteristics (Table 1). The effect of feeding systems on sensorial attributes is not clear in the literature, and results described are often contradictory. Summers *et al.* (1978) and Kemp *et al.* (1981) did not detect any significant differences in tenderness when comparing animals fed blue-grass clover, concentrate or both. In contrast, Paul *et al.* (1964) and Crouse *et al.* (1978) observed greater tenderness when animals were concentrate-fed rather than grass-fed. The different results on tenderness may be due to many factors which affect it. Energy and protein intake can have an effect. Solomon *et al.* (1986) found that meat from lambs reared on a low-energy diet was more tender than meat from animals reared on a high-energy diet. The protein content of the diet is only important when the differences between diets are significant, showing a positive relationship between protein level and tenderness (Kemp *et al.*, 1976; Fhamy *et al.*, 1992). Factors such as the type of forage (Field *et al.*, 1978; Vipond *et al.*, 1995; Hopkins and Nicholson, 1999) and weaning (Summers *et al.*, 1978; Sañudo *et al.*, 1998) did not affect meat tenderness.

Similarly, juiciness was not affected by the feeding system. The energy level of the diet (Crouse *et al.*, 1978; Solomon *et al.*, 1986), its protein content (Kemp *et al.*, 1976, 1981), type of forage (Field *et al.*, 1978; Vipond *et al.*, 1995; Hopkins and Nicholson, 1999) and weaning (Summers *et al.*, 1978; Vipond *et al.*, 1995; Sañudo *et al.,* 1998) had no effect on the juiciness of lamb meat.

Odour and flavour were similar in forage- and concentrate-fed animals (Paul *et al.*, 1964; Solomon *et al.*, 1996). There is evidence that a pasture-based diet promotes slightly stronger odours than maize-concentrate diets (Rousset-Akrim *et al.*, 1997) and that replacing forage with concentrate reduces the intensity of meat flavour (Field *et al.*, 1978; Fisher *et al.*, 2000; Angood *et al.*, 2008). Priolo *et al.* (2002) reported that typical lamb flavour and fat flavour were more developed in meat from stall lambs, while liver flavour was stronger in grass-fed lambs' meat. Finally, it was demonstrated that the overall rating was not affected by the energy level of the diet (Crouse *et al.,* 1978), its protein content (Kemp *et al.*, 1976), type of pasture (Vipond *et al.*, 1995; Hopkins and Nocholson, 1999) or weaning (Sañudo *et al.*, 1998).

From these results it can be concluded that the feeding system did not affect any of the sensory characteristics of light lambs, and so grazing systems may be a valid alternative to traditional indoor-feeding systems.

Chemical composition of meat

The feeding system affected moisture ($p < 0.01$) and protein content ($p < 0.001$), but had no effect on intramuscular fat content ($p > 0.05$) (Table 2). Grazing lambs (GR, GR+S) showed a higher concentration of

Table 1. Effect of feeding system on some sensory attributes of m. *Longissimus dorsi* in Churra Tensina light lambs reared under grazing (GR), grazing with supplement (GR+S), drylot lambs with rationed grazing-ewes (DRL-GRE) and drylot lambs with ewes fed in confinement (DRL)

Attributes	GR	GR+S	DRL-GRE	DRL	SE[1]	Effect[2]
Lamb odour intensity (1-10)	5.8	6.0	6.0	5.6	0.25	NS
Abnormal odour intensity (1-10)	4.2	4.6	3.9	3.9	0.38	NS
Tenderness (1-10)	6.0	6.0	5.7	6.1	0.27	NS
Juiciness (1-10)	5.2	5.1	5.4	5.4	0.29	NS
Lamb flavour intensity (1-10)	6.5	7.0	6.6	6.3	0.25	NS
Fat flavour intensity (1-10)	5.8	6.1	5.6	5.4	0.32	NS
Abnormal flavour intensity (1-10)	4.9	4.8	3.8	4.7	0.38	NS
Overall liking (1-10)	4.4	4.6	5.2	4.6	0.28	NS

[1] SE: standard error. [2] NS: no significant ($p > 0.05$).

