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Comparison of Meat Quality from Three-way Crossbred Pigs

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Abstract

To compare the pork quality, eight three-way crossbreeds were selected. The pigs with an initial weight of 25 kg were selected and raised to 115 kg under similar nutritional levels. The meat quality, fatty acid composition, and free amino acid contents of loins (longissimus dorsi) and butts (supraspinatus) were compared after the trial. The results showed that the Canadian Duroc × France Landrace × France Yorkshire (GC) pig loins had the highest pH_{24h} value ($P<0.05$). The PIC399 × France Landrace × France Yorkshire (GP) pig loins had the highest inosine monophosphate content ($P<0.05$), whereas the old American-line Duroc (imported before 2013) × new American-line Landrace × new American-line Yorkshire (XO) pig loins had the highest total, essential, and delicious amino acid contents ($P<0.05$). The chemical composition, sensory evaluation, and fatty acid composition of all pork were similar ($P>0.05$). These results suggest that the GC pig loins had a long shelf life, the GP pig loins were appealing, and the XO pig loins were delicious and nutritious. Thus, while choosing crossbreeds, it is important to recognize that the meat quality relies on the hybridization.

Keywords: Crossbred pig; Meat quality; Fatty acid composition; Amino acids composition

Introduction

Both populations and incomes have grown in the past two decades, and the demand for higher value foods (e.g., meats) is growing rapidly in emerging economies [1]. Global meat consumption over the past 50 years (1961–2011) has increased from 23.10 to 42.20 kg/head/year [2]. Pork consumption in China accounts for nearly 50% of global consumption [3]. Global meat consumption over the past 50 y (1961–2011) has increased from 23.10 to 42.20 kg/head/year [2].

Because people tend to prefer high-quality pork, the production of high quality pork is becoming increasingly important. The consumers looked for quality certification while buying pork, followed by appearance and traceability information [4]. Crossbreeding is widely used to improve total pork production efficiency, so it is essential to recognize, when adopting a proper hybridization strategy that meat quality relies on crossbreeding [5].

The production of finishing pigs at farms in Shanghai, China is based on three-way hybridization, including Duroc × Landrace × Yorkshire (DLY) and PIC × Landrace × Yorkshire, and Duroc is usually used as the terminal sire breed. The meat of Duroc breed is characterized by high pH, juiciness, flavor, and intramuscular fat (IMF) content; and by low drip and cooking losses [6]. Furthermore, the Duroc crosses also contains high intramuscular fat content [7], and the inclusion of the Duroc breed in maternal lines affects the meat quality and fatty acid composition [8]. The meat of Landrace pigs exhibited significantly higher lightness and drip loss, but Duroc pigs produced meat that was more tender than that of Landrace and Yorkshire pigs [9]. Each breed has its own characteristics, and different strains of the same breed vary. For instance, the Finnish Landrace × Yorkshire crossbred sows mated with the Finnish Landrace (FL) pigs exhibited lighter loin color and a higher redness value than those of the Finnish Landrace × Yorkshire crossbred sows mated with Norwegian Landrace (NL) pigs [10], thus indicating the importance of breed strain to meat quality. The PIC pig, an imported five-way crossbreed, represents one of the best pig breeds in the world because of its fast growth, high carcass lean meat rate, well-distributed intermuscular fat, and high litter size. PIC pigs had higher 45 min and 24 h post-mortem L^*, and pH_{45min} than PIC and DLY pigs, but they exhibited lower pH_{24h} [11]. The TOPIGS pig, originally bred in the 1960s by the world's second largest pig breeding company (Holland International Company), is characterized by fast growth, high-lean meat rate, and low-fat growth [12].

From these previously reported results, it is clear that meat quality can vary between crossbreeds; a better understanding of this variation could lead to improvements in the meat quality of crossbred pigs, and thereby meet the demands of the increasingly discerning market for high-quality pork. Therefore, this study investigated the effects of three-way crossbreeding on meat quality in Shanghai based on meat quality traits, fatty acid composition, amino acid composition, and inosine monophosphate (IMP) content of longissimus muscles among the eight local representative crossbreeds.

Materials and Methods

Ethical considerations

All animal care and experimental procedures in this study were conducted in compliance with the requirements of the Animal Care and Use at the Animal Ethics Committee of Shanghai Breeding Pig Testing Center, and were in accordance with the standards of international regulations.

Animals, management and sampling

The present study was organized by the Shanghai Breeding Pig Testing Center. A total of 48 weaned pigs (half castrated males and half females; randomly selected at 25 kg in weight) represented the following eight native three-way crossbreeds: new American-line (imported after 2013) Duroc × new American-line Landrace × new American-line

