Breed, slaughter weight and ageing time effects on physico-chemical characteristics of lamb meat

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Abstract

The effects of breed, slaughter weight and ageing time on the meat quality of the three most important Spanish breeds were considered. Two hundred and twenty-five lambs of Rasa Aragonesa-local meat breed-, Churra-local dairy breed- and Spanish Merino were used. Animals (75 of each breed) were slaughtered at three different live weights (10–12, 20–22 or 30–32 kg), and the meat was aged for 1, 2, 4, 8 or 16 days. The meat pH, colour, amount of haem pigments, intramuscular fat, moisture, hydroxyproline content and sarcomere length were measured at 24 h post-mortem. Meat texture was measured by compression after each ageing time. The pH of the samples ranged from 5.50 to 5.58. Meat colour varied with breed and slaughter weight (P 6 0.01), the M. longissimus thoracis was lighter in the youngest animals and in the Churra breed and redder in Merinos. Intramuscular fat increased and moisture decreased for heavier lambs. Differences in collagen were associated with breed (P 6 0.01); total and insoluble collagen contents were higher in the Churra breed. Sarcomere length was only slightly affected by slaughter weight. Meat from the Churra breed had the highest values at high levels of compression. Suckling lambs (10–12 kg) had greater myofibrillar toughness than heavier lambs and ageing strongly influenced myofibrillar tenderness.

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1. Introduction

The European lamb market is quite diverse. In northern Europe, consumers prefer meat from heavy carcasses, but in the south, light carcasses are favoured (Alfonso, 2000; Zygoyiannis, Kyriazakis, Stamataris, Friggens, & Katsaounis, 1997). In Mediterranean countries, meat from light lambs is thought to be of better quality (be more tender and have less flavour than heavier animals). Many products are also associated with specific breeds, quality brands or Protected Geographical Indications (Sierra, Alfonso, & Sañudo, 2003). However, in a global market, the quality of other productive options also needs to be considered.

The physico-chemical characteristics of meat determine its quality and acceptability. Meat colour is the most important deciding factor for consumers at the moment of purchase, if meat odour is not detected first (Renerre, 1982). Textural parameters (collagen content, sarcomere length, intramuscular fat and water, instrumental texture, etc.) also affect meat tenderness, which is appreciated by consumers after purchase.

Many studies have analysed the effect of breed and slaughter weight on the physico-chemical characteristics of lamb meat, but most have only considered one ageing time (Fourie, Kirton, & Jury, 1970; Hoffman, Muller,

As a general rule, increasing the ageing time will increase tenderness (Devine & Graafhuis, 1995). Lamb meat aged quickly (Ilian, El-Din Bekhit, & Bickerstaffe, 2004), but little is known about how the ageing process can vary in terms of breed or slaughter weight in this species. Here we consider the effects of breed, slaughter live weight (according to the marketable weights of each breed) and ageing time on some instrumental quality parameters of lamb meat.

2. Materials and methods

2.1. Animals and sampling

Meat samples were obtained from 225 entire male lambs from the three major Spanish breeds; 75 Rasa Aragonesa lambs from the Aragón region (local meat breed), 75 Churra lambs from Castilla-León (local dairy breed) and 75 Spanish Merino lambs from Extremadura (specialised meat breed). Lambs were slaughtered at 10–12 kg live weight (suckling lambs), 20–22 kg (light lambs) or 30–32 kg (early fattening lambs). Twenty-five lambs were analysed within each breed and slaughter weight.

Each breed has an official quality label associated with a specific production system and environment that have been maintained throughout the years (including specifications about breed, feeding system, slaughter age-weight and fatness score). The European quality label (PGI) for the Rasa Aragonesa is called Ternasco de Aragón (European Union, 1996) and Lechazo de Castilla y León for the Churra (European Union, 1999). Cordero de Extremadura is the regional quality label for the Spanish Merino (Diario Oficial de Extremadura, 1995).

Rasa Aragonesa lambs suckle dam’s milk until they are 45–55 days old, when they are weaned and fattened on concentrate and cereal straw. Slaughter live weights range from 20 to 24 kg (70–90 days old). Churra lambs only receive dam’s milk and are slaughtered between 9 and 12 kg live weight (about 35 days old). Merino lambs are raised in an extensive system on dam’s milk and very small amounts of forage until 15 kg live weight, then fattened on concentrate and cereal straw ad libitum. Slaughter live weight ranges from 23 to 28 kg, slightly less for females, and lambs are between 80 and 100 days old.

