Pig sire type and sex effects on carcass traits, meat quality and physicochemical and sensory characteristics of Serrano dry-cured ham

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Abstract: This study demonstrates that improvements in animal line selection by breeding enterprises exert a strong effect on carcass traits, meat quality and sensory characteristics of Serrano dry-cured ham. A total of 461 pigs from the offspring of a Duroc (DU) × Landrace (LD) sow mated with two DU terminal sires were significantly different (P < 0.05) in carcass conformation, backfat thickness, ham and loin yields, raw ham traits, myoglobin concentration and total pigments formed during the curing process; in addition, the two lines provided different percentages of hams (54 vs 91%) with sufficient subcutaneous fat and weight to manufacture dry-cured Serrano hams using a slow ripening process (11 months). The DU × LW sire had the best carcass and ham traits from an economic standpoint and obtained highest scores for sensory characteristics of Serrano ham evaluated by a trained panel test; furthermore, this line provided 84% of total hams suitable for manufacturing Serrano hams by a slow process. When the sex effect was analysed, carcass and ham traits of females were more favourable, but females presented a higher incidence of pale, soft and exudative (PSE) meat and a lower percentage of hams with sufficient subcutaneous fat and weight to produce Serrano hams using a slow ripening process (61% for females and 91% for castrates). On the other hand, castrates provided Serrano hams cured by a slow procedure with better organoleptic characteristics than females. Right and left hams were similar.

Keywords: pig; sire type; sex; carcass traits; meat quality; sensory characteristics; Serrano ham

INTRODUCTION

Serrano ham has been designated a Traditional Speciality Guaranteed (TSG) and the name set aside (Off J Eur Commun 13/11/1999). This provides protection for traditional production of this Spanish product while assuring quality and attributes, which can be expected to boost consumer confidence and thereby lead to higher sales.

White pigs for cured ham production in Spain come principally from female Landrace (LD) × Large White (LW) or LD × Duroc (DU) crosses, which are highly prolific and show good production parameters and carcass yield, whereas the most commonly used finisher boars are cross LW × Pietrain and, for high-quality production, LW × DU. The Belgian Landrace breed is also used for heavily muscled boars. It is well accepted that highly muscled pig genotypes (ie Pietrain and Belgian Landrace) are less appropriate for the production of high-quality dry-cured hams owing to higher processing losses and lower product quality.1,2

The manufacture of Serrano hams requires a certain amount of intramuscular fat to help regulate water loss and thus ensure sensory quality. Several studies have shown that crossbreeds containing DU have higher percentages of intramuscular fat3–8 and higher concentrations of muscle pigments.7

The LW breed produces animals that offer meat quality similar to that of the DU breed but with less intramuscular fat, less dry matter and a higher protein content.3,4,9,10

Guerrero et al11 compared the DU breed with a heavily muscled strain formed from the purebreeds Pietrain and Belgian Landrace and with another cross consisting of DU × LW. They found that, after curing for 9 months, hams from DU animals had lower processing weight losses, more marbling and stronger cured aroma and flavour. Čandek-Potokar et al12 also found that DU crosses exhibited higher intramuscular fat content and marbling and lower weight losses during the processing of Carso dry-cured ham from Slovenia.


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Improvements in animal selection by breeding enterprises exert as great an effect on production parameters, carcass traits and meat quality as breed. Nowadays, purebreds do not have homogeneous characteristics owing to selection by enterprises or geographic areas based on different criteria to produce end-products and to satisfy consumer demands.

The objective of the present paper was to determine the effect of terminal sire and sex on meat quality parameters, carcass and ham traits and Serrano ham quality in order to select the most appropriate terminal sire taking into account the needs of farmers, producers and consumers. Comparison was made of the offspring of DU × LD sows mated with three commercial terminal sire lines, namely two lines of DU and a terminal sire of DU × LW. In addition, the effects of the anatomical location of the ham with respect to the carcass side were studied for physicochemical and sensory parameters.

MATERIALS AND METHODS

Animals

Two Duroc boars from breeding enterprises in England (DU_E) and Spain (DU_S) and one Duroc × Large White boar from an enterprise in The Netherlands (DU × LW_NL) were selected commercially and mated with Duroc × Landrace (DU × LD) sows. The offspring were born from seven DU_E boars, 10 (DU × LW_NL) boars, seven DU_S boars and 134 DU × LD dams. A total of 461 animals were used for the study.

The pigs were housed at two farms located in Soria, Spain, 244 pigs at farm A and 217 pigs at farm B. When the piglets weighed around 20 kg, they started the fattening stage. All animals underwent the same feeding regimen during the fattening stage and were slaughtered at the slaughterhouse located at Olvega (Soria). The distance to the slaughterhouse was 12 km from farm A and 80 km from farm B. Ante mortem and post mortem handling of the animals from both farms was the same. Animals from farm A were slaughtered in July and farm B slaughtered in September and October. Sex (suckling and 2 respectively), while those from farm B were slaughtered in September and October (slaughters 3 and 4 respectively). Animals were slaughtered at a mean age of 6 months 18 days and their live body weights were recorded. The average slaughter weights for DU_E, (DU × LW_NL) and DU_S-sired pigs were 111.6 ± 3.5, 113.0 ± 4.2 and 110.6 ± 3.9 kg respectively. There was a 1 day resting and fasting period, after which pigs were weighed and slaughtered using stunning electrocancerosis (350 V for 4–5 s) in accordance with Spanish regulations. The numbers of pigs within line, sex, slaughter date and farm are given in Table 1.