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Yorkshire (XN, N=6); old American-line Duroc (imported before 2013) × new American-line Landrace × new American-line Yorkshire (XO, N=6); new American-line Duroc × TOPIGS A × TOPIGS N (QN, N=6); new American-line Duroc × new American-line Landrace × France Yorkshire (MX, N=6); American Duroc × Danish Landrace × France Yorkshire (GA, N = 6); Canadian Duroc × France Landrace × France Yorkshire (GC, N=6); PIC399 × France Landrace × France Yorkshire (GP, N=6); and Taiwan (China) Duroc × new American-line Landrace × France Yorkshire (MZ, N=6). Animals were housed in individual pens during trial periods. All pigs were fed individually twice daily, and were provide ad libitum access to feed and water. Normal epidemic prevention measures were taken. The pigs were raised until their live weight reached approximately 115 kg. Experimental pigs were raised on corn-soybean-based diets, which were balanced with vitamin and trace mineral supplements, during the four different growth phases. The pigs were reared on a diet containing 3208 kJ metabolizable energy and 16.10% crude protein from the beginning of the trial until 95 days of age, 3170 kJ metabolizable energy and 16.02% crude protein from 96 to 120 days of age, 3090 kJ metabolizable energy and 14.81% crude protein from 121 to 145 days of age, and 3040 kJ metabolizable energy and 14.20% crude protein from 146 days of age until their body weight reached 115 kg (Table 1). Animals were slaughtered via electrical stunning, and were subsequently exsanguinated, scalded, depilated, labeled, eviscerated, rinsed, divided into halves, and chilled at 0°C for 24 h. Parts of the loin (*M. longissimus dorsi*) on the left side from the tenth to the last ribs and butts (*M. supraspinatus*) were removed to measure meat quality parameters. Furthermore, samples used to determine IMF content and fatty acid composition were taken from the hip end of the loin, and the samples were then vacuum packed and frozen. Samples for color measurements were excised at roughly 7 cm from the hip end of the loin. Meat quality traits were then evaluated at the Animal Husbandry Laboratory of Shanghai City Animal Husbandry Technology Centre. The remaining loins were vacuum packed, frozen, and stored at -20°C until use for sensory analysis.

pH measurement

The pH of the longissimus muscle samples collected from animals slaughtered after 45 min (pH_{45min}) and 24 h (pH_{24h}) post mortem were determined using a pH meter (MATTHAUS PH-STAR Carcass Meat Quality Direct Measuring Instrument; MATTHAUS Co., Germany) with a spear-type electrode. Initially, the electrode was calibrated using standard buffers of pH 4.01 and 7.00. The setting temperature of the pH meter was consistent with the actual temperature of the standard solution during calibration. The calibrated pH glass electrode, which was sleeved in the metal blade segment, was directly inserted into the sample to measure the actual sample temperature. After verifying that the setting temperature of the pH meter was consistent with the actual temperature of the sample, the pH value was recorded when the reading was stable for approximately 15–20 sec. The pH of each sample was measured in triplicates, and the average value was used in subsequent analyses.

Determination of meat color

Color parameters (L^*=lightness, a^*=redness, and b^*=yellowness) of a 24 h postmortem carcass were determined using a spectrophotometer (CI60, X-rite Co., Shanghai, China) containing a white fluorescent lamp (D65) as light source, and the instrument was calibrated with a white plate before use. The color of the loin of freshly cut meat was determined by taking three measurements across the surface 1 h after blooming at room temperature. The color parameter values of each sample were obtained using the average value of three repeated measurements taken at different locations of the carcass.

Shear force test

The pork loin samples were placed in polypropylene bags, and then placed in a 72°C water bath, such that the meat samples were completely immersed, but not the top of the bags. The time required for the internal temperature of the meat to reach 70°C was recorded, and the samples were removed immediately. The bags containing meat samples were placed under running water for 30 mins to cool (such that the water did not enter the bags), and then stored at 4°C for 12 h. Subsequently, the chilled, cooked meat samples were equilibrated to room temperature for 30 min. Qualitative filter papers were used to dry the samples, and then the samples were cut parallel to the longitudinal axis of the muscle fibers to obtain 2 × 1 × 1 cm (length

Ingredient	71–95 days	96–120 days	121–145 days	146–170 days
Corn (%)	41.0	46.0	58.0	54.0
Barley (%)	20.0	20.0	20.0	20.0
Wheat middling (%)	0.0	0.0	0.0	7.0
Wheat flour (%)	8.0	5.0	0.0	0.0
Soybean oil (%)	1.0	0.5	0.0	0.0
Fish meal (%)	2.0	2.0	0.0	0.0
Expanded full-fat soybean (%)	6.0	4.0	0.0	0.0
Soybean meal (%)	18.0	18.5	18.0	15.0
Premix† (%)	4.0	4.0	4.0	4.0
Total (%)	100.0	100.0	100.0	100.0
Calculated analysis				
Crude protein (%)	16.10	16.02	14.81	14.20
Calcium (%)	0.82	0.78	0.78	0.77
Total phosphorus (P) (%)	0.41	0.38	0.36	0.39
Available P (%)	0.25	0.22	0.22	0.23
Digestive energy (kJ/kg)	3338	3300	3205	3151
Metabolic energy (kJ/kg)	3208	3170	3090	3040

†Premix (per kg) contains: copper 200 mg, iron 150 mg, zinc 140 mg, manganese 50 mg, vitamin A 16000 IU, vitamin D 3500 IU, vitamin E 40 IU, nicotinic acid 25 mg, pantothenic acid 30 mg, riboflavin 4.0 mg, vitamin B12 0.08 mg, biotin 0.15 mg, and choline 0.95 mg.

Table 1: Formula and nutrient levels of basal diets (% DM basis).

× width × height) sized pieces. The digital display muscle tenderness apparatus (C-LM3; Tenovo International Co., Limited, Beijing, China) with Warner-Bratzler shear device was used at a speed of 5 mm/s to shear the samples perpendicular to the longitudinal axis of the muscles and the shear force was determined. The shear force of each sample was measured in triplicates, and the average value (kg·f) was used in subsequent analyses.