Table 2. Effect of feeding system on chemical composition of m. *Longissimus dorsi* in Churra Tensina light lambs reared under grazing (GR), grazing with supplement (GR+S), drylot lambs with rationed grazing-ewes (DRL-GRE) and drylot lambs with ewes fed in confinement (DRL)

Chemical composition	GR	GR+S	DRL-	DRL	SE[1]	Effect[2]
Moisture (%)	77.39[a]	77.24[a]	76.56[b]	76.72[b]	0.501	**
Intramuscular fat (%)	1.44	1.63	1.50	1.67	0.080	NS
Crude protein (%)	20.27[a]	20.02[a]	19.30[b]	19.07[b]	0.208	***
C14:0 (Myristic)	5.46	4.89	4.83	4.62	0.303	NS
C16:0 (Palmitic)	21.51[b]	21.82[b]	24.05[a]	23.86[a]	0.351	***
C16:1 (Palmitoleic)	2.42	2.61	2.65	2.45	0.105	NS
C18:0 (Estearic)	14.10[a]	12.58[b]	12.44[b]	13.34[ab]	0.352	*
C18:1 (Oleic)	36.64	37.50	38.13	38.35	0.754	NS
C18:2n-6 (Linoleic)	5.04[c]	6.18[b]	7.02[b]	8.53[a]	0.387	***
C18:3n-3 (Linolenic)	2.27[a]	2.46[a]	1.29[b]	0.46[c]	0.157	***
C20:0 (Arachidic)	2.10[a]	1.93[a]	1.14[b]	0.60[c]	0.102	***
C20:4 (Arachidonic)	2.38[b]	2.04[b]	2.19[b]	2.98[a]	0.198	**
C20:5 (Eicosapentaenoic) EPA	1.42[a]	1.47[a]	0.90[b]	0.36[c]	0.162	***
C22:6 (Docosahexaenoic) DHA	1.14[a]	1.17[a]	0.71[b]	0.59[b]	0.081	***
Total SFA[3]	43.17	41.21	42.46	42.42	0.576	NS
Total MUFA[4]	39.06	40.12	40.78	40.79	0.754	NS
Total PUFA[5]	12.24	13.32	12.11	12.91	0.74	NS
PUFA/SFA	0.29	0.33	0.29	0.31	0.021	NS
C18:2n-6/C18:3n-3	2.26[c]	2.53[c]	6.34[b]	18.64[a]	0.537	***
n-6/n-3	1.61[c]	1.64[c]	3.64[b]	8.44[a]	0.352	***

[1] SE: standard error. [2] NS: no significant; ** $p \leq 0.01$; *** $p \leq 0.001$. [3] SFA: saturated fatty acids. [4] MUFA: monounsaturated fatty acids. [5] PUFA: polyunsaturated fatty acids. n-6/n-3 = (C18:2n-6 + C20:4) / C18:3n-3 + C20:5 + C22:6).

moisture and protein than either drylot treatment (DRL, DRL-GRE) ($p < 0.05$). Low-energy diets, such as forage diets, increase the daily protein accretion rate more than fat accretion, which involves an increase in water content in the muscles. So when forages are included in the diet instead of concentrate, an increase in the meat's moisture and protein and a decrease in its fat content are expected (French *et al.*, 2001; Velasco *et al.*, 2004; Lee *et al.*, 2008).