Carcass traits and meat quality measurements

Following slaughter, carcasses were hung from the right leg until butchering. The killing-out proportion was expressed as the percentage ratio of the carcass weight (kg) after 16 h of carcass refrigeration at 4 °C to the live body weight (kg) after the 1 day resting and fasting period. For the conformation measurement the animal muscle bulk was graded by assigning a value ranging from 1 for the poorest to 3 for the best conformation. For the backfat thickness at the level of the sacral vertebrae, values ranging from 1 for the leanest to 4 for the fattest carcasses were assigned. The carcass length (cm) was measured from the anterior edge of the pubic symphysis to the recess of the first rib.

The pH was measured using a portable Crison pH meter (Crison Instruments SA, Barcelona, Spain) at 45 min and 24 h post mortem in the Semimembranosus muscle in both hams of each carcass and also at 24 h post mortem in the right and left parts of the Longissimus dorsi muscle. Electrical conductivity (EC) was measured using a Pork Quality Meter conductometer (PQM-I-INTEK GmbH, Garbsen, Germany) in the Semimembranosus muscle in both hams of each carcass at 24 h post mortem.

The carcass was butchered and the hams were dissected before the skin was cut away except for a V-shaped flap left covering the hock. Shoulder and ham yields were calculated as the percentage ratio of the sum of the weight of the shoulders and hams from each animal to the carcass weight; loin yield was calculated as the percentage ratio of the left loin weight to the carcass weight. Raw hams were selected in order to manufacture Serrano hams using a slow ripening process, considering a minimum weight and subcutaneous fat. Cured ham produced using a slow ripening process normally presents better organoleptic characteristics than ham cured by a fast procedure. The percentages of hams selected from each terminal sire were 54% from DU_E, 82% from (DU × LW_NL) and 91% from DU_S, while those from each sex were 61% from females and 91% from castrates. The raw hams were weighed whole and the bone, subcutaneous fat, skin, outside muscles (the Semimembranosus being the largest in this muscle group) and inside muscles (the Biceps femoris being the largest in this muscle group) were all weighed as well.

Curing process

Hams were processed after 5 days of storage at 4 °C, after which time softening of the meat had attained 80% at refrigeration temperature.13 The following curing procedure was used. An amount of 100 g of

Table 1. Number of pigs within line, sex, slaughter date and farm

<table>
<thead>
<tr>
<th>Line</th>
<th>DU_E</th>
<th>DU × LW_NL</th>
<th>DU_S</th>
<th>Sex</th>
<th>F</th>
<th>C</th>
<th>F</th>
<th>C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm A</td>
<td>Slaughter 1</td>
<td>22</td>
<td>25</td>
<td>19</td>
<td>22</td>
<td>22</td>
<td>32</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slaughter 2</td>
<td>21</td>
<td>16</td>
<td>21</td>
<td>16</td>
<td>15</td>
<td>13</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>Farm B</td>
<td>Slaughter 3</td>
<td>12</td>
<td>9</td>
<td>30</td>
<td>39</td>
<td>20</td>
<td>22</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slaughter 4</td>
<td>16</td>
<td>17</td>
<td>15</td>
<td>16</td>
<td>11</td>
<td>10</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>71</td>
<td>67</td>
<td>85</td>
<td>93</td>
<td>68</td>
<td>77</td>
<td>461</td>
<td></td>
</tr>
</tbody>
</table>

DU_E, English Duroc sired; DU × LW_NL, Dutch (Duroc × Large White) sired; DU_S, Spanish Duroc sired; F, female; C, castrate.
a mixture of salt and nitrifying agents (NaNO₂ and KNO₃) was rubbed into the surface of each ham. The hams were then held at 1–3°C for a period of 0.9 day kg⁻¹ ham. After salting, the hams were washed to remove the excess salt from the outside and then held at 3–4°C and a relative humidity of 70–80% for 45 days (resting period). This was followed by the drying/aging stage, where the temperature was increased stepwise (3, 8 and 18°C) and the relative humidity was decreased gradually from 80 to 70% over 5 months. On completion of this stage the hams underwent a drying stage at a temperature of 30–33°C and a relative humidity of 75–80%. Finally, the hams were aged at a temperature of 13–17°C and a relative humidity of 75% in an aging shed for a further 2 months.

To be eligible for use in the study, hams had to fulfil the requirements for raw material, processing and finished product set in the specification for entitlement to use the name Serrano ham issued by the Spanish Food Certification Authority Ltd.

Sample preparation

The raw hams from each of the lines considered were deboned and the Semimembranosus and Biceps femoris muscles were removed. All remnants of subcutaneous fat were trimmed from the muscles, which were stored frozen at −20°C pending analysis.

The cured hams were deboned and cut transversely at the level of the hip bone. A slice approximately 2 cm thick from the centre of the ham was collected and stored vacuum-packed at around 4°C pending analysis. The skin and subcutaneous fat were then removed and the Semimembranosus and Biceps femoris muscles were cut away from the rest of the slice.

Samples were comminuted and homogenised using a Moulinex (Barcelona, Spain) household blender.

Analytical determinations

Raw hams

Moisture, intramuscular fat and protein nitrogen contents were determined by near-infrared transmittance spectrometry using a Foss Meatspec 28 800 NIRSystem apparatus (Foss NIRSystems, MD, USA) previously calibrated and validated.14

Myoglobin content was analysed according to the method of Han et al.15

Cured hams

Moisture content was determined using the reference method from ISO standard 1442.16 Intramuscular fat was extracted using 60° petroleum ether in a Soxtec System HT 1043 extraction unit from Tecator (Höganäs, Sweden) according to ISO standard 1443.17 Total nitrogen (TN) was determined by the Kjeldahl method,18 and protein nitrogen (PN) was calculated as TN × 6.25.

