SENSORY PROPERTIES AND PHYSICO-CHEMICAL CHANGES IN THE *BICEPS FEMORIS* MUSCLE DURING PROCESSING OF DRY-CURED HAM FROM CELTA PIGS. EFFECTS OF CROSS-BREEDING WITH DUROC AND LANDRACE PIGS

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ABSTRACT

We investigated how cross-breeding Celta pigs with Landrace and Duroc pigs affected the physico-chemical properties and sensory characteristics of the *biceps femoris* muscle during the manufacturing of dry-cured ham. The intramuscular fat (IMF) content was significantly (P<0.001) affected by cross-breed: the IMF content of hams from the Duroc x Celta crosses (13.92%) was higher than that of hams from pure-bred Celta pigs (8.03%), and the IMF content of hams from the Landrace x Celta crosses was intermediate (12.27%). Instrumental colour parameters were also slightly affected by cross-breed: hams from cross-bred pigs were yellower (CIE b*-value) and lighter (CIE L*-value) than hams from the pure-bred Celta pigs. At the end of the process, shear force did not differ significantly (P>0.05) between groups, although the values were lowest in hams from Duroc x Celta crosses. In sensory analysis, panellists described hams from cross-bred pigs as of softer texture (P<0.01) and juicier (P<0.01) than hams from the pure-bred Celta pigs.

Keywords: *biceps femoris* muscle, crossbreeding, dry-cured ham, physico-chemical characteristics, sensory properties

1. INTRODUCTION

The Celta breed was the typical breed of pig raised on farms in Galicia (NW Spain) until the middle of the 20th century, when it underwent a strong decrease in numbers until near disappearance (< 200 head) due to the introduction of improved breeds and crosses (GÓMEZ and LORENZO, 2013). However, in recent years native pig breeds have become highly appreciated for their rusticity and also for the quality of their meat products. Dry-cured meat products have an important added value for the pig industry, and production of Celta pigs is mainly focused on obtaining raw meat to manufacture products such as dry-cured ham (BERMÚDEZ *et al.*, 2012), dry-cured "lacón" (LORENZO *et al.*, 2014) and sausages (GÓMEZ and LORENZO, 2013).

Dry-cured meat products represent a large proportion of the meat products on the European market, especially in the Mediterranean countries, and dry-cured ham is recognised as a high quality product of increasing economic importance (JIMÉNEZ-COLMENERO *et al.*, 2010). However, the quality of the end product is closely linked to the characteristics of the raw material, especially those related to the degree of marbling and the fatty acid composition, which in turn depend on factors such as breed, slaughter age and finishing feed (BERMÚDEZ *et al.*, 2012; GARCÍA-GONZÁLEZ *et al.*, 2008). In this regard, FRANCI *et al.* (2007) concluded that breed had a marked effect on the physico-chemical and sensory properties of Tuscan dry-cured ham.

Current pig breeding schemes in Europe are based on a backcross or on a three-four cross. In Spain, the most common cross is one that uses different breeds such as Landrace, Large White, Pietrain and Belgian Landrace. During the last few years, the Duroc breed has been introduced by national breeders to supply dry-cured meat producers who prefer hams with higher levels of intramuscular fat (GOU *et al.*, 1995). One of the options most often used to improve the productive parameters of the Celta pig is to cross this breed with the Duroc or Landrace breed (FRANCO *et al.*, 2014). FRANCO *et al.* (2014) concluded that cross-breeding with Landrace and Duroc lines affected the carcass characteristics and meat quality. Therefore, the Landrace and Duroc genotypes may affect the physico-chemical and sensorial properties of Celta dry-cured ham. The aim of this study was to evaluate how cross-breeding Celta pigs with Landrace and Duroc pigs affects the physico-chemical and sensorial properties of the *bicep femoris* muscle throughout the manufacturing of dry-cured ham.

2. MATERIALS AND METHODS

2.1. Animals and management

A total of 52 pigs (26 entire females [EF] and 26 castrated males [CM]) were divided into three groups according to genotype: 16 pure-bred Celta pigs (C), 20 Landrace x Celta (C × L) cross-bred pigs, and 16 Duroc x Celta (C × D) cross-bred pigs. The pigs in each group were balanced for gender (half males/half females), they were born at around the same time and the live weight at birth of all pigs was similar. All of the Celta pigs were registered in the record of births in the farm stud book. Animals were reared all together in an outdoor system by *Porco Celta* (a pig farming co-operative operating in the province of Lugo, Galicia, NW Spain). The pigs were fed ad libitum a commercial diet (17% protein, 2.4% fat and 3250 kcal/kg metabolic energy) and were provided free access to water. As the pigs were reared in a natural environment, part of the diet was obtained from natural vegetation. Campsite style huts and trees in the area provided shade. The pigs were reared following the recommendations of the legislation for pig welfare and protection

(COUNCIL DIRECTIVE 2008/120/EC, 2009). The pigs were slaughtered when they reached live weights of 167.30±11.65, 168.90±14.81 and 165.43±7.54 kg (P>0.05) for the C, C×L and C×D groups respectively; these weights were achieved at an age of around 12 months for C group, and at around 10 months for the C×L and C×D groups. The animals were transported to the abattoir the day before slaughter. The pigs from different groups were not mixed at any time, and various measures were taken to minimize stress. Pigs were slaughtered in an accredited abattoir (*Matadero Municipal de Sarria*, Lugo, Spain) and were stunned using carbon dioxide, according to the specifications outlined in the Spanish legislation.