The most abundant fatty acids observed in this study were oleic, palmitic and stearic acids, as expected. They accounted for approximately two thirds of the total amount of fatty acids (Table 2), in line with the results reported by several authors (Kemp *et al.*, 1981; Rowe *et al.*, 1999; Kosulwat *et al.*, 2003; Velasco *et al.*, 2004; Arana *et al.*, 2006). The feeding system had an effect on all fatty acids except C14:0, C16:1 and C18:1. In addition, the feeding system affected C18:2/C18:3 and n-6/n-3 ratios, whereas no effect was found on either SFA, MUFA or PUFA proportions or the PUFA/SFA ratio. These results were in line with those of several authors (Rowe *et al.*, 1999; Santos Silva *et al.*, 2002b; Nuernberg *et al.*, 2008; Joy *et al.*, 2008b). Grazing lambs (GR, GR+S) presented lower proportions of C16:0 and higher proportions of C20:0 than drylot lambs (DRL-GRE and DRL; $p < 0.05$, Table 2). The similar C16:0 content obtained in GR and GR+S was unexpected, since concentrate intake reportedly increases levels of this FA (Aurousseau *et al.*, 2007a). Nevertheless, it has been stated that the FA composition of grazing ewes' milk is reflected in suckling lambs' meat (Velasco *et al.*, 2004; Scerra *et al.*, 2007). Thus, it seems that in this study the unweaned status of the GR+S group helped maintain low C16:0 content. In addition, Joy *et al.* (2008b) found values similar to these results when comparing the FA profile of unweaned grazing light lambs to that of weaned indoor lambs fed grazing ewes' milk until weaning. The C18:0 content in GR was higher than that found with the treatments receiving concentrate, although it was significantly different only in the cases of GR+S and DRL-GRE ($p < 0.05$). Grazing lambs showed higher concentrations of saturated long-chain FAs in the form of C18:0 and C20:0 ($p < 0.05$), in line with the findings of several authors (Kemp *et al.*, 1981; Velasco *et al.,* 2001; Aurousseau *et al.,* 2004, 2007a, b; Nuernberg *et al.*, 2008).

Several studies have concluded that fat from grass-fed ruminants is more saturated than fat from concentrate-fed lambs (Rhee *et al.,* 1992; Rowe *et al.*, 1999;

Scerra *et al.*, 2007) mainly due to the higher proportion of C18:0. In general, fresh forage lipids are characterised by a predominance of C18:3, a precursor of the n-3 series, whereas concentrate contains relatively high levels of C18:2, precursor of the n-6 series (Petrova *et al.*, 1994; Enser and Wood, 1995; Fisher *et al.*, 2000; Velasco *et al.*, 2001; Oriani *et al.*, 2005). The fat of both grazing treatments (GR and GR+S) showed a higher proportion of C18:3 n-3 than their indoor counterparts ($p < 0.05$), and a lower proportion of C18:2 n-6 (Rowe *et al.,* 1999; Velasco *et al.*, 2001; Santos-Silva *et al.*, 2002b; Scerra *et al.*, 2007; Nuernberg *et al.*, 2008). Supplementing grazing lambs (GR+S) did not reduce the percentage of C18:3 n-3 in comparison with GR, in line with the results of Velasco *et al.* (2001). Moreover, there was a significant difference between DRL-GRE and DRL lambs, despite the fact that these lambs were fed on the same concentrate throughout the experiment. The significantly higher content of C18:3 n-3 in DRL-GRE than in DRL may be a consequence of ewes' diet during the lactation period. In the DRL-GRE treatment, the ewes' diet was based on pasture grazing plus 500 g of barley grain, while DRL ewes received only a dry mixed ration with no fresh forage. This result may support the aforementioned effect of ewes' diet on the FA composition of meat in light lambs, even after weaning.

C20:5 and C22:6 levels were nearly twice as high in grazing lambs (GR and GR+S) than in drylot lambs (DRL-GRE and DRL) ($p < 0.05$), due to the higher levels of their precursor, C18:3 n-3 (Rhee, 1992; Demirel *et al.*, 2006; Scerra *et al.*, 2007). This result supports the premise that in ruminants the n-6/n-3 ratio is affected more by genetic factors than by dietary sources of n-3 (Raes *et al.*, 2004).

