Physicochemical characteristics and sensory attributes of meat from heavy-weight Iberian and F1 Large White × Landrace pigs finished intensively or in free-range conditions¹

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ABSTRACT: Iberian (IB, $n = 60$) and crossbred Large White × Landrace (F1, $n = 58$) pigs were slaughtered at 160 kg, after finishing under intensive conditions or on pasture and acorns. The study was carried out as a factorial arrangement of treatments, and physicochemical properties and sensory attributes of meat were assessed in *Longissimus thoracis* samples. Physical characteristics included the assessment of drip loss, cooking loss, shear force, and color coordinates in meat samples processed at 2 and 9 d postmortem. The interactions of genetic group and finishing system were significant ($P < 0.05$) for cooking loss in meat aged for 9 d and for sensorial tenderness and global acceptability of meat, but none of the other physicochemical, color coordinates, and sensory variables analyzed showed a significant interaction. Genetic group was the main factor influencing the variables analyzed, with a major ($P < 0.01$) influence on all meat physicochemical

characteristics and sensory attributes. Relative to F1 pigs, the IB produced meat with higher intramuscular fat content and marbling score, more appealing color coordinates, lower shear force, and higher sensorial tenderness. The finishing systems affected ($P < 0.05$) most physical characteristics, but not chemical composition of meat and their impact on sensory properties was small. The tenderness, juiciness, and global acceptability of meat were much higher in IB pigs, and flavor was also more desirable, but the difference was smaller. The differences in sensory properties between meats originating from the two genetic groups were largely explained by the higher fat deposition in IB pigs, such that a higher level of marbling was positively associated with all the sensory attributes evaluated. Ageing meat for up to 9 d postmortem benefited pork quality, improving meat tenderness, and color, particularly in crossbred pigs and those finished intensively.

Key words: ageing, color, pork quality, sensorial analysis, swine

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INTRODUCTION

In recent years, selection for lean growth in pigs resulted in a reduction of meat quality, with a decline in pork tenderness, juiciness, and flavor (Merks, 2000). Yet, meat quality in local pig breeds is often considered better (Pugliese and Sirtori, 2012) and Iberian (IB) pigs are recognized for the excellent quality of their dry-cured products. These products reach premium prices, particularly when they are obtained from animals raised on acorn and pasture (Ruiz et al., 2002; Čandek-Potokar and Škrlep, 2012), produced in line with consumer concerns regarding ethics of production, animal welfare, and environmental impact (Rodríguez-Estevéz et al., 2012). However, the slow growth rate and poor reproductive performance of IB pigs have prompted in the last few years the use of crossbreeding as a way to obtain more affordable processed products.

The attributes of fresh meat from IB pigs are an important way to add value to this product. Traditionally, IB pigs are raised in free-range conditions with acorn and pasture, but indoor finishing has also coexisted in the recent past (Isabel, 2003; Robina et al., 2013). It is known that the sensory properties of IB dry-cured products are better when they are obtained from heavy-weight free-range pigs (Ventanas et al., 2007b). Still, the impact of finishing system on the palatability of fresh meat is not well demonstrated, but preliminary results suggest that consumers do not detect differences between pork derived from pigs finished extensively or intensively (Martínez et al., 2012). On the other hand, the comparative properties of pork obtained from IB and commercial crossbred pigs have not been fully evaluated.

This work was carried out to investigate how the genetic group (Iberian and F1 Large White × Landrace) and the finishing system (raising in oak-tree forests or conventional intensive systems) affect physicochemical properties and sensory attributes of the *Longissimus thoracis* in heavy-weight pigs.

MATERIALS AND METHODS

All animals used in this study were raised according to Portuguese and European legislation for pig production, and all procedures described were in compliance with European Union legislation concerning the protection of animals used for scientific purposes (European Parliament, 2010).

Animals and Treatments

A total of 118 barrows belonging to the Iberian (IB, $n = 60$) and F1 Large White × Landrace (F1,

$n = 58$) genetic groups were used in this study. The pigs of each genetic group were the offspring of at least 4 sires and 20 dams, and no more than 3 pigs from the same litter were allowed to enter the experiment. After weaning, pigs of both genetic groups were provided with the same commercial feed until they reached an average weight of 85 kg in November. Given the faster growth rate of F1 pigs in the growth period, at this stage their mean age was 5 mo, while for IB pigs of the same weight the mean age was 8 mo. This age difference was maintained up to slaughter at 160 kg and, as growth rate was similar in the two genetic groups throughout the finishing period, they reached the target slaughter weight in a similar timeframe, between April and May.

When pigs reached a live weight of 85 kg, 30 IB and 30 F1 pigs were randomly assigned to be finished under standard intensive conditions (group IN), and pigs were slaughtered when they reached the target live weight of 160 ± 5 kg. The diet was formulated to have 14.7% crude protein and 13.7 MJ/kg DM of gross energy, and was composed of barley (40.4%), wheat (30.0%), soybean meal (16.2%), corn (10.0%), soybean oil (0.5%), and vitamins and minerals (2.9%). The facilities were appropriate for the finishing phase, and pigs were allocated to pens with an area of 7.8 m², at a density of 3 pigs per pen, with free access to water. Dry feed was administered on an individual basis, according to individual intake, at a level of up to 4% (dry matter) of live weight, distributed twice daily at 9:00 a.m. and 4:00 p.m. In each pen, pigs had access to individual trap-cages to be fed, so that feed consumption could be recorded daily for each animal and adjusted on a weekly basis. Throughout the finishing period between 85 and 160 kg live weight, the means for individual daily feed intake were 4.77 ± 0.25 kg for IB and 3.33 ± 0.38 kg for F1 pigs.

One other group of IB ($n = 30$) and F1 ($n = 28$) pigs with a mean live weight of 85 kg and similar age as described above for the first group was randomly assigned to be finished in free range (group EX), in an oak- and cork-tree forest where they had access to the fruit of those trees (acorn) and grass. Starting in November, the 58 finishing pigs were kept under free-range conditions in six fenced parks with an area of about 10 ha each. These parks had about 15 to 30 trees per hectare, mostly oaks (*Quercus ilex*) and cork-trees (*Quercus suber*), and native and cultivated pasture, including oats (*Avena sativa*), vetch (*Vicia villosa*), and clover (*Trifolium subterraneum*). In this system, acorns are on the ground between November and March–April, but

their availability depends on the number of pigs per hectare and productivity of the trees. All the pasture-raised pigs were kept simultaneously on the same park, and a rotational grazing system was adopted, such that pigs were moved from one park to another at intervals of about 2 to 3 wk. Given the seasonal nature of acorn and pasture production, the finishing period under extensive conditions started in November and the animals were kept on pasture until they reached the mean target weight of 160 kg, which occurred between April and May.