To avoid transport stress, the lightest lambs in each breed (unweaned) were slaughtered in the region of origin. The rest were transported to the same collecting place (indoors), divided in two lots according to slaughter weight and fattened with concentrate (43.3% barley, 25.0% corn, 22.3% soya-44, 4.0% acid whey, 2.1% calcium carbonate, 2.0% beet molasses, 0.5% palm oil, 0.4% mineral mix and 0.4% plain salt) and cereal straw ad libitum using the same facilities. Each lamb was weighed individually every week until they reached their target slaughter weight.

Lambs were slaughtered using standard commercial procedures. Carcasses were suspended by the Achilles tendon and maintained at ambient temperature (12 ± 2 °C) for 6 h to avoid cold shortening. Subsequently, they were refrigerated at 2 °C (± 2 °C) until 24 h post-mortem. After chilling, 180 carcasses were weighed (20 by breed and slaughter weight) and classified according to the same EU scale (European Union, 1992, 1993, 1994), divided in 15 or 12 points for carcass conformation, fatness score and meat colour. The scores and the slaughter weights are shown in Table 1.

Table 1

Means (± standard deviation) of slaughter live weight (SLW), cold carcass weight (CCW), European carcass conformation (EUconf), European fatness score (EUf) and European carcass colour (EUcolour) of 180 lamb carcasses from three Spanish breeds, slaughtered at three live weights (20 by breed and slaughter live weight)

<table>
<thead>
<tr>
<th>Breed</th>
<th>10–12 kg (SLW)</th>
<th>20–22 kg (CCW)</th>
<th>30–32 kg (EUconf)</th>
<th>20–22 kg (EUf)</th>
<th>30–32 kg (EUcolour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rasa Aragonesa (local meat breed)</td>
<td>11.72 (0.61)</td>
<td>21.30 (1.02)</td>
<td>31.40 (1.51)</td>
<td>10.83 (0.97)</td>
<td>21.70 (1.16)</td>
</tr>
<tr>
<td>Churra (local dairy breed)</td>
<td>5.41 (0.41)</td>
<td>10.08 (0.65)</td>
<td>15.32 (0.96)</td>
<td>5.40 (0.58)</td>
<td>10.01 (0.74)</td>
</tr>
<tr>
<td>Spanish Merino</td>
<td>11.70 (1.01)</td>
<td>21.96 (1.49)</td>
<td>30.61 (1.49)</td>
<td>6.12 (0.74)</td>
<td>10.11 (0.79)</td>
</tr>
</tbody>
</table>

Notes:
- Scale 1–15 points: 1 = P−, 2 = P (poor), 3 = P+, 4 = O−, 5 = O (normal), 6 = O+, 7 = R−, 8 = R (good), 9 = R+, 10 = U−, 11 = U (very good), 12 = U+, 13 = E−, 14 = E (excellent), and 15 = E+.
- Scale 1–12 points: 1 = 1−, 2 = 1 (very scarce), 3 = 1+, 4 = 2−, 5 = 2 (scarce), 6 = 2+, 7 = 3−, 8 = 3 (medium), 9 = 3+, 10 = 4−, 11 = 4 (important), and 12 = 4+.
- Scale 1–12 points: 1 = 1−, 2 = 1 (pale pink), 3 = 1+, 4 = 2−, 5 = 2 (pink), 6 = 2+, 7 = 3−, 8 = 3 (red), 9 = 3+, 10 = 4−, 11 = 4 (other colour), and 12 = 4+.
At 24 h post-mortem, all 225 carcasses were cut in half through the spinal chord and sampled. Meat pH, colour, chemical analyses (haem pigments, intramuscular fat and moisture percentages) and instrumental texture were measured on the classified carcasses (180). Samples for pH, colour and chemical analyses were taken from the longissimus thoracis (LT) (5th–8th rib level) from both halves of the carcass (right and left) and not aged further. Meat colour, pH and haem pigment content were determined on fresh meat. The other samples were vacuum packed, blast frozen and stored at −20 °C until further analysis. Samples for instrumental texture were taken from the M. longissimus thoracis (LT) (9th–13th rib level) from the two half carcasses (360 samples in total) and sealed into polyethylene bags under a vacuum. The samples were aged for 1, 2, 4, 8 or 16 days at 3 °C (± 1 °C) (samples from the same carcass were not included in the same ageing group), blast frozen, and stored at −20 °C.

