RESEARCH ARTICLE

J Anim Sci Technol 2023;65(5):1081-1093
https://doi.org/10.5187/jast.2023.e21

JAST
Journal of Animal Science and Technology
pISSN 2672-0191 eISSN 2055-0391

Comparison between Berkshire and crossbreed on meat quality, and investigation of the relationship with fatty acid composition and meat quality

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Abstract

This study aimed to compare meat quality traits between Berkshire and crossbreed (Landrace × Yorkshire × Duroc), and to investigate the relationship between meat quality traits and fatty acid composition. 20 Berkshire and 20 crossbreed pigs were used to compare pork loin quality and to determine the relationship between measured variables. 23 variables were measured including proximate composition, pH, drip loss and cooking loss, Warner–Bratzler shear force, and fatty acid composition. Berkshire had higher moisture content, pH, water-holding capacity, saturated fatty acids, and redness than the crossbreed pig ($p < 0.05$). The fat content and polyunsaturated fatty acid were low ($p < 0.05$) in Berkshire. Correlation analysis showed a negatively correlation between moisture and fat content, and a positively correlation between saturated fatty acid and fat content. Moreover, saturated fatty acid and polyunsaturated fatty acid were negatively correlated. As a result of factor analysis and partial least square regression, saturated fatty acid and polyunsaturated fatty acid were estimated to be the main factors affecting quality characteristics of pork. Pig breed is associated with differences in meat quality, and fatty acid composition can have an effect on meat quality parameters.

Keywords: Berkshire, Landrace × Yorkshire × Duroc (LYD), Pig breed, Pork quality, Fatty acid composition, Relationship

Check for updates

Received: Dec 20, 2022
Revised: Jan 24, 2023
Accepted: Feb 22, 2023

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Competing interests
No potential conflict of interest relevant to this article was reported.

Funding sources
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology

INTRODUCTION

It is known that there are more than 1,000 pig breeds throughout the world. However, since the late 20th century, a relatively small number of breeds have been used for pig production due to intensive selective breeding and genetic improvement. The modern breeding environment and long-term selective breeding have resulted in improved breeding and growth rates, increased carcass yield, muscle growth efficiency, and improved intramuscular fat (IMF) content [1]. Following this trend, the pork industry in Korea is dominated by the LYD, produced by crossing Landrace, Yorkshire, and Duroc,

(Project No. 2017R1D1A1B0403564414).

Acknowledgements
Not applicable.

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

Authors' contributions
Conceptualization: Seo JK.
Data curation: Seo JK.
Formal analysis: Seo JK, Eom JU.
Methodology: Seo JK, Yang HS.
Software: Seo JK, Eom JU.
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Investigation: Seo JK, Eom JU, Yang HS.
Writing - original draft: Seo JK.
Writing - review & editing: Seo JK, Eom JU, Yang HS.

Ethics approval and consent to participate
All animals used in this research were approved by the Gyeongsang National University (GNU) Institutional Animal Care and Use Committee (GNU-IACUC; approval number: GNU-210614-P0058), Korea.

because of their improved productivity and meat quality characteristics. LYD are also widely used outside of Korea for their improved meat quality, excellent reproductive ability (high productivity), and increased muscle mass that results from crossing Landrace and Yorkshire pigs [2]. On the other hand, Berkshire have been reported to have lower productivity than LYD, but greater water holding capacity. Berkshire have deeper meat color, higher pH, lower drip and cooking loss than LYD [3]. Also, Berkshire have a high ratio of Type I muscle fiber compared to other breeds, and excellent protein solubility and water-holding capacity [4]. As a result, the meat quality characteristics are significantly different between pig breeds. With a more precise understanding of the meat quality characteristics of each breed, Korean consumers could be provided with additional purchasing opportunities for pork products along with LYD.

In pork, representative fatty acids in C16:0, C18:0 (in saturated fatty acid, SFA), C18:1, and C18:2 (in unsaturated fatty acid, UFA) constitute more than 80% of the total fatty acid composition. Also, long-chain fatty acids such as C18:3 and C20-22 are present in relatively high proportions. Many previous studies have argued differences in the fatty acid composition according to pig breed. Berkshire showed significantly higher SFA and lower monounsaturated fatty acid (MUFA) content than Duroc and Landrace [5]. Previous studies have suggested that differences in palmitoleic acid, oleic acid, linoleic acid, and linolenic acid between Pulawska (native species) and Polish Landrace (industrial breed) contribute to improved meat quality of native species [6]. Therefore, changes in meat quality characteristics and fatty acid composition could be attributed to pig breed. Thus, the characteristics of meat that consumers can recognize will be affected by these changes.