2.2. Samples

Ham pieces were obtained after refrigerating the carcasses for 24 h at 4 °C. A total of 90 ham pieces (30 randomly chosen from each group) were used in the study. Raw pieces were dry salted with an excess of coarse salt (approximately 0.5 kg/kg of ham). A pile was formed by alternating layers of ham pieces and salt. The pieces were thus totally covered with salt. Ham pieces were salted for 11 days in a salting room at 2-5 °C and 90-95% relative humidity. After the salting stage, the pieces were removed from the pile and then brushed, washed and transferred to a post-salting room where they were held for 120 days at 3-6 °C and around 85-90% relative humidity. After the post-salting stage, the pieces were ripened for 115 days in a room where the temperature was gradually increased to 30 ºC and the relative humidity was gradually decreased to 40% for adequate drying of the thighs. The hams were then left to mature for a further 11 months ("bodega" step) in a chamber at 12-24 ºC and 70-80% relative humidity.
Samples were taken from the fresh pieces, and at the following times: end of the salting stage, end of the post-salting period, end of the drying-ripening stage and after 165 and 330 days of the "bodega" step. At each stage, a total of five ham pieces from each group were randomly collected and analyzed. Hams were transported to the laboratory under refrigerated conditions (< 4 °C) for analysis. Once in the laboratory, the entire pieces were skinned, boned, and the *biceps femoris* (BF) muscles were obtained. The muscle samples were vacuum packed and stored at -30 ºC for no more than four weeks until analysis.

2.3. Determination of pH, water activity and colour parameters

The pH of the samples was measured using a digital pH-meter (Thermo Orion 710 A+, Cambridgeshire, UK) with a penetrating probe. Water activity was assessed using a water activity meter Fast-lab (GBX, Romans-sur-Isère Cédex, France), previously calibrated with sodium chloride and potassium sulphate solutions. Colour measurements were made with a CM-600d colorimeter (Minolta Chroma Meter Measuring Head, Osaka, Japan). Briefly, at each stage of the process the muscle from each ham piece was cut and, after a blooming period of 30 min, the colour of the slices was measured three times. The CIELAB colour space lightness (L*), redness (a*) and yellowness (b*) were determined. Before each series of measurements, the instrument was calibrated with a white ceramic tile.

2.4. Determination of the chemical composition

Moisture, fat, ash and protein (Kjeldahl N x 6.25) were quantified according to the respective ISO recommended standards - 1442:1997 (ISO, 1997), 1443:1973 (ISO, 1973), 936:1998 (ISO, 1998) and 937:1978 (ISO, 1978). Total chlorides were quantified according to the Charpentier-Volhard method (ISO standard 1841-1:1996) (ISO, 1996).

2.5. Warner-Bratzler (WB) test

A Texture Analyzer TA-XT2 (Stable Micro Systems Ltd., Godalming, Surrey, UK) was used to perform Warner-Bratzler (WB) test. The samples for WB shear test were obtained by cutting pieces of approximately 1 x 1 x 2.5 cm (height x width x length). The pieces were cut across the fibers with a WB shear blade with a triangular slot cutting edge (1 mm thickness) at a crosshead speed of 3.33 mm/s. Maximum shear force, shear firmness and total work required to cut the samples were determined.

2.6. Assessment of lipid oxidation

Lipid stability was evaluated using the method proposed by VYNCKE (1975) with the modifications described by LORENZO and CARBALLO (2016). Briefly, a meat sample (2 g) was dispersed in 5% trichloroacetic acid (10 mL) and processed in an Ultra-Turrax homogenizer (Ika T25 basic, Staufen, Germany) for 2 min. The homogenate was maintained at -10 °C for 10 min and centrifuged at 2360 x g for 10 min. The supernatant was filtered through a Whatman No. 1 filter paper. The filtrate (5 mL) was reacted with a 0.02 M TBA solution (5 mL) and incubated in a water bath at 96 °C for 40 min. The absorbance was measured at 532 nm. Thiobarbituric acid reactive substance (TBARs) values were derived from a standard curve for the quantification of malondialdehyde (MDA), constructed using known concentrations of 1,1-3,3 tetraetoxipropane. The TBARs values were expressed as mg MDA/kg sample.

2.7. Sensory analysis

At the end of the manufacturing process (after 330 days of the bodega step), samples from the *biceps femoris* muscle of the five pieces of each pig group were analysed by sensory evaluation. The sensory evaluation was conducted by eight panellists from the Meat Technology Centre of Galicia. Therefore, forty qualifications were obtained for each attribute in each pig group. The panellists received training (for four months) in the attributes and the scale to be used according to the method proposed by the ISO regulations (ISO, 2012). The panellists carried out the sensory evaluations in individual cubicles, according to the ISO regulations (ISO, 2007). The panellists were given water at the beginning of the session and between tasting samples to clean the palate and remove residual flavours. The samples were individually labelled with random three-digit numbers. Ten sensory traits of the muscle, grouped according to appearance (lightness, colour of lean meat, fat yellowness and marbling), odour (intensity, rancidity and cured), taste (saltiness), and texture of the lean meat (hardness and juiciness) were assessed according to the methodology proposed by the ISO regulations (ISO, 1991; ISO, 1994; ISO, 2006). The intensity of each attribute was expressed on a structured scale ranging from 0 (very low) to 9 (very high). The normality of data was checked using the Shapiro-Wilk's normality test.