The remaining 45 carcasses (5 by breed and slaughter weight), which were randomly selected from the total 225 animals, were used to measure collagen (hydroxyproline) content and sarcomere length. Samples were removed at 24 h post-mortem from the LT (sarcomere) and the M. longissimus lumborum (LL) (hydroxyproline). Samples for measuring sarcomere length were vacuum packed, blast frozen and maintained at −20 °C. Samples used to determine the hydroxyproline content were divided into two portions, one was solubilised (Kopp & Bonnet, 1981) and frozen at −20 °C and the other was vacuum packed and frozen at −20 °C.

2.2. pH, meat colour and chemical composition (haem pigments, fat and moisture)

The meat pH was measured at 24 h post-mortem, at 8 ± 2 °C, in the LT (5th–8th rib level) with a penetrating electrode connected to a portable CRISON 507 pH-meter.

Meat colour was measured at 24 h post-mortem, at 8 ± 2 °C, on the surface of the section of the LT (5th–8th rib level) after 1 h blooming at 3 °C in a plastic tray covered with a gas permeable film. A calibrated reflectance spectrophotometer was used (MINOLTA CM-2002), with standard illuminant C and 2° standard observer (Alcalde & Negueruela, 2001), using the CIE L*a*b* system (CIE, 1976). The sample values were taken as the average of three measurements.

Haem pigments were measured at 24 h post-mortem according to Hornsey (1956) and expressed as μg haematin/g fresh muscle. After thawing samples in tap water, intramuscular fat and moisture percentages were determined following the ISO, 1443–1973 and ISO, 1442–1973 methods, respectively.

2.3. Collagen content and sarcomere length

Total and insoluble collagen contents were also measured on thawed samples and expressed as μg hydroxyproline/g fresh muscle, as in Bonnet and Kopp (1984). The solubilised samples were used to measure insoluble collagen content and the rest for total collagen content. The value per sample was the average of four measurements. Solubility percentages were calculated from these results.

Sarcomere length was measured on small cubes of thawed samples (approximately 5 × 5 mm) after fixing in glutaraldehyde solution (2.5% v/v) for 1 h (Torrescano, Sánchez-Escalante, Giménez, Roncalés, & Beltrán, 2003). Four or five bundles of 2–3 fibres were removed from six randomly selected regions. Then, 10 consecutive sarcomeres were measured on a phase contrast NIKON microscope (10 × 100 magnifications, model L-ke). The value per sample was the average of the six selected regions.

2.4. Instrumental measurement of texture

Samples were thawed in tap water until an internal temperature of 17–20 °C for about 1.5 h. Then, rectangular parallelepipeds, around 1 × 1 cm-thick and 2–3 cm-long, were cut parallel to the muscle fibres. Raw meat texture was measured in the longitudinal configuration using an INSTRON 4301 fitted with a modified compression device that avoids transverse elongation (Lepetit & Culioli, 1994). Stress was measured at 20% (C20) and 80% maximum compression (C80), expressed as N/cm².

2.5. Statistical analysis

All statistical analyses were performed using SPSS 8.0 for Windows. Data were analysed using the GLM procedure to determine the significance of effects (breed, slaughter live weight and, for instrumental texture, ageing) and their interactions. Duncan’s test was used to measure differences among means. Differences were considered significant at the P ≤ 0.05 level.

3. Results and discussion

3.1. pH, meat colour and chemical composition (haem pigments, fat and moisture)

The effects of breed and slaughter live weight on pH, meat colour and chemical composition are summarised in Table 2.