Measurement of pressing loss

Cylindrical pieces of meat (1 cm height and 2.5 cm diameter) were cut in the vertical direction of the muscle fiber and weighed (A). They were then wrapped in double gauze cloth and packed in 16 layers of qualitative filter paper. The packed samples were pressed by applying a 35 kg weight on them using an infinite compression machine (YYW-2, Nanjing Soil Instrument Co., Nanjing, China) for 5 min. Subsequently, the gauze cloth and filter papers were removed, and the samples were weighed (B). Pressing loss (%) was calculated using following equation.

$$\text{Pressing loss (\%)} = [(A - B) / A] \times 100$$

Determination of moisture, crude protein, and intramuscular fat content

The moisture and crude protein content of *longissimus dorsi* were determined according to the methods of Su et al. [13]. The IMF content was analyzed according to the method of Cecchinato et al. [14]. A near infrared spectrometer (Antaris II FT-NIR Analyzer; Thermo Electron Co., Massachusetts, USA) integrating sphere diffuse reflection sampling system, result operation software, and TQ Analyst 6.2 spectrum analysis software was used for this purpose. The moisture and crude protein contents of each sample were measured in triplicates, and the average values were used in subsequent analyses.

Evaluation of sensory traits

The sensory analysis was performed by a well-trained 10-member tasting panel skilled in assessing cooked meat [15]. Poached *longissimus dorsi* muscle, poached abdominal steaky pork, and braised abdominal steaky pork were used for sensory analyses. The following procedure was employed to poach the *longissimus dorsi* muscle or abdominal steaky pork: 2 cm thick dorsal longissimus or abdominal steaky pork was taken, the peripheral fat and connective tissue was removed, and the remaining muscle sample was washed. The sample was then placed in a pot containing cold water (the water should inundate the pork), the content of the pot was boiled, and the heat was turned to medium for 40 min until the meat was ripe. The samples were then removed, cooled for 10 min, and cut into 1 cm × 1 cm × 1 cm cubes before placing them on a plate. For the braised abdominal steaky pork, the hair was shaved off the samples, and the samples were cut into 2 cm × 2 cm × 3 cm pieces. The pieces were then blanched in boiling water (the water should inundate the pork) and the foam was skimmed. The samples were then removed, rinsed under running cool water, and stir fried in rapeseed oil at 170°C for 1 min. The pieces were then added to cold water (the water should submerge the pork) and boiled. The heat was turned to low for 40 min, and then the samples were boiled over high heat for 1 min before placing them on the plate. The sensory evaluation of all the samples followed a blind assessment (i.e., the information about the pork samples was not provided to the panelists). The experts tasted and scored the poached longissimus muscle, poached abdominal steaky pork, and braised abdominal steaky pork in order. During the tasting process, the experts were provided toothpicks and warm water after each tasting. According to the Meat Standards Australia (MSA) rating system, the tenderness, juiciness, flavor, and overall acceptability of the meat were scored using a centesimal system. The weight of the four indices was 0.3, 0.1, 0.3, and 0.3 respectively. The four indices were converted into a meat quality score MQ4. The samples were assigned to one of the four meat quality groups according to the MQ4 scores: unsatisfactory quality (unsatisfactory, MQ4<45.5), good everyday quality (3*, 45.5<MQ4<63.5), better everyday quality (4*, 63.5<MQ4<76.5), and premium quality (5*, MQ4>76.5) [16].

Determination of fatty acid composition

The fatty acid composition of *longissimus dorsi* was determined according to the method described by Choi et al. [17] with some modifications. The sample was saponified and methyl esterified in a 80°C water bath for 1 h, and then heptane was added and the top layer that formed was collected. Finally, a gas chromatograph (GC-14B; Shimadzu Co., Tokyo, Japan) equipped with a 100 m × 0.25 mm (length × internal diameter) capillary column of film thickness 0.20 μm was used to separate and quantify the samples. Nitrogen was used the carrier gas. The oven temperature was initially maintained at 100°C for 13 min, increased to 180°C at a rate of 10°C/min and maintained for 6 min, increased to 200°C at a rate of 1°C/min and maintained for 20 min, and finally increased to 230°C at a rate of 4°C/min and maintained for 10.5 min. The injector and detector temperatures were maintained at 270°C and 280°C, respectively.

Determination of inosine monophosphate content

The *longissimus dorsi* samples were washed, minced, and mixed. Thirty milliliter of 5% pre-chilled perchloric acid was added to 10 g of the sample [18]. The sample was homogenized and centrifuged at 4000 rpm for 5 min. The supernatant was transferred to a beaker, 30 mL of 5% perchloric acid was added to the residue, and mixed for 5 min. The sample was then centrifuged at 4000 rpm for 5 min. The pH of the supernatant was adjusted to 6.5 using KOH solution. The resulting solution was filtered, and the filtrate was made up to 100 mL. A 0.45 μm cellulose filter membrane was used for filtration before determining the IMP content [19]. A liquid chromatography column equipped with a 4.6 mm × 250 mm capillary column of film thickness 5 μm was used. The mobile phase used was methanol/phosphate solution (5:95), and the column temperature was 25°C. The flow rate was 0.8 mL/min, the sampling quantity was 10 μL, and the detection wavelength was 248 nm.