Chloride concentration was determined according to the method of Möhr.19 Sodium nitrite concentration was measured colorimetrically,20 and potassium nitrate concentration by high-performance liquid chromatography (HPLC).21

Haem pigments were analysed according to the procedure put forward by Hornsey,22 with nitroso pigments and total pigments being expressed as ppm haematin.23 The pigment conversion rate was calculated as the percentage ratio of nitroso pigment to total pigment.

Non-protein nitrogen (NPN) was determined using the procedure published by Keresse.24 The proteolysis index was calculated as the percentage ratio of NPN to TN.

Instrumental texture analysis

Shear strength of the cured ham muscles was tested using a 4301 Instron texturometer (Instron Corp, Canton, MA, USA) equipped with a Warner–Bratzler shear attachment. A 1 kN load cell was used with a crosshead speed of 50 mm min⁻¹ and a displacement of 34 mm.25 Samples took the form of cubes measuring 1 cm on a side cut from four different regions within each muscle. Cubes were placed in the testing device so that the direction of shear was perpendicular to the muscle fibres. The Instron Series IX computer program was used.

Sensory evaluation of Serrano hams

Before undertaking the sensory evaluations, a test panel composed of 16 panellists underwent training in the sensory evaluation of Serrano hams.26 Slices 2 mm thick measuring 2.5 cm × 7 cm were cut from the centre of the ham, from the Biceps femoris muscle of 10 slowly cured Serrano hams from each line (five from females and five from castrates). Tasting sessions were performed in a tasting room set up according to Spanish standard UNE 87-004-79,27 following the basic sample presentation rules published by Guerrero.28 Four hams were evaluated per session. Unstructured interval scales were employed to rate the attributes dry-cured ham odour, hardness, juiciness, masticability, salty taste and dry-cured ham flavour. Linear scales 10 cm long with two anchor points were used. The visual attributes were rated using structured interval scales. The scale for colour intensity had four points along the line, while the scale for marbling had five points, all matched with corresponding reference pictures.

Statistical analysis

Statistical analyses were made using the SPSS program.29 Data on carcass traits, meat quality and physicochemical composition were analysed using the general linear model of the SPSS statistical program. Fixed effects of terminal sire, sex and slaughter group were used in the analyses of carcass traits, main cuts of carcass, pH and EC. Live body weight was included as a covariate in the analyses of carcass traits, being adjusted to 114 kg by the model; carcass weight was included as a covariate in the analyses of main cuts of carcass, being adjusted to 85 kg. Differences between the lines in the number of animals with pale, soft and exudative (PSE) and dark, firm and dry (DFD)
meat were tested using a $\chi^2$ test with two degrees of freedom.

Fixed effects of terminal sire, sex, slaughter group and anatomical location of ham with respect to carcass side (right or left) were used in the analyses of main cuts of raw ham, compositional parameters of raw and dry-cured ham and weight losses and sensory attributes of dry-cured ham. Carcass weight was included as a covariate in the analyses of main cuts and compositional parameters of raw ham, being adjusted to 83 kg by the model; raw ham weight was included as a covariate in the analyses of weight losses, being adjusted to 10.8 kg; finally, dry-cured ham weight was included as a covariate in the analyses of compositional parameters and sensory attributes of Serrano dry-cured ham, being adjusted to 7.7 kg.

Principal component analysis (PCA) was performed on the attribute rating data from the sensory evaluations. Simple Pearson correlation analysis was performed to examine the relationships among the different sensory attributes and between the sensory attributes and the chemical and instrumental variables.

RESULTS AND DISCUSSION
Carcass traits and meat quality measurements
The killing-out proportion, conformation, backfat thickness and carcass length at constant live body weight (114 kg) for different genetic types and sexes are shown in Table 2. Live body weight was proportional to killing-out proportion ($P < 0.05$), conformation ($P < 0.01$), backfat thickness ($P < 0.01$) and carcass length ($P < 0.01$). These data are consistent with Armero et al. Significant ($P < 0.05$) terminal sire × slaughter group interaction was detected. Killing-out proportion was higher for (DU × LW)$_{NL}$ than for DU$_{E}$. Other studies$^{4,31}$ have found no differences in killing-out when comparing similar sires, except for a higher value for DU as compared with LW.$^{6}$ Concarcass length was higher for DU$_{E}$ than for (DU × LW)$_{NL}$. Bittante et al.$^{32}$ reported that from various trials it appeared that carcasses from DU-sired pigs are shorter than those of pigs sired by white breeds. Other authors$^{31,33}$ did not find any difference in carcass length between DU and LW sires. Backfat thickness showed highest scores for (DU × LW)$_{NL}$ and DU$_{S}$. McGloughlin et al.$^{34}$ observed that DU sires had lower backfat thickness than LW sires. The two DU lines showed significant differences ($P < 0.05$) for conformation and backfat thickness but similar values for killing-out and carcass length. Sex had no significant effect on killing-out, conformation and carcass length; however, backfat thickness was higher for castrates, in agreement with Rauw et al.$^{35}$ who found higher backfat thickness for males than for females.

