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Carcass and meat quality traits of Iberian pigs as affected by sex and crossbreeding with different Duroc genetic lines

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Abstract

A total of 144 pigs were used to study the effects of sex (barrows or gilts) and terminal sire line (Iberian or three genetic lines of Duroc: Duroc 1, Duroc 2 and Duroc 3) on performance and carcass and meat quality traits. Gilts showed slightly lower average daily gain, shoulder weight and trimming losses, but slightly better primal cuts yields and higher loin weight, while there was no significant effect of sex on meat quality traits or on the fatty acid composition of lard and muscle. There were important differences in performance and in carcass and primal cuts quality traits between pure Iberian pigs and all Iberian × Duroc crossbreeds evaluated, partly due to the lower slaughter weights reached by the formers. The different sire lines showed differences in several traits; Duroc 1 group showed lower backfat thickness and ham and shoulder trimming losses, and higher primal cut yields than Duroc 2 and Duroc 3 groups. Intramuscular fat (IMF) content remained unaffected by crossbreeding, but meat color resulted more intense and redder in crosses from the Duroc 1 sire line. The accumulation of fatty acids in lard was not affected by Duroc sire line, while animals of the group Duroc 2 showed higher levels of monounsaturated fatty acid and lower of polyunsaturated ones in IMF. These results highlight the importance of considering not only performance, but also carcass and meat quality traits when deciding the Duroc sire line for crossbreeding in Iberian pig production.

Additional key words: biopsies; primal cuts; backfat thickness; fatty acid profile; color; intramuscular fat.

Introduction

The free-range rearing of Iberian pigs in the southwest of Spain is mainly supported by the elaboration of dry-cured meat products of special and highly valued sensory characteristics (Ruiz *et al.,* 2002). In order to increase yields and to reduce the high cost of this productive system, crossbreeding and indoor rearing have been adopted as common productive strategies in recent years (Isabel *et al.,* 2003). Such modifications of the traditional productive system of pigs have led to a decrease in the sensory quality of dry-cured products (Muriel *et al.,* 2004; Ventanas *et al*., 2007a).

Iberian meat and meat products quality is based, among others factors, in the presence of high levels of intramuscular fat (IMF), the great concentrations of heme pigments and the high levels of monounsaturated fatty acids (MUFA) (Ruiz *et al.,* 2002). Accordingly, marbling and color intensity are considered as quality indexes by consumers (Muriel *et al.,* 2004; Ventanas *et al.,* 2007b). IMF also contributes to the technological quality of meat and meat products from Iberian pigs (Ruiz *et al.,* 2002; Morcuende *et al.,* 2003); it influences aroma development due to the lipolytic and oxidative processes that occur during the curing process (Antequera *et al.,* 1993; Muriel *et al.,* 2007). Thus,

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Abbreviations used: ADG (average day gain); CW (carcass weight); FA (fatty acid); FAME (fatty acid methyl esters); GC-FID (gas chromatograph-flame ionization detector); GC-MS (gas chromatograph-mass spectrometer); IMF (intramuscular fat); LM (*longissimus dorsi* muscle); LW (live weight); MUFA (monounsaturated fatty acids); PUFA (polyunsaturated fatty acids); SFA (saturated fatty acids); SM (*semimembranosus* muscle); SW (slaughter weight).

crossbreeding aimed to improve productive traits has been mainly performed using the Duroc breed, minimizing the reduction in IMF content that could be occasioned if other pig breeds were used (Ramírez & Cava, 2007).

Nevertheless, consumers consider that dry-cured products rom purebred Iberian pigs show better sensory traits than those from crossbred genotypes (Ventanas *et al.,* 2007b). Therefore, the selection of the Duroc lines aimed to crossbreeding with Iberian pigs is a key factor for optimizing productive performance without detrimental effects on quality. The worldwide distribution of Duroc breed has favoured a great heterogeneity, since genetic selection has been carried out following different productive and meat quality criteria (Jonnes, 1998). Several authors have found differences in carcass and meat quality traits between different Duroc genetic lines (Soriano *et al.,* 2005; Cilla *et al.,* 2006). Moreover, the effect of crossbreeding Iberian pigs with different Duroc genetic lines on carcass and meat quality traits has also been highlighted (Ramírez & Cava, 2007). However, further research about this topic, considering side effects such as the sex of the animal, and paying attention to the potential effect of the terminal sire on the variations of the fatty acid (FA) profile throughout the fattening phase of Iberian and Iberian × Duroc pigs, is needed in order to progress in the selection of genetic lines, that help in the improving of the productive parameters without detrimental effects on Iberian meat and meat products quality.

Thus, the aim of the present work was the evaluation of the effect of crossbreeding Iberian pigs with different Duroc genetic lines as sire breed, together with the effect of using castrated males or gilts on performance and carcass and meat quality traits and on the accumulation of fatty acids in the lard throughout the fattening phase.

