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EFFECT OF GENOTYPE AND SLAUGHTER AGE ON CARCASS TRAITS AND MEAT QUALITY OF THE CELTA PIG BREED IN EXTENSIVE SYSTEM*

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Abstract

The objective of this study was to investigate the effects of genotype and slaughter age on carcass traits and meat quality of the Celta pig breed. Samples from 95 pigs of three lines (Barcina, Santiaguesa and Carballina) slaughtered at two different ages (12 and 16 months) were analysed. Pigs' slaughter at 16 months showed significantly (P<0.001) higher live weight (157.2 *vs.* 178.9 kg), cold carcass weight (122.9 *vs.* 141.9 kg) and killing out percentage (77.7 *vs.* 79.5%; P<0.001) compared to those slaughtered at 12 months. Genotype also affected the live weight and cold carcass weight, both of which were highest in the Santiaguesa line. Changes in meat quality in relation to slaughter age and genotype were observed. The fat content increased with slaughter age, but did not vary with genotype. Regarding colour parameters, the L* values (48.53) were lower and a* values (11.55) were higher in samples of the Barcina line, indicating that the meat was darker and redder than in the other two lines. Both slaughter age and genotype had significant effects on texture parameters measured by the Warner Bratzler test, whereas textural profile analysis revealed significant differences mainly due to genotype.

Key words: slaughter age, genotype, carcass traits, meat quality, Celta pig breed

The Celta breed was the most important breed of pig in Galicia (NW Spain) until the beginning of the 20th century, after which its importance decreased as a result of the introduction of improved breeds and crosses. Nowadays, the Celta pig breed (4,128 pigs; MAGRAMA, 2015) is included in the Official Catalogue of Livestock Breeds of Spain as being in danger of extinction (R.D. 2129/2008). The traditional rearing system of the Celta pig is typical of outdoor pig production and the ani-

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mals feed on woodland pastures, chestnuts and acorns (Temperán et al., 2014). The Celta pig breed includes three lines of similar morphotype but with differences in skin pigmentation: Barcina, Carballina and Santiaguesa. Although available information about this breed is generally very basic and scant, recent studies have reported growth curves (Franco et al., 2014; Vázquez et al., 2012), carcass and meat quality of different lines (Franco et al., 2014) and fatty acid profiles of intramuscular fat and backfat (Domínguez and Lorenzo, 2014; Franco et al., 2014; Lorenzo et al., 2012).

Consumption of fresh meat from Celta pigs has increased in the last few years; however, dry-cured meat products provide added value to the pig industry. The breed is highly appreciated by consumers for the succulent meat produced by the profuse infiltration of fat into the lean meat (Franco et al., 2014), and farming of these pigs mainly focuses on the manufacture of dry-ripened meat products such as ham (Bermúdez et al., 2012, 2014 a, b; Lorenzo et al., 2013), "lacón" (Lorenzo et al., 2014; Lorenzo and Fonseca, 2014; Lorenzo and Purriños, 2013), dry-cured loin (Pateiro et al., 2015) and sausages (Gómez and Lorenzo 2013). The heavier slaughter weights required for the manufacture of these products necessitate longer rearing periods and added economic input, and therefore producers and the industry demand better quality traits in meat destined for processed and cured products.

The aims of this study were to describe how slaughter age (12 and 16 months) and line (Barcina, Carballina and Santiaguesa) affect the most important carcass and meat quality (chemical composition and texture) traits of the Celta pig breed and to explore the use of these physicochemical and nutritional parameters as discriminating factors for the identification of genotype and slaughter age.

Material and methods

Experimental design and animal management

For this study, 95 pigs were obtained from different breeders who are members of the association of Celta pig breeders (ASOPORCEL). All specimens were registered in the record of births in the ASOPORCEL stud book. The experimental farms participating in the study are located in Cee O Pino (A Coruña, Spain) and Taboada (Lugo, Spain). Barrows (castrated male pigs) and gilts (entire female pigs) of the Celta pig breed were used in the study.