Determination of amino acid composition

The amino acid composition of *longissimus dorsi* was determined spectrophotometrically using the ninhydrin reagent. Approximately 0.1 g of the degreased, dried sample powder was placed in a hydrolytic tube and 10 mL of 6 mol/L hydrochloric acid was added to the sample and mixed. Subsequently, 3-4 drops of phenol were added, and then the sample was hydrolyzed and frozen in liquid nitrogen for 3-5 mins. After sealing, the sample was placed in a 110°C electrothermal blower thermostat, hydrolyzed for 22 h, and cooled to room temperature. Subsequently, the samples were filtered to a 50 mL bottle. The hydrolysate was rinsed 2-3 times with water and filtered into a bottle. The samples were then dried by decompression at 50°C using an evaporator. The residue obtained was dissolved in 2 mL water and decompression dried. Subsequently, 2 mL of sodium citrate buffer (pH 2.2) was added to the tube, the resulting solution was mixed, and filtered through a 0.22 μm filter membrane. Finally, 1 mL filtrate was taken and analyzed in an automatic amino acid analyzer (L-8900; Hitachi, Ltd., Tokyo, Japan).

Statistical analyses

Data were analyzed by one-way analysis of variance (ANOVA) using SPSS software version 20.0. Duncan's test was applied to determine the significance of mean values of the crossbreeds. The data are represented as mean ± standard error of the mean (SEM). The differences were considered significant at $P<0.05$.

Results

Chemical composition and quality traits of longissimus muscle

The pork chemical composition and quality traits of the longissimus muscles from all pigs are shown in Table 2. The pH_{45min} was between 6.10 and 6.34, and the pH_{24h} was between 5.54 and 5.75. The pH of the sample decreased about 45 min to 1 h after slaughter. The pH_{24h} of the GC pigs was significantly higher than that of the XO, GP, and XN pigs ($P<0.05$). However, there were no significant differences in the pH_{45min}, L^*, a^*, b^*, pressing loss, shear force, and IMF, crude protein, and moisture content among the crossbreeds.

Sensory evaluation of loin and belly meat

The results of the sensory evaluation of pork loin and belly meat—poached *longissimus dorsi*, poached steaky pork, and braised steaky pork—of all the crossbred pigs are given in Table 3. The quality of all the pork types was rated excellent (category 4^*–5^*). There were no significant differences ($P>0.05$) in juiciness, tenderness, flavor, overall acceptability, nor MQ4 of poached longissimus dorsi and poached steaky pork in all crossbred pigs.

Fatty acid composition of the longissimus muscles

The fatty acid composition of the longissimus muscle of three-way crossbred pigs is summarized in Table 4. The major fatty acids included oleic, palmitic, linoleic, and stearic acid, with oleic acid being the most abundant (0.41–0.83 g/100 g). Palmitic acid (0.35–0.52 g/100 g), oleic acid (0.41–0.83 g/100 g), and linoleic acid (0.32–0.47 g/100 g) were the most abundant saturated, monounsaturated, and polyunsaturated fatty acids, respectively. There was no significant difference in the fatty acid composition ($P>0.05$) among the crossbred pigs.

IMP content and free amino acid composition of longissimus muscle

The IMP content and free amino acid composition of the longissimus muscle of three-way crossbred pigs are presented in Table 5. The content of IMP was between 766.67 and 962.83 mg/kg.

Parameter	MX	QN	GP	MZ	GA	XN	XO	GC
pH_{45min}	6.34 ± 0.11	6.33 ± 0.07	6.33 ± 0.09	6.17 ± 0.15	6.34 ± 0.13	6.10 ± 0.15	6.12 ± 0.06	6.26 ± 0.19
pH_{24h}	5.69 ±0.03^{bc}	5.64±0.02^{abc}	5.62 ±0.03^{ab}	5.69 ±0.03^{bc}	5.69 ±0.03^{bc}	5.63 ±0.02^{ab}	5.54 ± 0.04^{a}	5.75 ± 0.07^{c}
L^*	43.99 ± 0.73	44.08 ± 1.06	43.81 ± 0.45	44.92 ± 0.67	42.47 ± 1.14	46.74 ± 2.47	42.73 ± 0.51	47.18 ± 0.85
a^*	5.52 ± 0.59	6.62 ± 0.43	5.90 ± 0.56	6.09 ± 0.37	5.56 ± 0.26	6.98 ± 0.69	6.29 ± 0.46	6.21 ± 0.62
b^*	5.79 ± 0.35	7.17 ± 0.64	5.73 ± 0.34	6.23 ± 0.35	5.84 ± 0.54	7.08 ± 0.87	5.50 ± 0.31	7.29 ± 0.56
Pressing loss (%)	10.64 ± 0.62	11.52 ± 0.23	11.62 ± 0.77	12.43 ± 0.61	11.87 ± 0.74	14.22 ± 4.86	11.26 ± 0.28	12.89 ± 1.19
Shear force (kg·f)	5.05 ± 0.41	4.22 ± 0.30	3.37 ± 0.17	4.32 ± 0.21	4.17 ± 0.19	3.69 ± 0.34	4.73 ± 0.63	3.84 ± 0.43
IMF (%)	1.83 ± 0.17	1.45 ± 0.12	1.40 ± 0.13	2.00 ± 0.32	1.81 ± 0.32	1.86 ± 0.47	1.58 ± 0.12	1.98 ± 0.31
Crude protein (%)	23.93 ± 0.22	23.93 ± 0.28	24.48 ± 0.30	23.94 ± 0.20	23.91 ± 0.25	23.69 ± 0.15	23.68 ± 0.14	23.58 ± 0.41
Moisture (%)	74.53 ± 0.09	74.84 ± 0.14	74.27 ± 0.42	73.96 ± 0.39	74.70 ± 0.19	74.42 ± 0.55	74.96 ± 0.23	74.61 ± 0.24
Mean ± SEM; n = 6. a–cmeans within a row with different letters are significantly different at P < 0.05.								