2.8. Statistical analysis

Analysis of variance (ANOVA) was applied to all variables considered in the study by using IBM SPSS Statistics 19.0 software (IBM Corporation, Somers, NY, USA). The least squares means (LSM) were separated using Duncan's t-test. A significance level of $P<0.05$ was used in all LSM tests. Cross-breed and ripening time were included as fixed effects in the model, to study physico-chemical and sensorial properties of the BF muscle.

The model used was expressed as follows:

$$Yij = \mu + Ci + Rj + \varepsilon ij$$

where Yij represents the observed values of the dependent variables, μ is the overall mean, Ci is the effect of cross-breed, Rj is the effect of ripening time, and εij is the residual random error associated with the observation. Pearson´s linear correlation coefficients were determined for the different variables with the above-mentioned statistical software package.

3. RESULTS AND DISCUSSION

3.1. Influence of cross-breed on physico-chemical changes during the manufacturing of dry-cured ham

The effects of cross-breed on the pH, water activity and chemical composition (moisture, intramuscular fat, protein, ash and chlorides) of BF muscle throughout the manufacturing process of dry-cured ham from Celta pig are summarized in Table 1. The mean pH (at 24 h) of samples from Duroc x Celta cross-bred pigs was significantly higher (P<0.01) than the mean pH of the samples from the other pigs. This is consistent with findings reported by ALONSO *et al.* (2009), who noted a relatively high pH of meat from Duroc crosses, and could be related to a lower glycogen content or to a higher buffer capacity in the Duroc x Celta pig muscle. Significant differences (P<0.001) in pH values were observed during the manufacturing of dry-cured ham. An increase in the final pH relative to the pH of raw pieces (from 5.59, 5.82 and 5.69 to 6.00, 5.92 and 5.90 for respectively C, C×D and C×L) was observed. The final pH values were similar to those reported by other authors for different types of ham, such as Iberian (MARTÍN *et al.*, 1998) and Serrano ham (GOU *et al.*, 1995), but lower than those reported for Teruel P.D.O. dry-cured hams matured for 20 months (CILLA *et al.*, 2005). The increase in pH values throughout the manufacturing process may be related to the release of low-weight nitrogen molecules and ammonia ascribed to endogenous and exogenous proteolytic enzyme activities (VIRGILI *et al.*, 2007).
The average moisture content in raw pieces was similar across groups, although the lowest values corresponded to samples from the Celta x Landrace cross-bred pigs (73.69%, 73.48% and 73.16% for respectively C, C×D and C×L). The water content decreased during the post-salting stage (around 4-5%) owing to the osmotic effect produced by the salt covering the entire surface of the hams. At subsequent stages (drying-ripening and "bodega") the decrease is due to dehydration process. The water loss during the drying-ripening and "bodega" stages of hams from pure-bred Celta pigs was significantly (P<0.05) higher than in hams from the cross-bred pigs (around 5-6%, Table 1). In terms of water loss, the dehydration was more intense during the "bodega" stage due to the duration of this stage and the environmental conditions (higher T and lower RH) in the storage chamber. The moisture content was significantly (P<0.001) higher in hams from the cross-bred pigs than in those from pure-bred Celta pigs (52.36%, 58.30%, and 58.93% for respectively C, C×D and C×L). This outcome is not consistent with findings reported by CARRAPISO and GARCÍA (2005), who did not observe any significant effect (P>0.05) of cross-breed on the moisture content of Iberian ham. Moisture contents were positively correlated with instrumental colour attributes of CIE L*-values (r = 0.722, P<0.01), CIE a*-values (r = 0.633, P<0.01) and CIE b*-values (r = 0.555, P<0.01) and negatively correlated with pH values (r = -0.666, P<0.01). Similarly, water activity decreased gradually throughout the manufacturing process (Table 1).

The decrease in water activity can be attributed to salt diffusion and the intense dehydration that the pieces undergo during the drying-ripening stage. The a_w values were positively correlated with moisture content (r = 0.918, $P<0.01$) and negatively correlated with salt content (r = -0.882, $P<0.01$). In addition, a_w was also correlated with shear force (WB test) (r = -0.285, $P<0.05$).

The IMF content of fresh pieces from the Duroc x Celta cross-bred pigs (13.92%) was significantly higher ($P<0.001$) than in hams from pure-bred Celta pigs (8.03%), while the levels were intermediate in hams from the Landrace x Celta cross-bred pigs (12.27%). This finding is consistent with those reported by ALONSO *et al.* (2009) and LATORRE *et al.* (2003), who observed a higher IMF content in meat from Duroc cross-bred pigs, as Duroc pigs are generally fatter than the other breeds. However, other authors (CARRAPISO and GARCÍA, 2005; TEJEDA *et al.*, 2002) observed that the Duroc line did not modify the IMF content in crosses with the Iberian pig. Finally, FRANCI *et al.* (2007) found that the IMF content was higher in hams from Cinta Senese pigs than in hams from Large White pigs, and the IMF contents of hams from the crosses between these breeds were intermediate. Data on IMF contents are of particular interest because of the influence of this parameter on essential quality traits. IMF has a clear effect on quality of meat as it reduces the shear force during chewing, making separation of muscle fibres easier, thus improving the sensations of juiciness and tenderness (LAWRIE, 1998). The contribution of IMF to juiciness is particularly important in dry-cured ham because of the strong dehydration of the product during the ripening process (VENTANAS *et al.*, 2005). Juiciness has been indicated to be the main trait influencing the overall quality of Iberian dry-cured ham (RUIZ *et al.*, 2002) and IMF has been closely associated with this parameter (RUIZ CARRASCAL *et al.*, 2000). The significantly higher IMF contents in the BF muscle of hams from Duroc x Celta and Landrace x Celta cross-bred pigs than in those from pure-bred Celta pigs may affect the acceptability of the final product.