Slaughter and Sample Collection

Upon reaching the target weight of 160 ± 5 kg, pigs were transported and slaughtered in an experimental abattoir. There were 28 d of experimental slaughter, and up to six animals were slaughtered on the same day. In the pre-slaughter waiting period, animals were kept in groups of two to three pigs per holding pen, avoiding mixing animals of different origin. After a period of 16 h of resting, with fasting and water available ad libitum, the animals were electrically stunned, bled, singed, and eviscerated according to standard procedures. The carcasses were split longitudinally, and chilled at 4 °C for 24 h postmortem. Carcasses were separated into the major joints, as described by Bressan et al. (2016), and a sample of 100 g was collected from the *M. Longissimus thoracis* (LT) between the 9th and 11th vertebrae for chemical analyses. External fat and *epimysium* were removed from meat samples, which were then individually minced in a commercial mixer-blender, vacuum-packaged, and frozen at -18 °C until further processing for proximate composition determination. In addition, meat samples were collected from the LT between the 12th and 16th vertebrae, to carry out physical analyses (500 g from right half-carcass) and sensory analyses (500 g from left half-carcass). The samples destined to physical analyses were split perpendicular to the muscle fiber into two subsamples, which were individually vacuum-packaged and refrigerated at 2 °C. One of the subsamples was randomly assigned to perform physical analyses at 2 d postmortem, while the other subsample was stored at 2 ± 0.2 °C and analyzed at 9 d postmortem. Samples destined to sensory analysis were individually vacuum-packaged and aged at 2 ± 0.2 °C until 9 d postmortem. Samples for texture and sensorial analysis were frozen at -18 °C and stored until further processing, which took place within approximately 2 to 3 mo after slaughter.

Analyses of Proximate Composition

Meat samples were thawed at 4 °C for 24 h, after approximately up to 60 d of frozen storage. Analyses of moisture, fat, protein, and ash content were performed in duplicate using AOAC (2000) methods. Briefly, protein was quantified using the micro-Kjeldahl method (method 954.01 of AOAC, 2000) with a block digester and nitrogen distiller. Fat content was determined according to the Soxhlet method (method 920.39 of AOAC, 2000) using a Soxhlet extractor (VELP Scientifica SER 148/6 Solvent Extractor, Italy). Moisture content was determined in an oven at a temperature of 105 °C until a constant sample weight was obtained (method 950.46 of AOAC, 2000). Determination of ash was performed by carbonization and incineration of the samples in a muffle furnace at a temperature of 550 °C (method 920.153 of AOAC, 2000).

Analyses of Physical Characteristics

Meat pH was measured at 24 h postmortem by making a scalpel incision in the LT between the 10th and 11th vertebrae, and inserting a glass electrode, model FC200 (Hanna Instruments, Leighton Buzzard, UK), attached to a portable pH meter, approximately 2.5 cm into the muscle. From each point sampled, three pH measurements were taken, and the mean of these measurements was used for statistical analyses.

Drip loss at 2 and 9 d postmortem was determined in meat samples destined to physical analyses, and was measured as the weight loss under vacuum-packaging up to 2 and 9 d postmortem. Samples were weighed either at 24 h and 2 d or at 24 h and after 9 d of ageing. Before each weighing the surface of the samples was gently dabbed with paper towels. Drip loss was computed as the difference in weight of samples up to 2 and 9 d, expressed as a percentage of sample weight at 24 h.

Level of marbling was visually evaluated in the surface cut of the LT, according to the Pork Quality Standards (National Pork Board, 2015), using a 6-point scale, where 1 = total absence of marbling, and 6 = high level of marbling. Each sample was evaluated for level of marbling at 9 d postmortem by two trained technicians, and the mean was used for statistical analyses.

The objective measurement of meat color was performed at 2 and 9 d postmortem with a colorimeter Cr-400 (Minolta Camera Co., Ltd., Osaka, Japan), with the illuminant D₆₅, at an observer angle of 2°, with a diameter of measurement area of 1 cm

(Mancini and Hunt, 2005). The color coordinates were obtained after 60 min of blooming at 4 °C, by averaging three readings performed in the median region of each sample, at regular distance intervals in the mid-space of 45 mm, which corresponds to the average diameter of each piece. Lightness (L^*), redness (a^*), and yellowness (b^*) of the surface of the LT were recorded, according to the CIE color scores. The C^* (chroma or saturation) and H° (hue angle) values were calculated as $C^* = ((a^*)^2 + (b^*)^2)^{0.5}$ and $H^\circ = \arctan(b^*/a^*)$ (McGuire, 1992).

Cooking loss was estimated in samples stored for 2 and 9 d postmortem, according to the procedures recommended by AMSA (2015). Briefly, the samples with 200 ± 25 g were weighed and boiled in water at 80.0 ± 0.2 °C, until reaching an internal temperature of 75.0 °C, measured with a thermocouple (type T fine-gage thermocouples read with Omega RDXL4SD, Omega Engineering, Inc., Manchester, USA). After cooling, samples were weighed again, and the difference in weight before and after cooking, expressed as a percentage of initial weight, was considered to correspond to cooking loss. Cooked samples were stored at 4 °C for temperature stabilization, and after 24 h they were cut parallel to the direction of the muscle fibers ($1 \times 1 \times 3$ cm). These subsamples were sheared by using a texturometer TA-XT2 (Stable Micro System, Surrey, England), equipped with a Warner-Bratzler shearing device at a crosshead speed of 300 mm/min, and the results were expressed in kilograms. Meat samples from each experimental animal, aged for 2 or 9 d postmortem, were analyzed, and the mean of 15 to 25 measurements per sample was used for statistical analyses.

Sensory Analyses

Samples of meat aged for 9 d were used for sensory analysis and, due to logistic constraints, the test was performed with 85 of the 118 samples that were collected. The samples used for sensory analysis were distributed as follows: 27 IB-EX, 18 IB-IN, 28 F1-EX, and 12 F1-IN.

Sensory evaluation was carried out by a trained panel of 10 members, both male ($n = 4$) and female ($n = 6$), with age ranging from 30 to 60 years. The judges were chosen from the staff of an experiment station, and they were all experienced in the profile assessment of different meats and trained according to International Organization for Standardization (2012). There were 17 trial sessions, with 1 session per day. In a given session, up to six different samples were served to all judges in a random order,

with samples chosen to represent the four treatment combinations, plus one to two samples chosen randomly between the others to be evaluated, to fulfill the desired number. This was done to avoid that panelists knew in advance that all the four treatment combinations (and only those) were represented in a given session, which could result in an “expectation error.” These additional samples were assigned to trial days in a random manner.

Meat samples were thawed at 4 °C nearly 20 h prior to roasting. After removing external fat, samples of about 250 ± 25 g were placed in aluminum trays with a thermocouple (type T fine-gage thermocouples read with Omega RDXL4SD, Omega Engineering, Inc., Manchester, USA) inserted into each roast. The roasts were cooked in a preheated electric natural convection oven at 170 °C, to an endpoint core temperature of 70 °C. After 10 min of stabilization at 40 °C, the external surface of the roast was discarded, and the remainder sliced (thickness of 1.0 cm). The slices were sectioned in cubes ($1 \times 1 \times 1$ cm) and two cubes were placed in a preheated glass Petri dish, covered and held at 40 °C until evaluation (no longer than 30 min). Samples were made available to each judge in groups of two samples, along with an evaluation card sheet where different meat properties were scored in a scale of 1 to 8, according to AMSA (2015). The meat attributes evaluated were juiciness (1 = extremely dry; 8 = extremely juicy), tenderness (1 = extremely tough; 8 = extremely tender), flavor intensity (1 = extremely mild; 8 = extremely intense), flavor acceptability, and global acceptability (1 = extremely unacceptable; 8 = extremely acceptable).

Statistical Analyses

Data were considered to have originated from a 2×2 factorial treatment arrangement, with two genetic groups (IB and F1 Landrace $\times$ Large White) and two finishing systems (intensive and extensive). The GLM procedure of SAS (SAS Institute Inc., Cary, NC) was used in analyses of variance of the various physicochemical variables, with a linear model including the main effects of genetic group, finishing system and their interaction, plus the fixed effect of slaughter date. For sensory attributes, the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) was used, with a mixed model which included the fixed effects of genetic group, finishing system and their interaction, and the random effects of judge and trial session. For all variables analyzed, least-squares means were obtained for

the main effects of genetic group, finishing system and their combination, and tests of significance were carried out using Bonferroni adjustment for multiple tests. If the interaction was not significant ($P > 0.05$), means were reported and comparisons were carried out only for main effects which differed in ANOVA.