Material and methods

Husbandry and diets

All the experimental procedures used were approved by the Animal Ethics Committee of Universidad de Extremadura and were in compliance with the Spanish guidelines for the care and use of animals in research (BOE, 2005). We studied the influence of gender (barrows or gilts) and crossbreeding (pure Iberian —Iberian— or Iberian ♀ from the same genetic line crossbreed with three different lines of Duroc ♂ —Duroc 1, Duroc 2, Duroc 3—) on carcass and meat quality traits of fattened pigs slaughtered, using a total of 144 pigs (n = 18 for each group), coming from 16 different litters. Duroc 1 and Duroc 2 lines were from "Agropecuaria Robina S.L." and "Ibéricos Señorón S.L.", respectively. Duroc 3 line was from Stamboek (The Netherlands). The Duroc 1 and Duroc 2 sire lines had been selected in the industry for their good carcass performance. The Duroc 3 was selected because of its good productive parameters and meat quality traits. Insemination was carried out with the mix of the semen from three different boars of each line.

The males used in these experiments were castrated at 5 ± 2 d of age and the females were ovariectomized at 60 d of age. At the start of the experiment, pigs weighed 25.4 ± 4.1 kg (79 ± 3.2 d of age). The experiment was conducted at two adjacent natural-environment finishing barns (20 m × 60 m) in which all pigs received the same feeding program and were under similar husbandry conditions. Individual body weight (LW) was recorded at 79, 177, 194, 227, 289 and 324 d on trial, calculating the average daily gain (ADG).

The diets were formulated to meet or exceed pig requirements at these ages according to FEDNA (2006) and were offered for ad libitum consumption. The ingredient composition and the calculated nutrient value (FEDNA, 2003) of the diets are shown in Table 1.

Biopsies sampling

Two subcutaneous shot-biopsies were taken on the same animals during the trial for the determination of the FA profile evolution on the subcutaneous fat tissue following the methodology described by Martín *et al*. (2007). Six animals were randomly selected from each group. The first biopsy was taken at 194 days live time and the second one was taken 33 days later (227 days). In addition, a third backfat sample was taken following the same procedure immediately after slaughter.

Biopsy samples of subcutaneous fat were taken at 6 cm beside the backbone at the level of the last rib using Czech gun (PPB-2 Biotech, Nitra, Slovakia) with an adapted cannula (diameter 0.25 cm) with a sharpened edge. All necessary precautions were taken to prevent animal discomfort during and after the in vivo sampling processes. This included tranquillisation with 40 mg of azaperon (Stressnill, Labopica, Madrid) 1 h before taking the biopsy and local anaesthesia with 2%

Table 1. Ingredient composition and nutritive value of the diets (%, as-fed basis)

Item	Live weight	
	25-87 kg	> 87 kg
Ingredient		
Barley	24.2	15.3
Corn	27.5	16.0
Wheat	13.0	30.2
Rye	5.0	8.0
Peas	8.5	12.5
Soybean meal (47% CP)	17.5	8.6
Wheat bran	—	3.5
Iberian pig lard	0.8	1.7
Calcium carbonate	1.55	1.20
Dicalcium phosphate	0.80	0.40
Sodium chloride	0.40	0.40
Vitamin and mineral premix	1.80[a]	0.20[b]
Calculated analysis[c]		
Metabolizable energy (kcal kg^{-1})	3,150	3,205
Crude protein	15.77	14.50
Ether extract	4.05	4.30
Crude fiber	3.85	4.00
Total ash	6.55	5.30
Total lysine	1.00	0.70
Calcium	0.80	0.78
Total phosphorus	0.66	0.54

[a] L-Lys, DL-Met, L-Thr; 12.000 UI kg^{-1} vit A, 2.400 UI kg^{-1} vit D_3, 25.0 mg kg^{-1} vit E, 25 mg kg^{-1} Cu ($CuSO_4 \cdot 5H_2O$), 2.060 B.G.U. kg^{-1} ENDO-1.4-beta-glucanase; 5.410 F.X.U. kg^{-1} ENDO-1.4-beta-xilanase; 500 FTU kg^{-1} phytases; potasic diformate; formic acid; propionic acid; etoxiquin; B.H.T.; citric acid. [b] 4.680 UI kg^{-1} vit A; 935 UI kg^{-1} vit D_3; 6.7 mg kg^{-1} vit E; 16 mg kg^{-1} Cu ($CuSO_4 \cdot 5H_2O$); formic acid; propionic acid; etoxiquin; B.H.T.; citric acid. [c] According to FEDNA (2003).

lidocaine-HCl immediately prior to sample collection. Biopsies always contained the whole backfat thickness, including both the outer and the inner layers. Afterwards, animals received a 2 mL penicillin intramuscular injection (300,000 IU mL^{-1}, Labopica, Madrid). All samples were vacuum-packaged in plastic bags and frozen at –80°C till analysis.

Carcass traits

All crossbred pigs were slaughtered by electrical stunning and exsanguination at a local slaughterhouse at an average weight of 148.1 kg (pooled SD = 4.7 kg). Iberian pigs were slaughtered 35 d after, in order to reach an acceptable commercial slaughter weight (134.6 kg pooled SD 4.2). Carcass traits were determined in the same six animals used for biopsy sampling. Carcasses were split down the centre of the vertebral column and weighed, and the hot carcass yield was calculated. Carcass length (from cranial border of the first rib to cranial border of the symphysis pubis) and backfat thickness at the level of the last rib were also measured at the slaughterhouse. At 45 min postmortem an incision was made into the *semimembranosus* muscle (SM) of each left ham and the initial pH (pH45; 45 min from slaughter) was measured using a Crison pH meter (Crison 507, Crison Instruments S.A., Barcelona, Spain) equipped with a glass electrode (model 52-11, Crison Instruments S.A., Barcelona, Spain).

