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The effects of breed and gender on meat quality of Duroc, Pietrain, and their crossbred

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Abstract

This study evaluated the effects of breed and gender in Duroc (D), Pietrain (P), and crossbred (DP) pigs. Loin samples were collected from D (n = 79), P (n = 42), and DP (n = 45) pigs. Intramuscular fat content was significantly lower in P ($p < 0.001$), and pH was lowest in DP pigs ($p < 0.001$). Gilts had higher intramuscular fat (IMF) and pH values than did castrated males ($p < 0.05$). Water-holding capacity was lower in DP pigs than that in D and P pigs ($p < 0.001$). Shear force in DP pigs was higher than that in D and P pigs ($p < 0.001$). Lightness and yellowness of meat in DP pigs was increased compared with coloring of P pig meat ($p < 0.01$). Meat from DP pigs was redder compared with meat from in D and P pigs, and it was higher in gilts than in castrates ($p < 0.001$). The C16:0 content was lower in P and DP pigs than in D pigs ($p < 0.01$). C18:2 content was higher in P and DP pigs than in D pigs ($p < 0.001$). Unsaturated and saturated fatty acids increased in P pigs compared with levels in D pigs ($p < 0.05$). Our results suggest that meat quality can be controlled by crossbreeding to increase or reduce selected properties. This study provides the basic data on the meat characteristics of F1 DP pigs. Thus, further study should be conducted to estimate the meat quality of various crossbreeds.

Keywords: Breed, Crossbreeding, Gender, Meat quality

INTRODUCTION

Global meat consumption is expected to increase due to the rapidly growing world population [1]. In particular, pork is consumed by approximately 37% of the world's people, which amounts to a total meat intake of 110 million metric tons (mmt), followed by 67 mmt for beef and 104 mmt for chicken [2]. Thus, pork is one of the key protein sources. Currently, pork is produced mostly from three-way hybrids (Landrace × Yorkshire × Duroc, or LYD) or more highly crossbred pigs owing to their good growth performance and meat quality [3]. These improvements are mostly due to heterosis, which increases the performance of offspring compared with that of the paternal or maternal lines [4]. Lately, swine breeders have focused on growth traits [1,2]. In crossbreeds, Duroc (D) pigs are generally used as terminal sires due to their superior growth and superior meat quality, with high fat content and pH [5,6].

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Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Sa SJ.
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Ethics approval and consent to participate
All procedures were approved by the Institutional Animal Care and Use Committees at National Institute of Animal Science (No. 2017-235).

Recently as a result of examining the stock of pork at the Korea Rural Economic Institute, the pork belly increased from 5,117 t in 2017 to 9,976 t in 2018, and the sirloin was reduced from 7,388 t to 3,006 t [7]. This is thought to be because consumers are more concerned with appearance, and interest in maintaining health has increased, and interest in low-fat foods has increased [8]. However, unlike foreign countries, South Korean consumers are less likely to choose meat. Thus, the swine industry will need to consider the development of new breeding strategies or programs to produce pork possessing the desired properties. Previous studies have reported the meat quality comparison of progenies sired by a marbling breed, such as D, or a leaner breed, such as Pietrain (P) [9,10]. They reported that D pig progenies showed better pH, fat content, and water-holding capacity (WHC); however, they produced ham, back, and shoulder yields lower than those of P pig progenies. However, these are crossbreeds between other pure breeds and sire breeds, such as D or P pigs. We hypothesized that D × P hybrid pigs will contain both lean and fatty traits. This study was conducted to confirm the loin meat quality and offspring of D pigs and P pigs, and was intended to be used as a basic data for developing a peer train as a terminal sires suitable for domestic conditions.

MATERIALS AND METHODS

Animals and management

D, P, and the crossbred D × P (DP) pigs were obtained from Darby Genetics. The pure breed pigs of D and P pigs were produced by mating a boar to five sows of the same breed. The crossbred DP pigs were produced by inseminating five D gilts with the semen of a P boar. Piglets post birth were reared according to the guidelines of the National Institute of Animal Science. Feed and water were freely accessible using self-feeders and nipple waterer. The three breeds (D, P, and DP pigs) were selected when the pig reached 180 d, which is 110–115 kg of market weight. The number of castrate and gilts used in this study were 29 and 50 in D pigs (n = 79), 12 and 30 in P pigs (n = 42), and 16 and 29 in DP pigs (n = 45), respectively. All procedures were approved by the Institutional Animal Care and Use Committees at National Institute of Animal Science (No. 2017-235).