Differences observed between meat samples at 2 and 9 d postmortem were computed for drip loss, cooking loss, shear force, and color coordinates. These differences were analyzed with the same linear model described above for physicochemical properties, to assess the effects of genetic group and finishing system on meat ageing for 9 d. Moreover, in these analyses a mean difference between 2 and 9 d, which differed from zero ($P < 0.05$) indicated that a significant change had occurred with the ageing process.

Sensory variables were also analyzed by stepwise regression with the REG procedure of SAS (SAS Institute Inc., Cary, NC), to assess how they were influenced by physical properties of meat. The scores assigned to the various attributes by different judges in various trial sessions were pooled by animal, and the prediction model was obtained for each sensory variable as a potential function of meat physical characteristics assessed at d 9 of ageing. The full model included as candidate independent

variables the marbling score, shear force, CIE Lab color coordinates, drip loss and cooking loss, and the PROC REG of SAS (SAS Institute Inc., Cary, NC) was used with the backward elimination procedure, assuming a threshold of $P = 0.10$ for a variable to be retained in the model. In the final prediction model, regression coefficients of the sensory attributes on the physical properties of meat were obtained. These regression coefficients were also estimated as standardized coefficients (i.e., expressed in standard deviation units of the sensory variables per standard deviation unit of the predictor variables), to compare the relative strength of the various predictors in the model.

RESULTS

Interactions among genetic group and finishing system were detected ($P < 0.05$) for cooking loss up to 9 d and sensorial tenderness and global acceptability of meat, but not for the other physicochemical characteristics, color coordinates, and sensory variables (Tables 1–3). Therefore, least-squares means were only reported for the main effects of genetic group and finishing system, and specifically mentioned in the few cases where the interaction was significant. Overall, genetic group was clearly the major factor influencing the variables

Table 1. Chemical composition and physical characteristics determined at 2 or 9 d postmortem in *L. thoracis* samples of Iberian (IB) and F1 Large White × Landrace (F1) pigs finished extensively (EX) or intensively (IN)¹

Variables	Genetic group		Finishing system		<i>P</i> -value ⁴			RSD ⁵
	IB	F1	EX	IN	GG	FS	GG × FS	
	(<i>n</i> = 60)	(<i>n</i> = 58)	(<i>n</i> = 58)	(<i>n</i> = 60)				
Chemical composition (%)								
Moisture	67.93 ^b	72.85 ^a	70.48	70.31	<0.01	0.61	0.80	1.56
Protein	21.04 ^b	23.14 ^a	22.14	22.04	<0.01	0.59	0.52	0.80
IMF	10.58 ^a	3.28 ^b	6.74	7.12	<0.01	0.38	0.38	1.87
Ash	1.04 ^b	1.12 ^a	1.08	1.08	<0.01	0.85	0.12	0.06
Physical characteristics ²								
Marbling score ³	3.79 ^a	1.58 ^b	2.27 ^b	3.11 ^a	<0.01	<0.01	0.44	0.83
pH	5.65 ^a	5.55 ^b	5.65 ^a	5.55 ^b	<0.01	<0.01	0.12	0.07
Drip loss _{2d} (%)	2.87 ^b	4.98 ^a	5.08 ^a	2.78 ^b	<0.01	<0.01	0.14	1.41
Drip loss _{9d} (%)	4.62	5.36	6.66 ^a	3.32 ^b	0.31	<0.01	0.07	1.64
Cooking loss _{2d} (%)	21.33	22.45	21.34	22.44	0.53	0.21	0.23	4.02
Cooking loss _{9d} (%)	21.74	22.04	21.33 ^a	22.45 ^b	0.72	<0.01	<0.01	1.87
Shear force _{2d} (kg)	4.83 ^a	5.67 ^b	4.73 ^a	5.76 ^b	0.02	<0.01	0.15	0.79
Shear force _{9d} (kg)	3.77 ^a	4.91 ^b	3.77 ^a	4.91 ^b	<0.01	<0.01	0.34	0.65

¹Least-squares means for genetic groups or finishing systems with different superscript differ ($P < 0.05$).

²Subscripts 2d and 9d correspond to variables measured at 2 and 9 d postmortem.

³Scored from 1 (no marbling) to 6 (high marbling).

⁴*P*-values for the effect of genetic group (GG), finishing system (FS), and GG × FS interaction.

⁵RSD = residual standard deviation.

Table 2. Meat color coordinates, determined at 2 or 9 d postmortem in *L. thoracis* samples of Iberian (IB) and F1 Large White × Landrace (F1) pigs finished extensively (EX) or intensively (IN)¹

	Genetic group		Finishing system		P-value ³			RSD ⁴
	IB (n = 60)	F1 (n = 58)	EX (n = 58)	IN (n = 60)	GG	FS	GG × FS	
Color coordinates ²								
L* _{2d}	53.90	56.88	56.09	54.69	0.07	0.09	0.98	3.66
L* _{9d}	53.33 ^a	58.81 ^b	56.10	56.04	<0.01	0.95	0.31	3.97
a* _{2d}	12.31 ^a	8.36 ^b	11.92 ^a	8.75 ^b	<0.01	<0.01	0.49	1.49
a* _{9d}	12.10 ^a	8.97 ^b	11.55 ^a	9.52 ^b	<0.01	<0.01	0.31	1.28
b* _{2d}	7.85 ^a	6.28 ^b	7.89 ^a	6.24 ^b	<0.01	<0.01	0.13	1.34
b* _{9d}	7.54	7.23	7.87 ^a	6.90 ^b	0.58	<0.01	0.37	1.28
Chroma* _{2d}	14.62 ^a	10.53 ^b	14.35 ^a	10.79 ^b	<0.01	<0.01	0.28	1.84
Chroma* _{9d}	14.25 ^a	11.56 ^b	14.02 ^a	11.79 ^b	<0.01	<0.01	0.84	1.67
Hue* _{2d}	32.17 ^a	37.08 ^b	33.14 ^a	36.11 ^b	<0.01	<0.01	0.63	3.63
Hue* _{9d}	32.07 ^a	38.84 ^b	34.40 ^a	36.50 ^b	<0.01	<0.01	0.10	3.39

¹Least-squares means for genetic groups or finishing systems with different superscript differ ($P < 0.05$).

²Subscripts 2d and 9d correspond to variables measured at 2 and 9 d postmortem.

³P-values for the effect of genetic group (GG), finishing system (FS) and GG × FS interaction.

⁴RSD = residual standard deviation.

Table 3. Sensorial attributes determined in *L. thoracis* samples from Iberian (IB) and F1 Large White × Landrace (F1) pigs finished extensively (EX) or intensively (IN)¹

	Genetic group		Finishing system		P-value ³			RSD ⁴
	IB (n = 45)	F1 (n = 40)	EX (n = 55)	IN (n = 30)	GG	FS	GG × FS	
Scores ²								
Juiciness	5.65 ^a	4.02 ^b	4.88	4.80	<0.01	0.40	0.09	1.04
Tenderness	6.09 ^a	5.00 ^b	5.56	5.54	<0.01	0.82	0.02	0.99
Flavor intensity	3.70 ^a	3.36 ^b	3.44	3.62	<0.01	0.11	0.85	1.07
Flavor acceptability	6.13 ^a	5.65 ^b	5.82	5.96	<0.01	0.12	0.30	0.94
Global acceptability	6.19 ^a	5.13 ^b	5.59	5.74	<0.01	0.11	0.04	0.90

¹Least-squares means for genetic groups or finishing systems with different superscript differ ($P < 0.05$).