Carcasses were jointed to yield hams, shoulders and loins and their weights were measured 2 h postmortem (fresh untrimmed weight). They were subsequently suspended in the air and chilled for 24 h at 4°C. At 24 h post-mortem, hams and shoulders were trimmed of external fat and weighed again, and the trimmed ham and shoulder yields were calculated, and the ultimate pH (pH24) of the SM was measured.

Measurements and analysis

After collection of the carcass data, a sample (300 ± 25 g) and a 1.5 cm thick chop (aprox 45 g) of the *longissimus dorsi* muscle (LM) were excised at the level of the last rib from the left side of six carcasses from each group, which corresponded to the same animals used for biopsy sampling. Objective measures of pork color were determined next day on fresh chops after a 20 min blooming period using a Minolta Colorimeter CR-300 (Minolta Camera Co., Osaka, Japan), programmed to use the built-in internal illuminant D65. Before each series of measurements, the instrument was calibrated using a white ceramic tile. The average of three random readings per sample was used to measure the lightness (L*) and the two color coordinates (redness, *a**; yellowness, *b**). Additionally, the chroma (C*) as $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$ and the hue angle (H°) as $H° = \arctan(b^*/a^*)$ were calculated as estimators of color intensity (Wyszcecki & Stiles, 1982).

Meat samples were weighed, vacuum packaged and frozen at –80°C during 50 d for subsequent analyses.

The IMF were extracted with chloroform/methanol (2:1, vol:vol), according to the method described by Pérez-Palacios *et al.* (2008). Moisture content was determined by drying the ground samples (5 g) at 102°C

(AOAC, 2000). Protein content was determined by the Kjeldahl method (AOAC, 2000).

Fatty acid methyl esters (FAMEs) from backfat biopsies and IMF were prepared by transesterification in presence of sodium metal (0.1 N) and sulfuric acid in methanol (Sandler & Karo, 1992). FAMEs were analysed by gas chromatography using an Agilent 6890N gas chromatograph equipped with a flame ionization detector (FID). Separation was carried out on a polyethyleneglycol capillary column (60 m long, 0.32 mm id and 0.25 mm film thickness) (Supelcowax-10, Supelco, Bellafonte, PA, USA). Oven temperature programming started at 180°C. Immediately, it was raised 5°C min^{-1} to 200°C, held for 40 min at 200°C, increased again at 5°C min^{-1} to 250°C, and held for the last 21 min at 250°C. Injector and detector temperatures were 250°C. The carrier gas was helium at a flow rate of 0.8 mL min^{-1}. Individual FAME peaks were identified by comparing their retention times with those of standards (Sigma, St Louis, MO, USA). To confirm identification, selected samples were subjected to gas chromatography coupled to mass spectrometry (GC-MS) in a HP5890GC series II gas chromatograph (Hewlett-Packard) coupled to a mass selective detector (HP-5971 A, Hewlett-Packard). FAMEs were separated using the same column as that used for GC-FID, with helium operating at 41.3 kPa of column head pressure, resulting in a flow of 1.45 mL min^{-1} at 180°C. The injector and oven program temperatures were the same as for the GC-FID analysis. The transfer line to the mass spectrometer was maintained at 280°C. The mass spectra were obtained by electronic impact at 70 eV, a multiplier voltage of 1756 V, and collecting data at a rate of 1 scan s^{-1} over the m/z range of 30-500. Compounds were tentatively identified by comparing their mass spectra with those contained in the NIST/EPA/NIH and Wiley libraries.

Statistical analysis

Data were analysed as a completely randomized design with gender, crossbreed and their interaction as main effects using the SAS (1990) GLM procedure. The experimental unit was the animal for all traits and the number of pigs per group was 18 for carcass quality traits and 6 for meat quality traits. Initial body weight was used as a covariate for the performance parameters, meanwhile body weight at biopsies sampling was used as a covariate for the fatty acid profile of biopsies, and carcass weight at slaughter was used as a covariate for the carcass and meat quality traits. Data in tables are presented as least square means.

The effect of time of sampling and its respective interaction with gender, crossbreed and gender × crossbreed on the FA profile of subcutaneous shot-biopsies was evaluated by a three-way mixed model repeated-measures test using the SAS (1990) GLM procedure; gender, crossbreed and gender × crossbreed levels being the between-subject effects and time of sampling the within-subject effect.

Means were computed and separated by a t-test. An α value of 0.05 was considered as a significant difference.

Results

Productive performance

Individual LW and ADG during the trial of Iberian swine as affected by gender and crossbreeding are exposed in Table 2. Crossbreeding affected significantly both LW and ADG, while gender led to differences in ADG in the last phases of fattening, and the combined effect crossbreeding × gender did not influence these parameters. Throughout the trial, Iberian × Duroc pigs had higher LW and ADG than Iberian ones. In fact, slaughter weight (SW) was much lower for pure Iberian pigs (134.6 kg), even though these animals were kept until an older slaughter age in order to reach commercial slaughter weights.