The experimental design included 3 genotypes [Barcina (n=34), Carballina (n=34) and Santiaguesa (n=27)] and two slaughter ages [12 months (n=44) and 16 months (n=51)]. Animals were distributed as follows: [3 Barcina barrows slaughtered at 12 months, 5 Barcina barrows slaughtered at 16 months, 4 Barcina gilts slaughtered at 12 months, 5 Barcina gilts slaughtered at 16 months, 3 Carballina barrows slaughtered at 12 months, 5 Carballina barrows slaughtered at 16 months, 4 Carballina gilts slaughtered at 12 months, 5 Carballina gilts slaughtered at 16 months, 4 Santiaguesa barrows slaughtered at 12 months, 4 Santiaguesa barrows slaughtered at 16 months, 3 Santiaguesa gilts slaughtered at 12 months and

3 Santiaguesa gilts slaughtered at 16 months] from O Pino farm and [3 Barcina barrows slaughtered at 12 months, 4 Barcina barrows slaughtered at 16 months, 5 Barcina gilts slaughtered at 12 months, 5 Barcina gilts slaughtered at 16 months, 4 Carballina barrows slaughtered at 12 months, 4 Carballina barrows slaughtered at 16 months, 4 Carballina gilts slaughtered at 12 months, 5 Carballina gilts slaughtered at 16 months, 4 Santiaguesa barrows slaughtered at 12 months, 3 Santiaguesa barrows slaughtered at 16 months, 3 Santiaguesa gilts slaughtered at 12 months and 3 Santiaguesa gilts slaughtered at 16 months] from Taboada farm. Sex effect was initially taken into account in the statistical analysis, but as it did not have significant effect on any of the variables studied, the distribution is not specified here. The pigs were reared in an extensive system in a forest of area 1500 m^2 (75 m^2 per animal) composed by *Eucalyptus* spp. and *Castanea sativa* trees. The animals grazed on existing grass and their diet was supplemented *ad libitum* with a commercial feed of 15.3% protein, 3.5% fat and 3.25 Kcal digestible energy. Table 1 shows the chemical composition and fatty acid profile of the commercial concentrate.

Table 1. Chemical composition and fatty acid profile of commercial feed used to feed the pigs

Chemical composition (%)	
Crude protein	15.3
Ash	5.5
Fat	3.5
Crude fibre	4.4
Cellulose	3.5
Starch	40.2
Lysine	0.7
Methionine	0.2
Phosphate	0.5
Ca	1.1
Na	0.1
Fatty acid profile (%)	
C16:0	15.56
C16:1	0.12
C18:0	2.63
C18:1*n9c*	25.24
C18:2*n6c*	48.89
C20:0	0.42
C18:3*n-3*	6.23
C22:0	0.45
C20:5*n-3*	0.11
C24:1	0.19
SFA	19.15
MUFA	25.56
PUFA	55.28
P/S	0.24
Σ*n-6*/Σ*n-3*	7.70

The concentrate was formulated using the following ingredients (%): 40 wheat, 25.5 barley, 15 soybean flour, 14.6 corn, 1.5 soybean oil, 2 calcium carbonate, 1 dicalcium phosphate and 0.20 sodium chloride.

The day before slaughter, the animals were weighed and transported to the abattoir (68 km from O Pino and 10 km from Taboada); measures were taken to minimize stress in the animals. On the day before slaughter, the animals were fasted from 11:00 AM, and they were then slaughtered no later than 10:30 AM in an accredited abattoir (Taboada, Lugo) after being stunned with carbon dioxide.

Carcass measurements

Forty-five minutes *postmortem*, the pH (pH_{45}) was measured on the left half of the carcass with a pH meter equipped with a penetration probe (Thermo Orion 710 A+, Cambridgeshire, UK) at the level of the fifth rib. On the right half of the carcass, morphometric parameters [carcass length (CL), hand length (HL), leg length (LL), ham length (HmL), maximum perimeter of the ham (HmP) and wrist perimeter (WP)] were measured with a flexible tape, as described by Peinado et al. (2004). The dorsal fat thickness (DFT) also was measured with a flexible tape at the level of the first rib (DFT1), the last rib (DFT2), at the level of the *gluteus medius* in the area of the thickest dorsal fat (cranial extreme, DFT3), and in the area where the dorsal fat was thinnest (DFT4) (Peinado et al., 2004). Carcasses were chilled at 4°C in a cold chamber for 24 h and the cold carcass weight (CCW) and pH (pH_{24}) were recorded. The killing out percentage was calculated as the CCW expressed as a proportion of the slaughter weight.

The day after slaughter, the right half-carcass was dissected in the Meat Technology Centre pilot plant. Ten joints were obtained (top loin, loin, sirloin, ham, shoulder, belly, bacon, fat, head and tail) and weighed with calibrated scales, accurate to 50 g (Teaxul, mod. TXL-1075-E, Spain). The following day (i.e. 48 hours *postmortem*), a portion of the loin muscle, *longissimus dorsi* (LD), between the fourth and tenth ribs, was sampled for meat quality determinations. The LD was cut into six steaks of thickness 2.5 cm. Two steaks were used to determine colour and proximate composition. Another two steaks were used to determine the water holding capacity and texture parameters, respectively. One steak was used to determine the fatty acid profile composition, and the final steak was used for sensorial analysis. Dorsal and ventral fat was also excised for colour measurements. Samples for texture testing were frozen at –18ºC for 7 days.