²Samples scored in a scale of 1 to 8 (higher values desirable).

³P-values for the effect of genetic group (GG), finishing system (FS) and GG × FS interaction.

⁴RSD = residual standard deviation.

analyzed, with a significant influence for nearly all the analyzed physicochemical characteristics, color coordinates, and sensory properties of meat. On the other hand, the influence of finishing system was significant for most physical characteristics, including the majority of the color coordinates, but for none of the chemical variables and sensory properties.

Chemical Composition

Meat chemical composition (Table 1) was similar between finishing systems ($P > 0.05$). On the other hand, differences between genetic groups were large ($P < 0.01$), IB pigs showing an intramuscular fat (IMF) content higher by 7.30% relative to F1 pigs, while their mean moisture and protein contents were lower by 4.92% and 2.10%, respectively.

Also, ash content was higher in IB pigs by 0.08% relative to F1 pigs.

Physical Characteristics

The mean marbling score was higher by 2.21 points in IB pigs ($P < 0.01$, Table 1), in line with the differences observed in IMF content. Marbling also differed among finishing systems, with mean levels higher by 0.84 points in intensively finished pigs ($P < 0.01$). The pH of meat was higher by 0.10 points in IB relative to F1 pigs and in EX-relative to IN-finished animals. Drip loss at 2 d was lower by 2.11% in IB pigs ($P < 0.01$), but after 9 d of ageing it was similar to that observed in F1 pigs ($P > 0.05$). Between finishing systems, drip loss was higher in EX pigs ($P < 0.01$), differing from IN pigs by 2.30 and 3.34% at 2 and 9 d postmortem, respectively.

For cooking loss after 9 d of ageing, an interaction existed between genetic group and finishing system ($P < 0.01$, means not shown), such that in IB pigs the cooking loss was lower by 3.62% in EX-finished animals ($P < 0.05$), while in F1 pigs a lower cooking loss was observed in IN, with a difference of 1.31% relative to EX-pigs ($P < 0.05$). Mean shear force was lower in IB when compared with F1 pigs, by 0.84 kg at 2 d and 1.14 kg after 9 d of ageing ($P < 0.01$). Between finishing systems, meat from EX-finished animals had shear force lower by 1.03 and 1.14 kg at 2 and 9 d, respectively ($P < 0.01$).

Color Coordinates

The means for color coordinates at 2 and 9 d postmortem are in Table 2. Meat produced by F1 pigs was lighter than that of IB ($P < 0.01$) after 9 d of ageing, but differences were small at 2 d ($P > 0.05$). On the other hand, differences in lightness at day 2 and day 9 were minor among finishing systems ($P > 0.05$). The means for redness at 2 and 9 d postmortem were higher ($P < 0.05$) in IB than in F1 pigs (mean a^* higher by 3.95 and 3.13 points at day 2 and day 9, respectively), and in EX than in IN (mean a^* higher by 3.17 and 2.03 points, respectively). The degree of yellowness at 2 d postmortem was higher ($P < 0.01$) by 1.57 points in IB than in F1 pigs, but at 9 d the difference was minor ($P > 0.05$). The meat from EX pigs had a stronger yellow color ($P < 0.01$), with a difference relative to IN of 1.65 and 0.97 points at 2 and 9 d postmortem, respectively. The mean Chroma values at 2 and 9 d postmortem were higher in IB than in F1 pigs (difference of 4.09 and 2.69, respectively) and in EX-relative to IN-finished animals (difference of 3.56 and 2.23). When values for Hue angle were compared, the mean was higher in F1 relative to IB (difference of 4.91 and 6.77 at 2 and 9 d postmortem, respectively), and in IN-relative to EX-finished pigs (difference of 2.97 and 2.10 at 2 and 9 d postmortem, respectively).

Sensory Attributes

Mean scores for meat sensory attributes (Table 3) indicate that the major differences were observed between genetic groups, with higher scores in all traits consistently attributed to meat produced by IB pigs. On the other hand, finishing system generally had a minor effect on sensory attributes of meat ($P > 0.05$), except for the case of meat tenderness and global acceptability, where

an interaction between genetic group and finishing system was observed ($P < 0.05$).

When compared with F1 pigs, meat from IB had mean juiciness higher by 1.63 points ($P < 0.01$), while flavor intensity and acceptability were higher by 0.34 and 0.48 points, respectively ($P < 0.01$). The results for the interaction between genetic group and finishing system in sensory variables where it was significant are shown in Figure 1. The results indicate that meat tenderness was higher in IB when compared with F1 pigs, by 0.90 and 1.28 points in the EX and IN systems, respectively. On the other hand, meat tenderness of IB pigs was higher in IN by 0.17 points when compared with EX, while for F1 pigs tenderness was higher in EX by 0.21 points. Overall, global acceptability was higher in IB when compared with F1 pigs, but the advantage of IB was more pronounced when they were finished intensively, with a difference relative to F1 of 1.20 in IN and 0.91 in EX-finished pigs. On the other hand, global acceptability of meat was similar in F1 pigs from either finishing system, but IB meat received a higher score in IN-finished animals, with a difference of 0.29 points relative to those finished in EX.

The stepwise regression analyses of sensory panel variables as a function of physical properties of meat (Table 4) indicate that, in the data set analyzed, color characteristics and pH did not have a significant influence on the various sensory attributes considered ($P > 0.10$). The standardized regression coefficients indicate that the more consistent and more influential physical variable relating to all sensory attributes was marbling ($P < 0.05$), such that there was an increase in the score of the various sensory variables analyzed when marbling score increased, with regression coefficients ranging from 0.154 (flavor intensity) to 0.509 (juiciness) points per unit of marbling score. The second more influential physical variable was shear force, which had a negative relationship with juiciness, tenderness, flavor acceptability, and global acceptability. Moreover, an increased cooking loss was associated with increased tenderness, flavor acceptability, and global acceptability, while an increased drip loss had a minor impact on global acceptability. Differences in flavor intensity were poorly explained by variability in marbling ($r^2 = 0.33$). However, for the remaining sensory properties the coefficient of determination of the prediction model ranged between about 0.59 and 0.83, indicating that the few physical characteristics included in the linear model, especially marbling, explained relatively well the variability observed in sensory attributes. Overall, global acceptability of meat increased as

Figure 1. Least-squares means for sensorial tenderness and global acceptability determined by a taste panel in *L. thoracis* samples from Iberian (IB) and F1 Large White $\times$ Landrace (F1) pigs finished extensively (EX) or intensively (IN). Sensory variables were scored in a scale of 1 to 8 (higher values desirable). Means with different letter differ ($P < 0.05$).

Table 4. Regression coefficients estimated by multiple regression of sensory panel variables on the physical properties of meat in Iberian and F1 Large White $\times$ Landrace pigs finished extensively or intensively, and coefficient of determination of the prediction model¹

Physical properties	Sensory panel variables ²				
	Juiciness	Tenderness	Flavor intensity	Flavor acceptability	Global acceptability
Intercept	4.458 (0)	4.029 (0)	2.944 (0)	4.384 (0)	3.838 (0)
Marbling	0.509 (0.863)**	0.393 (0.767)**	0.154 (0.575)*	0.232 (0.664)**	0.308 (0.679)**
Cooking loss		0.101 (0.481)*		0.082 (0.573)*	0.114 (0.612)**
Drip loss					-0.058 (-0.312) [†]
Shear force	-0.169 (-0.200) [†]	-0.287 (-0.392)*		-0.204 (-0.410) [†]	-0.250 (-0.385)*
R ²	0.834	0.689	0.332	0.588	0.787

Standardized coefficients are in brackets.