There were scarce differences between the three Iberian × Duroc groups. Duroc 2 presented higher LW (27.4 kg) than Duroc 1 and Duroc 3 pigs (24.9 and 24.8 kg, respectively) at 79 d, and between 227-289 d the ADG was significantly higher in Duroc 3 (703 g) than in Duroc 1 and Duroc 2 animals (587 and 632 g, respectively). In relation to the effect of gender, between 79-177 d and 177-194 d, the ADG was lower in gilts (586 and 589 g, respectively) than in barrows (645 and 647 g, respectively).

Carcass quality traits and primal cuts

Table 3 shows the carcass traits of the different groups of Iberian swine of this study. Crossbreeding significantly influenced carcass weight (CW), carcass length and backfact thickness ($p < 0.001$ for all these

Table 2. Productive performance of Iberian swine as affected by gender and crossbreeding

	Crossbreeding				Gender		SEM[1]	Significance[2]		
	Iberian	Duroc 1	Duroc 2	Duroc 3	Gilts	Barrows		P_C	P_G	$P_{C\times G}$
LW (kg)[3]										
79 days	24.6^{b}	24.9^{b}	27.4^{a}	24.8^{b}	25.2	25.7	0.39	0.02	NS	NS
177 days	65.5^{b}	77.0^{a}	78.9^{a}	73.4^{a}	74.2	72.3	1.34	< 0.001	NS	NS
194 days	71.5^{b}	87.2^{a}	88.8^{a}	84.6a	84.7	81.4	1.35	< 0.001	NS	NS
227 days	87.3^{b}	107.6^{a}	110.1^{a}	107.2^{a}	103.5	102.6	1.45	< 0.001	NS	NS
289 days	121.4^{b}	144.5^{a}	149.2^{a}	150.7^{a}	140.2	142.7	1.73	< 0.001	NS	NS
324 days	134.6	—	—	—	132.8	136.4	3.23	—	NS	—
ADG (g)[4]										
79-177 days	390^{b}	528^{a}	547^{a}	491^{a}	499	479	12.7	< 0.001	NS	NS
177-194 days	429^{c}	539^{b}	543^{b}	670^{a}	558	533	18.2	< 0.01	NS	NS
194-227 days	499^{b}	619^{a}	657^{a}	688^{a}	586	645	14.3	< 0.001	0.040	NS
227-289 days	549^{c}	587^{bc}	632^{b}	703^{a}	589	647	13.5	0.007	0.044	NS
289-324 days	423	—	—	—	369	477	29.9	—	0.096	—

[1] SEM: standard error of the mean. [2] P_C: significance of crossbreeding effect; P_G: significance of gender effect; $P_{C\times G}$: significance of their interaction; NS: not significant. Different superscripts within the same row indicate significant differences ($p < 0.05$). [3] LW: live weight. [4] ADG: average day gain.

variables). Measured CW were much lower for Iberian ($p < 0.05$), and was significantly higher for the Duroc 2 crossbred ($p < 0.05$), while the Duroc 1 and Duroc 3 crossbreds showed similar and intermediate values. Carcass yield was around 80% for all groups without any significant difference.

Despite showing lower SW and CW, backfat thickness was significantly higher ($p < 0.05$) in pure Iberian animals (6.6 cm), while crossbred animals from the Duroc 1 sire line showed the lowest ($p < 0.05$) values (4.4 cm) among Iberian × Duroc crosses, and those from the Duroc 2 sire line showed the highest (5.0 cm), with those from the Duroc 3 line obtaining intermediate values (4.5 cm). Finally, carcass length was significantly ($p < 0.05$) shorter in pure Iberian pigs (80.3 cm), while it did not show differences between the different

Table 3. Carcass quality traits and primal cuts parameters of Iberian swine as affected by crossbreeding and gender

	Crossbreeding				Gender		SEM[1]	Significance[2]		
	Iberian	Duroc 1	Duroc 2	Duroc 3	Gilts	Barrows		P_C	P_G	$P_{C\times G}$
Carcass weight (kg)	108.9^{c}	118.7^{b}	123.9^{a}	118.4^{b}	115.3	119.7	1.34	< 0.001	0.067	NS
Carcass lenght (cm)	80.3^{b}	86.5^{a}	85.4^{a}	85.1^{a}	84.6	84.1	0.38	< 0.001	NS	NS
Carcass yield (%)	80.5	80.3	80.2	79.3	80.2	80.0	0.21	NS	NS	NS
Backfat thickness (mm)	6.6^{a}	4.4^{c}	5.0^{b}	4.5^{bc}	5.0	5.3	0.10	< 0.001	NS	NS
Ham lenght (cm)	50.7^{d}	54.7^{a}	53.7^{b}	52.8^{c}	52.8	53.1	0.18	< 0.001	NS	NS
Ham perimeter (cm)	69.3^{b}	75.1^{a}	76.1^{a}	75.1^{a}	73.7	74.1	0.32	< 0.001	NS	NS
Fresh ham weight (kg)	11.0^{c}	14.0^{ab}	14.2^{a}	13.7^{b}	13.2	13.3	0.09	< 0.001	NS	NS
Fresh ham yield (%)	10.2^{c}	11.9^{a}	11.5^{b}	11.6^{b}	11.4	11.1	0.03	< 0.001	< 0.001	< 0.01
Ham trimming losses (%)	21.4^{a}	16.7^{c}	18.0^{b}	17.6^{b}	18.0	18.8	0.21	< 0.001	0.02	NS
Fresh shoulder weight (kg)	7.8^{b}	9.5^{a}	9.4^{a}	9.3^{a}	8.8	9.2	0.06	< 0.001	0.044	NS
Fresh shoulder yield (%)	7.14^{d}	8.05^{a}	7.64^{c}	7.86^{b}	7.68	7.67	0.03	< 0.001	NS	0.094
Shoulder trimming losses (%)	24.2^{a}	20.1^{c}	21.3^{b}	21.1^{b}	21.3	22.1	0.22	< 0.001	0.039	NS
Loin weight (kg)	1.6^{c}	2.5^{a}	2.4^{a}	2.3^{b}	2.3	2.1	0.02	< 0.001	< 0.001	< 0.01
Fresh loin yield (%)	1.5^{c}	2.1^{a}	1.9^{b}	1.9^{b}	1.9	1.8	0.02	< 0.001	< 0.001	<0 .001