Correlations

Pearson coefficients between some carcass traits and chemical or sensory characteristics are shown in Table 3. Carcass weight was correlated only with some fatty

Table 3. Pearson correlations between some carcass characteristics and meat characteristics in Churra Tensina light lambs reared under grazing (GR), grazing with supplement (GR+S), drylot lambs with rationed grazing-ewes (DRL-GRE) and drylot lambs with ewes fed in confinement (DRL). Only significant coefficients were shown

	Pull of the data			GR			GR+S			DRL-DRE			DRL		
	CCW[1]	FAT[2]	CONF[3]	CCW	FAT	CONF	CCW	FAT	CONF	CCW	FAT	CONF	CCW	FAT	CONF
Lamb odour											*–0.62*				
Abnormal odour															
Tenderness															
Juiciness															
Lamb flavour		*0.31*													
Fat flavour											**–0.75**				
Abnormal flavour															
Overall liking															
Moisture															
Intramuscular fat									**0.77**						
Protein		*0.37*													
C14:0							*0.79*								
C16:0	**0.42**						*0.81*	*0.72*							
C16:1	**0.60**	**0.44**					*0.81*	*0.69*		*0.63*					
C18:0	**–0.52**	*–0.33*								*–0.61*	*–0.62*				
C18:1						*–0.68*									
C18:2							*–0.72*						*0.79*		
C18:3							*–0.76*								
C20:0															
C20:4															
C20:5							*–0.76*						*–0.77*		
C22:6															

[1] CWW: cold carcass weight. [2] FAT: fatness degree of the carcass. [3] CONF: conformation score. Coefficients in bold were significant at 0.01 level. Coefficients in italics were significant at 0.05 level.

acids, such as C16:1 (r = 0.60**) and C18:0 (r = –0.52**), when all data were studied together. When data were analysed by feeding system, treatment GR did not show any correlation between CCW and FA, whereas the other treatments had various correlations.

The degree of fatness affected the intensity of lamb flavour (0.31*), protein (r = 0.37*), C16:1 (r = 0.44**) and C18:0 (r = –0.33*), on the basis of the pull of the data. When the treatments were studied separately, significant correlations were found only with some FAs (C16:0, r = 0.72*; and C16:1, r = 0.69*) in the GR+S system, whereas in the DRL-DRE treatment correlations were observed with lamb odour (r = –0.62*), fat flavour (r = –0.75**) and C18:0 (r = –0.62*). Carcass conformation did not affect any of the variables studied except in treatment GR, which showed a significant correlation with C18:1 (r = –0.68*), and in GR+S, with intramuscular fat content (r = 0.77**).

Relationships between sensory and chemical variables were shown in the PCA figures. Since carcass characteristics were in general only weakly correlated with meat quality characteristics, the former were not included in the PCA figures. Also, in order to improve the clarity of the figures, total SFA, total MUFA, total PUFA, PUFA/SFA ratio and C18:2/C18:3 ratio were not depicted. PCA for the whole pull of data is shown in Figure 1, and the PCAs for each treatment are shown in Figures 2 to 5.

For the whole pull of data and both indoor treatments (DRL, DRL-GRE), the total variability was around