Total chloride content (expressed as g/100 g of dry matter) increased significantly ($P<0.001$) during the salting and post-salting stages as a result of diffusion of salt throughout the whole pieces. During the next steps, the concentration of total chlorides in BF muscle continued to increase until the end of the process (Table 1). In this type of muscle (internal muscle), the differences between groups may be due to intrinsic heterogeneity, because the connective tissue, skin, fat, bones, etc. act as barriers to NaCl diffusion. The BF muscle, which is covered by subcutaneous fat and also contains intermuscular fat, is one of the muscles with the lowest concentration of sodium chloride during the first stages of the process; the concentration depends on thickness of subcutaneous fat. The final mean contents (15.87%, 15.14% and 16.59% of dry matter for respectively C, C×D and C×L) were within the range of values (13-20% of dry matter) reported by other authors (BUSCAILHON *et al.*, 1994; GOU *et al.*, 1995) for dry-cured hams. However, these NaCl contents were higher than those reported by some authors for Iberian ham (MARISCAL *et al.*, 2004; MARTIN *et al.*, 1998), Serrano ham (MARISCAL *et al.*, 2004), and Italian ham (MØLLER *et al.*, 2003) (9.29-11.4% of dry matter).

The colour of dry-cured ham is one of the most important characteristics of appearance (RUIZ *et al.*, 2002) and it is assumed to influence the consumer's choice of sliced ham in the supermarket. The influence of ripening time and cross-breed on colorimetric parameters is shown in Table 2. The luminosity (CIE L*-value) values decreased throughout the whole process. Lightness is related to the thin aqueous layer on the muscle surface, and the CIE L*-value depends on the movement of moisture (dehydration) towards the surface.

Table 1. Effect of cross-breeding on the changes of pH, water activity and proximate composition of *bicep femoris* muscle during the manufacture of dry-cured Celta ham. Results expressed as means±standard deviation of values from five samples in each group and sampling point.

	Fresh piece	After salting	After post-salting	After drying-ripening	"Bodega" stage		SEM	Significance time
					First point	Second point		
pH								
C	5.59±0.06^{a,1}	5.63±0.06^{a,1}	5.76±0.03^{b}	5.90±0.05^{c}	5.86±0.05^{c,1}	6.00±0.05^{d,2}	0.03	***
C×D	5.82±0.09^{a,2}	5.77±0.05^{a,2}	5.85±0.06^{a,b}	5.98±0.10^{c,d}	6.04±0.04^{d,2}	5.92±0.028^{b,c,1}	0.02	***
C×L	5.69±0.09^{a,1}	5.59±0.11^{a,1}	5.80±0.09^{b}	5.98±0.07^{c}	5.98±0.05^{c,2}	5.90±0.02^{b,c,1}	0.03	***
Sig. genotype	**	**	n.s.	n.s.	***	***		
a_w								
C	0.98±0.00^{e,2}	0.96±0.00^{d,2}	0.96±0.01^{d}	0.94±0.01^{c}	0.90±0.01^{b,1}	0.87±0.02^{a,1}	0.01	***
C×D	0.96±0.00^{d,1}	0.99±0.01^{e,3}	0.94±0.01^{c}	0.95±0.01^{c}	0.92±0.01^{b,2}	0.90±0.01^{a,2}	0.01	***
C×L	0.99±0.00^{d,3}	0.95±0.01^{c,1}	0.96±0.01^{c}	0.95±0.01^{c}	0.92±0.01^{b,2}	0.90±0.01^{a,2}	0.01	***
Sig. genotype	***	***	n.s.	n.s.	***	*		
Moisture (%)								
C	73.69±0.81^{e}	72.46±0.46^{e,2}	68.05±0.59^{d}	65.36±0.93^{c}	56.56±1.60^{b,1}	52.36±3.09^{a,1}	1.47	***
C×D	73.48±0.58^{f}	71.29±0.80^{e,1}	67.82±0.46^{d}	65.67±1.36^{c}	61.01±1.17^{b,2}	58.30±1.01^{a,2}	1.00	***
C×L	73.16±0.58^{f}	70.63±0.61^{e,1}	67.29±1.34^{d}	65.34±0.99^{c}	61.97±1.13^{b,2}	58.93±1.19^{a,2}	0.92	***
Sig. genotype	n.s.	**	n.s.	n.s.	***	***		
IMF (% dry matter)								
C	8.03±0.24^{a,b,1}	7.74±0.09^{a,1}	8.28±0.53^{b,1}	8.02±0.34^{a,b,1}	8.03±0.28^{a,b,1}	7.83±0.42^{a,b,1}	0.07	n.s.
C×D	13.92±1.29^{b,c,d,3}	15.21±2.68^{d,2}	14.86±1.97^{c,d,3}	12.78±0.40^{a,b,c,3}	11.07±0.96^{a,2}	12.43±1.45^{a,b,2}	0.38	**
C×L	12.27±1.05^{b,2}	13.94±0.94^{c,2}	10.17±0.69^{a,2}	11.39±0.50^{b,2}	10.20±0.37^{a,2}	11.95±0.37^{b,2}	0.27	***
Sig. genotype	***	***	***	***	***	***		
Protein (% dry matter)								
C	85.04±1.15^{e,2}	83.40±1.16^{d,3}	75.86±1.36^{c}	73.32±0.92^{b,2}	71.00±1.13^{a,2}	71.49±1.34^{a,2}	1.09	***
C×D	80.93±2.35^{e,1}	76.70±1.31^{d,1}	71.33±2.15^{c,1,2}	68.44±1.96^{b,1}	69.02±1.01^{b,1}	65.11±0.69^{a,1}	1.03	***
C×L	81.12±0.81^{f,1}	78.78±1.33^{e,2}	74.99±0.79^{d,2}	71.73±0.72^{c,2}	70.32±1.00^{b,1,2}	66.59±1.37^{a,1}	0.94	***
Sig. genotype	**	***	***	***	*	***		
Ash (% dry matter)								
C	4.59±0.18^{a,1,2}	8.28±0.71^{b,2}	14.86±0.95^{c,3}	16.60±1.26^{d}	19.80±1.06^{e,2}	19.68±1.11^{e}	1.09	***
C×D	4.33±0.14^{a,1}	6.09±0.76^{b,1}	11.49±1.17^{c,1}	15.98±0.86^{d}	17.11±1.17^{d,1}	18.32±0.85^{e}	1.02	***
C×L	4.85±0.31^{a,2}	5.92±0.69^{b,1}	12.82±0.65^{c,2}	15.95±0.47^{d}	18.22±0.96^{e,1}	19.80±1.29^{f}	1.08	***
Sig. genotype	*	***	***	n.s.	**	n.s.		