Sample preparations

The selected animals were sacrificed in a local slaughterhouse. After the carcasses were chilled at 1℃ for 24 h, samples of *longissimus dorsi* muscle were collected from their loins between the 10 and 11th ribs and lumbar vertebra. A total of 166 samples (D = 79, P = 42, and DP = 45, respectively) were vacuum-packed in impermeable polyethylene bags and immediately transferred to the laboratory. The samples were kept at −20℃ for 24 h until the analysis of meat quality was conducted. The frozen meats were defrosted for 48 h at 4℃ before the further analysis of meat quality.

pH measurement

The 3 g of sample was placed into 50 mL tube with 27 mL of distilled water. Subsequently, they were homogenized for 60 s by a homogenizer (Polytron PT 10-35GT, Kinematica AG, Switzerland). The homogenate was centrifuged at 13,000×g during a min, and then strained through filter paper. The pH of the filtrate was identified by a pH meter (Orion 2 Star, Thermo Scientific, Waltham, MA, USA) at room temperature [11].

Moisture contents

Moisture content was determined according to the process described by AOAC [12]. Briefly, 3 g of the sample was weighed in an aluminum dish and then dried in an oven at 104℃ for 24 h. The moisture content was obtained as the percentage of the difference between the normal and dry

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sample weights.

Cooking loss and shear force

Cooking loss was obtained by estimating the weight loss by heating until the internal temperature of the sample block (3 × 3 × 3 cm) in the electronic grill reached 72 ± 2℃ [13]. The WHC was determined using a previously reported method [13]. Briefly, 5 g of sample was added in a tube with a micro filter and collection vial and centrifuged at 2,000 g for 15 min. The water loss was identified by weighing the sample before and after centrifugation. The WHC was calculated using the following equation: [1 – (Moisture content extracted by centrifugation / Moisture content in original meat)] × 100.

A sample block of approximately 3 cm in height was placed in a polyethylene bag. The package was weighted and heated in a water bath at 80℃ for 30 min and cooled at room temperature for 30 min. Warner-Bratzler Shear Force (WBSF) was measured in the cooked samples (4 cm × 3 cm × 2.5 cm) after chilling. Each chilled sample was cut into six replicate core samples of 0.5-inch diameter, and WBSF was measured using an Instron Universal Testing Machine (Model 4400; Instron, MA, USA).

Meat color

The color on the surface of the meat sample was estimated using a meat color meter (CR-410, Minolta, Japan), measuring lightness (L*), redness (a*), and yellowness (b*). The meter was standardized according to a calibration plate (L* = 89.2, a* = 0.921, and b* = 0.783) and thereafter, the meat sample was bloomed for 30 min at room temperature prior to measuring the color. Each sample was measured three times and expressed as an average value.

Fatty acids analysis

Intramuscular fat (IMF) was extracted from 5 g meat samples using Folch solution containing chloroform/methanol (2:1, v/v) as per the extraction processes described by Folch et al. [14]. The extracted fat was collected and stored at −70℃ to analyze the fatty acids in the meat sample. Fatty acids were analyzed using the fat extracted from the 5 g meat sample by Folch solution with butylated hydroxytoluene [14]. This fat was methylated with 3 mL of 15% BF3 with methanol incubation for 20 min in a 90℃ water bath. Fatty acid methyl esters (FAME) in the incubated fluid were vortexed after adding 3 mL water and vortexed again to supply 3 mL hexane. The mixture was centrifuged at 1,000 g for 5 min at 4℃. The upper hexane layer with FAME was dehydrated by anhydrous sodium sulfate and collected into a vial as a sample for fatty acid analysis. The FAME was analyzed using a gas chromatography (Hewlett Packard 6890 series, Agilent Technologies, CA, USA) equipped with a flame ionization detector and an Omega wax 320 column (30 m × 0.32 mm × 0.25 μm, Supelco, Bellefonte, PA, USA). The oven temperature was initially maintained at 180℃ for 5 min and gradually elevated to 250℃ at a rate of 0.5℃/min. Finally, they were isothermally maintained at 250℃ for 25 min. Temperatures of the injector and detector were 250℃ and 260℃, respectively. The carrier gas was nitrogen gas with 1 mL/min flow rate. The injection volume and split ratio of the sample were 1 μL and 100:1, respectively. Fatty acids in the meat sample were identified by comparing the retention times between each fatty acid of the sample and Supelco 37 component FAME Mix (CRM47885, Sigma-Aldrich, St. Louis, MO, USA). The identified fatty acids were expressed as a percentage of each fatty acid to the total fatty acids. Further, the aggregate or ratios of saturated fatty acid (SFA), unsaturated fatty acid (UFA), monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA), UFA/SFA, and n6/n-3 were computed.