Estimated means and standard errors of ham, shoulder and loin yields at constant carcass weight (85 kg) for different lines and sexes are given in Table 3. Carcass weight was proportional to shoulder and loin yields ($P < 0.01$) and also to ham yield ($P < 0.01$). No significant ($P < 0.05$) interaction was found between terminal sire, sex and slaughter group. Ham and loin yields were lowest for DU$_{S}$ and hence dressing results were least favourable for that sire. Females showed a significantly ($P < 0.05$) higher ham yield than castrates, Armero et al.$^{36}$ also found a higher percentage of ham in females than in males.

Table 2. Estimated means and standard errors of killing-out, conformation, backfat thickness and length of carcass, studied by terminal sire and sex at constant live body weight (114 kg)

<table>
<thead>
<tr>
<th>Sire</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DU$_E$</td>
</tr>
<tr>
<td>Killing-out (%)</td>
<td>78.00 ± 0.43a</td>
</tr>
<tr>
<td>Conformation</td>
<td>1.64 ± 0.06a</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>80.24 ± 0.57a</td>
</tr>
<tr>
<td>Backfat thickness</td>
<td>2.63 ± 0.09a</td>
</tr>
</tbody>
</table>

DU$_E$, English Duroc sired; (DU × LW)$_{NL}$, Dutch (Duroc × Large White) sired; DU$_{S}$, Spanish Duroc sired.
Means within a row and an effect with different letters are significantly different ($P < 0.05$).

Table 3. Estimated means and standard errors of ham, shoulder and loin yields, studied by terminal sire and sex at constant carcass weight (85 kg)

<table>
<thead>
<tr>
<th>Sire</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DU$_E$</td>
</tr>
<tr>
<td>Ham yield (%)</td>
<td>26.68 ± 0.27a</td>
</tr>
<tr>
<td>Shoulder yield (%)</td>
<td>15.72 ± 0.20</td>
</tr>
<tr>
<td>Loin yield (%)</td>
<td>3.07 ± 0.06a</td>
</tr>
</tbody>
</table>

DU$_E$, English Duroc sired; (DU × LW)$_{NL}$, Dutch (Duroc × Large White) sired; DU$_{S}$, Spanish Duroc sired.
Means within a row and an effect with different letters are significantly different ($P < 0.05$).
in the Semimembranosus muscle from right and left hams, and estimated means and standard errors of pH measured at 24 h post mortem in the Longissimus dorsi muscle, right and left parts, studied by terminal sire and sex. No significant (P < 0.05) interaction was found between terminal sire, sex and slaughter group. pH and EC values were similar in both right and left sides; this indicated that hanging the carcass from the right leg in the slaughterhouse had no effect on these quality parameters. (DU × LW)NL had the highest values for pH45, pH24 and EC24 measured in the Semimembranosus muscle of right hams, and also for pH24 and EC24 measured in the Semimembranosus muscle of left hams, which is consistent with Rauw et al.13 who found a higher EC24 in Semimembranosus muscle of the offspring of an LW sire and an LW/Pietrain sire compared with two DU terminal sires. No significant differences (P < 0.05) between females and castrates were observed in meat quality measurements except for EC24, with females having the highest values measured in both right and left hams. This indicated that females could have a higher incidence of PSE meat.

Table 4 shows the percentage of animals per line with PSE and DFD meat of the Semimembranosus muscle from the right ham depending on the threshold chosen for pH45, EC24 and pH24. According to Oliver et al.,34 PSE meat presented a pH < 6 at 45 min post mortem and an EC > 10 at 24 h post mortem. Meat is considered as DFD meat when pH > 6.2 at 24 h post mortem.35–37 There were no significant differences (P < 0.05) between the percentage of animals with PSE or DFD meat obtained for the different lines. Females showed a higher incidence of PSE meat than castrates. Armero et al.30 did not find any differences between males and females in meat quality classification.

Table 6 gives the estimated means and standard errors of the weight (kg) of different parts obtained

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### Table 4. Estimated means and standard errors of pH measured at 45 min post mortem and pH and electrical conductivity at 24 h post mortem in Semimembranosus muscle (SM) from right and left hams, and pH measured at 24 h post mortem in Longissimus dorsi muscle (LD), right and left parts, studied by terminal sire and sex.

<table>
<thead>
<tr>
<th>Sire</th>
<th>DU_E</th>
<th>(DU × LW)NL</th>
<th>DU_S</th>
<th>Sex</th>
<th>Female</th>
<th>Castrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH45SM</td>
<td>6.13 ± 0.03</td>
<td>6.26 ± 0.03</td>
<td>6.14 ± 0.04</td>
<td>6.11 ± 0.03</td>
<td>6.21 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>pH24SM</td>
<td>5.69 ± 0.02</td>
<td>5.92 ± 0.02</td>
<td>5.86 ± 0.02</td>
<td>5.77 ± 0.02</td>
<td>5.81 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>EC24SM</td>
<td>6.63 ± 0.31</td>
<td>9.87 ± 0.26</td>
<td>6.14 ± 0.35</td>
<td>7.68 ± 0.25</td>
<td>6.97 ± 0.27</td>
<td></td>
</tr>
<tr>
<td>pH45LD</td>
<td>6.31 ± 0.04</td>
<td>6.39 ± 0.03</td>
<td>6.39 ± 0.04</td>
<td>6.31 ± 0.03</td>
<td>6.39 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Left side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH45SM</td>
<td>6.22 ± 0.04</td>
<td>6.33 ± 0.03</td>
<td>6.30 ± 0.04</td>
<td>6.22 ± 0.03</td>
<td>6.31 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>pH24SM</td>
<td>5.71 ± 0.02</td>
<td>5.90 ± 0.02</td>
<td>5.86 ± 0.02</td>
<td>5.77 ± 0.02</td>
<td>5.80 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>EC24SM</td>
<td>6.02 ± 0.31</td>
<td>9.83 ± 0.26</td>
<td>5.12 ± 0.34</td>
<td>7.29 ± 0.26</td>
<td>6.21 ± 0.28</td>
<td></td>
</tr>
<tr>
<td>pH45LD</td>
<td>6.38 ± 0.03</td>
<td>6.40 ± 0.03</td>
<td>6.40 ± 0.04</td>
<td>6.34 ± 0.03</td>
<td>6.43 ± 0.03</td>
<td></td>
</tr>
</tbody>
</table>

DU_E, English Duroc sired; (DU × LW)NL, Dutch (Duroc × Large White) sired; DU_S, Spanish Duroc sired.