¹Physical variables were retained in the backward elimination procedure model if $P < 0.10$.

²All sensory panel variables scored in a scale of 1 to 8 (higher values desirable).

[†] $P < 0.10$, * $P < 0.05$, and ** $P < 0.01$ represent the significance of regression coefficients.

marbling and cooking loss increased, and declined with increased shear force and drip loss.

Effects of Ageing

Changes in meat physical properties with ageing between 2 and 9 d postmortem were evaluated, and the corresponding results are in Table 5. The more consistent result was a decline in shear force of about 0.9 kg with ageing for 9 d ($P < 0.05$), which was similar in the genetic groups and finishing systems studied. Drip loss increased with ageing by about 1.8% in IB ($P < 0.05$), and by about 1.6% in EX-finished pigs, while the increase in drip loss in F1 and IN-finished pigs was minor ($P < 0.05$). On the other hand, cooking loss did not change with ageing ($P > 0.05$). Ageing caused an increase ($P < 0.05$) in meat L*, a*, b*, and Chroma in IN pigs, while EX pigs showed a significant increase in Hue but no changes ($P > 0.05$) in the other color coordinates. Ageing did not affect ($P > 0.05$) the color coordinates of meat in

IB pigs, but in F1 there was an increase ($P < 0.05$) in L*, b*, Chroma value, and Hue angle with 9 d of ageing.

DISCUSSION

IB pigs are usually reared in the southwest of the IB Peninsula under free-range conditions, in oak- and cork-tree forests, in a system known as “dehesa” in Spain, and “montado” in Portugal, where acorns and pasture are the major feed source (Rodríguez-Estevéz et al., 2012). The majority of IB meat is consumed as high-quality dry-cured products, which are highly priced, especially when they are produced under “dehesa” conditions (Andrés et al., 2000). However, in this production system it may take up to 2 years for pigs to reach the target slaughter weight of 150 to 160 kg (Lopez-Bote, 1998; Mayoral et al., 1999), and crossbreeding and indoor rearing have been adopted as possible alternatives in the last few years (Robina et al., 2013). It is well known that the quality of dry products is affected by both crossbreeding and finishing system

Table 5. Changes in meat properties with ageing for 9 d, considering physical characteristics and color coordinates determined in *L. thoracis* samples from Iberian (IB) and F1 Large White × Landrace (F1) pigs finished extensively (EX) or intensively (IN)^{1,2,3}

Change with ageing from day 2 to day 9 <i>pm</i>	Genetic group		Finishing system		<i>P</i> -value ⁴			RSD ⁵
	IB (<i>n</i> = 60)	F1 (<i>n</i> = 58)	EX (<i>n</i> = 58)	IN (<i>n</i> = 60)	GG	FS	GG × FS	
Drip loss (%)	1.79*	0.43	1.59*	0.63	0.13	0.06	0.01	2.00
Cooking loss (%)	0.42	−0.42	−0.01	0.01	<0.67	0.99	0.87	4.42
Shear force (kg)	−1.07*	−0.77*	−0.96*	−0.87*	0.47	0.64	0.57	0.93
L*	−0.58	1.93*	0.01	1.34*	0.12	0.09	0.27	3.58
a*	−0.21	0.61	−0.36 ^a	0.76 ^{*b}	0.19	<0.01	0.10	1.40
b*	−0.31 ^a	0.95 ^{*b}	−0.02 ^a	0.66 ^{*b}	0.03	0.02	0.49	1.30
Chroma	−0.37	1.04*	−0.32 ^a	1.00 ^{*b}	0.07	<0.01	0.19	1.76
Hue	−0.10	1.76*	1.27*	0.39	0.19	0.21	0.24	3.17

¹Differences, expressed as least-squares means, calculated as trait determined at 9 d—trait determined at 2 d postmortem.

²Mean differences with * differ from zero ($P < 0.05$), indicating that a significant change occurred with ageing.

³Least-squares means for genetic groups or finishing systems with different superscript differ ($P < 0.05$).

⁴*P*-values for the effect of genetic group (GG), finishing system (FS), and GG × FS interaction.

⁵RSD = residual standard deviation.

(Cava et al., 2000; Ventanas et al., 2007a), but it is also important to investigate how the quality of fresh meat is affected by these factors.

The mean pH of meat at 24 h ranged between about 5.5 and 5.7 for the various groups analyzed, which is in the normal range for pigs (O'Neill et al., 2003) and should allow an appropriate meat acidification. Drip loss reflects water holding capacity of meat, and in this study it was higher in meat originating from extensively finished pigs, in line with the results reported in the review by Lebret (2008). On the other hand, meat from crossbred animals had higher drip-loss values than meat from IB pigs, possibly as a result of the slightly lower pH observed in meat from F1 pigs (Fischer, 2007).

The mean marbling score was more than twice as high in IB when compared with F1 pigs, reflecting the much higher deposition of fat in the former group, as the mean IMF of meat, pooled across finishing systems, was about 10% in IB and 3% in F1 pigs. The very high IMF found here in IB is a common feature of this breed, which is further enhanced when pigs are slaughtered above 150 kg (Lopez-Bote, 1998; Robina et al., 2013). However, this is a desirable goal in this breed, because IMF enhances the quality of dry-cured products (Fernandez et al., 1999). The strong adipogenic ability of genetically unimproved local breeds is widely known (Labroue et al., 2000; Franci et al., 2003), while commercial breeds have been strongly selected for leanness over the last decades (Sellier and Rothschild, 1991), thus reducing their tendency to deposit fat. Nevertheless, breed differences in IMF strongly depend on slaughter weight, such that when IB pigs are slaughtered

at a weight near 100 kg the amount of IMF tends to be about 3% (Serra et al., 1998; Estévez et al., 2003; Cava et al., 2004), therefore much closer to other breeds, but the difference widens as slaughter weight increases, given the much higher deposition of adipose tissue in IB pigs.

The differences between genetic groups in IMF were very consistent across finishing systems, which did not differ significantly from each other. It could therefore be concluded that both the commercial and the acorn-rich diet provided enough energy for adipogenesis by the IB pig (Rodríguez-Estévez et al., 2012), even though the response in fat deposition by IB pigs may differ according to the muscle considered (Morales et al., 2003). In our study, the remaining chemical components of meat essentially reflected the high level of IMF in IB pigs, which had lower levels of moisture and protein when compared with F1 pigs.