Statistical analysis

The data in this study were respectively 79, 42, and 45 pigs, in a factorial design with 3 breeds and 2 genders. The data were statistically analyzed using two-way ANOVA with a GLM procedure in SAS 9.4 (2003). Significance among breeds or between sexes was estimated by Duncan's test at a p-value below 0.05. The variability of the data was presented as the standard error.

RESULTS

Physicochemical traits

The physicochemical properties of loin meat are listed in Table 1. The moisture content was not influenced by either breed or gender; IMF was significantly higher in DP pigs and statistically lower in P pigs among all breeds ($p < 0.001$); and gender effects were higher in the gilts than in the castrated males ($p < 0.05$). Further, P and DP pigs had the highest and lowest pH, respectively ($p < 0.001$), whereas the pH of gilt meat was also greater than that of the castrates ($p < 0.01$). In addition, D and P pigs exhibited lower cooking loss ($p < 0.05$) and Warner-Bratzler shear force (WBSF) ($p < 0.001$) than DP pigs; WHC was higher in D and P pigs than in DP pigs ($p < 0.001$). Interaction between the two independent variables was observed in the pH and WHC ($p < 0.01$).

Meat color

Effects of breed and gender on meat color of the loin in D, P, and DP pigs are listed in Table 2. The loins from D and DP pigs were lighter in color than those from P pigs (Table 2; $p < 0.01$). The meat from DP pigs was redder than that from D and P pigs, and redder in gilts than in castrates ($p < 0.001$). The yellowness was the lowest in P pigs; further, it was also lower in D pigs than in DP pigs ($p < 0.001$).

Fatty acid analysis

In the compositions of each SFA, concentrations of capric acid (C10:0) and myristic acid (C14:0) were lower in P pigs than in D and DP pigs (Table 3; $p < 0.05$). Lauric acid (C12:0) concentrations were lowest in P pigs, whereas they were highest in DP pigs ($p < 0.001$). In addition, the effect of gender in gilts was greater than that in castrates ($p < 0.05$). Palmitic acid (C16:0) concentrations were lower in P pigs and DP pigs than in D pigs ($p < 0.01$). There was an interaction between breed and gender for C10:0 and C14:0 ($p < 0.05$).

The compositions of each UFA are listed in Table 3. D and P pigs exhibited greater palmitoleic

Table 1. Physicochemical traits from Duroc, Pietrain and their crossbred pigs (Duroc × Pietrain)

	Breed			Gender		SEM	Significance		
	D	P	DP	C	G		Breed	Gender	Breed × Gender
Moisture (%)	74.14	74.61	74.20	74.29	74.27	0.077	ns	ns	ns
IMF (%)	2.46^{b}	1.85^{c}	3.25^{a}	2.22^{b}	2.68^{a}	0.096	***	*	ns
pH	5.63^{b}	5.77^{a}	5.54^{c}	5.61^{b}	5.66^{a}	0.014	***	**	**
Cooking loss (%)	12.80^{b}	12.34^{b}	14.73^{a}	13.13	13.25	0.335	*	ns	ns
WHC (%)	74.89^{a}	76.58^{a}	69.85^{b}	72.14	74.13	0.581	***	ns	***
WBSF (kg/cm^{2})	4.17^{b}	4.39^{b}	5.23^{a}	4.66	4.43	0.102	***	ns	ns

Values are expressed as means and SEM.

$^{a-c}$Means in a same row with different superscript letter differ significantly at $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

D, Duroc (n=79); P, Pietrain (n=42); DP, crossbred Duroc × Pietrain (n=45); C, castrate; G, gilt; SEM, standard error of means; ns, not significant; IMF, intramuscular fat; WHC, water-holding capacity; WBSF, Warner-Bratzler shear force.

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Table 2. Meat color of loin meat from Duroc, Pietrain and their crossbred pigs (Duroc × Pietrain)

Meat color	Breed			Gender		SEM	Significance		
	D	P	DP	C	G		Breed	Gender	Breed × Gender
Lightness	44.43[a]	43.34[b]	44.83[a]	44.64	44.06	0.170	**	ns	ns
Redness	15.44[b]	15.29[b]	16.07[a]	15.21[b]	15.76[a]	0.080	***	***	ns
Yellowness	5.49[b]	4.46[c]	7.12[a]	5.47	5.77	0.125	***	ns	ns

Values are expressed as means and SEM.

[a–c]Means in a same row with different superscript letter differ significantly at $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

D, Duroc (n=79); P, Pietrain (n=42); DP, crossbred Duroc × Pietrain (n=45); C, castrate; G, gilt; SEM, standard error of means; ns, not significant.

acid (C16:1) content than did DP pigs, whereas linoleic acid (C18:2) content was lower ($p < 0.001$). DP pigs had higher linolenic acid (C18:3) content than P pigs ($p < 0.01$). Eicosadienoic acid (C20:2) concentrations were greater in DP pigs than in D and P pigs, and also higher in gilts than in castrates ($p < 0.001$). An interaction effect was exhibited between C18:3 and C20:2.