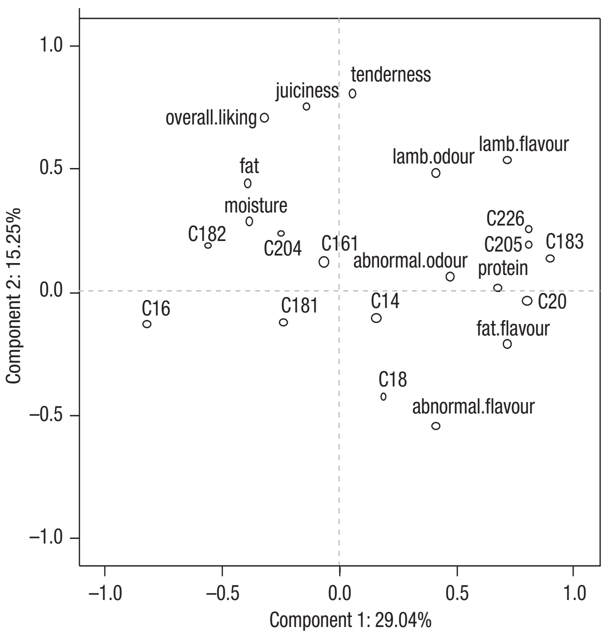

Figure 1. PCA showing relationships between some chemical and sensorial characteristics in Churra Tensina light lambs: data from all animals. Only significant coefficients were shown. Fat: intramuscular fat content. Fatty acids were codify as follows: C16 = C16:0; C204 = C20:4, etc.

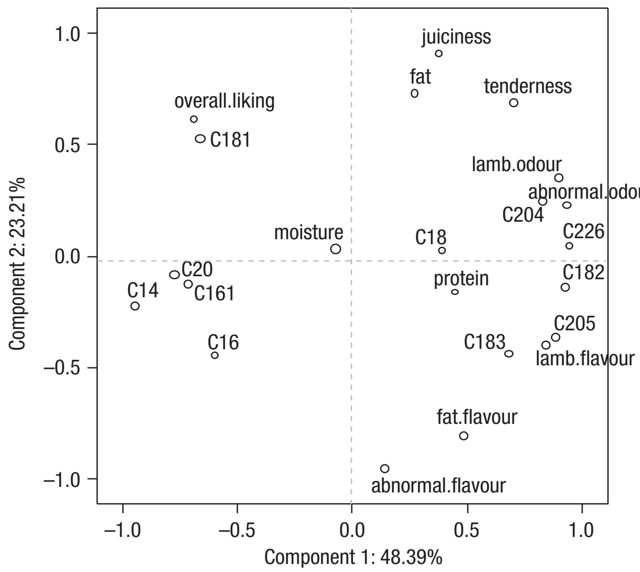

Figure 2. PCA showing relationships between some chemical and sensorial characteristics in Churra Tensina light lambs reared under grazing (GR) feeding system. Only significant coefficients were shown. Fat: intramuscular fat content. Fatty acids were codify as follows: C16 = C16:0; C204 = C20:4, etc.

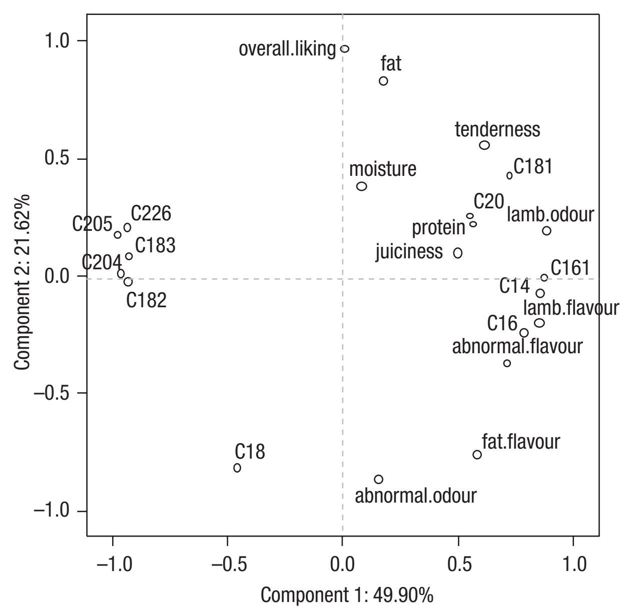

Figure 3. PCA showing relationships between some chemical and sensorial characteristics in Churra Tensina light lambs reared under grazing with supplement (GR+S) feeding system. Only significant coefficients were shown. Fat: intramuscular fat content. Fatty acids were codify as follows: C16 = C16:0; C204 = C20:4, etc.