In this study, the major differences in instrumental meat color were found between genetic groups, such that meat from IB pigs had a globally more intense color, showing a darker, redder, and yellower color at 2 d postmortem, and these differences were largely maintained after 9 d of ageing. According to the quality classification system proposed by van Laack et al. (1994), both IB and F1 pigs produced meat with no intrinsic quality deviations, with a mean L* between 52 and 58 and drip loss (2 d) of less than 5%. Juárez et al. (2009) evaluated the color of the tenderloin in various strains of IB and in crossbred pigs, and found differences for color parameters between breeds comparable to those in our study. Similar findings were reported

by Serra et al. (1998), who also detected lower values of L^* and Hue^* and higher values of $Chroma^*$ in the *L. lumbarum* of IB when compared with Landrace pigs. These authors also found significant differences in histochemical characteristics between breeds, which may justify color differences, with a higher content of oxidative fibers in IB than in LR pigs. In our study we compared IB and crossbred F1 (LW $\times$ LR) pigs, and it has been shown (Serra et al., 1998) that strains selected for faster growth and leanness normally present a higher percentage of fast fibers (IIB) and stronger glycolytic metabolism than native breeds. Juárez et al. (2009) reported that the proportion of oxidative fibers is higher in muscles of IB pigs, than in more selected breeds such as Duroc. As a consequence, muscles from IB pigs may have more heme pigments than those from crossbred pigs, as indicated by Franco et al. (2014), who reported a close relationship between meat color and heme pigment concentration in Celtic pigs. Overall, in our study the pork obtained from IB had a more desirable color, as an intense color is preferable for consumers as well as for manufacturing dry-cured meat products (Muriel et al., 2004). Pigs raised in EX showed higher values for L^* , a^* and b^* , with the largest difference in the red component. In agreement with our results, Lebret et al. (2006) reported a minor increase in L^* , a^* , and b^* mean values in Longissimus, Biceps femoris, and Semimembranosus from F1 (LW $\times$ LR) pigs raised outdoors when compared with those raised indoors.

In our study, the shear force of meat at 2 d postmortem was considerably lower in IB pigs when compared with meat from F1 pigs, and the difference increased after 9 d of ageing. In the finishing systems analyzed, shear force was significantly lower in EX when compared with IN, both at 2 and 9 d postmortem. These results indicate that meat from IB consistently has a much lower shear force than F1 meat and a similar pattern was observed among finishing systems, with a more pronounced reduction in shear force when pigs are extensively finished. Surprisingly, few authors have assessed meat shear force in the *L. thoracis* and *lumbarum* of IB in comparison with commercial pigs. Still, our results for IB are of the same magnitude as those reported by Tejerina et al. (2012) who studied IB pigs slaughtered at 90 kg after intensive or extensive finishing, and found no difference between shear force in the two systems. Lebret et al. (2015), on the other hand, reported a higher meat shear force in Basque pigs raised extensively when compared with those under conventional intensive

finishing, and van der Wal et al. (1993) found the same pattern when comparing pigs raised outdoors or indoors. Juárez et al. (2009) evaluated shear force of the tenderloin in various strains of IB and in crossbred pigs, and found no differences among them. This study confirms the lower shear force observed in meat from IB in comparison with crossbred pigs, and of meat from animals finished on acorn and pasture relative to those finished intensively. This is a very important result, which could be used to add value to fresh meat obtained from IB pigs raised extensively, thus contributing to support the sustainability of this production system (Lopez-Bote, 1998).

The evaluation of tenderness obtained in the taste panel was consistent with the pattern found for instrumental shear force, with a much higher tenderness score in IB pigs, regardless of the finishing system. Indeed, all the sensory traits evaluated received a higher score in IB meat, particularly for juiciness and global acceptability. Differences in flavor intensity and flavor acceptability were smaller, but still in favor of IB relative to F1 pigs, which could be a consequence of the higher IMF in IB pigs, or due to the different fatty acid profiles of IMF in the two genetic groups, with higher amounts of MUFA cis-9 and lower amounts of PUFA n-6 and n-3 in IB pigs (Bressan et al., 2017).

The results of the multiple regression analyses in our study supported that the differences observed between meats originating from the two genetic groups were largely explained by the higher fat deposition in IB pigs, such that a higher level of marbling was positively associated with all the sensory attributes evaluated. On the other hand, a higher shear force (which was observed in F1 pigs) was negatively associated with the scores attributed by the taste panel to juiciness, tenderness, flavor acceptability, and global acceptability. The general conclusion was that, from the standpoint of sensory attributes, the most desirable meat should have a high amount of marbling and low shear force, and this corresponded to the profile of IB meat, regardless of the finishing system considered. This result reflects the well-known positive correlation of IMF with tenderness, juiciness, and flavor of pork, confirming that marbling contributes to better meat palatability (Savell and Cross, 1988). However, the high IMF level in IB pigs may have a negative impact on the nutritional value of their meat, since it contributes negatively to the fat balance in human diets (Schmid, 2010).

The differences in sensory attributes between meats originating from the two finishing systems

were much smaller than those due to genetic groups, but global acceptability and flavor were slightly higher in intensively finished animals. This is in contrast with dry-cured IB products, where those obtained from extensively finished animals consistently receive higher scores (Muriel et al., 2004; Ventanas et al., 2007a). However, the results in the literature are somewhat inconsistent regarding the effect of indoor versus outdoor rearing on the sensory properties of fresh meat in pigs. For example, Enfält et al. (1997) with Duroc- and Yorkshire-sired pigs, and Jonsäll et al. (2001) with Hampshire-sired pigs, found that the ham from outdoor-raised pigs had lower tenderness, juiciness, and meat acceptability than when ham was obtained from indoor-raised pigs. However, van der Wal et al. (1993) found no differences in those sensory properties when assessed in the loins of breed-undefined pigs finished indoors or outdoors. Martínez et al. (2012) compared the sensory properties of commercially purchased meat from IB pigs (finished on acorns or intensively) and commercial white pigs, in a consumer panel. In this work, panelists were able to discriminate between meats originating from IB and commercial pigs, mostly due to differences in texture and flavor, but differences between fresh meats from IB pigs finished on acorns or intensively were minor. Overall, the results published so far are conflicting, and probably reflect the inconsistencies that can be expected from studies that use very different indoors and outdoors finishing systems, which will inevitably have different consequences in terms of meat sensory attributes.

Ageing is not as common in pork as it is in beef, but it may nevertheless be an interesting alternative to improve pork quality (Farouk et al., 2009). Several authors have investigated the benefits of ageing in pork, covering a broad range of breeds and production systems, and have consistently reported a decline in meat shear force (Channon et al., 2004; Bowker et al., 2010), often accompanied by an improvement in meat color (Lindahl et al., 2006; Juárez et al., 2011) and sensory attributes (Ellis et al., 1998). In our study, ageing meat for 9 d resulted in a decrease in shear force of about 0.9 kg, which was similar in the various groups assessed. Ageing also caused some increase in drip loss of meat, but cooking loss did not change significantly. Changes in meat color with ageing were more pronounced in meat from F1 and intensively finished animals, with increased lightness, redness, and yellowness over the ageing period, thus resulting in meat with more appealing color coordinates. Taken together, our results

confirm that wet-ageing for 9 d benefits the quality of pork, with a significant improvement of instrumental meat tenderness and some enhancement of meat color, particularly in crossbred pigs and the group finished intensively.

CONCLUSIONS

In our study we compared meat obtained from IB and crossbred Large White × Landrace pigs finished intensively or on pasture and acorn. For all the traits analyzed, genetic group had a much stronger effect than finishing system, and interactions of the two factors were seldom observed. Overall, IB pigs produced meat with slightly higher pH, much higher marbling and IMF, more intense darker and redder color, lower shear force, and more desirable sensory properties. The effect of finishing system was moderate, but flavor acceptability and global acceptability were slightly higher in intensively finished pigs, in spite of a higher shear force. In conclusion, our results indicate that the well-known superiority of dry-cured products obtained from IB pigs is also observed in their fresh meat, but no clear benefits could be demonstrated in the properties of fresh meat from animals finished on acorns and pasture.