Chlorides (% dry matter)								
C	0.51±0.19^{a}	3.62±1.10^{b}	11.74±1.87^{c,2}	13.02±1.79^{c}	16.15±1.14^{d,2}	15.87±1.81^{d}	1.16	***
C×D	0.34±0.41^{a}	3.24±0.74^{b}	8.18±1.06^{c,1}	13.09±1.14^{d}	12.20±2.04^{d,1}	15.14±0.80^{e}	1.02	***
C×L	0.69±0.20^{a}	2.85±0.51^{b}	9.57±0.60^{c,1}	14.35±0.56^{d}	14.45±1.18^{d,2}	16.59±1.52^{e}	1.13	***
Sig. genotype	n.s.	n.s.	**	n.s.	**	n.s.		

$^{a-f}$Means in the same row (corresponding to the same genotype and parameter) not followed by a common letter are significantly different (P<0.05; Duncan test) (differences among sampling points). $^{1-3}$Means in the same column and parameter not followed by a common number are significantly different (P<0.05; Duncan test) (differences among genotypes). Significance: n.s.: not significant; * (P<0.05); ** (P<0.01); *** (P<0.001). SEM is the standard error of the mean.

Table 2. Effect of cross-breeding on the changes of colour parameters of *bicep femoris* muscle during the manufacture of dry-cured Celta ham. Results expressed as means±standard deviation of values from five samples in each group and sampling point.

	Fresh piece	After salting	After post-salting	After drying-ripening	"Bodega" stage		SEM	Sig. time
					First point	Second point		
Lightness (L*)								
C	48.90±2.39^{d}	47.84±2.28^{d,1}	40.35±1.45^{b,1}	43.06±1.19^{c,1}	39.73±1.46^{a,b,1}	37.12±2.51^{a,1}	0.89	***
C×D	50.59±1.72^{c}	50.17±2.44^{c,2}	45.58±2.00^{a,b,2}	47.53±1.67^{b,2}	46.14±1.14^{b,2}	43.65±0.96^{a,2}	0.64	***
C×L	47.97±1.57^{d}	47.03±2.46^{d,1}	41.22±1.25^{a,1}	45.03±1.74^{c,d,1}	44.23±2.26^{b,c,2}	41.87±1.27^{a,b,2}	0.60	***
Sig. genotype	n.s.	*	***	**	***	***		
Redness (a*)								
C	18.14±0.27^{c,2}	18.16±1.98^{c,2}	13.48±1.17^{b}	13.05±0.86^{a,b,1,2}	13.82±1.63^{b,2}	11.52±0.98^{a}	0.52	***
C×D	13.43±1.68^{b,c,1}	13.97±0.27^{c,1}	13.32±1.13^{b,c}	12.01±0.80^{a,1}	12.30±0.87^{a,b,1,2}	11.02±0.68^{a}	0.31	***
C×L	16.69±1.89^{b,2}	16.44±2.17^{b,1,2}	13.53±0.97^{a}	13.59±1.45^{a,2}	11.60±1.14^{a,1}	11.18±1.31^{a}	0.49	***
Sig. genotype	***	*	n.s.	n.s.	*	n.s.		
Yellowness (b*)								
C	13.13±1.17^{b,2}	13.00±1.66^{b}	7.55±0.91^{a,1}	7.65±0.79^{a,1}	7.15±0.97^{a,1}	8.63±0.80^{a,1}	0.52	***
C×D	11.35±1.40^{b,1}	12.24±0.79^{c}	12.24±1.54^{b,c,3}	9.71±1.14^{a,2}	11.13±0.64^{a,b,2}	11.04±0.81^{a,b,2}	0.27	***
C×L	12.96±0.99^{c,1,2}	13.30±0.62^{d}	9.83±0.67^{a,b,2}	8.94±0.51^{a,2}	10.39±0.87^{b,2}	10.09±0.67^{b,2}	0.37	***
Sig. genotype	n.s.	n.s.	***	**	***	**		

$^{a-d}$Means in the same row (corresponding to the same genotype and parameter) not followed by a common letter are significantly different (P<0.05; Duncan test) (differences among sampling points). $^{1-3}$Means in the same column and parameter not followed by a common number are significantly different (P<0.05; Duncan test) (differences among genotypes). Significance: n.s.: not significant; * (P<0.05); ** (P<0.01); *** (P<0.001). SEM is the standard error of the mean.