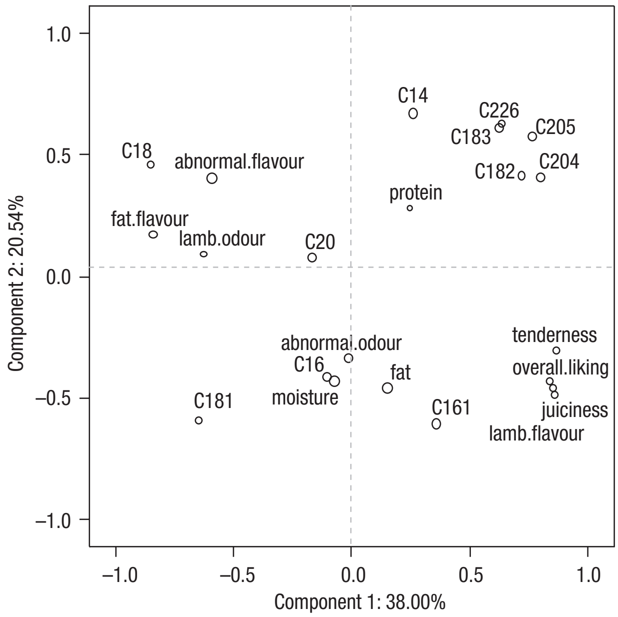

Figure 4. PCA showing relationships between some chemical and sensorial characteristics in Churra Tensina light lambs reared under drylot lambs with rationed grazing-ewes (DRL-DRE) feeding system. Only significant coefficients were shown. Fat: intramuscular fat content. Fatty acids were codify as follows: C16 = C16:0; C204 = C20:4, etc.

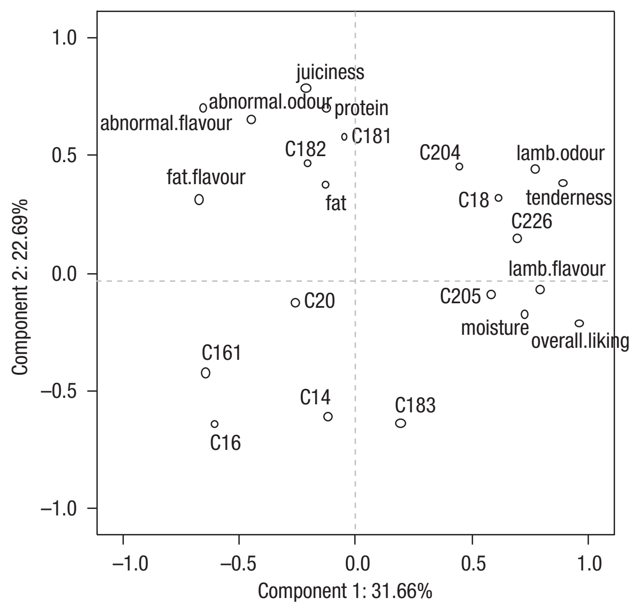

Figure 5. PCA showing relationships between some chemical and sensorial characteristics in Churra Tensina light lambs reared under drylot lambs with ewes fed in confinement (DRL) feeding system. Only significant coefficients were shown. Fat: intramuscular fat content. Fatty acids were codify as follows: C16 = C16:0; C204 = C20:4, etc.

50%, whereas in both grazing systems (GR, GR+S) total variability reached 71%. This implies that there was more correlation between variables in the grazing systems.

Considering the whole pull of data (Fig. 1), moisture was correlated only with abnormal flavour (r = –0.33*) and protein content (r = 0.73**). In contrast, any significant correlation was found when feeding systems were studied separately, except the correlation between moisture and protein (r = –0.75*) observed in the DRL-DRE system.

Intramuscular fat content was correlated with long fatty acids such as C16:1 (r = –0.38*) and C18:2 (r = 0.39*) when all data were analysed. In treatment GR+S, a positive correlation was found between intramuscular fat content and overall rating (r = 0.86**). Correlations between the meat's chemical and sensory characteristics were rarely described in the literature, but moisture and fat content were those most frequently considered. Cañeque *et al.* (2004) described a positive significant correlation between moisture and fat flavour, whereas Jeremiah *et al.* (2003) reported a negative correlation between moisture and juiciness, and a positive correlation between fat content and juiciness. When chemical contents are correlated, negative correlation between intramuscular fat content and moisture is observed (Okeudo and Moss, 2005).