The fatty acid composition could affect the firmness of adipose tissue, shelf-life, and flavor among other meat quality characteristics [7]. To summarize the arguments of authors for each factor: 1) firmness of adipose tissue: each fatty acid has a different melting point, so if the composition is different, the melting point of the whole fat is different; 2) shelf-life: the oxidation tendency of UFAs leads to an increase in oxidation color with an increase in lipid oxidation; 3) flavor: changes in fatty acid composition can affect final sensory properties by causing changes in volatile compounds, which are Maillard reaction products. The previous study established the correlation between fatty acids and sensory properties [8]. Among a total of nine fatty acids, only the n-6:n-3 ratio was negatively correlated with tenderness ($r = -0.23$), softness ($r = -0.26$), chewiness ($r = -0.27$) and rate of breakdown ($r = -0.30$) [8]. The proportion of UFAs and fat firmness were negatively correlated, and the correlation between fatty acid content and lean meat quality was insignificant [9]. Also, the correlations between fatty acid composition, protein, and fat content in Duroc, Landrace, Hampshire, and Pietrain [10]. The protein correlated positively with PUFA and correlated negatively with SFA, while fat concentration correlated negatively with PUFA [10].

Therefore, based on previous studies, fatty acid composition and meat quality seem to have a very high scientific relationship. Taken together, scientific evidence has demonstrated that the variation in meat quality characteristics and fatty acid composition between pig breeds is a fact. However, limited information is available regarding the relationship between pork fatty acid composition and meat quality characteristics. Therefore, the aim of this study is to not only compare meat quality between Berkshire and crossbreed, but also to characterize the relationship between pork fatty acid composition and meat quality.

The purpose of this study is to compare meat quality characteristics according to pig breed to identify meat quality characteristics by pig breed and investigate the relationship between fatty acid composition and meat quality properties (proximate components, pH, instrumental color, water holding capacity, and Warner-Bratzler shear force).

https://doi.org/10.5187/jast.2023.e21

MATERIALS AND METHODS

Sample preparation

The pigs were in the same feeding condition according to the Korean Feeding Standard for Swine [11] for 175–185 days. Twenty pigs for each breed were randomly selected from a local slaughterhouse in Korea. A total of 40 pigs were used in the experiment. 20 Berkshire and 20 LYD pigs were slaughtered by Livestock Products Sanitation Management Act. The average slaughter weight was 105–110 kg. The Korean commercial procedures were applied during the slaughter, and the pork loin was removed from the carcass after 24 h. The pork loins were transported to the laboratory from the slaughterhouse and analyzed after refrigerating for 16 h at 4℃ (2 days postmortem).

Proximate composition

The moisture (oven drying method, 950.46) and ash (dry ashing method, 942.05) content were determined using AOAC [12], and fat content analysis was conducted using the method generated by Folch [13]. The results were expressed in % of the sample. Protein content was analyzed using a nitrogen analyzer (SpeedDigester K-425; Distillation Unit K-350, Büchi, Flawil, Switzerland), and % nitrogen was calculated using 6.25 (conversion factor of total nitrogen to protein).

Instrumental color and pH

The instrumental color was measured using a colorimeter (CR-400, Konica Minolta, Tokyo, Japan) and was taken 10 times per whole muscle sample. The color value was obtained from the average. The measuring conditions were D65 illuminant and 2° standard observer, and Commission Internationale de l'Eclairage (CIE) L*, a*, and b* were determined. Before measuring, the colorimeter was calibrated using a white calibration plate (Y = 81.2; x = 0.3191; y = 0.3263).

The 3-g pork loin sample was homogenized with 27 mL of distilled water. The pH was measured using a pH meter (S20 SevenEasyTM, Geifensee, Switzerland) and calibrated to 7.00, 4.01, and 9.21 using a pH buffer. The measurement was repeated three times per sample, and the average value was utilized.