The decrease in CIE L*-values may be related to decrease in moisture content (r = 0.722, $P<0.01$). To this regard, SANABRIA *et al.* (2004) observed that moisture loss increased the concentrations of pigments (e.g. myoglobin) and led to a reduction in CIE L*-values. On the other hand, CIE L*-values also decreased as salt concentration increased (r = -0.741, $P<0.01$). A similar trend in CIE L*-values was reported by MARUŠIĆ *et al.* (2011) and PÉREZ-PALACIOS *et al.* (2011) for dry-cured ham. However, CILLA *et al.* (2005) did not report any significant changes in the colour parameters, except for the BF muscle redness index in dry-cured Teruel P.D.O hams matured for different lengths of time (between 12 and 26 months). Relative to CIE a*-values, a decrease in redness was observed until the end of the process; this may be due to the decrease in moisture content (r = 0.633, $P<0.01$) and an increase in salt content (r = -0.644, $P<0.01$). The final values were within the range of those described by SANABRIA *et al.* (2004) in Iberian ham, and very similar to those reported by MARUŠIĆ *et al.* (2011) for Istrian ham and by CILLA *et al.* (2005) for Teruel ham. Finally, the yellowness values decreased as the processing time increased, and the decrease was more pronounced during the post-salting stage (Table 2). The decrease in CIE b*-values may also be due to a decrease in moisture content (r = 0.555, $P<0.01$) and an increase in salt content (r = -0.696, $P<0.01$). A similar pattern was reported by SANABRIA *et al.* (2004) for Iberian ham. The final values of this parameter were also similar to those reported by other authors for different varieties of ham (CILLA *et al.*, 2005; MARUŠIĆ *et al.*, 2011; PÉREZ-PALACIOS *et al.*, 2011). The instrumental colour parameters were also slightly affected by cross-breed (Table 2), as hams from the cross-bred pigs were yellower (CIE b* value) and lighter (CIE L* value) than those from pure-bred Celta pigs. Thus, the higher lightness (CIE L*) values in dry-cured hams from crosses between Celta pigs and both Duroc and Landrace pigs may be related to the higher IMF content. This is consistent with the findings of RAMÍREZ and CAVA (2008), who reported a positive correlation between CIE L*-value and IMF content in Iberian ham. In the present study, CIE L*-value was positively correlated with the IMF content (r = 0.535, $P<0.01$).

The changes in TBARs values during the manufacturing of dry-cured ham are shown in Fig. 1. The TBARs values increased significantly ($P<0.001$) during the salting and post-salting periods, reaching the highest values after the drying-ripening period in hams from C and C×L groups, and after the post-salting stage in hams from the Celta x Duroc cross-bred pigs. The increase in malondialdehyde contents during the post-salting and drying-ripening stages may be related to the pro-oxidant action of metallic ions present as impurities in the salt used in the curing process. The TBARs values were positively correlated with NaCl content (r = 0.542, $P<0.01$). From these maximum values, a significant decrease ($P<0.001$) was observed until the end of the process, reaching final average values of 1.33, 1.07 and 1.00 mg MDA/kg of muscle for C, C×D and C×L respectively. The decrease in TBARs values was associated with the advanced reactions of secondary lipid oxidation products with protein residues, especially for conditions of low water activity to yield oxidatively modified proteins (KIKUGAWA *et al.*, 1991). Increased TBARs values in dry-cured ham during the first stages of production followed by a decrease toward the final stages have previously been reported for Iberian ham (ANDRÉS *et al.*, 2004) and Parma ham (KOUTINA *et al.*, 2012). At the end of the process, there were no significant differences ($P>0.05$) between groups, although the fat of hams from pure-bred Celta pigs tended to be more oxidized. This finding seems contravene previous observations, since lipid oxidation is usually positively related to fat content (JO *et al.*, 1999). However, the highest fat unsaturation of Celta pig compared to most of the other pig breeds (FRANCO *et al.*, 2006) could be responsible for the highest oxidation of fat in hams from pure Celta breed.