Table 2: Comparison of chemical composition and quality traits of the loins of three-way crossbreeds.

	Parameter	MX	QN	GP	MZ	GA	XN	XO	GC
Poached longissimus dorsi	Juiciness	7.50 ± 0.43	6.75 ± 0.42	6.55 ± 0.42	7.05 ± 0.44	7.40 ± 0.27	7.30 ± 0.36	7.50 ± 0.17	7.25 ± 0.37
	Flavor	24.60 ± 0.56	20.60 ± 1.47	21.10 ± 0.77	21.30 ± 1.65	23.40 ± 0.65	22.10 ± 1.09	23.10 ± 0.89	21.80 ± 1.05
	Tenderness	24.10 ± 0.75	20.90 ± 1.67	21.90 ± 0.86	20.20 ± 1.63	23.90 ± 0.94	21.80 ± 1.11	22.00 ± 1.23	22.40 ± 1.54
	Overall acceptability	24.80 ± 0.88	21.30 ± 1.36	22.20 ± 0.93	21.60 ± 1.33	24.15 ± 0.72	23.10 ± 0.95	23.60 ± 0.92	23.80 ± 0.71
	MQ4	81.00 ± 2.11	69.55 ± 4.56	71.75 ± 2.71	70.15 ± 4.80	78.85 ± 2.24	74.30 ± 3.16	76.20 ± 2.71	75.25 ± 3.28
	Category	5^*	4^*	4^*	4^*	5^*	4^*	4^*	4^*
Poached steaky pork	Juiciness	8.40 ± 0.21	7.95 ± 0.41	7.55 ± 0.44	7.75 ± 0.48	7.60 ± 0.33	8.15 ± 0.32	8.10 ± 0.23	7.45 ± 0.44
	Flavor	25.10 ± 0.82	24.60 ± 1.02	23.30 ± 1.04	24.15 ± 1.05	24.70 ± 0.79	25.10 ± 0.80	25.00 ± 0.77	23.90 ± 1.02
	Tenderness	24.90 ± 1.21	24.80 ± 1.00	23.70 ± 1.05	24.15 ± 1.10	24.55 ± 0.93	24.80 ± 1.00	24.80 ± 1.06	23.30 ± 1.20
	Overall acceptability	25.90 ± 0.81	25.20 ± 1.12	24.55 ± 1.10	23.80 ± 1.25	24.20 ± 0.89	25.60 ± 0.78	25.80 ± 0.66	23.60 ± 0.93
	MQ4	84.30 ± 2.91	82.55 ± 3.38	79.10 ± 3.54	79.85 ± 3.74	81.05 ± 2.68	83.65 ± 2.66	83.70 ± 2.44	78.25 ± 3.36
	Category	5^*	5^*	5^*	5^*	5^*	5^*	5^*	5^*
Braised steaky pork	Juiciness	7.65 ± 0.28	7.40 ± 0.40	6.65 ± 0.43	7.30 ± 0.40	7.90 ± 0.37	7.25 ± 0.34	7.15 ± 0.18	6.80 ± 0.33
	Flavor	24.90 ± 1.00	25.20 ± 0.98	22.30 ± 1.24	23.10 ± 1.17	25.30 ± 0.93	23.00 ± 0.95	23.70 ± 0.97	21.70 ± 1.14
	Tenderness	24.70 ± 0.82	24.90 ± 0.99	22.60 ± 1.39	23.40 ± 1.12	25.40 ± 0.93	23.40 ± 1.03	23.50 ± 0.98	22.70 ± 0.94
	Overall acceptability	25.20 ± 0.83	24.40 ± 0.99	22.90 ± 1.07	24.30 ± 1.03	26.00 ± 0.87	24.80 ± 0.77	24.70 ± 0.58	23.30 ± 0.76
	MQ4	82.45 ± 2.64	81.90 ± 3.06	74.45 ± 3.90	78.10 ± 3.43	84.60 ± 2.93	78.45 ± 2.60	79.05 ± 2.46	74.50 ± 2.89
	Category	5^*	5^*	4^*	5^*	5^*	5^*	5^*	4^*
Mean ± SEM, n = 6.									

Table 3: Sensory evaluation of the loin and belly meat of three-way crossbred pigs.