Drip loss and cooking loss

A sample from which connective tissue and visible fat were removed was cut into 3-cm^3 pieces for drip loss. The experimental procedure was conducted using the method of Honikel [14], which was slightly modified. The surface of the prepared sample was lightly wiped off with a paper towel, and the initial weight was measured. The sample was hung in the middle of a plastic container, preventing contact with walls and outside air, and left to stand for 48 h at a constant temperature of 4℃ then weighed. The calculation was expressed as a percentage of the difference in weight before and after standing.

The cooking loss samples were prepared in the form of steaks (2.5 cm height, 6 cm width, and 6 cm length), and after initially weighing, they were placed in a plastic bag and heated in a water bath at 72℃ until the core temperature reached 70℃. At this time, the plastic bag was not sealed, and the prepared samples were observed with a thermocouple (HT-9815, Xintai Instrument, Guangdong, China). The weight was measured after heating was completed, and the calculation expressed the difference in weight before and after heating as a percentage. Drip loss and cooking loss were measured twice per sample, and the average value was used.

Warner-Bratzler shear force

For WBSF, 10 cores of 1.27 cm diameter were taken from each sample in the horizontal direction of the muscle fibers after measuring the cooking loss. The measurement was tested on a universal tensile testing machine (EZ-SX, Shimadzu, Kyoto, Japan) with a 500-N load cell and a blade shear jig. The speed of the crosshead was set to 100 mm/min. The mean value of the cores was used for each sample.

Fatty acid composition

Lipid extraction was conducted by Folch et al. [13], as well as saponification, methylation, and gas chromatography under learning conditions employed by Seo et al. [15]. The amount of fatty acids was expressed as a percent of total fatty acids.

Statistical analysis

Data analysis was conducted using SAS software (9.4 ver., SAS Institute, Cary, NC, USA). Data were used for the analysis of a total of 40 pigs and were expressed as averages. Twenty-three dependent variables and one independent variable were used, and a general linear model was used to test the pig breed effect. One-way analysis of variance and Duncan's multiple range test were used to compare 23 dependent variables including fatty acid composition, proximate composition, color, pH, WBSF, drip loss, and cooking loss, which were tested with 95% significance. Factor analysis was conducted on all pork quality variables used in this study to find the main variables affecting pork quality. At this time, the pig breed effect was removed, and the proc factor was used for analysis. The principal component method was used for the initial factor extraction. The varimax was used as a rotated method to minimize the number of variables with high loadings for each factor and to simplify factor analysis. The results were expressed as a pattern plot of factors 1 and 2.

RESULTS AND DISCUSSION

Mean, maximum, minimum, standard deviation, and coefficient of variation of pork quality traits from all pork loin

Table 1 shows the mean, maximum, minimum, standard deviation, and coefficient of variation of the proximate composition, pH, instrumental color, drip loss, cooking loss, WBSF, and fatty acid composition of the pork loin. The mean of pH, L*, and drip loss were 5.75, 52.25, and 2.11%, respectively. The L* is approximately two points higher than the criteria for classification between normal and abnormal pork loin proposed by Warner et al. [16] and Chmiel et al. [17]. However, considering the pH and drip loss, it can be judged that our pork loin was sufficiently within the normal meat range. In terms of proximate composition, fat content was approximately 3%. The fat percentage of most pork loins from pigs raised in Korea is 3% [18], which is comparable to the pork loin used in our study of common quality. C16:0, C18:0, C18:1, and C18:2 are the main fatty acids in pork loin.

Effect of pig breed on meat quality traits and fatty acid composition

Table 2 shows the effect of pig breeds on the physicochemical traits and fatty acid composition in pork loin. Moisture and fat content were significantly different according to the pig breed. The Berkshire had high moisture content while LYD had high-fat content ($p < 0.05$). According to a previous study, the fat content of Berkshire was lower than that of a Duroc used as a terminal sire among crossbred pigs [19,20]. In this study, the compared subject was LYD, and as a result, the findings were the same as in previous studies. Additionally, according to the authors, the moisture

 https://doi.org/10.5187/jast.2023.e21

Table 1. Descriptive statistics for meat quality traits and fatty acid composition of pork loin