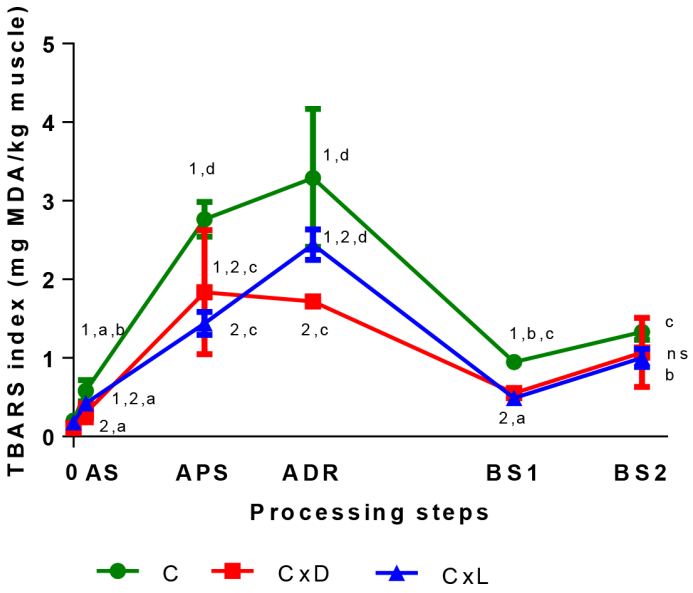

Figure 1. Effect of cross-breed on the changes in TBARs index of *bicep femoris* muscle during the manufacture of dry-cured Celta ham. Plotted values are means and standard deviations from five samples in each group and sampling point. AS = After salting, APS = After post-salting, ADR = After drying-ripening, BS1 = After bodega stage 1, BS2 = After bodega stage 2. [a-d] Means in the same genotype not followed by a common letter are significantly different ($P<0.05$) (differences among processing steps). [1-2] Means in the same processing step not followed by a common number are significantly different ($P<0.05$) (differences among genotypes).

The final mean value (1.13±0.17 mg MDA/ kg muscle) was two times higher than values obtained in Istrian ham (MARUŠIĆ *et al.*, 2011), Iberian ham (ANDRÉS *et al.*, 2004) and Teruel P.D.O. ham (CILLA *et al.*, 2006).

The changes in maximum shear force during the manufacturing of dry-cured hams are shown in Fig. 2. Shear force increased significantly ($P<0.001$) during the process. The final mean value of shear force (3.58 kg/cm^2) was lower than those obtained by SORIANO PÉREZ (2001) and FRANCI *et al.* (2007), who reported values of 6.84 kg/cm^2 and 20.9 kg/cm^2 respectively. A similar trend was observed by SERRA *et al.* (2005), who suggested a negative non-linear relationship between hardness and water content. In the present study, moisture content was negatively correlated with shear force (r = -0.541, $P<0.01$). In addition, texture has previously been linked to IMF content (RUIZ-RAMÍREZ *et al.*, 2005); this is consistent with our observations as IMF content was negatively correlated with shear force (r = -0.756, $P<0.01$). MONIN *et al.* (1997) also included other variable in the dry-cured ham process, such as level of proteolysis, because they observed that changes in hardness depended on both water content and protein state. These authors found that muscles initially became harder during the early processing stages, because of the decrease in protein solubility and water content, and they then became softer in texture as proteolysis occurred. At the end of process, shear force did not differ significantly ($P>0.05$) between groups, although the lowest values were found in hams from Landrace x Celta cross-bred pigs (see Fig. 2). This finding is consistent with those reported by FRANCI *et al.* (2007) who observed that shear force values were higher in pure-bred Cinta Senese pigs than in Cinta Senese x Large White cross-bred pigs.

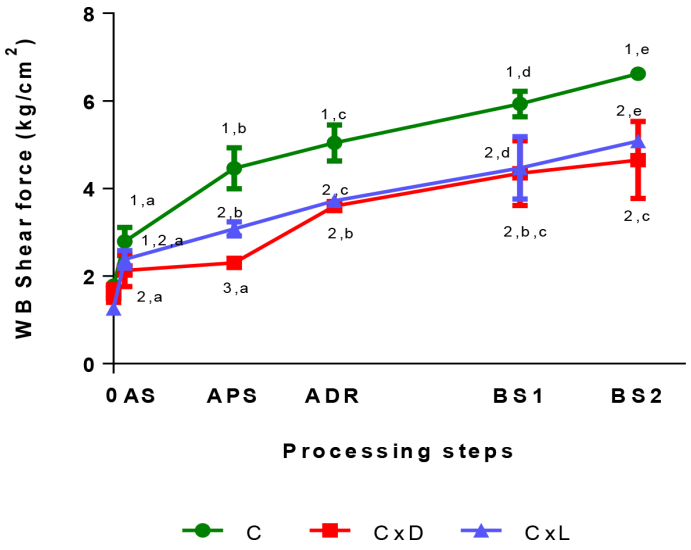

Figure 2. Effect of cross-breed on the changes in maximum shear force of *bicep femoris* muscle during the manufacture of dry-cured Celta ham. Plotted values are means and standard deviations from five samples in each group and sampling point. AS = After salting, APS = After post-salting, ADR = After drying-ripening, BS1 = After bodega stage 1, BS2 = After bodega stage 2. [a-e] Means in the same genotype not followed by a common letter are significantly different ($P<0.05$) (differences among processing steps). [1-3] Means in the same processing step not followed by a common number are significantly different ($P<0.05$) (differences among genotypes).

3.2. Influence of cross-breed on sensory characteristics

Ten descriptors were evaluated in the sensory analysis of the dry-cured ham (Fig. 3). Within appearance, lightness and lean redness scores were similar for the dry-cured hams from all three groups of pigs considered, although the lightness values were highest for samples from cross-bred pigs, while the redness of the lean meat was highest in samples from pure-bred Celta pigs. Instrumental and sensory results of lean meat colour indicate that discrimination between Celta and crosses with Landrace and Duroc pigs is difficult. This confirms the results obtained in other comparisons between local breeds and cross-breeds (Iberian compared with Iberian×Duroc) by CARRAPISO *et al.* (2003), who concluded that instrumental colour measurement of the lean portion of dry-cured ham is not particularly useful for assessing differences perceived by panellists. However, marbling scores differed significantly between groups and were highest in ham samples from cross-bred pigs (1.5, 5.6 and 5.4, $P<0.001$ for C, C×D and C×L respectively). These outcomes are consistent with data reported for instrumental colour determination and IMF and moisture contents. Thus, the CIE L* values were positively correlated with IMF content (r = 0.751, $P<0.01$), marbling (r = 0.516, $P<0.01$) and moisture content (r = 0.617, $P<0.01$). These findings are consistent with those reported by CARRAPISO and GARCÍA (2008) and RAMÍREZ and CAVA (2008), who also obtained a significant correlation between the CIE L* value and marbling and suggested that the colour of Iberian ham is more strongly influenced by fat distribution than by the chemical IMF content of the muscle.