The sums and ratios of UFA and SFA are listed in Table 3. The MUFA content was higher in D and P pigs than in DP pigs ($p < 0.05$), but the opposite was observed for PUFA content ($p < 0.05$). P and DP pigs had UFA content higher than that of D pigs ($p < 0.05$). The UFA/SFA ratio was higher in P pigs than in D pigs ($p < 0.05$). Similarly, the n-6/n-3 ratio was elevated in DP pigs sired by P pigs relative to D pigs ($p < 0.05$). Interaction between breed and gender was not observed.

Table 3. Fatty acid composition of loin meat from Duroc, Pietrain and their crossbred pigs (Duroc × Pietrain)

Fatty acid (%)	Breed			Gender		SEM	Significance		
	D	P	DP	C	G		Breed	Gender	Breed × Gender
C10:0	0.12[a]	0.11[b]	0.12[a]	0.12	0.12	0.001	*	ns	*
C12:0	0.10[b]	0.09[c]	0.12[a]	0.11[a]	0.10[b]	0.002	***	*	**
C14:0	1.34[a]	1.23[b]	1.38[a]	1.34	1.32	0.013	***	ns	ns
C16:0	23.42[a]	22.80[b]	22.79[b]	23.40	22.94	0.101	**	ns	ns
C18:0	11.59	11.16	11.74	11.63	11.47	0.073	ns	ns	ns
C16:1	3.40	3.42	2.87	3.37	3.21	0.042	***	ns	ns
C18:1	42.36	42.40	41.56	42.23	42.11	0.207	ns	ns	ns
C18:2	9.26	9.76	11.26	9.51	10.15	0.183	***	ns	ns
C18:3	0.64	0.62	0.67	0.66	0.63	0.008	**	ns	*
C20:2	0.28	0.26	0.33	0.27	0.30	0.004	***	***	***
C20:3	0.32	0.33	0.33	0.32	0.33	0.008	ns	ns	ns
C20:4	2.20	2.44	2.28	2.25	2.30	0.067	ns	ns	ns
C24:1	0.33	0.35	0.34	0.32	0.34	0.008	ns	ns	ns
SFA	36.58[b]	35.39[a]	36.15[ab]	36.59	35.94	0.168	ns	ns	ns
USFA	59.07[a]	59.91[b]	59.95[b]	59.23	59.67	0.142	**	ns	ns
MUFA	46.38[b]	46.5[b]	45.08[a]	46.23	45.94	0.215	*	ns	ns
PUFA	12.69[a]	13.41[a]	14.87[b]	13.00	13.71	0.246	***	ns	ns
UFA/SFA	1.62[a]	1.70[b]	1.66[ab]	1.63	1.67	0.010	*	ns	ns
n6/n3	14.92[a]	16.14[ab]	17.65[ab]	15.04	16.46	0.390	*	ns	ns

Values are expressed as means and SEM.

[a–c]Means in a same row with different superscript letter differ significantly at $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

D, Duroc (n=79); P, Pietrain (n=42); DP, crossbred Duroc × Pietrain (n=45); C, castrate; G, gilt; SEM, standard error of means; ns, not significant; SFA, saturated fatty acid; USFA, unsaturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; UFA, unsaturated fatty acid.

DISCUSSION

Breed effects

Water loss in meat causes a decrease in pH and loss of adenosine triphosphate (ATP) [15]. The moisture content found in this study ranged from 74.1% to 74.6% (Table 1), and no significant difference was found between all groups. Moisture content was similar to values from previous studies (73.8% and 73.6%, respectively) using a population of F2 DP pigs [16] and DP progenies of P pigs sired by D pigs [17]. Other studies showed non-significant values among two-way crossbred pigs, including Yorkshire (Y) sired by Landrace (L), Berkshire, or Chester White [13], and between three-way crossbred pigs from LY progeny sired terminally by either D pigs or Korean native pigs [5]. However, few studies reported differences between the two hybrid pigs, although they were numerically insignificant (0.5% and 0.4%) [17,18]. The results obtained in these previous studies and those in our study indicate that crossbreeding does not have a significant effect on the moisture in pork.