Parameter	MX	QN	GP	MZ	GA	XN	XO	GC
Palmitic acid (C16:0)	0.48 ± 0.08	0.36 ± 0.08	0.35 ± 0.11	0.41 ± 0.06	0.52 ± 0.09	0.40 ± 0.07	0.48 ± 0.06	0.36 ± 0.07
Stearic acid (C18:0)	0.22 ± 0.06	0.22 ± 0.04	0.20 ± 0.06	0.23 ± 0.03	0.37 ± 0.09	0.23 ± 0.04	0.24 ± 0.03	0.19 ± 0.04
Oleic acid (C18:1n9)	0.83 ± 0.12	0.44 ± 0.10	0.45 ± 0.14	0.58 ± 0.09	0.66 ± 0.16	0.55 ± 0.10	0.67 ± 0.09	0.41 ± 0.09
Linoleic acid (C18:2n6)	0.37 ± 0.07	0.36 ± 0.09	0.34 ± 0.06	0.36 ± 0.04	0.47 ± 0.09	0.38 ± 0.08	0.39 ± 0.04	0.32 ± 0.04
Saturated fatty acid	0.72 ± 0.14	0.60 ± 0.13	0.57 ± 0.17	0.66 ± 0.10	0.91 ± 0.17	0.65 ± 0.11	0.75 ± 0.09	0.56 ± 0.12
Monounsaturated fatty acid	0.88 ± 0.14	0.48 ± 0.11	0.49 ± 0.15	0.64 ± 0.10	0.77 ± 0.16	0.60 ± 0.11	0.73 ± 0.10	0.45 ± 0.10
Polyunsaturated fatty acid	0.44 ± 0.09	0.45 ± 0.10	0.41 ± 0.07	0.45 ± 0.05	0.58 ± 0.11	0.46 ± 0.10	0.47 ± 0.04	0.39 ± 0.05
Total unsaturated fatty acid	1.32 ± 0.19	0.93 ± 0.21	0.90 ± 0.22	1.09 ± 0.14	1.36 ± 0.26	1.05 ± 0.18	1.20 ± 0.13	0.84 ± 0.15
Mean ± SEM, n = 6.								

Table 4: Comparison of fatty acid composition (g/100 g) of the longissimus muscles of three-way crossbred pigs.

Parameter	MX	QN	GP	MZ	GA	XN	XO	GC
IMP	958.33 ± 38.24^{b}	770.67 ± 36.2^{0}a	962.83 ± 37.1^{7}b	915.67 ± 30.38^{b}	871.00 ± 32.96^{ab}	866.17 ± 27.43^{ab}	766.67 ± 47.9^{4}a	852.33 ± 49.30^{ab}
Asp	2.18 ± 0.04^{ab}	2.32 ± 0.05^{bc}	2.19 ± 0.06^{ab}	2.32 ± 0.03^{bc}	2.18 ± 0.06^{ab}	2.19 ± 0.05^{ab}	2.41 ± 0.07^{c}	2.08 ± 0.04^{a}
Glu	3.45 ± 0.08^{ab}	3.76 ± 0.09^{c}	3.41 ± 0.08^{a}	3.69 ± 0.06^{bc}	3.49 ± 0.10^{ab}	3.41 ± 0.09^{a}	3.83 ± 0.11^{c}	3.33 ± 0.05^{a}
Try	0.25 ± 0.00^{b}	0.25 ± 0.00^{b}	0.25 ± 0.00^{b}	0.26 ± 0.01^{b}	0.22 ± 0.01^{a}	0.22 ± 0.00^{a}	0.23 ± 0.01^{a}	0.22 ± 0.00^{a}
Val	0.34 ± 0.01	0.34 ± 0.01	0.33 ± 0.01	0.33 ± 0.01	0.30 ± 0.01	0.33 ± 0.01	0.33 ± 0.01	0.33 ± 0.02
Met	0.66 ± 0.02^{ab}	0.71 ± 0.02^{bc}	0.65 ± 0.02^{ab}	0.71 ± 0.01^{bc}	0.67 ± 0.02^{ab}	0.65 ± 0.02^{a}	0.73 ± 0.03^{c}	0.63 ± 0.01^{a}
Ile	1.05 ± 0.02^{bcd}	1.09 ± 0.02^{cd}	0.94 ± 0.02^{a}	1.07 ± 0.02^{cd}	1.04 ± 0.03^{bcd}	0.97 ± 0.04^{ab}	1.12 ± 0.04^{d}	1.02 ± 0.02^{bc}
Leu	2.21 ± 0.05^{abc}	2.32 ± 0.05^{cd}	2.15 ± 0.05^{ab}	2.30 ± 0.04^{bcd}	2.20 ± 0.06^{abc}	2.16 ± 0.06^{abc}	2.42 ± 0.08^{d}	2.11 ± 0.03^{a}
Tyr	0.84 ± 0.02^{ab}	0.89 ± 0.02^{bc}	0.83 ± 0.02^{ab}	0.89 ± 0.02^{bc}	0.84 ± 0.02^{ab}	0.83 ± 0.02^{ab}	0.92 ± 0.03^{c}	0.81 ± 0.01^{a}
Phe	1.08 ± 0.02^{ab}	1.11 ± 0.02^{bc}	1.05 ± 0.03^{ab}	1.11 ± 0.02^{bc}	1.06 ± 0.03^{ab}	1.05 ± 0.03^{ab}	1.16 ± 0.03^{c}	1.03 ± 0.01^{a}
Lys	1.84 ± 0.04^{abc}	1.96 ± 0.04^{cd}	1.80 ± 0.04^{ab}	1.94 ± 0.03^{bcd}	1.84 ± 0.05^{abc}	1.81 ± 0.05^{ab}	2.01 ± 0.07^{d}	1.78 ± 0.02^{a}
His	0.94 ± 0.02	0.89 ± 0.02	0.92 ± 0.02	0.93 ± 0.02	0.86 ± 0.03	0.93 ± 0.03	0.94 ± 0.04	0.84 ± 0.03
Arg	1.55 ± 0.03^{ab}	1.64 ± 0.03^{bc}	1.49 ± 0.04^{a}	1.62 ± 0.03^{bc}	1.53 ± 0.04^{ab}	1.51 ± 0.04^{a}	1.72 ± 0.03^{c}	1.47 ± 0.02^{a}
Cys	0.30 ± 0.01	0.31 ± 0.01	0.32 ± 0.03	0.32 ± 0.02	0.34 ± 0.02	0.35 ± 0.06	0.31 ± 0.02	0.32 ± 0.01
Ala	1.44 ± 0.03^{ab}	1.49 ± 0.03^{b}	1.41 ± 0.03^{ab}	1.50 ± 0.02^{b}	1.41 ± 0.04^{ab}	1.39 ± 0.04^{a}	1.60 ± 0.02^{c}	1.34 ± 0.03^{a}
Gly	1.02 ± 0.03^{ab}	1.00 ± 0.02^{ab}	0.95 ± 0.03^{ab}	1.02 ± 0.01^{b}	0.97 ± 0.03^{ab}	0.98 ± 0.04^{ab}	1.18 ± 0.10^{ab}	0.92 ± 0.02^{a}
Ser	0.96 ± 0.02^{ab}	1.02 ± 0.02^{bc}	0.96 ± 0.02^{ab}	1.01 ± 0.02^{bc}	0.94 ± 0.03^{a}	0.95 ± 0.02^{ab}	1.05 ± 0.03^{c}	0.92 ± 0.01^{a}
Pro	0.81 ± 0.02^{a}	0.75 ± 0.01^{a}	0.76 ± 0.02^{a}	0.81 ± 0.02^{a}	0.75 ± 0.02^{a}	0.76 ± 0.03^{a}	0.92 ± 0.04^{b}	0.76 ± 0.01^{a}
Thr	1.11 ± 0.02^{abc}	1.18 ± 0.02^{cd}	1.10 ± 0.03^{ab}	1.16 ± 0.02^{bcd}	1.09 ± 0.03^{ab}	1.09 ± 0.03^{ab}	1.20 ± 0.04^{d}	1.07 ± 0.01^{a}
TAA	22.01 ± 0.41^{abc}	23.03 ± 0.46^{cd}	21.50 ± 0.52^{ab}	22.98 ± 0.37^{bcd}	21.72 ± 0.55^{abc}	21.59 ± 0.59^{abc}	24.07 ± 0.53^{d}	20.97 ± 0.28^{a}
EAA	8.28 ± 0.15^{abc}	8.71 ± 0.18^{cd}	8.02 ± 0.19^{ab}	8.63 ± 0.15^{bcd}	8.19 ± 0.23^{abc}	8.07 ± 0.23^{ab}	8.96 ± 0.28^{d}	7.97 ± 0.11^{a}
DAA	8.08 ± 0.17^{ab}	8.58± 0.19^{bc}	7.95 ± 0.20^{a}	8.53 ± 0.13^{bc}	8.05 ± 0.21^{ab}	7.97 ± 0.21^{a}	9.03 ± 0.15^{c}	7.67 ± 0.13^{a}
EAA/TAA (%)	37.63 ± 0.07	37.80 ± 0.08	37.28 ± 0.09	37.52 ± 0.08	37.69 ± 0.12	37.35 ± 0.11	37.19 ± 0.47	38.01 ± 0.11
DAA/TAA (%)	36.71 ± 0.13	37.24 ± 0.10	37.00 ± 0.08	37.12 ± 0.06	37.06 ± 0.04	36.91 ± 0.15	37.52 ± 0.29	36.57 ± 0.14
Mean ± SEM, n = 6. a–dmeans within a row with different letters are significantly different at P < 0.05.								