Traits	Mean	Max	Min	SD	CV
Moisture (%)	73.82	75.42	68.79	1.45	1.97
Protein (%)	22.03	25.74	19.87	1.15	5.23
Fat (%)	2.84	6.34	1.29	1.53	49.53
Ash (%)	1.32	1.56	0.85	0.19	16.23
pH	5.75	6.18	5.48	0.16	2.81
L*	52.25	57.72	45.22	2.77	5.31
a*	7.80	13.38	4.58	2.46	31.59
b*	4.36	7.64	2.41	1.10	25.29
Drip loss (%)	2.11	3.20	0.62	0.52	24.82
Cooking loss (%)	26.93	32.66	21.14	3.11	11.53
WBSF (N)	23.14	33.41	15.26	4.56	19.71
C14:0	1.62	2.97	1.09	0.35	21.90
C16:0	24.29	29.15	21.66	2.04	8.39
C16:1	3.79	4.46	2.55	0.37	9.73
C17:1	0.61	1.25	0.19	0.30	48.99
C18:0	11.68	15.92	9.02	1.32	11.28
C18:1	42.66	45.52	37.73	1.75	4.11
C18:2	12.17	16.05	7.34	2.14	17.58
C18:3	0.79	1.22	0.35	0.30	37.34
C20:4	1.77	3.82	0.54	0.79	44.75
SFA	38.02	46.74	32.70	3.02	7.95
MUFA	47.06	50.19	41.03	1.76	3.74
PUFA	14.74	19.63	8.43	2.77	18.81

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

CV, coefficient of variation; WBSF, Warner-Bratzler shear force; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

content was affected by the fat content. This is very helpful in understanding our results. Berkshire was higher in a* and lower in b* than LYD ($p < 0.05$), but L* did not significantly differ in both pig breeds ($p > 0.05$). Lee et al. [21] reported 8.47 as a result of measuring redness in 1,942 Berkshires, which was similar to our result. Also, Subramaniyan [3] compared meat quality characteristics between Berkshire and LYD, which was similar to our redness and b* values except for L*. Drip loss and cooking loss, which represented the water-holding capacity, were significantly higher in LYD than Berkshire ($p < 0.05$). Additionally, the WBSF of Berkshire was lower than that of LYD ($p < 0.05$). Subramaniyan et al. [3] reported that there was no significant difference in the drip loss and WBSF between Berkshire and LYD but the cooking loss was significantly lower than that of LYD. Collectively, based on the results obtained from the physicochemical properties, the main differences are fat content, a*, pH, and water-holding capacity (drip loss and cooking loss). In addition, Barlocco et al. [22] reported a positive correlation between IMF and shear force (r = 0.31), as in our results, in experiments related to predictive models of IMF, moisture, and shear force in pork. On the other hand, Fortin et al. [23] reported a negative correlation (r = −0.47) between IMF and shear force but argued that it still needed to debate with pork tenderness and IMF levels. Therefore, considering our results, the high WBSF despite the high fat content of LYD may be due to the higher cooking loss compared to Berkshire.

The nine fatty acids were detected in our experiment of which C16:0, C17:1, C18:0, C18:2,

Table 2. Effect of pig breed on meat quality properties and fatty acid composition in pork loin

Traits	Berkshire	LYD	SE
Moisture (%)	74.81**	72.83	0.28
Protein (%)	22.12	21.94	0.23
Fat (%)	1.79	3.88***	0.16
Ash (%)	1.28	1.35	0.02
pH	5.86*	5.64	0.03
L*	51.63	52.87	0.61
a*	8.35*	7.24	0.54
b*	3.92	4.80*	0.22
Drip loss (%)	1.80	2.42*	0.08
Cooking loss (%)	24.96	28.90**	0.49
WBSF (N)	20.44	25.83*	0.72
C14:0	1.64	1.59	0.07
C16:0	25.59*	23.00	0.35
C16:1	3.61	3.97	0.07
C17:1	0.42	0.80*	0.05
C18:0	12.49**	10.86	0.22
C18:1	42.86	42.46	0.39
C18:2	10.71	13.64***	0.34
C18:3	0.85	0.73	0.06
C20:4	1.36	2.18***	0.14
SFA	39.81**	36.22	0.52
MUFA	46.89	47.23	0.39
PUFA	12.92	16.55**	0.47