The odour (intensity, rancidity and cured) traits were not significantly ($P>0.05$) affected by cross-breed, although odour intensity was highest in samples from pure-bred Celta pigs (7.8, 7.3, 7.2, $P>0.05$ for C, C×D and C×L respectively). Similarly, the IMF content was negatively correlated with odour intensity (r = -0.543; $P<0.01$) as reported by RAMÍREZ

and CAVA (2008), who observed a close relationship between IMF/marbling, aroma and odour intensity. On the other hand, salty taste was not significantly (P>0.05) affected by cross-breed, although slightly higher values were obtained in ham samples from the crosses (5.3, 5.7 and 5.5 for C, C×D and C×L respectively).

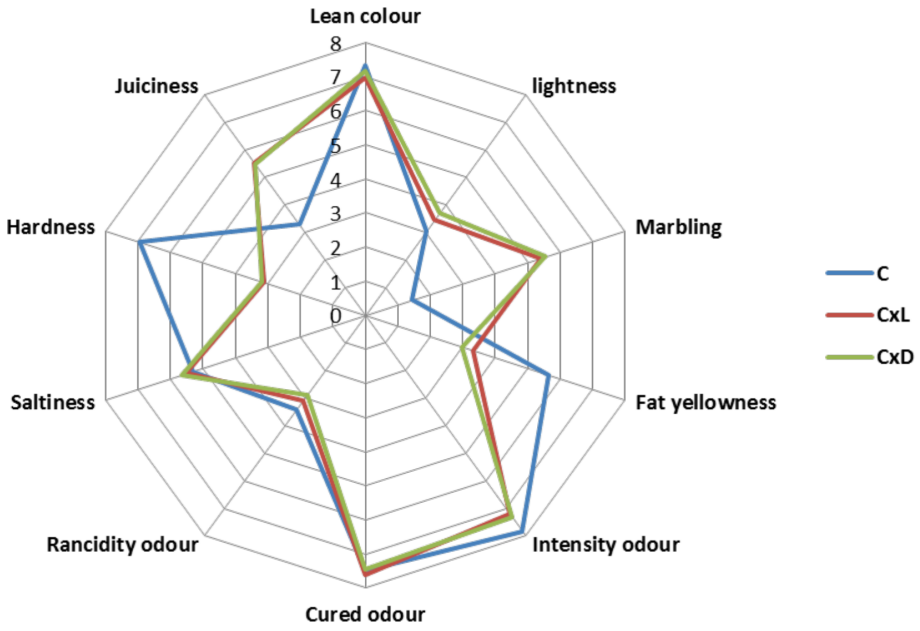

Figure 3. Effect of cross-breed on the sensory characteristics of dry-cured Celta ham at the end of the manufacturing process. Plotted value for each attribute and pig group is the mean of forty evaluations.

Finally, panellists observed significant between-group differences in texture traits that were consistent with those detected by instrumental methods (see Fig. 2). Hardness scores were correlated with WB shear force (r = 0.574, P<0.01). Panellists described hams from the cross-bred pigs as softer in texture (P<0.01) and juicier (P<0.01) than hams from pure-bred Celta pigs (Figure 3). These results are consistent with those reported by RAMÍREZ and CAVA (2008), who also observed a positive correlation between hardness scores and TPA hardness and WBSF.

Differences in sensory textural attributes can be caused by several factors: (i) the final pH of fresh meat, (ii) the IMF content and (iii) the moisture content (RAMÍREZ and CAVA, 2008). Increasing the IMF content reduces the force required to chew the meat, by easing separation of muscle fibres, and causes an enhanced perception of meat tenderness (ESSÉN-GUSTAVSON *et al.*, 1994). Thus, better sensory texture parameters have been reported in Iberian hams with higher IMF content, with significant positive correlations between marbling and juiciness (RAMÍREZ and CAVA, 2008). In the present study, juiciness scores were correlated with IMF content (r = 0.529, P<0.01), marbling (r = 0.585; P<0.01) and moisture content (r = 0.527, P<0.01).

4. CONCLUSIONS

The physico-chemical and sensory properties of dry-cured ham from Celta pig can be improved by crossing this breed with others. Hams from Celta x Duroc and Celta x Landrace cross-bred pigs had more intramuscular fat than hams from pure-bred Celta

pigs. The results of the WB test also suggest an effect of cross-breed, as hams from Celta x Duroc and Celta x Landrace cross-bred pigs were of softer texture than hams from pure-bred Celta pigs. Sensorial analysis demonstrated that hams from Celta pure breed were harder and less juicy than those from crosses. Although the two crosses improve the quality of hams, overall considering the texture and sensory traits it seems that the crossing with the Duroc genotype has the better improvement results.

ACKNOWLEDGEMENTS

Authors are grateful to Xunta de Galicia (The Regional Government) (Project FEADER 2010/15) for providing financial support for this research. Special thanks to "ASOPORCEL" (Asociación de Criadores de Ganado Porcino Celta) for the ham samples supplied for this research.

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Paper Received February 22, 2016 Accepted September 20, 2016