The pH at 24 h ranged from 5.50 to 5.58, indicating that animals were not stressed at the time of slaughter. In general, there were no differences in pH measurements among breeds or live weights, although there were
Table 2
Means (± standard deviation) of the meat pH, colour and chemical composition (fresh basis) of 180 lambs from three Spanish breeds, slaughtered at three live weights

<table>
<thead>
<tr>
<th></th>
<th>Rasa Aragonesa (local meat breed)</th>
<th>Churra (local dairy breed)</th>
<th>Spanish Merino</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10–12 kg</td>
<td>20–22 kg</td>
<td>30–32 kg</td>
<td>B</td>
</tr>
<tr>
<td>pH 24 h</td>
<td>5.57±bx</td>
<td>5.52±ax</td>
<td>5.55±ax</td>
<td>5.50±bx</td>
</tr>
<tr>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.14)</td>
<td>(0.05)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>Meat colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>43.08±y</td>
<td>39.94±x</td>
<td>39.03±xs</td>
<td>47.28±by</td>
</tr>
<tr>
<td>(1.71)</td>
<td>(2.82)</td>
<td>(2.16)</td>
<td>(2.70)</td>
<td>(3.09)</td>
</tr>
<tr>
<td>a*</td>
<td>10.51±ax</td>
<td>15.43±sy</td>
<td>16.19±by</td>
<td>10.52±ax</td>
</tr>
<tr>
<td>(1.71)</td>
<td>(1.60)</td>
<td>(1.23)</td>
<td>(2.22)</td>
<td>(1.76)</td>
</tr>
<tr>
<td>b*</td>
<td>6.66±bx</td>
<td>10.65±by</td>
<td>6.98±ax</td>
<td>5.33±ax</td>
</tr>
<tr>
<td>(0.90)</td>
<td>(2.67)</td>
<td>(1.78)</td>
<td>(1.23)</td>
<td>(2.59)</td>
</tr>
<tr>
<td>Haem pigments (µg haematin/g fresh muscle)</td>
<td>69.64±ax</td>
<td>92.03±y</td>
<td>112.46±az</td>
<td>78.67±bx</td>
</tr>
<tr>
<td>(10.09)</td>
<td>(16.70)</td>
<td>(30.33)</td>
<td>(19.78)</td>
<td>(25.07)</td>
</tr>
<tr>
<td>Intramuscular fat (%)</td>
<td>1.28±ax</td>
<td>1.88±y</td>
<td>2.79±az</td>
<td>1.56±bx</td>
</tr>
<tr>
<td>(0.29)</td>
<td>(0.47)</td>
<td>(0.84)</td>
<td>(0.40)</td>
<td>(0.71)</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>76.74±y</td>
<td>76.31±y</td>
<td>75.23±ax</td>
<td>76.63±y</td>
</tr>
<tr>
<td>(0.68)</td>
<td>(0.55)</td>
<td>(1.00)</td>
<td>(0.80)</td>
<td>(0.93)</td>
</tr>
</tbody>
</table>

Significance of breed (B), slaughter live weight (SLW) and their interaction (B × SLW). n.s. = Not significant differences.

a,b Different superscripts represent significant differences among breeds (within slaughter live weight) (P ≤ 0.05).
s,y,z Different superscripts represent significant differences among slaughter live weights (within breed) (P ≤ 0.05).

* P ≤ 0.05.
** P ≤ 0.01.
*** P ≤ 0.001.
individual differences according to Duncan’s test. These results agree with Vergara, Molina, and Gallego (1999), who did not find differences in meat pH measured at 0 and 45 min and 24 h post-mortem in lambs slaughtered at a live weight of 21.68 ± 0.16 kg or 27.77 ± 0.16 kg. In our study, there was a significant interaction between both effects (breed and slaughter weight) without a clear trend.

Meat colour was influenced by both effects ($P \leq 0.01$), but the effect of live weight was greater than that of breed ($F$ values 64.60, 136.94 and 38.13 for live weight and 23.37, 7.64 and 5.84 for breed for $L^*$, $a^*$ and $b^*$ parameters, respectively). $L^*$ values were higher in the Churra breed at all slaughter weights. Within breed, sucking lambs had lighter meat. As slaughter weight increased, meat lightness decreased, as shown by Sañudo et al. (1996), who compared three carcass weights from the Rasa Aragonesa breed. The redness index ($a^*$) for sucking lambs was a bit higher in Merino lambs, possibly because they were initially reared outdoors where they could consume some grass during the suckling period. Meat was redder at 20 kg than 10 kg live weight, as observed in Rasa Aragonesa and Lacha breeds (Beriai et al., 2000). However, the increase from 20 to 30 kg did not affect redness, which suggested that the change in diet (milk to concentrate) probably had a greater effect on meat colour than carcass weight or age. In addition, these results of meat from sucking lambs (lighter and less red) could be due to the low iron content of ewe milk, leading to lower myoglobin synthesis in muscle (Lawrie, 1985). Meat from sucking and light lambs was more yellow ($b^*$) in the Rasa Aragonesa breed. There were no differences among breeds in the early fattening lambs (30–32 kg). Haem pigments contents were more affected by slaughter weight ($F$ value = 64.16) than breed ($F$ value = 6.24) and were higher in heavier animals (see also, Boccard & Dumont, 1976), as happened with $a^*$. Spanish Merinos had the highest pigment content. This could be because this breed is adapted to exercise, as a result of the traditional production system (long transhumance).