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

LYD, Landrace×Yorkshire×Duroc; WBSF, Warner-Bratzler shear force; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

C20:4, SFA, and polyunsaturated fatty acid (PUFA) significantly differed according to pig breed ($p < 0.05$). The C16:0 and C18:0 in SFA were higher in Berkshire than in LYD, and the C17:1, C18:2, and C20:4 in UFA were lower in Berkshire than in LYD. Thus, SFA was high in Berkshire whereas PUFA was low. Alonso et al. [24] analyzed the fatty acid composition in three crossbred pigs using different sire lines. Similar to our results, PUFA decreased in crossbred pigs with increased SFA, and there was no difference in MUFA in all crossbreeds. Also, C16:0 and C18:0 showed the highest significance level for the effect of the pig breed. However, in our study, C18:2 and C20:4 had the highest significance level in the PUFA, whereas Alonso [24] reported that C18:3 had the highest significance level. Pigs are monogastric animals and are more affected by diet systems than ruminants; this means that feed consumed by pigs is absorbed in the small intestine, and stored in tissues without any chemical changes, such as hydrogenation in ruminants [25]. Therefore, the differences in our experiment may have been due to feeding systems and breeding, and several previous studies have shown that differences in PUFA could be attributed to animal type or breeding [24]. This is the effect of the specification, and because our study made the same specification, the results of previous studies do not apply to us. It has been suggested that the changes in muscle C17:0 and C17:1 in pigs are due to endogenous synthesis of ingested dietary fiber derived from propionic acid produced by fermentation in the posterior intestine [25]. Also, according to Álvarez-Rodríguez et al. [26], there is a greater possibility that undigested starch will

 https://doi.org/10.5187/jast.2023.e21

decrease than the proportion of structural carbohydrates reaching the posterior intestine. Therefore, further research should be conducted in this regard. Additionally, Cannata et al. [27] reported that C20:4 was affected by the content of IMF and increased significantly with increasing IMF. The authors found that there was a negative correlation with fat content. Although C17:1 and C20:4 occupy a small proportion of pork loin, they may be significant fatty acids in relation to meat quality.

The fatty acids showing significant differences in our sample are known as the major fatty acids in pork loin [25]. The melting points of C16:0, C17:1, C18:0, C18:2, and C20:4 showing significance were 62.9℃, 61.3℃, 69.3℃, -12℃, and -4℃, respectively. The melting point of UFAs in the subzero temperature range was lower than the melting point of SFAs detected in the experiment. In terms of processed meat, it can act as a negative factor with an increase in UFAs with a low melting point. To explain, most of the UFAs detected in pork exists in oil form. Thus, this causes the texture characteristics of pork fat to soften. Increased softening of pork fat is greatly influenced by increasing amounts of UFAs, significantly impacting overall pork texture [28].

In our fatty acid results, PUFA was significantly higher in LYD than in Berkshire by approximately 4%; this may affect shelf life in addition to the previously described aspects of pork quality characteristics. Inserra et al. [29] investigated fat oxidation and fatty acid composition of pork produced through different feeding systems, and the authors mentioned that PUFA in IMF, which can be easily oxidized, can provide information on meat oxidation. The authors also reported that PUFAs increased with an increase in the TBARS (2-thiobarbituric acid reactive substances). Therefore, an increase in PUFA may have a negative effect on the oxidation of pork lipids, leading to a decrease in storage properties.

Relationship between meat quality traits and fatty acid composition

The correlation coefficients between significant physicochemical traits are shown in Table 3. Moisture content was negatively correlated with protein, fat, and cooking loss, and it was positively correlated with drip loss. Fat content showed a positive correlation between the cooking loss and WBSF, and a negative correlation with drip loss. Additionally, WBSF showed a strong negative correlation with protein content but a positive correlation with drip loss and cooking loss. Instrumental color (L*, a*, and b*) showed a significant correlation with pH and negative correlations in all items. Additionally, b* showed a negative correlation with moisture content but a positive correlation with fat content. Taken together, proximate composition causes percent change