Means within a row and an effect with different letters are significantly different (P < 0.05).

### Table 5. Percentage of animals with PSE and DFD meat of Semimembranosus muscle from right ham.

<table>
<thead>
<tr>
<th>Sire</th>
<th>DU_E</th>
<th>(DU × LW)NL</th>
<th>DU_S</th>
<th>Sex</th>
<th>Female</th>
<th>Castrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSE</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>12a</td>
<td>5b</td>
<td></td>
</tr>
<tr>
<td>DFD</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

DU_E, English Duroc sired; (DU × LW)NL, Dutch (Duroc × Large White) sired; DU_S, Spanish Duroc sired.

Means within a row and an effect with different letters are significantly different (P < 0.05).

### Table 6. Estimated means and standard errors of weight (kg) of different parts obtained from raw hams at dressing from different lines, studied by terminal sire, sex and anatomical location of ham at constant carcass weight (83 kg).

<table>
<thead>
<tr>
<th>Sire</th>
<th>DU_E</th>
<th>(DU × LW)NL</th>
<th>DU_S</th>
<th>Sex</th>
<th>Female</th>
<th>Castrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of hams</td>
<td>17</td>
<td>23</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Raw ham</td>
<td>10.80 ± 0.09</td>
<td>10.77 ± 0.08</td>
<td>10.34 ± 0.09</td>
<td>10.79 ± 0.07</td>
<td>10.46 ± 0.08b</td>
<td>10.55 ± 0.07</td>
</tr>
<tr>
<td>Bones</td>
<td>2.00 ± 0.05</td>
<td>1.78 ± 0.05</td>
<td>1.87 ± 0.05</td>
<td>1.87 ± 0.04</td>
<td>1.88 ± 0.04</td>
<td>1.85 ± 0.04</td>
</tr>
<tr>
<td>Trimmed fat</td>
<td>0.66 ± 0.06</td>
<td>0.86 ± 0.05</td>
<td>0.93 ± 0.06</td>
<td>0.69 ± 0.05a</td>
<td>0.98 ± 0.05b</td>
<td>0.83 ± 0.05</td>
</tr>
<tr>
<td>Trimmed skin</td>
<td>0.66 ± 0.05ab</td>
<td>0.71 ± 0.04a</td>
<td>0.52 ± 0.05b</td>
<td>0.65 ± 0.04</td>
<td>0.61 ± 0.04</td>
<td>0.63 ± 0.04</td>
</tr>
<tr>
<td>Outside muscles</td>
<td>1.85 ± 0.05</td>
<td>1.80 ± 0.04</td>
<td>1.73 ± 0.05</td>
<td>1.88 ± 0.04a</td>
<td>1.69 ± 0.04b</td>
<td>1.77 ± 0.04</td>
</tr>
<tr>
<td>Inside muscles</td>
<td>1.61 ± 0.03</td>
<td>1.60 ± 0.03</td>
<td>1.54 ± 0.04</td>
<td>1.65 ± 0.03a</td>
<td>1.51 ± 0.03b</td>
<td>1.57 ± 0.02</td>
</tr>
</tbody>
</table>

DU_E, English Duroc sired; (DU × LW)NL, Dutch (Duroc × Large White) sired; DU_S, Spanish Duroc sired.

Means within a row and an effect with different letters are significantly different (P < 0.05).
from the raw hams at dressing from different lines, studied by terminal sire and sex. Whole ham weight was proportional to carcass weight \((P < 0.01)\) and also to the weight of outside and inside muscles \((P < 0.05)\). Terminal sire \(\times\) sex interaction and slaughter group \(\times\) sex interaction were significant \((P < 0.05)\). DU_S provided hams with the lowest weight of whole ham and trimmed skin but the highest weight of trimmed fat, the last two being shared with DU_E and \((DU \times LW)_{NL}\) respectively. Hams from \((DU \times LW)_{NL}\) differed significantly \((P < 0.05)\) from those from DU_E in having less bone and more trimmed fat. Carrión et al.\(^{38}\) selected DU lines to increase the lean content, these lines provided hams with a fat thickness and bone weight similar to those from LW. When the sex effect was analysed, significant differences \((P < 0.05)\) were found in weight of ham, trimmed fat and outside and inside muscles. Females had the heaviest hams with less trimmed fat, in agreement with Ćandek-Potokar et al.\(^{12}\). No significant differences \((P < 0.05)\) were found between right and left hams.