Table 5: Comparison of IMP content (mg/kg) and free amino acid composition (g/100 g) of the longissimus muscles of three-way crossbred pigs.

The content of IMP in the GP (962.83 ± 37.17 mg/kg) pork was higher than that in the QN (770.67 ± 36.20 mg/kg) and XO (766.67 ± 47.94 mg/kg) pork (P<0.05). The analysis of free amino acid composition indicated that the major free amino acids of the longissimus muscles were glutamic acid (3.33 to 3.83 g/100 g), leucine (2.11 to 2.42 g/100 g), aspartic acid (2.08 to 2.41 g/100 g), and lysine (1.78 to 2.01 g/100 g). The XO pork had the highest total amino acids (TAA) content (24.07 g/100 g), followed by delicious amino acids (DAA) (9.03 g/100 g) and essential amino acids (EAA) contents (8.96 g/100 g), whereas the GC pork had the lowest TAA (20.97 g/100 g), EAA (7.97 g/100 g), and DAA (7.67 g/100 g) contents; the differences were significant (P<0.05). However, neither EAA to TAA (37.19% to 38.01%) nor DAA to TAA ratio (36.57% to 37.52%) exhibited significant differences among the three-way crossbred pigs (P>0.05).

Discussion

The quality traits, one of the essential objectives in pig production, include pH, color, tenderness, pressing loss, moisture content, and IMF content [20,21]. The pH value plays a major role in determining whether the meat is normal; pale, soft, exudative (PSE) meat is generally associated with a pH_{45min} value of <5.9; dark, firm, dry (DFD) meat is usually associated with a $pH_{24\ h}$ value of > 6.2; and acid meat condition is related to a $pH_{24\ h}$ value of<5.4–5.5 [22]. Because the metabolic activity of muscle glycogen ceases post mortem, anaerobic glycolysis leads to a decrease in pH value. The optimal IMF content for palatability is 2.5% [23]. In the present study, the pH_{45min} (6.10–6.34) and pH_{24h} (5.54–5.75) of all three-way crossbreeds were within the normal ranges, and there was no PSE meat, DFD meat, or acid meat. The content of IMF is related to the tenderness, juiciness, and flavor of pork [24]. In the present study, the IMF content (1.40%–2.00%) was less than 2.5% owing to the selection of highly lean pork. Furthermore, the $pH_{24\ h}$ value (5.62) and IMF content (1.40%) of the loin of GP pigs were lower than those of GC pigs (5.75, 1.98%); however, the difference in IMF content was not significant. This result is consistent with that of Jiang et al., who reported that the pH_{24h} value (5.63) and IMF content (1.35%) of PIC pigs was significantly lower than those of DLY pigs (5.92, 2.32%) [5]. Furthermore, the higher IMF content in the DLY breed than in the other breeds (PIC, TOPIGS) [25]. The decrease in