Chemical composition and colour traits

Moisture, intramuscular fat (IMF), protein (Kjeldahl N × 6.25) and ash were quantified according to the ISO recommended standards 1442:1997 (ISO 1997), 1443:1973 (ISO 1973), 937:1978 (ISO 1978), and 936:1998 (ISO 1998), respectively. A portable colorimeter (Konica Minolta CM-600d Osaka, Japan) with pulsed xenon arc lamp filtered to illuminant D65 lighting conditions, 0° viewing angle geometry and 8 mm aperture size, was used to estimate meat colour in the CIELAB space: lightness, (L*); redness, (a*); yellowness, (b*). Each LD was cut into slices (2.5 cm thick) and the colour of three slices was measured in the sample of each analytical point. Before each series of measurements, the instrument was adjusted using a white ceramic tile. Heme-iron was measured in duplicate in LD, according to the methodology of Hornsey (1956) with the following formula (Merck, 1989):

$$Hematin\ (\mu g\ hematin/\ g\ muscle) = Absorbance \times 342.44$$
$$Heme\ iron\ (mg/100\ g\ meat) = (Hematin \times 8.82)/100$$

Water-holding capacity (WHC) and texture profile analysis (TPA)

The WHC was measured in four ways: cooking loss, drip loss (DL), pressing loss (PL) and thawing loss (TL), as described by Franco and Lorenzo (2013). To evaluate cooking loss, two 2.5 cm thick steaks were packed individually under vacuum (97%) (TECNOTRIP model EV-15-1-D) and cooked in a water bath at 75°C for 45 min (Selecta Tectron Bio, Barcelona, Spain). Samples were cooled at room temperature and CL was calculated as follows:

$$Cooking\ loss = \frac{(Initial\ fresh\ meat\ weight - Cooked\ weight)}{(Initial\ fresh\ meat\ weight)} \times 100$$

To determine PL, a 5 g sample of minced meat was placed between two disks of Whatman No. 1 filter paper (Filter Lab, Spain). After weighing the meat, a mass of 2.5 kg was applied for 5 min. The percentage of released water was calculated as:

$$PL = \frac{(Initial\ fresh\ meat\ weight - Pressed\ weight)}{(Initial\ fresh\ meat\ weight)} \times 100$$

To determine DL, a sample of intact meat in a variable range of 80–100 g and 1.5 cm of thickness was weighed and put on top of a net, inside a container which is closed after filling in order to avoid evaporation into the environment. This container is placed in a refrigerated chamber at 4ºC for 48 hours and after this period is again weighed. DL percentage of water was calculated as:

$$DL = \frac{(Initial\ fresh\ meat\ weight - Meat\ after\ 48\ hours\ weight)}{(Initial\ fresh\ meat\ weight)} \times 100$$

To determine TL, samples were weighed and put in vacuum package bags, before freezing until textural analysis. Meat samples were thawed at 4ºC during 24 h in their vacuum-packed plastic bag, juice losses were eliminated and steaks were weighed again. The percentage of TL water was calculated as:

$$TL = \frac{(Initial\ fresh\ meat\ weight - Meat\ after\ thawing\ without\ juice)}{(Initial\ fresh\ meat\ weight)} \times 100$$

Texture analysis: Warner-Bratzler (WB) test and texture profile analysis (TPA)

Steaks were cooked placing vacuum package bags in a water bath with automatic temperature control (JP Selecta Model Tectron Bio, Spain) until reaching internal temperature of 70ºC, controlled by thermocouples type K (Comark, PK23M, UK), connected to a data logger (Comark Dilligence EVG, N3014, UK). The cooked meat was cooled at room temperature, placed in vacuum package bags in a circulating water bath at 18ºC for 30 minutes and the percentage cooking loss was recorded. All samples were cut or compressed perpendicular to the muscle fibre direction at a crosshead speed of 3.33 and 1 mm/s for WB and TPA tests respectively. The Texture Analyzer (TA.XT.plus of Stable Micro Systems, Vienna Court, UK) was used in both tests which were conducted according to AMSA guidelines (AMSA, 1995). Five meat pieces of 1×1×2.5 cm (height × width × length) were removed parallel to the muscle fibre direction and were heated to 30ºC in a heater apparatus (Lady Braun Epilette, CC20, Spain) 5 minutes before measurement. Samples were completely cut using a WB shear blade with a triangular slot cutting edge (1 mm of thickness). Maximum shear force, shear firmness and total necessary work performed to cut the sample were obtained. The first one, shown by the peak higher of the curve force-time, represents the maximum resistance of the sample to the cut. Shear firmness is represented by the slope from the beginning of the cut up to the highest point of the curve force-time and total work by the area under the curve.