LITERATURE CITED

- AMSA. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. Version 1.0. 2nd ed. American Meat Science Association and National Livestock and Meat Board, Chicago, IL, USA.
- Andrés, A. I., J. Ruiz, A. I. Mayoral, J. F. Tejeda, and R. Cava. 2000. Influence of rearing conditions and crossbreeding on muscle color in Iberian pigs Influencia de las condiciones de crianza y del cruce en el color de los músculos de cerdos Ibéricos. *Food Sci. Technol. Int.* 6:315–321. doi:10.1177/108201320000600406
- AOAC. 2000. Official methods of analysis of AOAC International. 17th ed. Association of Official Analytical Chemists Publisher, Gaithersburg, Maryland.
- Bowker, B. C., M. N. Liu, J. S. Eastridge, J. A. Callahan, E. W. Paroczay, and M. B. Solomon. 2010. Effect of post-mortem aging and hydrodynamic pressure processing on pork loin quality. *J. Muscle Foods.* 21:379–398. doi:10.1111/j.1745-4573.2009.00189.x
- Bressan, M. C., J. Almeida, J. Santos Silva, C. Bettencourt, A. Francisco, and L. T. Gama. 2016. Carcass characteristics and fat depots in Iberian and F large white × landrace pigs intensively finished or raised outdoors in oak-tree forests. *J. Anim. Sci.* 94:2592–2602. doi:10.2527/jas.2016-0276
- Bressan, M. C., C. Bettencourt, P. Portugal, J. Almeida, J. Santos-Silva, O. Moreira, A. T. Belo, S. P. Alves, R. Bessa, and L. T. Gama. 2017. Lipid profile of intramuscular fat in Iberian and F1 Large White x Landrace pigs finished intensively or in the “dehesa” system. *Proceedings of 4th Fatty Pig International Conference*; November 23–25, 2017; Badajoz, Spain. p. 117.

- Čandek-Potokar, M., and M. Škrlep. 2012. Factors in pig production that impact the quality of dry-cured ham: a review. *Animal* 6:327–338. doi:10.1017/S1751731111001625
- Cava, R., J. Manuel Ferrer, M. Estévez, D. Morcuende, and F. Toldrá. 2004. Composition and proteolytic and lipolytic enzyme activities in muscle *Longissimus dorsi* from Iberian pigs and industrial genotype pigs. *Food Chem.* 88:25–33. doi:10.1016/j.foodchem.2003.07.037
- Cava, R., J. Ventanas, J. Ruiz, A. I. Andrés, and T. Antequera. 2000. Sensory characteristics of Iberian ham: influence of rearing system and muscle location/ Características sensoriales del jamón Ibérico: influencia del sistema de engorde y del músculo. *Food Sci. Technol. Int.* 6:235–242. doi:10.1177/108201320000600306
- Channon, H. A., M. G. Kerr, and P. J. Walker. 2004. Effect of duroc content, sex and ageing period on meat and eating quality attributes of pork loin. *Meat Sci.* 66:881–888. doi:10.1016/j.meatsci.2003.08.010
- Ellis, M., M. S. Brewer, D. S. Sutton, H. Y. Lan, R. C. Johnson, and F. K. McKeith. 1998. Aging and cooking effects on sensory traits of pork from pigs of different breed lines. *J. Muscle Foods.* 9:281–291. doi:10.1111/j.1745-4573.1998.tb00661.x
- Enfält, A. C., K. Lundström, I. Hansson, N. Lundeheim, and P. E. Nyström. 1997. Effects of outdoor rearing and sire breed (Duroc or Yorkshire) on carcass composition and sensory and technological meat quality. *Meat Sci.* 45:1–15. doi:10.1016/S0309-1740(96)00101-5
- Estévez, M., D. Morcuende, and R. Cava López. 2003. Physico-chemical characteristics of *M. Longissimus dorsi* from three lines of free-range reared Iberian pigs slaughtered at 90 kg live-weight and commercial pigs: a comparative study. *Meat Sci.* 64:499–506. doi:10.1016/S0309-1740(02)00228-0
- European Parliament. 2010. Directive 2010/63/EU of the European Parliament and the Council of 22 September 2010 on the protection of animals used for scientific purposes. Available from <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:276:0033:0079:en:PDF> (accessed 2 February 2015).
- Farouk, M. M., E. Wiklund, and K. Rosenqvist. 2009. Carcass interventions and meat tenderness. In: J. P. Kerry, and D. Ledward, editors. *Improving the sensory and nutritional quality of fresh meat*. CRC Press LLC, Boca Raton, FL. p. 561–584.
- Fernandez, X., G. Monin, A. Talmant, J. Mourot, and B. Lebret. 1999. Influence of intramuscular fat content on the quality of pig meat — 1. Composition of the lipid fraction and sensory characteristics of *m. Longissimus lumborum*. *Meat Sci.* 53:59–65. doi:10.1016/S0309-1740(99)00037-6
- Fischer, K. 2007. Drip loss in pork: influencing factors and relation to further meat quality traits. *J. Anim. Breed. Genet.* 124(Suppl 1):12–18. doi:10.1111/j.1439-0388.2007.00682.x
- Franci, O., G. Campodoni, R. Bozzi, C. Pugliese, A. Acciaioli, and G. Gandini. 2003. Productivity of Cinta Senese and Large White x Cinta Senese pigs reared outdoors in woodlands and indoors. 2. Slaughter and carcass traits. *Ital. J. Anim. Sci.* 2:59–65. doi:10.4081/ijas.2003.59
- Franco, D., J. A. Vazquez, and J. M. Lorenzo. 2014. Growth performance, carcass and meat quality of the Celta pig crossbred with Duroc and Landrace genotypes. *Meat Sci.* 96:195–202. doi:10.1016/j.meatsci.2013.06.024
- International Organization for Standardization. 2012. *Sensory analysis - General guidance for selection, training and monitoring of assessors and expert sensory assessors*, ISO 8586:2012. International Organization for Standardization, Genève, Switzerland.
- Isabel, B., C. J. Lopez-Bote, L. de la Hoz, M. Timón, C. Garcia, and J. Ruiz. 2003. Effects of feeding elevated concentrations of monounsaturated fatty acids and vitamin E to swine on characteristics of dry cured hams. *Meat Sci.* 64:475–482. doi:10.1016/S0309-1740(02)00225-5
- Jonsäll, A., L. Johansson, and K. Lundström. 2001. Sensory quality and cooking loss of ham muscle (*M. Biceps femoris*) from pigs reared indoors and outdoors. *Meat Sci.* 57:245–250. doi:10.1016/S0309-1740(00)00097-8
- Juárez, M., W. R. Caine, M. E. R. Dugan, N. Hidirolou, I. L. Larsen, B. Uttaro, and J. L. Aalhus. 2011. Effects of dry-ageing on pork quality characteristics in different genotypes. *Meat Sci.* 88:117–121. doi:10.1016/j.meatsci.2010.12.011
- Juárez, M., I. Clemente, O. Polvillo, and A. Molina. 2009. Meat quality of tenderloin from Iberian pigs as affected by breed strain and crossbreeding. *Meat Sci.* 81:573–579. doi:10.1016/j.meatsci.2008.10.016
- van Laack, R. L., R. G. Kauffman, W. Sybesma, F. J. Smulders, G. Eikelenboom, and J. C. Pinheiro. 1994. Is colour brightness (L-value) a reliable indicator of water-holding capacity in porcine muscle? *Meat Sci.* 38:193–201. doi:10.1016/0309-1740(94)90109-0
- Labroue, F., P. Guillou, H. Marsac, M. Boisseau, M. Luquet, J. Arrayet, F. Martinat-Botté, and M. Terqui. 2000. Etude des performances de reproduction de 5 races locales porcines françaises. *Journ. Rech. Porc. en Fr.* 32:413–418.
- Lebret, B. 2008. Effects of feeding and rearing systems on growth, carcass composition and meat quality in pigs. *Animal* 2:1548–1558. doi:10.1017/S1751731108002796
- Lebret, B., P. Ecolan, N. Bonhomme, K. Méteau, and A. Prunier. 2015. Influence of production system in local and conventional pig breeds on stress indicators at slaughter, muscle and meat traits and pork eating quality. *Animal* 9:1404–1413. doi:10.1017/S1751731115000609
- Lebret, B., M. C. Meunier-Salaün, A. Foury, P. Mormède, E. Dransfield, and J. Y. Dourmad. 2006. Influence of rearing conditions on performance, behavioral, and physiological responses of pigs to preslaughter handling, carcass traits, and meat quality. *J. Anim. Sci.* 84:2436–2447. doi:10.2527/jas.2005-689
- Lindhagl, G., A. H. Karlsson, K. Lundström, and H. J. Andersen. 2006. Significance of storage time on degree of blooming and colour stability of pork loin from different crossbreeds. *Meat Sci.* 72:603–612. doi:10.1016/j.meatsci.2005.09.018
- Lopez-Bote, C. J. 1998. Sustained utilization of the Iberian pig breed. *Meat Sci.* 49:S17–S27. doi:10.1016/S0309-1740(98)90036-5
- Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. *Meat Sci.* 71:100–121. doi:10.1016/j.meatsci.2005.03.003
- Martínez, B., B. Rubio, M. Vaquero, and M. J. Sánchez. 2012. Consumers attitudes to Iberian pork meat. Options Méditerranéennes. Série A. Séminaires Méditerranéens. 101:463–466. Available from <http://om.ciheam.org/om/pdf/a101/00006728.pdf> (accessed 2 February 2015).