In general, the percentage of intramuscular fat was below 3%, less than previous studies on grass-fed lambs cited in the literature (Ponnampalam et al., 2001; Solomon, Lynch, & Lough, 1992), even though our lambs were fed high energy diets. But other authors have observed similar fat percentages to those observed in our work for lambs fattened with concentrate and slaughtered at similar weights (Crouse et al., 1978; Ockerman, Emsen, Parker, & Pierson, 1982). As expected, slaughter weight had a strong effect on intramuscular fat ($F$ value = 58.96). Fat content increased with age-slaughter weight, following a linear tendency in the three breeds. In general, breed did not have a significant effect on intramuscular fat, but, according to Duncan’s test, sucking lambs of the Churra breed were slightly fatter. We could have expected greater differences among breeds since the Churra breed is more precocious, has a lower adult live weight and is a dairy breed (Sañudo, Sánchez, & Alfonso, 1998).

Moisture varied little (75.23–76.74%), as in a Turkish study on four fat-tailed lamb genotypes (Esenbuga, Yarar, & Dayioglu, 2001) where breed did not have a significant effect on moisture ($P > 0.05$). Meat moisture decreased at the highest slaughter weights (30–32 kg).

### 3.2. Collagen content and sarcomere length

The total and insoluble hydroxyproline contents, collagen solubility percentages and sarcomere lengths are summarised in Table 3 for each breed and slaughter weight. Collagen concentrations were mainly influenced by breed ($P \leq 0.01$). Slaughter live weight had a slight effect on collagen solubility percentage ($P = 0.07$). Significant interactions were found between both effects. However, Santos-Silva, Mendes, and Bessa (2002) did not find significant differences in collagen contents among breeds, or slaughter weights, from Merino Branco or Ile de France × Merino Branco crossbreeds slaughtered at 24 or 30 kg. Those results may have been due to the genetic similarities between the pure breed and its crossbreed and similar slaughter weights. Collagen content varied among breeds in other ruminant species, such as cattle (Campo et al., 2000).

Total hydroxyproline content was 314.19 ± 86.18 μg/g, 415.09 ± 112.33 μg/g, 443.74 ± 104.78 μg/g fresh muscle for the Rasa Aragonesa, the Churra and the Spanish Merino lambs, respectively (average of the three slaughter weights). Thus, there were significant differences between the Rasa Aragonesa breed and the rest. Breed also affected insoluble hydroxyproline content. The overall mean for the three slaughter weights was significantly higher in the Churra breed (229.56 ± 45.65 μg/g fresh muscle), than the Rasa Aragonesa (183.32 ± 36.53 μg/g) or Spanish Merino breed (194.10 ± 50.55 μg/g). As reflected by the total and insoluble hydroxyproline contents, in general, the Spanish Merino lambs had the most soluble collagen. The solubility percentages only decreased clearly with increasing slaughter live weight-age in the Churra breed, as also reported by Bailey and Light (1989) and Young and Braggins (1993). On the contrary, the solubility percentages of the Spanish Merino lambs increased with weight. These differences in collagen solubility could be related to the different productive aptitudes of each breed. Specialised meat breeds could deposit less stable collagen crosslinks and thus have more soluble collagen to facilitate greater muscle growth.