In all treatments, the relationship between fat flavour and overall rating was significant and negative. The correlations between lamb odour and tenderness, and between lamb odour and lamb flavour, were also significant in all treatments, although in different directions. DRL-DRE showed a negative correlation, while the other treatments had a positive correlation. Tenderness, juiciness and overall rating were strongly positively correlated with each other in all cases except in DRL, where there was no significant correlation.

The relationship between lamb flavour and overall rating was significant and negative in all feeding systems except GR+S. Similarly, correlation between fat flavour and abnormal flavour was significant for all treatments except DRL-DRE. The relationship between lamb flavour and fat flavour was significant in all feeding systems except DRL. However, this correlation was positive in both grazing groups (GR, GR+S) and negative in the DRL-DRE group. The significant correlation between lamb flavour and overall rating observed except with GR+S was positive in both indoor groups (DRL and DRL-GRE) and negative in GR.

Two groups can be defined for the effect of the type of FA on taste characteristics. In both indoor systems, the fatty acids with the most effect on taste characteristics were mainly saturated (C16:0, C18:0) and monounsaturated (C16:1). In grazing systems, meanwhile, they were mainly PUFA (C18:1, C18:2, C20:4, C20:5, C22:6). In the DRL-DRE system, it was observed that the higher the proportion of C18:0, the higher the lamb odour and fat flavour and the lower the tenderness, juiciness, lamb flavour and overall rating. In contrast, the DRL group showed less tenderness when the C16:0 and C16:1 proportions were high. In both grazing groups (GR, GR+S), it was observed that when unsaturated acids increased, flavour, odour and overall rating decreased.

All these results show that correlations between sensory characteristics and fat composition vary according to the feeding system. It would therefore be reasonable to consider fatty acid profile as a possible traceability tool.

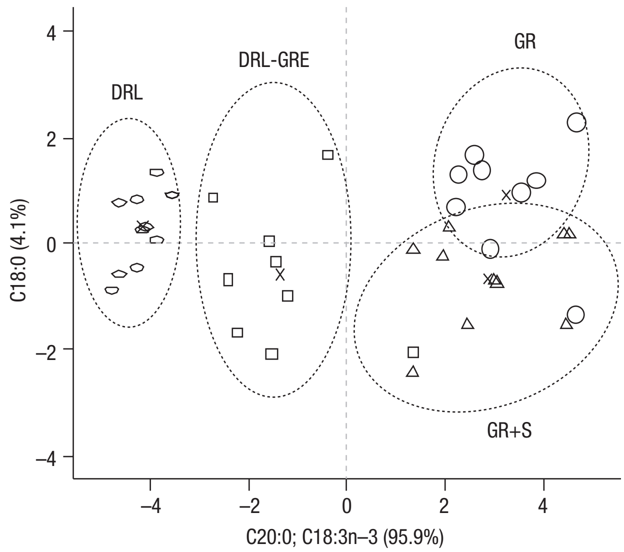

Figure 6. Discriminant analysis of fatty acids that discriminate lights lambs from four feeding systems: lambs reared under grazing (GR), grazing wiht supplement (GR+S), drylot lambs with rationed grazing-ewes (DRL-GRE) and drylot lambs with ewes fed in confinement (DRL).

Fatty acid composition as a tool for tracing feeding systems

Discriminant analysis is useful in predicting which group a given case must belong to on the basis of its characteristics. The procedure gives rise to a function (or more than one if there are more than two groups of cases) based on linear combinations of the predictive variables which allow the best discrimination between groups. To determine the suitability of FA profile as a tool to trace feeding systems in lambs, a discriminant analysis was carried out with fatty acid profile only (Fig. 6). It is difficult to implement this procedure online but it would be a good tool as a control in a random sampling test of IGPs or Guarantee Labelled products to guarantee the feeding system used to rear lambs.