Table 3. The correlation coefficient between meat quality traits

	Moisture	Protein	Fat	Ash	Drip loss	Cooking loss	WBSF	pH	L*	a*
Protein	−0.35*									
Fat	−0.55*	−0.13								
Ash	−0.22	−0.29	0.56							
Drip loss	0.37*	−0.12	−0.45*	−0.62						
Cooking loss	−0.37*	−0.20	0.60*	0.35	−0.25					
WBSF	−0.02	−0.80*	0.58*	0.64	0.33*	0.51*				
pH	0.13	0.00	−0.53*	−0.49	0.32*	−0.45*	−0.37*			
L*	−0.27	0.35*	0.13	0.04	0.01	0.16	−0.17	−0.55*		
a*	−0.19	0.09	0.26	0.07	−0.23	0.22	0.11	−0.31*	0.00	
b*	−0.60*	0.34*	0.48*	0.10	−0.09	0.29	0.01	−0.38*	0.60*	0.16

*$p < 0.05$ (represent significant correlations).

WBSF, Warner-Bratzler shear force.

between them, and this can affect the water-holding capacity in meat quality. Also, the color is closely related to pH, and b*, in particular, will be directly related to changes in moisture and fat content.

The correlation between fatty acids is shown in Table 4. The relationship between saturated versus UFAs in this study was confirmed. The correlation coefficients between SFA and MUFA or PUFA were −0.47 and −0.80, respectively, showing a stronger negative correlation between SFA and PUFA, while MUFA and PUFA were not significant. Additionally, in terms of individual fatty acids, C16:0 had a strong positive correlation with C18:0, and both of them showed a generally strong negative correlation with all UFAs (r = −0.47 to −0.79). The C17:1 had a negative correlation with C18:0 and C18:1 but showed a positive correlation with C18:2 and C20:4. Additionally, there was a positive correlation between C18:2 and C20:4. In summary, an increase in C16:0 led to an increase in C18:0, and an increase in SFAs leads to a decrease in UFAs. Additionally, C17:1 and C20:4 were found to be closely related to all fatty acids except for MUFAs.

Table 5 shows the correlation between physicochemical traits and fatty acid composition. C16:0 and C18:0 exhibited similar results; positive correlation with fat, cooking loss, L*, and b*; and negative correlation with drip loss and pH. Also, C16:0 exhibited a negative correlation with moisture content and a*, whereas C18:0 exhibited no significant correlation. C17:1, C18:2, and C20:4 showed opposite results with C16:0 and C18:0 and exhibited a positive correlation with moisture content and drip loss in detail, and a negative correlation with fat content, cooking loss, and b*. Additionally, C20:4 showed a correlation between pH and L*. The C18:3 was significant with pH and a*, which were negatively and positively correlated, respectively. Overall, SFA showed a positive correlation with fat content, cooking loss, L*, and pH, whereas drip loss, pH, and a* had a negative correlation with SFA. PUFA showed a positive correlation with moisture content, drip loss, and pH, whereas fat content, cooking loss, and L* had a negative correlation with PUFA. Additionally, MUFA was not significantly correlated with meat quality. This is because C16:1 and C18:1 (approximately 46%), which account for most of the detected MUFAs, did not show a correlation with meat quality.

Factor analysis was performed on all variables, and the factor loading is shown in Table 6. As a result of the rotated factor analysis, all variables of the study were classified into 5 factors, and the cumulative variance was about 97%. Factor 1 was assigned the most variables and showed an explained variance of 34.43%. SFA, C16:0, C18:0, lightness, cooking loss, C20:4 pH, PUFA,

Table 4. The correlation coefficient between fatty acid composition

	C14:0	C16:0	C16:1	C17:1	C18:0	C18:1	C18:2	C18:3	C20:4	SFA	MUFA
C16:0	0.38*										
C16:1	0.14	−0.05									
C17:1	−0.42*	−0.63*	0.17								
C18:0	0.00	0.85*	−0.27	−0.32*							
C18:1	−0.13	−0.19	0.19	−0.47*	−0.40*						
C18:2	−0.05	−0.79	−0.10	0.56*	−0.73*	−0.20					
C18:3	−0.57*	−0.47*	−0.36*	0.17	−0.21	0.33*	0.04				
C20:4	−0.16	−0.71*	−0.02	0.84*	−0.47*	−0.43*	0.66*	0.21			
SFA	0.24	0.96*	−0.10	−0.44*	0.95*	−0.37*	−0.77*	−0.41*	−0.56*		
MUFA	−0.17	−0.31	0.43*	−0.26	−0.51*	0.96*	−0.13	0.28	−0.29	−0.47*	
PUFA	−0.15	−0.86*	−0.12	0.69*	−0.72*	−0.24*	0.97*	0.20	0.82*	−0.80*	−0.15

*$p < 0.05$ (represent significant correlations).

SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

 https://doi.org/10.5187/jast.2023.e21

Table 5. Correlation coefficient between physicochemical traits and fatty acid composition in pork loin

	C14:0	C16:0	C16:1	C17:1	C18:0	C18:1	C18:2	C18:3	C20:4	SFA[1)]	MUFA[2)]	PUFA[3)]
Moisture	−0.17	−0.31*	0.16	0.69*	−0.08	−0.51*	0.38*	−0.06	0.53*	−0.17	−0.36*	0.44*
Protein	−0.21	0.08	0.04	−0.05	0.21	0.05	−0.19	−0.07	−0.08	0.17	0.04	−0.17
Fat	0.08	0.47*	−0.30	−0.58*	0.40*	0.27	−0.58*	0.16	−0.45*	0.40*	0.11	−0.56*
Ash	0.21	0.50*	−0.54*	−0.50*	0.50*	0.04	−0.50*	0.21	−0.38*	0.47*	−0.16	−0.47*
Drip loss	0.02	−0.33*	0.21	0.43*	−0.36*	−0.24	0.51*	−0.20	0.35*	−0.32*	−0.12	0.47*
Cooking loss	−0.18	0.46*	−0.24	−0.35*	0.46*	0.07	−0.51*	0.06	−0.37*	0.43*	−0.04	−0.49*
WBSF[4)]	0.15	0.25	−0.31	−0.35*	0.15	0.07	−0.18	0.17	−0.26	0.15	−0.05	−0.19
pH	0.25	−0.49*	0.19	0.27	−0.60*	0.04	0.61*	−0.37*	0.42*	−0.54*	0.13	0.55*
L*	−0.19	0.35*	0.05	−0.21	0.42*	0.04	−0.45*	0.21	−0.43*	0.39*	0.02	−0.45*
a*	−0.57*	−0.43*	−0.38*	0.15	−0.15	0.17	0.11	0.80*	0.30	−0.34*	0.11	0.26
b*	0.05	0.35*	−0.15	−0.44*	0.32*	0.05	−0.23	−0.04	−0.44*	0.34*	−0.06	−0.31

* $p < 0.05$ (represent significant correlations).

SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; WBSF, Warner-Bratzler shear force.

Table 6. Determination of factors with rotated factor pattern from total measured variables

	Factor1[1)]	Factor2	Factor3	Factor4	Factor5	Communality
SFA	0.87					0.98
C16:0	0.86					0.98
C18:0	0.85					0.94
Lightness	0.56					0.62
Cooking loss	0.53					0.54
C20:4	−0.67					0.83
pH	−0.72					0.78
PUFA	−0.93					0.98
C18:2	−0.93					0.91
MUFA		0.97				0.97
C18:1		0.96				0.96
Moisture			0.72			0.85
C16:1			0.69			0.73
C17:1			0.55			0.91
Fat			−0.55			0.75
Drip loss			−0.57			0.56
Yellowness			−0.72			0.72
C18:3				0.91		0.87
Redness				0.84		0.84
C14:0				−0.79		0.70
WBSF					0.92	0.91
Ash					0.61	0.72
Protein					−0.87	0.82
Eigenvalue	6.54	3.22	3.19	3.18	2.87	

[1)]The pattern was extracted by principal components analysis and rotated with varimax method.

SFA, saturated fatty acid; PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid; WBSF, Warner-Bratzler shear force.

and C18:2 were classified as factor 1. In addition, SFA, C16:0, C18:0, lightness, and cooking loss showed positive factor loading, and the rest showed negative factor loading. Factor 2 was assigned MUFA and C18:1 and showed explained variance of 16.96%. Therefore, SFA, PUFA, and MUFA in factors 1 and 2 were selected as the main variables in this study considering our correlation analysis.