D pigs or offspring with D pig sires have a higher marbling score and IMF than hybrid pigs with P pig sires [10,18,19]. Similarly, in this study, IMF values were higher (2.46% vs. 1.85%) in D pigs than in P pigs (Table 1). IMF was lowest in P pigs, possibly due to the higher percentage of lean meat in P pigs [17]. However, the IMF of DP pigs was 3.25%, the highest among the three breeds in this study. Other studies reported that the IMF was 3.27% in the F2 DP pig population [19] and the crossbred PD pig population contained 2.85% fat in the loin [17]. This result indicates that the IMF could be increased using crossbreeding technology. According to previously revealed results, the thickness of back fat was thin in the DP species born from the crossbreeding of the Pietrain and Duroc [20]. Therefore, it is thought that the thickness of back fat in DP is decreased and IMF is increased, so that both the health aspect and texture of meat can be increased to increase consumers' preference for meat. Crossbreeding causes an improvement in performance by the heterosis of either the maternal or paternal line [2]. Thus, high IMF in DP pigs would be caused by hybrid enrichment when compared with that in D pigs.

Meat from pure P pigs or their crossbreeds has a relatively low pH range (5.47–5.70) compared with that of pure D pigs or D hybrids (5.48–5.98) [9,19–23]. However, this study found a greater pH value in P pigs than in D pigs (5.77 vs. 5.63, Table 1). In addition, the pH of DP pigs in this study was 5.54, which was similar to the pH of 5.53 in the F2 DP pig population [16]. pH is an important factor related to several indexes of meat quality; further, pH is negatively correlated (–0.24) with cooking loss [21] and positively associated with the WHC [24]. These previous findings are in agreement with those of the present study, indicating high cooking loss and decreased WHC at low pH (Table 1). Previous studies have demonstrated that the decrease in meat pH was associated with a higher proportion of white muscle with glycolytic fibers (IIB) than red muscles rich in oxidized fibers [25]. It is also known that pietrain contain a large proportion of glycolytic fibers (IIB) [25]. Therefore, it is thought that the low pH in DP may be influenced by the high content of glycolytic fibers (IIB) in the peer train. Similarly, the WHC values among five breeds (D, L, Y, LY, and DLY) were not significantly different [2]. Furthermore, the WBSF exhibited a lower pH in D and P pigs than in DP pigs (4.17 and 4.39 vs. 5.23 kg/cm^2, respectively). In this study, the pH, cooking loss, WHC, and WBSF were higher or lower in DP pigs than in the other breeds. Thus, it was noted that breed altered the cooking and texture indexes.

The instrumentally measured color, lightness, redness, and yellowness were higher in DP pigs than in D and P pigs (Table 2). Previous studies have shown that a decrease in pH and WHC have an important effect on meat quality properties such as meat color [21]. Therefore, in this paper, these results are thought to be the result of the difference in pH and WHC in DP. Also, this ob-

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servation indicated that color depends on breed, which is similar to observations in previous studies [2,17,21]. Meat color is an important trait affecting the purchase behavior of consumers [2,17]. It is generally known that D crossbreeds taste better because of the rich IMF, whereas P pigs are leaner because of less fat deposition with respect to other crossbred pigs [17]. Thus, breed contributed weakly to the objective colors and preferences of meat.

The fatty acid composition of pork is influenced by breed [26]. In the profile of fatty acids (Table 3), the main SFAs (C16:0 and C18:0) and UFAs (C18:1 and C18:2) in pork constituted approximately 90% of the total fatty acid composition, which was similar to that observed in previous studies on crossbreeds and pure breeds [27]. Other studies reported that the content of major fatty acids were above 90% of total fatty acids in pure D [2] and P pigs [22]. In this study, C10:0, C12:0, C14:0, and C16:0 contents in P pigs were lower than those in D or P pigs, but the total SFA did not differ. The UFAs C18:2, C18:3, and C20:2 were higher in DP than in D or P pigs. In addition, MUFA was highest in P pigs and PUFA was significantly higher in D and P pigs than in DP pigs (Table 3). Cameron et al. [28] reported that increased MUFA content and decreased PUFA improved the taste of pork. UFA helps prevent diseases such as atherosclerosis and high blood pressure [3]. UFA was significantly higher in P pigs than in D pigs (59.91 vs. 59.07), and the UFA/SFA ratio was also significantly higher in P pigs than D pigs (1.70 vs. 1.62). The n-6/n-3 ratio was higher in DP pigs than in D pigs (17.65 vs. 14.92). These alterations are in agreement with those reported by Magowan et al. [22], who indicated that breed was strongly related to fatty acid composition.