A minimum of five meat pieces of 1×1×1 cm (height × width × length) parallel to the muscle fibre direction were removed for TPA test according to methodology proposed by Bourne. Textural parameters were measured by compressing to 80% with a compression probe of 19.85 cm^2 of surface contact. Between the first and second compression, the probe was paused for 2 seconds. Hardness (kg), cohesiveness (unitless), springiness (mm), gumminess (kg) and chewiness (kg * mm) were obtained. These parameters were obtained using the available computer software [Texture Exponent 32 (version 1.0.0.68), Stable Micro Systems, Vienna Court, UK].

Statistical analysis

A GLM procedure (SPSS 19.0, Chicago, IL, USA) was used to analyse the data on carcass and meat quality traits. Initially, the statistical model included genotype, age of slaughter and sex as fixed factors. However, as the sex effect only affected the loin and sirloin percentages within carcass measurements, and in relation to meat quality it only affected the cooking loss, intramuscular fat and protein content, it was eliminated from the initial model. When the genotype effect was significant ($P<0.05$), Duncan's test was used (considering a significance level of 5%) for pairwise comparison between sample means. Pearson's linear correlation was used to determine correlations between IMF and carcass weight, IMF and shear force and IMF and cooking loss ($P<0.05$), with the coefficient implemented in SPSS 19.0 for Windows (SPSS 19.0, Chicago, IL, USA).

Results

Carcass characteristics

The effects of slaughter age and genotype on live weight, carcass traits, morphology measurements and primal cuts are shown in Table 2. There were no significant differences (P>0.05) between sexes, except in loin percentages (3.20 vs. 3.74%, P<0.001, for barrows and females, respectively) and sirloin percentages (0.73 vs. 0.83%, P<0.001, for barrows and females, respectively) (data not shown). Genotype affected live weight at slaughter (157 vs. 172 vs. 180 kg, P<0.001, for Barcina, Carballina and Santiaguesa lines, respectively) and cold carcass weight (123 vs. 138 vs. 140 kg, P<0.001, for Barcina, Carballina and Santiaguesa lines, respectively). On the other hand, increasing age at slaughter increased LW (157.2 vs. 178.9 kg, P<0.001, for 12 and 16 months at slaughter, respectively) and CCW (122.9 vs. 141.9 kg, P<0.001, for 12 and 16 months at slaughter, respectively). A significant interaction (slaughter age × genotype) was detected for LW (P<0.05) and CCW (P<0.001); the increase in weight with age was more pronounced for the Barcina line than for the Carballina and Santiaguesa lines (Table 2).

Table 2. Effect of genotype and slaughter age on live weight, carcass weight, carcass measurements and carcass cuts of the Celta pig breed

	Genotype						SEM	SIG		
	Barcina		Carballina		Santiaguesa					
	Slaughter age (months)									
	12	16	12	16	12	16		A	L	A × L
1	2	3	4	5	6	7	8	9	10	11
LW (kg)	140.28	170.11	155.40	183.49	175.82	187.26	1.45	***	***	*
CCW (kg)	108.41	135.42	125.88	144.92	135.41	148.22	1.15	***	***	***
Killing out (%)	78.58	79.42	77.57	79.58	77.05	79.43	0.24	**	n.s.	n.s
pH_{45min}	6.07	6.03	6.45	6.49	6.25	6.44	0.02	n.s.	***	n.s.
Carcass measurements (cm)										
Carcass length	88.20	96.56	93.66	97.92	92.90	101.75	0.57	***	***	n.s.
Leg length	71.20	73.78	72.09	77.26	72.66	76.05	0.50	***	n.s.	n.s.
Hand length	40.45	41.71	41.54	44.00	41.17	43.70	0.30	**	*	n.s.
Ham length	43.62	45.12	45.18	47.46	44.95	46.70	0.26	**	*	n.s.
Ham perimeter	74.29	78.93	75.88	81.40	78.25	80.15	0.42	***	*	n.s.
Wrist perimeter	17.66	18.12	20.30	21.46	18.91	20.00	0.15	**	***	n.s.
CCI	1.21	1.40	1.25	1.50	1.41	1.44	0.10	***	***	***
DFT1	5.70	5.99	4.89	5.77	6.20	6.52	0.13	n.s.	*	n.s.
DFT2	3.58	4.01	4.09	4.21	4.43	4.67	0.09	n.s.	*	n.s.
DFT3	4.16	4.90	4.82	4.86	5.03	5.48	0.10	n.s.	*	n.s.
DFT4	3.66	4.26	4.27	4.20	4.21	4.44	0.10	n.s.	n.s.	n.s.
Primal cuts (% relative to carcass)										
Top loin	2.78	2.27	2.41	2.13	2.15	2.13	0.05	*	**	n.s.
Loin	3.67	3.19	4.32	3.67	2.88	3.08	0.05	**	***	*
Sirloin	0.92	0.74	0.84	0.76	0.70	0.75	0.01	***	***	***
Ham	22.31	20.96	21.26	20.89	19.96	19.11	0.13	**	***	n.s.
Shoulder	14.72	13.30	12.92	13.36	13.36	13.81	0.12	n.s.	*	**