In short, animals from the \((DU \times LW)_{NL}\) sire had the best carcass and ham traits from an economic standpoint, taking into account that \((DU \times LW)_{NL}\) provided a higher percentage of hams suitable for manufacturing dry-cured Serrano hams using a slow ripening process. Comparing the two DU sires, DU_S had the lowest conformation and the highest backfat thickness of carcass, the lowest ham and loin yields and the lightest ham with the highest subcutaneous fat, so it is considered that DU_S gave the worst results for the meat industry; however, DU_S provided the highest percentage of hams appropriate for producing slowly cured Serrano hams. Females from the three lines studied gave carcasses with less backfat thickness and higher ham yield as well as heavier hams with less subcutaneous fat, hence were more favourable for the dry-cured ham industry than castrates, but females had more incidence of PSE meat of ham and provided a lower percentage of hams to produce slowly cured Serrano hams.

### Analyses of hams

#### Raw hams

Table 7 shows the estimated means and standard errors of compositional parameters and myoglobin concentration for the Semimembranosus and Biceps femoris muscles in the raw hams of different lines, studied by terminal sire, sex and anatomical location of ham. Moisture and protein contents were proportional to carcass weight \((P < 0.05)\). Significant \((P < 0.05)\) slaughter group \(\times\) terminal sire interaction and slaughter group \(\times\) sex interaction were detected. Significant differences \((P < 0.05)\) were recorded for moisture, intramuscular fat and protein nitrogen contents in the Semimembranosus muscle. DU_S had the highest intramuscular fat content, while DU_E showed the lowest value. The mean intramuscular fat values found were in agreement with values published elsewhere.\(^{12,39}\) Total haem pigments expressed as myoglobin concentration were also significantly different among the three lines, DU_S having the highest values in both muscles.

Females presented less moisture and more protein nitrogen in Semimembranosus muscle than males, which tended to exhibit more intramuscular fat, though not significantly so. These results are in agreement with Ćandek-Potokar et al.\(^{12}\) who found that castrates from different genotypes had more intramuscular fat and less nitrogen in both muscles than females. Right hams had higher percentages of moisture and protein nitrogen in Semimembranosus muscle than left hams.

#### Processing weight losses

Table 8 shows the weight losses during different stages of ham processing. The initial weight of raw ham

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**Table 7.** Estimated means and standard errors of compositional parameters and myoglobin concentration for Semimembranosus (SM) and Biceps femoris (BF) muscles in raw hams of different lines, studied by terminal sire, sex and anatomical location of ham at constant carcass weight (83 kg)

<table>
<thead>
<tr>
<th>Sire</th>
<th>Sex</th>
<th>Ham</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DU_E</td>
<td>(DU (\times) LW)_{NL}</td>
</tr>
<tr>
<td>No of hams</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>67.41 ± 0.46a</td>
<td>74.32 ± 0.41b</td>
</tr>
<tr>
<td>Intramuscular fat (%)</td>
<td>74.24 ± 0.28</td>
<td>74.65 ± 0.25</td>
</tr>
<tr>
<td>Protein nitrogen (%)</td>
<td>5.24 ± 0.41a</td>
<td>2.82 ± 0.37ab</td>
</tr>
<tr>
<td>Myoglobin (mg g(^{-1}))</td>
<td>2.89 ± 0.50</td>
<td>3.34 ± 0.45</td>
</tr>
</tbody>
</table>

DU_E, English Duroc sired; (DU \(\times\) LW)_{NL}, Dutch (Duroc \(\times\) Large White) sired; DU_S, Spanish Duroc sired.

Means within a row and an effect with different letters are significantly different \((P < 0.05)\).
was proportional \((P < 0.05)\) to the total weight loss. Significant \((P < 0.05)\) terminal sire \(\times\) sex interaction was detected. At the end of the resting period, hams from \((D\bar{U} \times LW)_{NL}\) exhibited the highest weight loss and those from \(DUS\) the lowest. No significant differences \((P < 0.05)\) were found for weight losses at the end of drying and aging in a shed between lines, sexes and locations of hams. Candek-Potokar \(et\ al\)\(^{12}\) observed lower weight losses of hams for castrates than for females at every phase of processing.

**Cured hams**

Table 9 presents the estimated means and standard errors of compositional parameters, salt concentrations, nitroso pigment and total pigment contents, non-protein nitrogen concentration, proteolysis index and shear strength for the *Semimembranosus* and *Biceps femoris* muscles in the slowly cured hams of different lines, studied by terminal sire, sex and anatomical location of ham. Ham weight was proportional to moisture and protein nitrogen \((P < 0.05)\). Significant \((P < 0.05)\) terminal sire \(\times\) sex interaction was detected. Moisture content was similar to that reported by Guerrero \(et\ al\)\(^{11}\) in white pig hams also cured for 11 months, and was lower in *Semimembranosus* than in *Biceps femoris* muscle, which indicates that dehydration loss was more important in the former. Intramuscular fat content values were similar to those reported by Virgili \(et\ al\)\(^{39}\) for *Biceps femoris* muscle of Parma hams from three pure breeds, DU, LD and LW, cured for 13 months. Significant differences \((P < 0.05)\) were recorded for the protein nitrogen content in the *Biceps femoris* muscle from the three lines, with \(DUE\) having the highest value and \((D\bar{U} \times LW)_{NL}\), the lowest, the same as for the raw hams. The results obtained were comparable to those found by Flores \(et\ al\)\(^{40}\) in white pig hams and by Virgili \(et\ al\)\(^{39}\) in Parma hams. Sodium chloride concentration was similar in all three lines, and the values agreed with those observed in similar cured hams.\(^{40,41}\) Nitroso pigments generated by the reaction of myoglobin with nitric oxide formed by the reduction of nitrite and nitrate are the main factor responsible for the colour of cured hams. Therefore chemical analysis of colour formation involves determining nitroso pigment formation and the concentrations of the different nitroso pigments as a percentage of the total pigments present (including all the haematin pigments). The stability of the total pigments and nitroso myoglobin formation depend on microbiological, enzymatic and chemical processes, which are in turn influenced by factors such as pH, redox potential, curing salt concentration, temperature and moisture content.\(^{42}\) There were no significant differences \((P < 0.05)\) among the lines in respect of the residual sodium nitrite content, but there were significant differences in the potassium nitrate content in both muscles considered, with \(DUE\) having the lowest values. The values observed were similar to those reported in other work on white pig hams.\(^{43,44}\) The nitroso pigment contents in the three lines did not display any significant differences, unlike the total pigments, which were lowest in both muscles in \(DUE\) and highest in the *Biceps femoris* muscle in \(DUS\). Nitroso pigment contents recorded in this study were similar to the levels reported by Astiasarán \(et\ al\)\(^{41}\) in hams cured for 9 months. The pigment conversion rate was highest for \(DUE\) on account of the significantly lower \((P < 0.05)\) total pigment content in the *Semimembranosus* muscle as compared with the other two lines. No significant differences in shear strength were observed among the three lines, and the values recorded were similar to those reported by Peral and Pérez-Villarreal\(^{45}\) for hams cured for 10 months. The proteolysis index values were in agreement with those observed by Flores \(et\ al\)\(^{40}\) for white pig hams cured for 12 months and by Virgili \(et\ al\)\(^{25}\) for hams that had undergone 6.5 and 9 months of curing. In view of these findings, the compositional parameter values for the cured hams from all three lines proved to be similar, though the low value for total pigments in \(DUE\) and the high value for total pigments in \(DUS\) can be singled out.