Sarcomere length of the LT ranged from 1.54 to 1.73 μm, which is similar to values reported by Sañudo et al. (2003) in a large scale European project based on lambs from different production systems. There was a tendency
Table 3

Measures (± standard deviation) of total and insoluble hydroxyproline contents, collagen solubility and sarcomere length of 45 lambs from three Spanish breeds, slaughtered at three live weights

<table>
<thead>
<tr>
<th>Breed</th>
<th>slaughter live weight (kg)</th>
<th>B</th>
<th>SLW</th>
<th>B × SLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rasa Aragonesa</td>
<td>10–12</td>
<td></td>
<td>n.s.*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–22</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30–32</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>Churra</td>
<td>10–12</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–22</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30–32</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>Spanish Merino</td>
<td>10–12</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–22</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30–32</td>
<td></td>
<td>n.s.</td>
<td></td>
</tr>
</tbody>
</table>

**Total hydroxyproline content (g/g fresh muscle)**

- Rasa Aragonesa: 368.45 ± 260.35
- Churra: 421.44 ± 313.78
- Spanish Merino: 568.34 ± 678.20

**Insoluble hydroxyproline content (g/g fresh muscle)**

- Rasa Aragonesa: 156.96 ± 31.97
- Churra: 191.56 ± 190.08
- Spanish Merino: 247.33 ± 181.92

**% Collagen solubility**

- Rasa Aragonesa: 54.93 ± 21.55
- Churra: 21.55 ± 34.02
- Spanish Merino: 34.02 ± 55.23

**Sarcomere length (m)**

- Rasa Aragonesa: 1.56 ± 0.26
- Churra: 1.57 ± 1.60
- Spanish Merino: 1.64 ± 1.71

**Significance**

- n.s. = Not significant differences.
- * P < 0.05
- ** P < 0.01
- *** P < 0.001

For LT sarcomere length to increase with increasing slaughter live weight (P ≤ 0.05). This may be due to differences in the cooperative action of adjacent structures that support the carcass during animal development (Honikel, Kim, Hamm, & Roncales, 1986). The increase in LT was similar among breeds at 10–12 to 30–32 kg (0.16 μm Rasa Aragonesa, 0.14 μm Churra and 0.15 μm Spanish Merino).

Even though the effect of slaughter weight was also significant (P ≤ 0.05, F value = 4.27), it was second to the muscle effect (P ≤ 0.001, F value = 163.03) when sarcomere length was measured on four different muscles (Mm. semitendinosus-ST, semimembranosus-SM, gluteo biceps-GB and longissimus thoracis-LT) from the same lambs (unpublished results). The longest sarcomere was in ST (2.53 ± 0.31 μm), followed by GB (1.87 ± 0.26 μm), SM (1.71 ± 0.13 μm) and LT (1.64 ± 0.14 μm). These results could be related to the extent of muscle stretch from hanging (McCrae, Seccombe, Marsh, & Carse, 1971), since hanging the carcass by the Achilles tendon keeps the ST muscle from shortening but not others, as observed by Bouton, Harris, Shorthose, and Baxter (1973). For this reason, differences among muscles have been partially associated with the effect of the carcass hanging method (Suzuki, Yamadera, Kido, & Watanabe, 1997). Bouton and Harris (1972) showed that sarcomere length in the sheep biceps femoris – BF – (a portion of GB), SM and longissimus dorsi – LD – muscles could be increased by hanging the whole carcass from the pelvis instead of the Achilles tendon. Similarly, Quarrier, Carpenter, and Smith (1972) observed that the conventional hanging method produced more tension on the psoas major muscle than the tenderstretch method they used (aitch bone). However, LD, ST, SM and BF were favoured (longer sarcomeres) by the latter method, although the effect was much greater on SM and BF. The effect of muscle on sarcomere length has also been observed in beef (Torrescano et al., 2003) and pork (Wheeler, Shackelford, & Koohmaraie, 2000).

3.3. Instrumental measurement of texture

Breed, slaughter live weight, and ageing had significant effects on instrumental texture (Table 4) but the interactions were not significant.

The effect of breed was higher for C80 than C20, but the effect of slaughter weight was higher for C20 than C80. Ageing mainly influenced C20 values. In the same way, in cattle, Campo et al. (2000) found that breed affects C80 while ageing affects C20.