Table 2 – contd.

1	2	3	4	5	6	7	8	9	10	11
Belly	4.64	6.92	5.52	6.72	6.78	5.92	0.12	**	n.s.	***
Bacon	11.83	16.24	15.51	16.22	19.03	17.85	0.32	*	***	**
Fat	9.76	7.53	7.80	8.97	7.98	9.22	0.22	n.s.	n.s.	**
Head	8.54	8.96	8.09	8.37	8.88	8.73	0.12	n.s.	n.s.	n.s.
Tail	0.25	0.24	0.26	0.26	0.22	0.21	0.01	n.s.	n.s.	n.s.

LW=live weight, CCW=cold carcass weight, CCI=carcass compactness index, DFT=dorsal fat thickness. SEM=standard error measurement. Significance: *** (P<0.001), ** (P<0.01), * (P<0.05), n.s (not significant). A=age, L=line, A x L=interaction Age × Line.

Killing out percentage was not affected by genotype (79.0 vs. 78.7 vs. 78.1%, for Barcina, Carballina and Santiaguesa lines, respectively). However, the killing out percentage was higher (P<0.001) for older and heavier pigs (77.7 vs. 79.5%). The pH values measured at 45 min and 24 h *postmortem* in the LD muscle are shown in Table 2. No significant (P>0.05) differences between slaughter ages were observed in the pH_{45min} values. A significant interaction (slaughter age × genotype) was observed for pH values measured at 24 h *postmortem* (P<0.001).

Carcass length differed significantly (P<0.001) between genotypes, and this parameter increased linearly (P<0.001) with slaughter age (Table 2). However, significant interaction (slaughter age × genotype) was not observed for any measurements except for CCI (P<0.001). The carcass length, leg length, ham length and ham perimeter were lower in the Barcina genotype than in the other lines. On the other hand, ham length and wrist perimeter were higher in the Carballina line than in the other genotypes. Finally, the carcass compactness index (CCI) was significantly (P<0.001) affected by genotype and slaughter age, since Carballina line slaughtered at 16 months presented the highest values (1.50), while Barcina genotype slaughtered at 12 months showed the lowest values (1.21).

The four dorsal fat thickness (DFT) values indicated a high degree of fattening, varying between 6.52 cm for DFT1 and 3.58 cm for DFT2 (Table 2). No significant (P>0.05) differences in these parameters were observed between slaughter ages, while significant differences (P<0.05) were found between genotypes. The Barcina pigs slaughtered at 12 months yielded the highest proportion of noble pieces per carcass (44.4%), as the values for ham (22.31%) and shoulder (14.72%) were highest in these pigs. Regarding bacon, Santiaguesa line slaughteed at 16 months presented the highest values (19.03%), while Barcina pigs slaughtered at 12 months displayed the lowest percentages (11.83%). However, fat percentage did not show significant differences between genotypes or slaughter ages. Finally, a significant interaction (slaughter age × genotype) was observed for bacon and fat percentages.

Meat quality characteristics

Chemical composition, colour parameters, water holding capacity (WHC) and textural parameters of Celta pig meat are shown in Table 3. There were no significant differences (P>0.05) between sexes, except in protein content (22.44 vs. 23.01%, P<0.001, for barrows and females, respectively), intramuscular fat content (3.65 vs. 2.84%, P<0.05, for barrows and females, respectively) and cooking loss (19.81 vs.

22.49%, P<0.01, for barrows and females, respectively) (data not shown). However, slaughter age and genotype affected almost all of the variables studied. The moisture content ranged from 70.91% to 73.25%, protein content from 22.25% to 23.11% and ash percentage from 1.11% to 1.27%.