[1] SEM: standard error of the mean. [2] P_C: significance of crossbreeding effect; P_G: significance of gender effect; $P_{C\times G}$: significance of their interaction. NS: not significant. Different superscripts within the same row indicate significant differences ($p < 0.05$).

Iberian × Duroc crosses, reaching values between 85.1 and 86.5 cm.

There was a tendency of higher CW for barrows ($p = 0.067$) while the rest of carcass parameters were unaffected by sex.

Values for primal cuts of Iberian swine as affected by crossbreeding and gender are also shown in Table 3. Crossbreeding significantly influenced all measured parameters ($p < 0.001$ for all of them), with Iberian pig obtaining the lowest values ($p < 0.05$) for ham length, ham perimeter and ham, shoulder and loin weights and higher values for ham and shoulder trimming losses, in comparison to the three Iberian × Duroc crosses. Ham length showed significant differences among all these crosses, with Duroc 1 pigs showing the highest ($p < 0.05$) values (54.7 cm), followed by Duroc 2 (53.7 cm) and Duroc 3 (52.8 cm). Ham weight also showed significant differences between crosses, with Duroc 2 showing significantly higher values ($p < 0.05$) than the Duroc 3 group (14.2 kg *vs* 13.7 kg), and Duroc 1 showing intermediate values (14.0 kg). However, shoulder weights showed no significant differences between crossbreds (9.5, 9.4 and 9.3 kg for Duroc 1, Duroc 2 and Duroc 3 groups, respectively). Loin weight was significantly lower ($p < 0.05$) for the animals from the Duroc 3 crossbreed sire line (2.3 kg), while those of the Duroc 1 and Duroc 2 groups showed no differences between them (2.5 and 2.4 kg, respectively).

Ham and shoulder trimming losses were significantly ($p < 0.05$) lower for the animals from the Duroc 1 sire line (16.7 and 20.1%. respectively), while those from the Duroc 2 and Duroc 3 crossbreds showed no differences between them (14.2 and 13.7% for the ham trimming losses, and 21.3 and 21.1% for the shoulder, respectively).

The influence of gender was significant for ham and shoulder trimming losses ($p = 0.02$ and $p = 0.039$, respectively), such parameters showing higher values for barrows. Shoulder weight was significantly higher ($p = 0.044$) for barrows, while loin weight was significantly higher ($p < 0.001$) for gilts.

Meat quality parameters

Values for meat quality parameters in fresh loins from Iberian swine as affected by crossbreeding and gender are shown in Table 4. Gender did not show any significant influence on any of these meat quality traits. Similarly, crossbreeding showed no significant effect on moisture content (average values between 69.6% and 70.8%) and protein content (from 16.4% to 18.7%) or IMF content (from 7.8% to 10.5%).

As far as instrumental color parameters are concerned, all of them were significantly affected by crossbreeding. Thus, L* was significantly ($p < 0.05$) lower for meat of pure Iberian pigs (39.1), followed by crossbred animals from the sire lines Duroc 1 and Duroc 2 (43.1 and 44.0 respectively), while those from the crossbreds from the sire line Duroc 3 showed significantly higher values (47.1). On the other hand, crossbred animals from the sire line Duroc 1 showed significantly ($p < 0.05$)

Table 4. Meat quality parameters and fatty acid profile of loins from Iberian swine as affected by crossbreeding and gender

	Crossbreeding				Gender		SEM[1]	Significance[2]		
	Iberian	Duroc 1	Duroc 2	Duroc 3	Gilts	Barrows		P_C	P_G	$P_{C\times G}$
Moisture (%)	70.8	70.5	69.9	69.6	70.6	69.8	0.32	NS	NS	NS
Intramuscular fat (%)	8.3	8.0	7.8	10.5	8.6	8.7	0.68	NS	NS	NS
Protein (%)	18.0	18.5	18.7	16.4	17.7	18.1	0.54	NS	NS	NS
Color L*	39.1^c	43.1^b	44.0^b	47.1^a	43.2	43.5	0.65	< 0.001	NS	NS
Color a*	9.2^b	10.7^a	9.1^b	9.4^b	9.9	9.3	0.28	0.045	NS	NS
Color b*	2.1^b	3.7^a	3.2^a	4.2^a	3.4	3.2	0.19	< 0.01	NS	NS
Chroma	9.4^b	11.3^a	9.7^b	10.3^{ab}	10.5	9.9	0.28	0.038	NS	NS
Hue angle	12.1^c	18.8^b	19.3^b	23.8^a	18.7	18.3	0.91	< 0.001	NS	NS
Fatty acid profile[3]										
SFA	34.8^{ab}	32.9^c	34.1^{bc}	35.9^a	34.5	34.4	0.35	0.015	NS	NS
MUFA	59.1^a	58.2^{ab}	58.5^a	57.1^b	58.0	58.4	0.23	0.013	NS	NS
PUFA	6.1^c	9.0^a	7.4^b	7.0^{bc}	7.5	7.2	0.23	0.001	NS	NS