Gender effects

Variation in meat characteristics caused by gender can be explained by gender's influence on protein and body fat depositions [29]. Regarding the physicochemical traits (Table 1), the gilts in this study had greater IMF than castrates (2.68% vs. 2.22%). Previous studies reported differences in IMF based on gender. The gilts had more fat than castrates (6.09% vs. 3.79%) in Preto Alentejano pigs from Portugal [30]. Conversely, castrates exhibited higher IMF than gilts (2.47% vs. 1.72%) from LD sows sired by P boars [31]. However, other works reported similar IMF values between genders in crossbreeds, such as LYD and L × Large White [5,30]. In this study, the gilts had higher pH than did castrates (5.66 vs. 5.61); however, the difference was numerically very small. Some previous studies showed no significant difference in pH between castrates and gilts (average, 5.41 vs. 5.41) [27,32,33]. Furthermore, gender effects on moisture, cooking loss, WHC, and WBSF were not observed in this study. These results are similar to those obtained in previous studies [10,22,27,30,33]. In addition, the breed has greater effects than gender on meat quality [22]. Thus, the physicochemical traits of pork are unaffected by gender.

Previous studies indicated that the significance of instrumentally measured colors is not affected by the gender of loin meat in purebred and crossbred pigs [22,31–33]. However, in this study, meat was redder in gilts than in castrates (15.76 vs. 15.21). This observation was similar to the results of some previous studies but contradicted the results of others. According to Ramirez et al. [33], gilts had thigh meat redder than that of castrates (18.5 vs. 17.2); Latorre et al. [34] reported that redness was lower in gilts than in castrates (4.02 vs. 4.58). Interestingly, this study and previous studies by Latorre et al. [34] and Ramírez and Cava [33] showed no gender effects on either lightness or yellowness. This may be attributed to muscular pigments, such as myoglobin, which was positively correlated with redness at 0.45 [35]. In addition, they indicated a negative correlation of 0.20 between myoglobin and lightness, although it was not significant. Teixeira and Rodrigues [30] reported that castrates had more pigments than gilts in a Portugal native breed, but the opposite trend was observed in the pigment content in commercial pigs. This indicates that pork meat color can be entirely controlled by breed rather than gender. Furthermore, visual color difference in this study were

not based on gender, which is in agreement with a previous study [34].

Typically, fatty acid composition can vary greatly, depending on birth weight, sex of the pig, and carcass fat depots [36]. In the SFA composition, C12:0 content was lower in gilts than in castrates (0.10% vs. 0.11%) (Table 3). Comparably, C16:0 content was slightly more reduced in gilts than in castrates (22.94% vs. 23.40%; $p = 0.07$). The other SFAs were not significant based on gender. The total SFA content tended to be lower in gilts than in castrates (35.94% vs. 36.59%; $p = 0.10$), which was in agreement with a previous study [5]. As shown in the UFA composition in Table 3, C18:2 content was slightly numerically higher in gilts than in castrates (10.15% vs. 9.51%). C20:2 content was also greater in gilts than in castrates (0.30% vs. 0.27%), which was comparable with the findings in previous studies [27]. Male pigs have less backfat than gilts, and the fatty acid composition of pigs with less backfat is more unsaturated [36]. However, the compositions of other UFAs in this study did not differ between gilts and castrates. In addition, the MUFAs, PUFAs, UFA/SFA ratios, and n-6/n-3 ratios were not different based on gender (Table 3). Kim et al. [5] reported that gilts showed a greater n-6/n-3 ratio than castrates (13.04 vs. 11.45) in D or Woori black pigs sired by a Korean native sire line. Similarly, Franco et al. [32] reported that the n-6/n-3 ratio was higher in gilts than in castrates (18.31 vs. 17.09) from Celta sows sired by D or L pigs. These previous studies showed effects of gender on the compositions of fatty acids. However, Raminze et al. [33] reported no difference in fatty acid composition by gender. Moreover, profiles of fatty acid changed depending upon diet, breed, individual variation, and feeding environments [30].

Interaction effects

Interaction effects in this study were shown in the pH and WHC of physicochemical traits; in all parameters; and in C10:0, C12:0, C18:3, and C20:2 components of fatty acids. Generally, the two-way analysis of variance expressed the effects of independent variables on each dependent variable related to meat quality based on previous studies [27,30,33,37]. Further, it identified interaction effects between the independent variables on each dependent variable. The main effects can easily discriminate factors affecting dependent variables; however, each effect can be limited in its explanation of the dependent variables. For example, pH in this study was higher in P pigs according to the breed effect and higher in gilts based on the gender effect. According to these main effects of pH, we expected meat from P gilts to have the highest pH value. However, among the six animal groups, the greatest pH was in P castrates compared with that in the other animal groups (Table 1). Similarly, C20:2 content was increased in DP pigs and in gilts by both effects, whereas DP castrates exhibited a value higher than that of the other animal groups. The flavor and color, in common with C20:2, showed a comparable tendency. Moreover, other studies indicated that interaction effects occurred for various meat parameters, such as drip loss [38], WHC [5], IMF, a few fatty acids [27,30], eating quality [37], and a few cut yields of carcass [33]. This means that interaction effects on meat quality are uneven. Therefore, meat quality based on breed and gender is affected by both principal and interaction effects; however, these effects are limited and may be applied to only a few traits of meat quality because of a small or vague effect.