The means and standard deviations of C20 and C80 are shown in Table 5. The high standard deviations could be a result of individual variability, but also of the small LT size (9th–13th rib level) in lambs, especially in suckling animals, which did not allow more than 3–4 replicates. Dransfield and McFie (1980) recommend at
least 7–10 replicates to avoid local variations in connective and myofibrillar tissue. However, the variation coefficients of most texture measurements in the literature are also high. There were no significant differences among breeds within live weight and ageing but Merino and Churra breeds had the highest C20 values for suckling lambs aged for 1, 2 or 4 days. Suckling lambs had higher C20 values than light or early fattening lambs, especially at short ageing times. The enzymatic activity in the youngest animals may be reduced (Sanudo et al., 2003). C20 is associated with myofibrillar toughness (Lepetit & Culioli, 1994), and should vary with ageing time. Overall, C20 values decreased significantly from 1 to 8 days of ageing, representing 90.88% of the overall tenderisation at 16 days of ageing. In the Rasa Aragonesa breed (breed average), C20 only changed significantly from day 1 to 4 (from 11.17 to 7.20 N/cm²), but decreased to 5.80 N/cm² at 16 days of ageing. In addition, differences among breeds or slaughter weights were higher at 1 day of ageing (6.82 N/cm² considering all the results obtained) than at long ageing periods (1.84 N/cm² at 16 days), demonstrating that ageing tends to decrease differences in myofibrillar toughness.

C80 is more related to collagen content and collagen properties (Lepetit & Culioli, 1994) and was higher in the Churra breed. This confirms the C80-collagen relationship since the Churra breed had the greatest amount of insoluble hydroxyproline and one of the highest total hydroxyproline contents. In contrast, Merino lambs had the lowest C80 values, even though they had as much total collagen as the Churra breed animals, due to their small insoluble collagen content and high solubility percentage.

C80 values increased with slaughter live weight-age. However, it was not associated with collagen, unless it could be promoted by differences in collagen networks, because slaughter weight did not affect (P > 0.05) the hydroxyproline contents or collagen solubility. Along these lines, Rowe (1974) found that the undulation of collagen fibres increased with animal age, although these results were observed in rat tendons. On the other hand, even though C80 is not supposed to be affected by

### Table 4

Significance and F values for the instrumental texture, by the compression method, in raw longissimus thoracis lamb meat according to the effects of breed, slaughter live weight and ageing.

<table>
<thead>
<tr>
<th>Breed effect</th>
<th>Slaughter live weight effect</th>
<th>Ageing effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>C20 (N/cm²)</td>
<td>3.30***</td>
<td>30.84***</td>
</tr>
<tr>
<td>C80 (N/cm²)</td>
<td>21.54***</td>
<td>3.25</td>
</tr>
</tbody>
</table>

* Interactions among effects were not significant.

### Table 5

Means (± standard deviation) of the instrumental texture, by the compression method (C20 and C80), in raw longissimus thoracis lambs of three different Spanish breeds [Rasa Aragonesa (local meat breed)-RA-, Churra (local dairy breed)–CH– and Spanish Merino-ME-] slaughtered at three live weights and aged for different times.

<table>
<thead>
<tr>
<th>Ageing (days)</th>
<th>1 2 4 8 16</th>
<th>1 2 4 8 16 1 2 4 8 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>C20 (N/cm²)</td>
<td>RA 3.30***</td>
<td>19.22*** 30.84***</td>
</tr>
<tr>
<td>C80 (N/cm²)</td>
<td>RA 21.54***</td>
<td>10.42*** 3.25</td>
</tr>
</tbody>
</table>
ageing, in this study, C80 values decreased slightly from 1 to 2 days of ageing, but then increased, reaching the highest values at 8 or 16 days of ageing. This behaviour is hard to explain, but perhaps the three-dimensional collagen structure was also affected by degradation of the myofibrils (Grajales, 1999).

4. Conclusions

Breed had a significant effect on the physico-chemical characteristics of lamb meat and should be considered in programs to improve meat quality. Slaughter live weight also affected lamb quality, with a lesser effect on collagen than breed. As a result, quality labels should include a range of slaughter weights in their regulations in an attempt to offer consumers a product with homogeneous characteristics, including colour, chemical composition and texture. This could help to increase consumer loyalty, especially if the product is similar from one purchase to the next.

Ageing affected lamb meat texture, especially in the first 4 days. After that, the meat continued to age (myofibrillar) until 16 days but at low tenderisation rates. The long ageing times tended to decrease differences in meat texture, independently of breed and slaughter live weight.

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