[1] SEM: standard error of the mean. [2] P_C: significance of crossbreeding effect; P_G: significance of gender effect; $P_{C\times G}$: significance of their interaction. NS: not significant. Different superscripts within the same row indicate significant differences ($p < 0.05$). [3] SFA: Σ C14:0+C16:0+C17:0+C18:0+C20:0. MUFA: Σ C16:1+C17:1+C18:1+C20:1. PUFA: Σ C18:2+C18:3+C20:2+C20:3+C20:4.

higher a* values (10.7) than those of any of the other groups (9.2 for Iberian ones, 9.1 for Duroc 2 and 9.4 for Duroc 3). Loin from pure Iberian showed significantly lower ($p < 0.05$) b* values (2.1) than any of the Iberian × Duroc crossbreds evaluated (3.7, 3.2 and 4.2 for Duroc 1, Duroc 2 and Duroc 3, respectively). With respect to chroma, animals from the Iberian and Duroc 2 groups showed significantly lower ($p < 0.05$) values (9.4 and 9.7, respectively) than those form the Duroc 1 group (11.3), while animals from the Duroc 3 did not show any significant difference with the other groups (10.3). As far as the Hue angle is concerned, Iberian pigs showed the lowest ($p < 0.05$) values (12.1) followed by animals from the Duroc 1 and Duroc 2 groups (18.8 and 19.3, respectively), while the animals from the Duroc 3 groups showed significantly higher values than any other (23.8).

Subcutaneous shot-biopsies

Table 5 shows the proportion of saturated, monounsaturated and polyunsaturated fatty acids (SFA, MUFA and PUFA, respectively) of subcutaneous fat of Iberian swine throughout the fattening period as affected by gender and crossbreeding. All the FA groups of the backfat showed a significant variation throughout the fattening ($p < 0.001$). In fact, the interaction between time and crossbreeding was significant for SFA ($p = 0.002$) and MUFA ($p < 0.001$), while it was not significant for PUFA.

Breeding influenced the proportion of SFA only at slaughter ($p = 0.001$), with lower SFA values ($p < 0.05$) in pure Iberian (32.6%) than in any of the three Iberian × Duroc crossbreeding groups (34.3%, 33.9% and 34.7% respectively for Duroc 1, Duroc 2 and Duroc 3 groups). The level of MUFA showed a tendency for the crossbreeding at 90 kg LW ($p = 0.079$), and a significant effect at 110 kg LW ($p = 0.016$) and at slaughter ($p < 0.001$). Contrary to SFA, the proportion of MUFA was higher ($p < 0.05$) in Iberian (56.1% at slaughter) than in any of the Iberian × Duroc crossbreds (at slaughter: 52.9%, 53.6% and 52.8% respectively for Duroc 1, Duroc 2 and Duroc 3 groups). The proportion of PUFA was significantly affected by crossbreeding at the three sampling times ($p < 0.001$ for the three). At all times sampled, pure Iberian pigs showed the lowest PUFA values ($p < 0.05$). There were some differences between the different Duroc lines at 90 and 110 kg LW, but none at slaughter.

As far as gender is concerned, it did not influence the proportion of any of the FA groups, and there was only a trend to higher MUFA levels in barrows at slaughter ($p = 0.068$).

Table 5. Changes in the main fatty acid groups (% FAMEs) of subcutaneous fat of Iberian swine throughout fattening as affected by gender and crossbreeding

	Crossbreeding				Gender		SEM[1]	Significance[2]				
	Iberian	Duroc 1	Duroc 2	Duroc 3	Gilts	Barrows		P_C	P_G	$P_{C\times G}$	P_T	$P_{I\times C}$
SFA[3]											< 0.001	0.002
194 days	33.6	32.7	32.4	33.5	33.2	32.9	0.22	NS	NS	0.067		
227 days	33.6	32.8	32.5	33.1	33.1	32.9	0.21	NS	NS	NS		
Slaughter	32.6^b	34.3^a	33.9^a	34.7^a	34.1	33.6	0.21	0.001	NS	NS		
MUFA[4]											< 0.001	< 0.001
194 days	52.5	51.0	51.9	51.6	51.5	52	0.21	0.079	NS	0.053		
227 days	54.2^a	52.5^b	53.4^{ab}	53.2^{ab}	53.2	53.5	0.19	0.016	NS	NS		
Slaughter	56.1^a	52.9^b	53.6^b	52.8^b	53.6	54.2	0.18	< 0.001	0.068	0.012		
PUFA[5]											< 0.001	NS
194 days	14.0^c	16.3^a	15.7^{ab}	14.9^b	15.3	15.2	0.13	< 0.001	NS	NS		
227 days	12.2^c	14.7^a	14.1^{ab}	13.6^b	13.7	13.6	0.11	< 0.001	NS	NS		
Slaughter	11.3^b	12.8^a	12.5^a	12.4^a	12.3	12.2	0.11	< 0.001	NS	NS		