No significant differences \((P < 0.05)\) were found for compositional parameters, salt concentrations, pigment content, non-protein nitrogen concentration, proteolysis index and shear strength of the *Semimembranosus* and *Biceps femoris* muscles between sexes or anatomical locations of hams. Candek-Potokar \(et\ al\)\(^{12}\) did not find any differences in chemical traits of dry-cured hams between females and castrates.

**Quantitative descriptive sensory analysis of cured hams**

Figure 1 depicts a spider plot of the quantitative descriptive analysis results for the slowly cured hams of...
Table 9. Estimated means and standard errors of compositional parameters, salt concentrations, nitroso pigment and total pigment contents, non-protein nitrogen concentration, proteolysis index and shear strength for Semimembranosus (SM) and Biceps femoris (BF) muscles in Serrano dry-cured hams from different lines, studied by terminal sire, sex and anatomical location of ham at constant ham weight (7.7 kg).

<table>
<thead>
<tr>
<th>Sire</th>
<th>(DU × LW)NL</th>
<th>DUb</th>
<th>Female</th>
<th>Castrate</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of hams</td>
<td>25</td>
<td>34</td>
<td>38</td>
<td>45</td>
<td>52</td>
<td>48</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>45.32 ± 0.2</td>
<td>43.86 ± 1.0</td>
<td>44.66 ± 0.8</td>
<td>45.96 ± 0.3</td>
<td>45.18 ± 0.6</td>
<td>45.24 ± 0.6</td>
</tr>
<tr>
<td>Intramuscular fat (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>59.66 ± 0.49</td>
<td>58.60 ± 0.58</td>
<td>59.60 ± 0.43</td>
<td>59.59 ± 0.44</td>
<td>59.37 ± 0.34</td>
<td>59.36 ± 0.37</td>
</tr>
<tr>
<td>Protein nitrogen (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.49 ± 0.95</td>
<td>12.16 ± 1.11</td>
<td>12.69 ± 0.83</td>
<td>12.38 ± 0.84</td>
<td>12.66 ± 0.65</td>
<td>13.34 ± 0.71</td>
</tr>
<tr>
<td>Chloride (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.97 ± 1.24</td>
<td>12.84 ± 1.45</td>
<td>10.94 ± 1.08</td>
<td>12.48 ± 1.10</td>
<td>11.75 ± 0.85</td>
<td>12.16 ± 0.93</td>
</tr>
<tr>
<td>Sodium nitrate (ppm)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>75.62 ± 1.11</td>
<td>75.48 ± 1.30</td>
<td>76.12 ± 0.97</td>
<td>76.90 ± 0.99</td>
<td>75.23 ± 0.76</td>
<td>74.97 ± 0.84</td>
</tr>
<tr>
<td>Potassium nitrate (ppm)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.14 ± 0.43</td>
<td>12.20 ± 0.50</td>
<td>11.78 ± 0.37</td>
<td>11.40 ± 0.38</td>
<td>11.65 ± 0.29</td>
<td>11.59 ± 0.32</td>
</tr>
<tr>
<td>Nitroso pigments (ppm haematin)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.46 ± 0.87</td>
<td>5.59 ± 1.02</td>
<td>6.38 ± 0.76</td>
<td>5.69 ± 0.77</td>
<td>6.11 ± 0.60</td>
<td>6.97 ± 0.66</td>
</tr>
<tr>
<td>Total pigments (ppm haematin)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.19 ± 0.73</td>
<td>5.86 ± 0.86</td>
<td>6.18 ± 0.64</td>
<td>5.02 ± 0.65</td>
<td>6.16 ± 0.50</td>
<td>6.20 ± 0.55</td>
</tr>
<tr>
<td>Pigment conversion rate (%)</td>
<td>111.21 ± 11.08a</td>
<td>133.74 ± 12.35a</td>
<td>130.56 ± 9.67ab</td>
<td>142.19 ± 9.82</td>
<td>121.18 ± 7.57</td>
<td>137.80 ± 8.33</td>
</tr>
<tr>
<td>Proteolysis index (NPN/TN × 100)</td>
<td>157.98 ± 14.40a</td>
<td>180.59 ± 18.2ab</td>
<td>174.43 ± 17.9ab</td>
<td>186.64 ± 17.67</td>
<td>168.83 ± 13.63</td>
<td>179.84 ± 14.99</td>
</tr>
<tr>
<td>Non-protein nitrogen (mg g&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>79.63 ± 4.97</td>
<td>78.17 ± 5.82</td>
<td>78.09 ± 4.34</td>
<td>78.66 ± 4.40</td>
<td>78.02 ± 3.93</td>
<td>78.24 ± 3.73</td>
</tr>
<tr>
<td>Shear force (kg)</td>
<td>130.19 ± 9.93a</td>
<td>139.98 ± 11.62a</td>
<td>145.11 ± 8.66b</td>
<td>140.15 ± 8.78</td>
<td>140.91 ± 6.97</td>
<td>134.38 ± 7.45</td>
</tr>
<tr>
<td>Means within a row and an effect with different letters are significantly different (&lt;i&gt;P&lt;/i&gt; &lt; 0.05).&lt;sup&gt;a&lt;/sup&gt;</td>
<td>122.11 ± 10.48a</td>
<td>129.26 ± 12.40ab</td>
<td>135.76 ± 10.33b</td>
<td>130.32 ± 10.75</td>
<td>128.60 ± 8.30</td>
<td>132.24 ± 9.12</td>
</tr>
</tbody>
</table>