CONCLUSION

This study identified some differences among three pig breeds; however, few effects were based on gender. In particular, effects on eating quality, cooking loss, WHC, and WBSF were lower in DP pigs those in D and P pigs. These data indicated that DP may be an unsuitable crossbreed to meet consumer needs. However, a few parameters increased the preference for DP pigs, such as higher IMF, lightness, redness, and fewer UFAs relative to fatty acids in P pigs; whereas it was similar or

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greater compared with D pigs. Moreover, breeds for commercial meat production are typically obtained by crossbreeding among three or more lines. Therefore, our information supplies basic data on meat quality in crossbreeds between D and P pigs. Further studies will be necessary to estimate the effects of crossbreeding with additional lines.

REFERENCES

1. Teixeira A, Rodrigues S. Meat quality, brands and consumer trends. In: Lorenzo JM, Munekata PES, Barba JF, Toldra F, editors. More than beef, pork and chicken–the production, processing, and quality traits of other sources of meat for human diet. Cham: Springer; 2019. p. 21-9.
2. Zhang J, Chai J, Luo Z, He H, Chen L, Liu X, Zhou Q. Meat and nutritional quality comparison of purebred and crossbred pigs. J Anim Sci. 2018;89:202-10.
3. Kim GW, Kim HY. Physicochemical properties of M. longissimus dorsi of Korean native pigs. J Anim Sci Technol. 2018;60:2-5.
4. Keller LF, Waller DM. Inbreeding effects in wild populations. Trends Ecol Evol. 2002;17:230-41.
5. Kim YM, Choi TJ, Cho KH, Cho ES, Lee JJ, Chung HJ, et al. Effects of sex and breed on meat quality and sensory properties in three-way crossbred pigs sired by Duroc or by a synthetic breed based on a Korean native breed. Korean J Food Sci Anim Resour. 2018;38:544-53.
6. Lonergan SM, Huff-Lonergan E, Rowe LJ, Kuhlers DL, Jungst SB. Selection for lean growth efficiency in Duroc pigs influences pork quality. J Anim Sci. 2001;79:2075-85.
7. Korea Rural Economic Institute. Meat and distribution survey. Seoul: Korea Rural Economic Institute; 2018. Report No.:118.
8. Sim DW. Quality properties of low fat pork patties with olive, soybean and canola oil gel as pork fat replacers during cold storage. J East Asian Soc Diet Life. 2019;29:459-68.
9. Affentranger P, Gerwig C, Seewer GJF, Schwörer D, Künzi N. Growth and carcass characteristics as well as meat and fat quality of three types of pigs under different feeding regimens. Livest Prod Sci. 1996;45:187-96.
10. Ellis M, Webb AJ, Avery PJ, Brown I. The influence of terminal sire genotype, sex, slaughter weight, feeding regime and slaughter-house on growth performance and carcass and meat quality in pigs and on the organoleptic properties of fresh pork. J Anim Sci. 1996;62:521-30.
11. Yang HS, Hwang YH, Joo ST, Park GB. The physicochemical and microbiological characteristics of pork jerky in comparison to beef jerky. Meat Sci. 2009;82:289-94.
12. AOAC [Association of Official Analytical Chemists] International. Official methods of analysis of AOAC International. 17th ed. Washington, DC: AOAC International; 2002.
13. Lim DG, Jo C, Seo KS, Nam KC. Comparison of meat quality of loins and butts in different two-way crossbred pigs. Livest Sci. 2014;161:210-7.
14. Folch J, Lees M, Sloane Stanley GH. A simple method for the isolation and purification of total lipids from animal tissues. J Biol Chem. 1957;226:497-509.
15. Leygonie C, Britz TJ, Hoffman LC. Impact of freezing and thawing on the quality of meat: review. Meat Sci. 2012;91:93-8.
16. Edwards DB, Ernst CW, Raney NE, Doumit ME, Hoge MD, Bates RO. Quantitative trait locus mapping in an f2 Duroc× Pietrain resource population. II. carcass and meat quality traits. J Anim Sci. 2008;86:254-66.
17. Glinoubol J, Jaturasitha S, Mahinchaib P, Wicke M, Kreuzer M. Effects of crossbreeding Thai native or Duroc pigs with Pietrain pigs on carcass and meat quality. Agric Agric Sci Procedia. 2015;5:133-8.