Table 3. Effect of genotype and slaughter age on chemical composition, colour parameters, WHC and textural parameters of LD from the Celta pig breed

	Genotype						SEM	SIG		
	Barcina		Carballina		Santiaguesa					
	Slaughter age (months)									
	12	16	12	16	12	16		A	L	A × L
pH_{24h}	5.51	5.46	5.67	5.51	5.65	5.55	0.01	*	***	***
Chemical composition										
Moisture (%)	72.33	70.91	71.66	72.06	71.96	73.25	0.09	n.s.	***	***
IMF (%)	2.39	4.91	3.52	4.37	3.27	4.83	0.07	***	n.s.	***
Protein (%)	23.11	22.65	22.28	22.86	22.25	23.11	0.07	*	n.s.	**
Ashes (%)	1.27	1.13	1.17	1.13	1.27	1.11	0.04	***	n.s.	*
Fe-hem	0.73	0.97	0.66	0.64	0.67	0.74	0.01	***	***	***
Colour parameters										
Loin										
luminosity (L*)	50.54	47.26	53.07	50.57	53.41	49.31	0.41	***	*	n.s.
redness (a*)	9.64	13.07	9.36	9.64	10.15	10.37	0.18	**	***	***
yellowness (b*)	10.04	11.71	11.08	10.30	11.59	9.78	0.18	n.s.	n.s.	n.s.
Dorsal fat										
luminosity (L*)	79.57	80.48	80.35	81.54	81.02	81.29	0.10	***	***	n.s.
yellowness (b*)	5.35	6.01	6.61	4.97	5.78	6.53	0.10	n.s.	n.s.	n.s.
Water holding capacity (%)										
Cooking loss	27.31	19.74	21.06	20.45	23.41	19.75	0.33	***	**	***
Drip loss	4.65	1.77	2.06	2.24	2.83	2.98	0.06	***	***	***
Thawing loss	10.65	4.95	6.93	6.84	8.78	9.62	0.19	***	***	***
Pressing loss	29.50	23.98	27.68	26.78	27.70	25.90	0.30	***	n.s.	**
Textural parameters										
Shear force	5.16	3.64	3.49	3.54	3.87	3.15	0.09	***	***	**
Firmness	1.26	0.96	0.98	0.90	0.96	0.81	0.02	***	***	n.s.
Total work	23.75	16.03	16.26	16.97	17.74	15.44	0.55	**	*	**
Hardness	7.94	8.90	7.31	8.52	8.71	8.61	0.18	n.s.	n.s.	n.s.
Springiness	0.57	0.56	0.48	0.53	0.53	0.53	0.004	n.s.	***	**
Cohesiveness	0.57	0.54	0.56	0.52	0.53	0.55	0.003	**	*	***
Chewiness	2.60	2.80	2.14	2.44	2.32	2.56	0.06	n.s.	*	n.s.

Shear force (kg/cm^2), firmness (kg/s), total work (kg × mm), hardness (kg), springiness (mm), gumminess (kg) and chewiness (kg × mm).

SEM=standard error measurement. Significance: *** (P<0.001), ** (P<0.01), * (P<0.05), n.s (not significant).

A=age, L=line, A x L=interaction Age × Line.

Regarding moisture content, slaughter age did not show significant differences (P>0.05), while genotype displayed significant (P<0.001) differences among lines. A significant interaction (slaughter age × genotype) was observed for moisture con-

tent (P<0.001). Intramuscular fat of LD was affected by slaughter weight, and the IMF content was positively correlated with carcass weight (r = 0.305, P<0.01). The IMF of the LD did not differ significantly between Celta varieties (mean values of 3.68%, 3.94% and 4.05% for Barcina, Carballina and Santiaguesa, respectively); in addition, a high variation in the values was observed. A significant interaction (slaughter age × genotype) was observed for IMF values (P<0.001). Finally, protein content presented significant differences (P<0.05) among slaughter age, while protein content was not affected (P>0.05) by genotype. Also a significant interaction (slaughter age × genotype) was observed for protein values (P<0.001).

The colour measurement in the LD muscle showed significant differences between slaughter age and genotypes. The L* values were lowest (48.53) and the a* values were highest (11.55) in the Barcina line, indicating that the meat is darker and redder in colour than in the other two lines. The LD from younger pigs was lighter (52.45 vs. 49.01; P < 0.001) than the LD of older pigs (Table 3). Although the b* (yellowness) values did not differ between slaughter ages (10.91 vs. 10.69; P>0.05), the LD muscle from pigs slaughtered at 16 months was redder (P<0.01) than the LD from younger pigs (11.10 vs. 9.70). Finally, the a*/b* ratio values were higher (0.88 vs. 1.04, P<0.001) in the older pigs.

Dorsal fat luminosity differed significantly (P<0.001) between genotypes, with the Barcina line showing the lowest values (80.1). Slaughter age also significantly affected (P<0.001) the L* values, as the values were highest (81.1) in the older pigs. No differences in the colour traits of ventral fat were detected between lines or slaughter ages (data not shown).