<sup>a</sup> Result expressed as dry matter.
Salty taste was considered appropriate and appetising for all three lines, with a sensory score of around 5. Hams from (DU × LW)NL received the highest scores for overall impression along with marbling, juiciness and cured ham flavour. Hams from DU_S were rated the best for colour and also scored highest for hardness. Cured ham odour intensity scores for the hams from DU_S were similar to those for the hams from (DU × LW)NL. Hams from DU_E were rated the worst for ham odour and flavour intensity and were also the softest.

Figure 2 shows a spider plot of the quantitative descriptive analysis results for the cured hams of females and castrates. Hams from castrates showed more marbling, juiciness, salty taste and cured ham flavour than hams from females. In addition, hams from castrates received the highest scores for overall impression.

Nevertheless, no significant differences (P < 0.05) were observed in sensorial attributes between lines, sexes or anatomical locations of ham, except for salty taste which was higher for castrates than for females (data not shown).

PCA was run on the taste panel scoring of each sensory attribute. The first three principal components (PCs) explained 76% of the total variance. The attributes most closely associated with PC1 were marbling (0.943) and juiciness (0.884); with PC2, salty taste (0.883) and colour intensity (0.807); and with PC3, masticability (−0.778).

Figure 3 plots the samples on the co-ordinate grid defined by the first two PCs, which explained 60.5% of the total variance. The (DU × LW)NL samples can be observed to be located along the positive portion of PC1, meaning that these hams exhibited higher marbling and juiciness than the hams from DU_E and DU_S. Furthermore, the (DU × LW)NL samples exhibited less spread on the co-ordinate grid and hence, at least with respect to sensory attributes, this line can be said to provide more uniform hams than the other two lines considered.

**Correlations between sensory attributes**

Table 10 lists the Pearson correlation coefficients between the sensory attributes. Marbling was correlated with juiciness and dry-cured ham odour intensity, thus corroborating the earlier findings reported by Ruiz10 for Iberian hams. Guerrero et al11 also observed high correlation between marbling and cured ham odour intensity, which can be attributed to the effect
of lipolysis breakdown products on aroma. Overall impression was correlated with dry-cured ham odour intensity, dry-cured ham flavour intensity and juiciness. The correlation between odour intensity and overall impression ($r = 0.454$, $P < 0.01$) found by Ruiz~46 in Iberian hams was lower than that found in the present study, but he also recorded significant correlations of overall impression with juiciness and marbling. Eadie et al.~47 reported correlations of acceptability with dry-cured ham odour and flavour in different types of Serrano hams. The taste panellists therefore rated as best those hams with the strongest odour intensity, followed by those with a high dry-cured ham flavour intensity and juiciness. These results were in keeping with the findings reported by Ruiz~46 for Iberian hams.

Conclusions

The two DU terminal sires were significantly different ($P < 0.05$) in carcass conformation, backfat thickness, ham and loin yields, raw ham traits, myoglobin concentration, total pigments formed during the curing process, and the percentage of hams with sufficient subcutaneous fat and weight to manufacture dry-cured Serrano hams using a slow ripening process. This means that, when choosing animals for purchase from farms, it will be advisable to take into account the genetic traits selected and not just the animal breed. The DU × LW sire had the best carcass and ham traits for the meat industry and obtained highest scores for sensory characteristics of slowly cured hams; in addition, this terminal sire provided 84% of hams with sufficient subcutaneous fat and weight to produce Serrano hams by a slow ripening process. Females presented more favourable carcass and ham traits for the meat industry, but they also presented a greater incidence of PSE meat and a lower percentage of hams suitable for manufacturing slowly cured hams. On the other hand, castrates provided Serrano hams cured by a slow procedure with better organoleptic characteristics than females. Right and left hams were similar.

Acknowledgement

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References

6 Edwards SA, Wood JD, Moncrief CB and Porter SJ, Composition of the Duroc and Large White as terminal sire breeds.