- Mayoral, A. I., M. Dorado, M. T. Guillén, A. Robina, J. M. Vivo, C. Vázquez, and J. Ruiz. 1999. Development of meat and carcass quality characteristics in Iberian pigs reared outdoors. *Meat Sci.* 52:315–324. doi:10.1016/S0309-1740(99)00008-X
- McGuire, R. G. 1992. Reporting of objective color measurements. *HortScience* 27:1254–1255.
- Merks, J. W. M. 2000. One century of genetic changes in pigs and the future needs. In: W. G. Hill, S. C. Bishop, B. McGuirk, J. C. McKay, G. Simm, and A. J. Webb, editors. *The challenge of genetic change in animal production*. British Society of Animal Science, Edinburgh. p. 8–19.
- Morales, J., M. Baucells, J. Pérez, J. Mourrot, and J. Gasa. 2003. Body fat content, composition and distribution in Landrace and Iberian finishing pigs given ad libitum maize- and acorn-sorghum-maize-based diets. *Anim. Sci.* 77:215–224. doi:10.1017/S1357729800058951
- Muriel, E., J. Ruiz, J. Ventanas, M. Jesús Petró, and T. Antequera. 2004. Meat quality characteristics in different lines of Iberian pigs. *Meat Sci.* 67:299–307. doi:10.1016/j.meatsci.2003.11.002
- National Pork Board. 2015. Pork quality standards chart. <https://www.ams.usda.gov/sites/default/files/media/PorkQualityStandards.pdf> (Accessed 2 February 2015).
- O'Neill, D. J., P. B. Lynch, D. J. Troy, D. J. Buckley, and J. P. Kerry. 2003. Influence of the time of year on the incidence of PSE and DFD in Irish pigmeat. *Meat Sci.* 64:105–111. doi:10.1016/S0309-1740(02)00116-X
- Pugliese, C., and F. Sirtori. 2012. Quality of meat and meat products produced from southern European pig breeds. *Meat Sci.* 90:511–518. doi:10.1016/j.meatsci.2011.09.019
- Robina, A., J. Viguera, T. Perez-Palacios, A. I. Mayoral, J. M. Vivo, M. T. Guillen, and J. Ruiz. 2013. Carcass and meat quality traits of Iberian pig as affected by sex and crossbreeding with different Duroc genetic lines. *Spanish J. Agric. Res.* 11:1057. doi:10.5424/sjar/2013114-4637
- Rodríguez-Estévez, V., M. Sanchez-Rodríguez, C. Arce, A. R. Garcia, J. M. Perea and A. G. Gómez-Castro. 2012. Consumption of acorns by finishing Iberian pigs and their function in the conservation of the dehesa agroecosystem. In: D. M. Kaonga, editor. *Agroforestry for biodiversity and ecosystem services - science and practice*. InTech, Rijeka, Croatia. p. 1–22.
- Ruiz, J., C. García, E. Muriel, A. I. Andrés, and J. Ventanas. 2002. Influence of sensory characteristics on the acceptability of dry-cured ham. *Meat Sci.* 61:347–354. doi:10.1016/S0309-1740(01)00204-2
- Savell, J. W., and H. R. Cross. 1988. The role of fat in the palatability of beef, pork, and lamb. In: Committee on Technological Options to Improve the Nutritional Attributes of Animal Products, National Research Council, editor. *Designing foods: animal product options in the marketplace*. Academies Press (US), Washington (DC). p. 345–355.
- Schmid, A. 2010. The role of meat fat in the human diet. *Crit. Rev. Food Sci. Nutr.* 51:50–66. doi:10.1080/10408390903044636
- Sellier, P., and M. F. Rothschild. 1991. Breed identification and development in pigs. In: K. Majjala, editor. *Genetic resources of pig, sheep and goat, world animal science*. Elsevier Science Publishers, Amsterdam, The Netherlands. p. 125–143.
- Serra, X., F. Gil, M. Pérez-Enciso, M. Oliver, J. Vázquez, M. Gispert, I. Díaz, F. Moreno, R. Latorre, and J. Noguera. 1998. A comparison of carcass, meat quality and histochemical characteristics of Iberian (Guadyrvas line) and Landrace pigs. *Livest. Prod. Sci.* 56:215–223. doi:10.1016/S0301-6226(98)00151-1
- Tejerina, D., S. García-Torres, and R. Cava. 2012. Water-holding capacity and instrumental texture properties of m. Longissimus dorsi and m. serratus ventralis from Iberian pigs as affected by the production system. *Livest. Sci.* 148:46–51. doi:10.1016/j.livsci.2012.05.005
- Ventanas, S., J. Ventanas, and J. Ruiz. 2007a. Sensory characteristics of Iberian dry-cured loins: influence of cross-breeding and rearing system. *Meat Sci.* 75:211–219. doi:10.1016/j.meatsci.2006.07.003
- Ventanas, S., J. Ventanas, J. Tovar, C. García, and M. Estévez. 2007b. Extensive feeding versus oleic acid and tocopherol enriched mixed diets for the production of Iberian dry-cured hams: effect on chemical composition, oxidative status and sensory traits. *Meat Sci.* 77:246–256. doi:10.1016/j.meatsci.2007.03.010
- van der Wal, P. G., G. Mateman, A. W. de Vries, G. M. Vonder, F. J. Smulders, G. H. Geesink, and B. Engel. 1993. 'Scharrel' (free range) pigs: carcass composition, meat quality and taste-panel studies. *Meat Sci.* 34:27–37. doi:10.1016/0309-1740(93)90016-B