The WHC was significantly affected by slaughter age (P<0.001) and genotype (P<0.01). The cooking loss showed significantly (P<0.001) higher values in pigs slaughter at 12 months (23.93 vs. 19.97% for pigs slaughtered at 12 and 16 months, respectively). A similar behaviour was observed for PL, since the highest values were reported in younger pigs (28.29 vs. 25.55% for pigs slaughtered at 12 and 16 months, respectively). In addition, a significant interaction (slaughter age × genotype) was found for cooking loss values (P<0.001) and PL (P<0.01).

Both slaughter age and line had significant effects on texture parameters measured by the WB test, whereas textural profile analysis showed significant differences mainly due to line effect. For the Barcina and Santiaguesa lines, the shear force decreased as slaughter age increased (see Table 3). Resistance to cutting was lower in animals slaughtered at 16 months than in pigs slaughtered at the earlier age, which is consistent with the higher IMF of these animals. The Pearson's correlation revealed that IMF content was negatively related to shear force (r = –0.309, P<0.01).

Discussion

Carcass characteristics

The carcass weights are higher than the average commercial values for pigs slaughtered in Galicia and Spain (85.8 and 76.6 kg; MARM, 2011) and similar to

those reported by Franco et al. (2014) and Temperán et al. (2014) for the Celta pig breed. These differences are related to slaughter age, since Celta pigs are slaughtered at older age.

Killing out percentage is not consistent with the findings of Fischer et al. (2003), who reported that the magnitude of the increase in carcass yield with slaughter weight is breed-dependent. However, the killing out percentage was higher ($P<0.001$) for older and heavier pigs (77.7 vs. 79.5%), which is consistent with results reported by Correa et al. (2006), Latorre et al. (2004) and Virgili et al. (2003). The age increase is characterized by the growth of lean, bone, and fat, with greater fat deposition being largely responsible for the increase in dressing percentage detected in the older pigs (Virgili et al., 2003). Carcass yield increased 0.82 percentage units per each 10 kg increase in LW from 157 to 178 kg LW. Carcass yield value is within the range (76.6–80.2%) reported in the literature (Latorre et al., 2008).

No significant ($P>0.05$) differences between slaughter ages were observed in the pH_{45min} values, which are consistent with those reported by Latorre et al. (2008). The pH values may indicate that these pigs experienced greater pre-slaughter stress (Galián et al., 2008; Poto et al., 2007). Regarding genotype, the pH values showed a significant effect ($P<0.001$), since the pH_{45min} and pH_{24h} were lower in the Barcina line. The values observed at 45 minutes and 24 h *postmortem* were similar to those reported by Peinado et al. (2004) for Chato Murciano pigs and Pugliese et al. (2004 b) for Cinta Senese pigs.

The values of carcass length are consistent with those found by Fischer et al. (2003), who reported that the increase in carcass, ham and shoulder dimensions with LW depends on the breed. Carcass length increased at a rate of 2.59 cm for every 10 kg of increase in LW from 157 to 178 kg LW, more than the 2.0 cm reported by Latorre et al. (2004) for Pietrain sire pigs, or the 1.86 cm reported by Cisneros et al. (1996) for Hampshire sire pigs. In addition, ham size increased with LW: 0.99 cm in length and 2.03 cm in perimeter for each 10 kg of LW, close to the 1.1 cm in length reported by Latorre et al. (2004).

The four dorsal fat thickness (DFT) values indicated a high degree of fattening. The DFT values were high and related to the rusticity of this traditional breed. The values of DFT3 (range 4.16–5.48 cm) were higher than those found in commercial pig breeds selected for lean production, e.g. the values obtained by Diestre (1988) for different breeds were as follows: 1.0 cm for Pietrain, 1.43 cm for Belgian Landrace, 1.83 cm for standard Landrace, 2.23 cm for Large White and 1.73 cm for Duroc. In addition, a similar range was found for Celta pigs (LW 140 kg) (4.58 cm) (De Jesús, 2008) and Cinta Senese pigs (LW 136.2 kg) (4.93 cm Franci et al., 2005) and they were lower than those obtained for Torbiscal genotype (LW 130.1 kg) (5.2 cm; Dobao et al., 1987). In an intermediate situation, Chato Murciano pigs (LW 110 kg) yielded DFT values in the range 3.57–3.65 cm (Poto et al., 2007).