Function 1 accounted for 95.9% of the total variation between feeding systems and was mainly determined by C20:0 ($r = 0.62$) and C18:3 n-3 ($r = 0.58$). Function 2 accounted for 4.1% of the variation and was mainly determined by C18:0 ($r = 0.88$).

Feeding systems within Function 1 were distributed according to grass intake, indicating that FA was effective in distinguishing clearly between grass and drylot animals. The centroids of grazing lambs (GR, GR+S) appeared in the right quadrants (with high C20:0 and C18:3 n-3 contents), while the centroids of drylot lambs (DRL-GRE and DRL) were shown in the left quadrants (with low C20:0 and C18:3 n-3 contents). Several studies have demonstrated that C18:3 n-3 allows lambs to be classified by feeding system using statistical analysis. Using PCA, Aurousseau *et al.* (2007a, b) found that only C18:3 n-3 could distinguish between lambs from pasture and concentrate groups. Using discriminant analysis, Santos-Silva *et al.* (2002b) were able to distinguish between these two feeding systems using mainly C18:3 n-3, although they did not find any clear differences between grazing and supplemented grazing lambs.

Function 2, although it accounted for only 4.1% of the variation, was able to divide the grazing animals clearly into current feeding systems, since the GR centroid was located in the upper-right quadrant, whereas the GR+S centroid was shown in the bottom-right quadrant. As has already been said, the GR and GR+S animals differed significantly in C18:0 content. In contrast, it can be seen that in the drylot groups axis 2 was not able to separate animals from each group clearly, as animals from both groups were drawn in the upper-left or in bottom-left quadrant indifferently, perhaps because DRL-GRE and DRL lambs did not differ in their C18:0 content. Thus three fatty acids, C20:0, C18:3 and C18:0, allow feeding systems to be distinguished from each other clearly.

Table 4 shows the proportion of lambs correctly classified in their current groups. Some lambs from GR and GR+S were swapped around, and some DRL-GRE lambs were allocated to the DRL and GR+S groups.

Table 4. Proportions of animals classified correctly into their current groups according to a discriminant function based on fatty acids profile

Treatment	Predicted			
	GR	GR+S	DRL-GRE	DRL
Origin				
GR	77.8	22.2	—	—
GR+S	20.0	80.0	—	—
DRL-GRE	—	11.1	77.8	11.1
DRL	—	—	—	100.0

Lambs belonging to GR, GR+S, DRL-GRE and DRL were classified correctly in 77.8, 80.0, 77.8 and 100% of cases respectively. Overall, 83.9% of the lambs were correctly allocated to their feeding systems. These results open up a new perspective on the traceability of meat origin and deserve more attention.

These results allow us to conclude that no differences in any sensory attribute were found between treatments. As a result, grazing systems may be considered a valid alternative to traditional indoor feeding systems. In contrast, feeding system affected both the chemical composition and the fatty acid profile of meat. When comparing different indoor groups, it was observed that ewes' diet during the lactation period affected the FA composition of meat from light lambs.

The number and nature of the relationships between meat's chemical and sensory characteristics depend on the feeding system. Correlations were more numerous in grazing systems than in indoor systems. In general, in indoor systems fatty acids affecting sensory characteristics were mainly saturated medium-chain (C16:0, C18:0) and monounsaturated (C16:1) acids, whereas in grazing systems the fatty acids affecting sensory variables were mainly PUFA.

Discriminant analysis was able to classify the various feeding systems according to their FA profile. The high percentage of lambs allocated correctly suggests that study of the FA profile can be used effectively as a tool for tracing the feeding systems of lambs. This potential application of FA profiles may be of great interest, considering consumers' growing concern regarding food origins and safety.

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