18. Lowell JE, Schunke ED, Harsh BN, Bryan EE, Overholt MF, Stahl CA, et al. Correlation comparisons among early postmortem loin quality and aged loin and pork chop quality characteristics between finishing pigs from either Duroc or Pietrain sires. J Anim Sci. 2018;96:4644-57.
19. Edwards DB, Bates RO, Osburn WN. Evaluation of Duroc-vs. Pietrain-sired pigs for carcass and meat quality measures. J Anim Sci. 2003;81:1895-9.
20. Glinoubol J, Jaturasitha S, Mahinchaib P, Wicke M, Kreuzer M. Effects of crossbreeding Thai native or Duroc pigs with Pietrain pigs on carcass and meat quality. Agric Agric Sci Procedia. 2015;5:133-8.
21. Li YX, Cabling MM, Kang HS, Kim TS, Yeom SC, Sohn YG, et al. Comparison and correlation analysis of different swine breeds meat quality. Asian-Australas J Anim Sci. 2013;26:905-10.
22. Magowan E, Moss B, Fearon A, Ball E. Effect of breed, finish weight and sex on pork meat and eating quality and fatty acid profile. Antrim, UK: Agri-Food and Bioscience Institute; 2011. p. 15.
23. Oliver MA, Gispert M, Diestre A. The effects of breed and halothane sensitivity on pig meat quality. Meat Sci. 1993;35:105-18.
24. Huff-Lonergan E, Lonergan SM. Mechanisms of water-holding capacity of meat: the role of postmortem biochemical and structural changes. Meat Sci. 2005;71:194-204.
25. Wojtysiak D, Gorska M, Wojciechowska J. Muscle fibre characteristics and physico-chemical parameters of m. semimembranosus from Puławska, Polish Large White and Pietrain pigs. Folia Biologica. 2016;64:197-204.
26. Kim IS, Jin SK, Kim CW, Song YM, Cho KK, Chung KH. The effects of pig breeds on proximate, physicochemical, cholesterol, amino acid, fatty acid and sensory properties of loins. J Anim Sci Technol. 2008;50:121-32.
27. Alonso V, Del Mar Campo M, Español S, Roncalés P, Beltrán JA. Effect of crossbreeding and gender on meat quality and fatty acid composition in pork. Meat Sci. 2009;81:209-17.
28. Cameron ND, Enser MB. Fatty acid composition of lipid in longissimus dorsi muscle of Duroc and British Landrace pigs and its relationship with eating quality. Meat Sci. 1991;29:295-307.
29. Akit H, Collins C, Fahri F, Hung A, D'Souza D, Leury B, et al. Dietary lecithin improves feed efficiency without impacting meat quality in immunocastrated male pigs and gilts fed a summer ration containing added fat. Anim Nutr. 2018;4:203-9.
30. Teixeira A, Rodrigues S. Pork meat quality of Preto Alentejano and commercial Largewhite landrace cross. J Integr Agric. 2013;12:1961-71.
31. Gispert M, Oliver MA, Velarde A, Suarez P, Pérez J, I Furnols MF. Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci. 2010;85:664-70.
32. Franco D, Vazquez JA, Lorenzo JM. Growth performance, carcass and meat quality of the Celta pig crossbred with Duroc and Landrance genotypes. Meat Sci. 2014;96:195-202.
33. Ramírez R, Cava R. Carcass composition and meat quality of three different Iberian × Duroc genotype pigs. Meat Sci. 2007;75:388-96.
34. Latorre MA, Lázaro R, Gracia MI, Nieto M, Mateos GG. Effect of sex and terminal sire genotype on performance, carcass characteristics, and meat quality of pigs slaughtered at 117 kg body weight. Meat Sci. 2003;65:1369-77.
35. Kim GD, Jeong JY, Hur SJ, Yang HS, Jeon JT, Joo ST. The relationship between meat color (CIE L* and a*), myoglobin content, and their influence on muscle fiber characteristics and pork

https://doi.org/10.5187/jast.2020.62.3.409

quality. Korean J Food Sci Anim Resour. 2010;30:626-33.
36. Harris EK, Mellencamp MA, Johnston LJ, Cox RB, Shurson GC. Effectiveness of different corn dried distillers grains with solubles feeding strategies and increasing the time intervals between the second Improvest dose and slaughter of immunologically castrated pigs on belly and pork fat quality. Meat Sci. 2018;135:62-73.
37. Channon HA, Kerr MG, Walker PJ. Effect of Duroc content, sex and ageing period on meat and eating quality attributes of pork loin. Meat Sci. 2004;66:881-8.
38. Tang Z, Peng Z, Liu B, Fan B, Zhao S, Li X, et al. Effect of breed, sex and birth parity on growth, carcass and meat quality in pigs. Front Agric China. 2008;2:331-7.