The sum of noble pieces was lower than found for Chato Murciano pigs (46.4%), although this difference may be explained by regional differences in quartering methods. The ham percentage value for Barcina at 12 months was higher than those found in pigs of the Celtic stock (De Jesús, 2008) (22.31% vs. 20.70%), while shoulder percentage was lower (14.72% vs. 16.44%). In Chato Murciano and Iberian pigs,

percentages of hams and shoulder were 23.42 and 19.41% for hams and 14.78 and 13.8% for shoulder, respectively (Mayoral, 1994; Poto, 2003).

Meat quality characteristics

The moisture values are within the range of values reported by other authors for improved commercial breed hybrids destined for meat production (Latorre et al., 2003; Correa et al., 2006) and autochthonous breeds such as Nero Siciliano (Pugliese et al., 2004 a), Chato Murciano (Peinado et al., 2004) and Iberian pig (Estévez et al., 2003).

Intramuscular fat value is consistent with the findings of Candek-Potokar et al. (1998), who reported an increase in intramuscular fat with slaughter weight. However, other authors such as Correa et al. (2006) and Latorre et al. (2004) did not observe such a trend. Poto et al. (2007) also observed a high variability in the IMF in Chato Murciano pigs which is probably due to the special feeding conditions. It is generally accepted that traditional breeds, and in particular pigs reared in extensive systems, produce a higher IMF content (Franco et al., 2014). In this respect, the values reported here are lower than those reported in a previous study (5.22%, Franco et al., 2014) in Celta pigs, although similar to those reported for other rustic or traditional breeds such as Nero Siciliano (4.27%, Pugliese et al., 2004 a), Cinta Senese (4.04%, Pugliese et al., 2004 b) and Iberian pig (3.34%, Estevez et al., 2003).

The colour measurements are consistent with the dark and red meat of the autochthonous pig breeds (Franco et al., 2014). The average values of colour parameters (L*, a* and b*) reported in the literature for pork meat from different breeds vary widely (44–58, 5–10 and 4–9, for L* a* and b*, respectively) (Latorre et al., 2003; Correa et al., 2006). Fernández-López et al. (2000) stated that the a* values in pork depend on the concentration of myoglobin and not on its state (deoxygenated, oxygenated, or oxidized). The results shown in Table 3 demonstrate that extending the slaughter age for four months increased the redness of the pork colour. According to Fernández-López et al. (2000), a high a*/b* ratio is indicative of a high concentration of either myoglobin or oxymyoglobin on the surface of the meat, whereas a low a*/b* ratio is due to a high concentration of metmyoglobin. In this respect, a delay of 4 months in slaughtering may result in significant differences in colour, attributable to the amount of meat pigment and to its oxidative status. The L*values for dorsal fat were higher than reported by Poto et al. (2007) and Galián et al. (2009) for the Chato Murciano pig breed. Discrepancies in the results of different studies may be explained by the different breed, slaughter age, colorimeter used and other factors such as time *postmortem* that the measurement was made and cooling rate.

The WHC data are not consistent with those reported by Candek-Potokar et al. (1998) and Latorre et al. (2003), who showed a decrease in TL with slaughter age, while cooking loss did not differ in relation to slaughter weight. The mean cooking loss values of pigs slaughtered at 12 and 16 months (23.92% and 19.98%, respectively) were lower than those recorded for other local breeds: 24.25% in Nero Siciliano (Pugliese et al., 2004 a) and 28.45% in Cinta Senese (Pugliese et al., 2004 b). The differences in cooking loss may be related to the different cooking temperature used. It has been established that the cooking loss increases as temperature increases

(Lepetit et al., 2000). These authors found that the cooking loss increased with temperature, and in the range of 70–80°C the cooking loss increased by 20 to 32%. This may explain how small differences in the cooking temperature over a long time can affect the final result. The WHC is also influenced by the raw material composition, especially the content and distribution of IMF, since the presence of IMF decreases the moisture diffusivity coefficient (Muriel et al., 2004). The results of the present study are partly consistent with the aforementioned findings, as the Pearson's correlation test indicated that cooking loss was negatively correlated with IMF content ($r = –0.407$, $P<0.01$).

The values of maximum shear force obtained in this study (3.8 kg) were lower than those recorded for other local breeds: 9.27 kg in Nero Siciliano (Pugliese et al., 2004 a), 12.8.kg in Cinta Senese (Pugliese et al., 2004 b) and 4.56 kg in Iberian pigs (Juárez et al., 2009). There are multiple factors that influence tenderness of meat such as: *postmortem* proteolysis, intramuscular fat or marbling, connective tissue, and the contractile state of the muscle (Belew et al., 2003). These factors also contribute to the difference in tenderness between different muscles within the same beef carcasses. In addition, the shear force may have been lower in the present study because the samples were frozen at –18ºC for a week prior to analysis (Lagerstedt et al., 2008).

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