[1] SEM: standard error of the mean. [2] P_C: significance of crossbreeding effect; P_G: significance of gender effect; $P_{C\times G}$: significance of their interaction; P_T: significance of time; $P_{T\times C}$: significance of the interaction time × crossbreeding. NS: not significant. Different superscripts within the same row indicate significant differences ($p < 0.05$). [3] SFA: Σ C14:0+C16:0+C17:0+C18:0+C20:0. [4] MUFA: Σ C16:1+C17:1+C18:1+C20:1. [5] PUFA: Σ C18:2+C18:3+C20:2+C20:3+C20:4.

Meat fatty acid composition

Table 4 shows the proportion of SFA, MUFA and PUFA of the IMF of loin from Iberian swine as affected by gender and crossbreeding. Gender showed no significant influence on any of the FA groups, while crossbreeding significantly influenced all the three major groups of FA ($p = 0.015$ for SFA, $p = 0.013$ for MUFA and $p < 0.001$ for PUFA). The highest proportion of SFA was found in loins from Duroc 3 pigs (35.9%), followed by Iberian (34.8%), Duroc 2 (34.1%) and Duroc 1 (32.9%). On the other hand, crossbred pigs from the Duroc 3 sire line showed significantly ($p < 0.05$) lower MUFA proportions (57.1%) than animals from the Iberian (59.1%) and Duroc 2 (58.5%) groups, with those from the Duroc 1 showing intermediate values (58.2%). Loins from the Duroc 1 group showed the highest ($p < 0.05$) proportion of PUFA (9.0%). followed by animals from the Duroc 2 and Duroc 3 groups (7.4% and 7.0%. respectively), while pure Iberian pigs showed significantly ($p < 0.05$) lower values than any other (6.1%).

Discussion

Pure Iberian pigs showed worse productive performance than any of the Iberian × Duroc crossbreds evaluated, which was not surprising since crossbreeding of Iberian swine with the Duroc breed is mainly aimed to improve such parameters (López-Bote, 1998). In fact, this resulted in a somehow unbalanced design, since the pure Iberian pigs showed much lower LW at the same age and exactly the same rearing conditions than any of the crosses evaluated (Table 2). We decided to reach an acceptable commercial SW for the Iberian pigs, although some of the comparisons between this group and those of the crossbred pigs could be affected by this factor. As far as the objectives of the present study are concerned, there were no differences in LW between any of the Iberian × Duroc crossbreeds, except a small one at the beginning of the experiment. Animals from the Duroc 3 sire line showed a better ADG in some of the phases of the experiment, as compared to the other lines. Other authors have also found differences in such parameters between different Duroc genetic lines (Serrano *et al.*, 2008) and also between Iberian × Duroc crosses using different Duroc lines (Ramírez & Cava, 2007). In the present study, the differences in performance were so small that it would be hard to highlight one of the sire lines based on these parameters.

Pure Iberian pigs showed much worse carcass quality traits, with lower carcass weight and length, similar carcass yield, and a much thicker backfat despite to the lower CW. It is well known the crossbreeding with Duroc reduce backfat accumulation with respect to pure Iberian swine (Serrano *et al.*, 2008) since the latter is a breed with a tremendous tendency to accumulate fat (Mayoral *et al.,* 1999). Differences in backfat thickness between the studied Iberian × Duroc crossbreeds could be due to the effect of the CW, given that this variable showed a significant covariate effect ($p < 0.001$). However, this effect could be mostly due to the considerably lower CW of pure Iberian pigs, so that it results difficult to ascribe the small differences in backfat thickness between Iberian × Duroc crosses to their differences in CW or to other genetic factors. Other authors have detected differences in backfat thickness between different Duroc genetic lines (Cilla *et al.,* 2006), and also between Iberian × Duroc crosses using different genetic lines (Ramírez & Cava, 2007), although in this latter work the potential effect of SW on backfat thickness was not considered.

As far as the primal cuts are concerned, according to their lower carcass weight, the cuts from pure Iberian pigs resulted smaller in weight and size, but also they showed lower yields and higher trimming losses as compared to all Duroc crossbreeds tested, which was expected since it is in agreement to previous observations (López-Bote, 1998), being one of the reasons why the Duroc breed is used for crossbreeding with Iberian breed.

As far as the differences in primal cuts between the Iberian × Duroc crossbreeds, the crosses from the Duroc 1 sire line showed the overall best performance for yields and trimming losses, followed by the Duroc 3 and Duroc 2 crossbreeds. Previous works have pointed out an important effect of the Duroc sire line on the weights and yields of the ham, shoulder and loin, either (Ramírez & Cava, 2007; Serrano *et al.,* 2008). In our case, the sire line with overall better carcass quality traits was the Duroc 1 (lower backfat thickness, better primal cuts yield and lower trimming losses). These results highlight the great heterogeneity of the Duroc breed, and the importance of using an adequate sire line to improve the profitability of Iberian × Duroc farms.