pH significantly correlates with the meat quality parameters, such as color, water holding capacity (drip loss and pressing loss), and shelf life. Furthermore, low pH values within a certain range imply low meat quality [26]. Thus, the meat quality of the GC pigs seemed to be better than that of the GP pigs.

Although there were no significant differences in juiciness, tenderness, flavor, overall acceptability, nor MQ4 of poached longissimus dorsi and poached steaky pork in all crossbred pigs, the poached *longissimus muscles* and poached steaky pork of MX pigs both tended to have superior tenderness, flavor, overall acceptability, and MQ4 to those of other crossbred pigs. In addition, the braised steaky pork of GA pigs tended to have superior tenderness, flavor, overall acceptability, and MQ4 to those of other crossbred pigs. Higher sensory scores were assigned for the poached longissimus muscles and poached steaky pork of the MX pigs and the braised steaky pork of the GA pigs.

The major fatty acids included oleic, palmitic, linoleic, and stearic acid, with oleic acid being the most abundant. The observation of fatty acids composition is generally consistent with that of Oh et al. [27]. The concentration of palmitic acid, stearic acid, linoleic acid, saturated fatty acids, polyunsaturated fatty acids, and total unsaturated fatty acids in the GA pork tended to be higher than those in the other crossbred pork. The MX pork tended to have higher oleic acid and monounsaturated fat contents than those in the other crossbred pork. In the GC pork, the content of stearic acid, oleic acid, linoleic acid, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, and total unsaturated fatty acid tended to be lower than those in the other crossbred pigs; and the content of palmitic acid in the GP meat tended to be lower than that in the other crossbred pork.

The fatty acids constitute a major energy source for animals and affect the nutrition value and sensory quality of meat [28,17]. Polyunsaturated fatty acids, such as linoleic acid, exert beneficial health effects by reducing low-density lipoprotein cholesterol in blood. Positive correlations between several polyunsaturated fatty acids (C16:0, C18:0, and C18:1) and tenderness; a negative correlation between polyunsaturated fatty acid C18:2 and tenderness; a positive correlation between polyunsaturated fatty acid C16:0 and juiciness; and negative correlations between several polyunsaturated fatty acids (C18:0, C18:1, and C18:2) and juiciness at pH 5.5–5.8 [29]. Although the results of fatty acid compositions and contents in our study did no differ significantly, GA pigs did have higher polyunsaturated fatty acid and total unsaturated fatty acid content than did GC pigs, implying that the pork from GA pigs is superior in quality to that from GC pigs.

The nucleotides (IMP and sodium guanosine, 5′-GMP) and amino acids contribute significantly to taste. Inosine monophosphate is an important intermediate product of nucleic acid metabolism. It is mainly produced by the degradation of adenosine triphosphate (ATP) in the muscle [30]. However, IMP in the meat is unstable, and will further decompose, resulting in a bitter taste, under the action of the enzyme [31]. The loss of flavor and increase in bitterness during cold storage are closely related to the degradation of IMP [32]. Evaluation of the amino acid content can help assess the flavor and nutritional value of pork. Free amino acids are associated with the formation of certain flavors, aromas, and tastes, such as acidic taste, saltiness, and bitterness [33]. The amino acids can be divided into four categories: essential amino acids (arginine, histidine, isoleucine, lysine, leucine, methionine, phenylalanine, threonine, and valine), fragrant amino acids (phenylalanine and tyrosine), amino acids with sulfide group (cysteine and methionine), and sweet amino acids (alanine, glycine, serine, and threonine) [34]. The composition of free amino acids, especially the major free amino acids, in the longissimus muscles observed in the present study was similar to the results of Zhou et al. [34]. The present study showed that the GP pork (high IMP content) was more appealing and XO pork (high TAA, EAA, DAA content) was more delicious and nutritious. However, the GC pork was not as appealing in taste and was less nutritious (low TAA, EAA, and DAA content).

Conclusions

Eight three-way crossbreeds of Shanghai were studied for their meat quality traits to meet consumers' demands. The pH_{24h} value of the GC pig loins was the highest ($P<0.05$) indicating its long shelf life. GP pig loins had the highest ($P<0.05$) IMP content. XO pig loins had the highest TAA, EAA, and DAA contents, while GC pig loins had the lowest ($P<0.05$). The sensory evaluation, composition and content of fatty acids, and content of EAA and DAA of all the pig loins were similar ($P>0.05$). In conclusion, considering the high pH_{24h} value, the GC pork was found to be more beneficial because of its long shelf life. However, considering the IMP content, GP pork was more appealing; and considering the TAA, EAA, and DAA contents, XO pork was more delicious and nutritious. Thus, while choosing crossbreeds, it is important to recognize that meat quality depends on the hybridization.

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