Differences between barrows and gilts in carcass quality traits were scarce, although barrows showed heavier carcasses, worse loin and ham yields, and higher trimming losses than gilts. Overall, these results are in agreement with others from the scientific literature about Iberian swine (Latorre *et al.*, 2004; Muñoz *et al.*, 2011), pointing out to heavier carcasses and worse yields in barrows as compared to gilts, although Serrano *et al.* (2008, 2013) have found little effect.

Differences in meat quality between pure Iberian and any of the Iberian × Duroc crossbreeds evaluated were evident. Nevertheless, contrary to what Ventanas *et al.* (2006) and Serrano *et al.* (2008) have previously reported, Iberian pigs did not show higher IMF content than Iberian × Duroc crosses. Moreover, although not statistically significant due to the high variability, the highest IMF values were those from the Duroc 3 crossbreed. It has been shown that IMF content is a key factor determining the quality of Iberian meat and meat products quality (Ruiz *et al.*, 2002), and thus, it should be taken into consideration when selecting the more adequate Duroc sire line for crossbreeding of Iberian pigs. In this case, all three tested sire lines led to a similar IMF than pure Iberian pigs.

On the other hand, the meat from pure Iberian pigs showed a lower L* and Hue angle, which in terms of real color perception would mean a darker and redder meat surface. This is in agreement with Juárez *et al.* (2009) observations, and it is most likely due to the higher myoglobin content of the meat of this breed as compared to these authors' crosses with Duroc, which in turn is partly due to their higher proportion of oxidative fibers (Andrés *et al.*, 1999). When comparing the crosses from the three sire lines tested, those from the Duroc 1 showed higher Chroma and lower Hue angle compared to the other two sire lines, which would mean a less dull and redder meat color. Such differences could have important consequences in the market of Iberian meat and meat products, since consumers prefer more intense and brightly red colors (Ruiz *et al.*, 2002). Other authors have found only slight differences in meat color between different Duroc sire lines (Ramírez & Cava, 2007; Serrano *et al.,* 2008).

Obtained results indicate the notable influence of breed on the accumulation of FA in the subcutaneous fat from Iberian pigs, despite to the fact that all the animals had the same diet, which is in concordance with previous studies (Ventanas *et al.*, 2006), who found higher proportions of MUFA and lower of PUFA in the backfat from purebred Iberian than in that from crossbred (Iberian dams × Duroc sires) pigs. It has been proposed that the higher accumulation of oleic acid (C18:1 n-9) in the tissues of pure Iberian pig could be partly due to the different activity of the Δ^9-desaturase enzyme between Iberian and Duroc genotypes. Supporting this hypothesis, Morales *et al*. (2002) suggested that the activity of the enzymes involved in the synthesis of unsaturated FA could vary between adipose tissues from different pig breeds. This is relevant, since previous studies have found a link between the proportion of oleic acid in the raw material and the extent of lipid oxidation during the processing of Iberian dry-cured ham (Ruiz & López-Bote, 2002); moreover, the proportion of oleic acid has been shown to positively affect the fluidity of the subcutaneous fat of Iberian dry-cured ham (Ruiz-Carrascal *et al*., 2000), which in turn is positively related to acceptability (Ruiz *et al.*, 2002).

The Duroc sire lines used in this study only slightly affected the accumulation of FA in the subcutaneous fat throughout the fattening. In fact, only the proportion of PUFA at 90 kg and 110 kg LW showed significant differences between the three crossbreeds, while it did not show any significant difference at slaughter. Moreover, neither the proportion of SFA, nor that of MUFA showed any difference at any of the LW tested. Contrarily, there were some differences in the FA composition of IMF between the crossbreeds from different sire lines, with the pigs from the Duroc 1 sire line reaching lower levels of SFA and higher of PUFA than any of the other two crosses. Other authors (Ramírez & Cava, 2007; Muñoz *et al*., 2011) have shown a significant influence of the genotype of the Duroc sire line on the FA of the backfat, specifically the unsaturated FA. Differences in our study were scarce, but overall, and considering both lard and IMF, perhaps was the crossbreed with the Duroc 2 sire line the one with better technological quality for processing and for obtaining better sensory characteristics, given the higher MUFA and lower PUFA levels, which has been highlighted as important factors for obtaining a fluid fat with low susceptibility to lipid oxidation (Ruiz & López-Bote, 2002).

The effect of gender on the FA composition of the subcutaneous fat or the IMF was not significant and neither that of the combined effect of breeding × gender. Nevertheless, Muñoz *et al.* (2011) found an effect of the gender on fatty acid composition in Duroc × Iberian crossbred pigs, with females showing higher PUFA and lower SFA proportions than castrated males.

The accumulation of FA followed a similar pattern to that described in other works, with growing levels of SFA and MUFA, and decreasing proportions of PUFA (López-Bote, 1998), reflecting the growing accumulation of de novo synthetized FA in the subcutaneous tissue (Ruiz & López-Bote, 2002).

In conclusion, using different Duroc genetic lines as sire line for crossbreeding with Iberian pigs may affect performance, carcass and meat quality traits in a different extent. While farmers are usually more interested in faster growing, better yields and higher weights of primal cuts, those parameters related to meat and meat product quality should not be dismissed, since there are differences in color and fatty acid composition that may eventually lead to lower meat and meat products quality, which in the case of the Iberian pig, constitutes the basal factor for the profitability of the whole system.

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