Partial least squares (PLS) regression analysis was performed to figure out the causation of variables and the results are shown in Fig. 1. Based on the results of factor analysis, SFA, MUFA, and PUFA were used as explanatory variables used in the PLS model, and the other variables were assigned as response variables, and the results were expressed as PLS factors 1 and 2. Figs. 1A and 1B are correlation loading plots, and the explanatory power of PLS factors 1 and 2 changed according to the role of MUFA. In view of the results of Fig. 1C, it was decided that it is appropriate to use MUFA as a response variable rather than an explanatory variable because the variable importance value of MUFA is 0.8 or less. Therefore, the PLS model is shown in Fig. 1A which uses SFA and PUFA as explanatory variables. Fig. 1A explained the results of this study well. PLS factor 1 showed an R2 value of 89.8% on the X-axis and 15.7% on the Y-axis, and PLS factor 2 showed an R2 value of 10.2% and 10.4% on the X-axis and Y-axis, respectively. Therefore, in PLS factor 1, 89.8% of the total variables can be explained by SFA and PUFA, so it is considered to be the most important factor in this study.

Consequently, SFA affects fat content, water-holding capacity, and lightness, and while PUFA affects moisture and pH. These results are thought to be affected by the composition of SFA and PUFA, and changes in SFA lead to changes in fat content. Changes in fat content would lead to changes in the proximate composition result and ultimately affect water-holding capacity. Also, changes in fat directly affect lightness by changing reflectance for light. In the PLS correlation loading plot (Fig. 1A), SFA and PUFA are in opposite positions, and when the effect of SFA is considered, PUFA have the opposite result of SFA. Thus, only the relationship between PUFA and

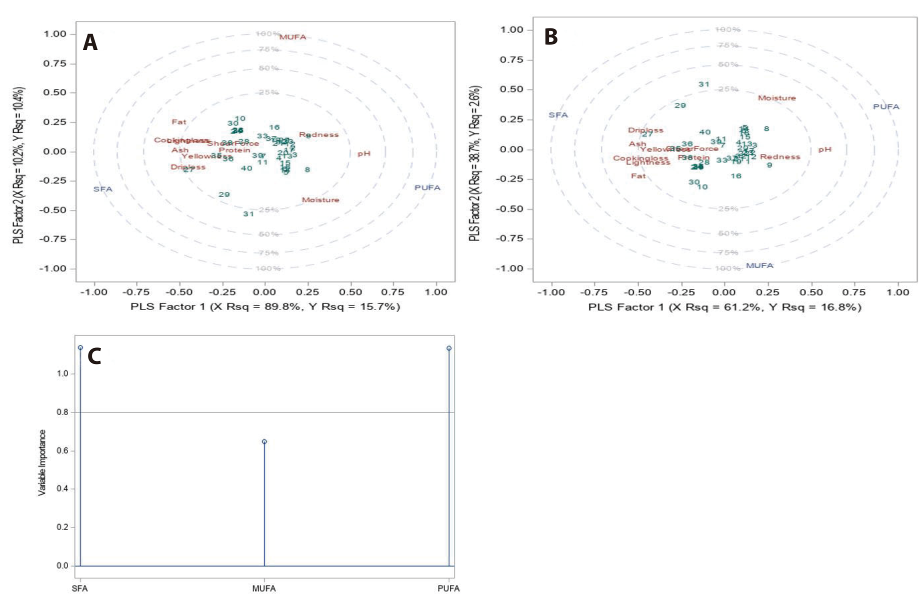

Fig. 1. Rotated factor pattern plot of physicochemical properties and fatty acid composition. 42.5% and 18.93% explained variance in factor 1 and factor 2, respectively. SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

 https://doi.org/10.5187/jast.2023.e21

pH should be considered. Leite et al. [30] reported that the effect of fat content was significant in pH, which was increased with increasing fat content. One possible logical explanation is that an increase in SFA will lead to an increase in fat content and ultimately an increase in pH. Therefore, PUFA shows the opposite result from SFA, so it can be considered a very appropriate interpretation.

CONCLUSION

This study aimed to investigate the effect of pig breeds on meat quality and fatty acid characteristics in pork loin. This study also aimed to figure out the relationship between the meat quality traits and fatty acid composition that determine the quality characteristics of pork using a PLS regression. The study was conducted on the pork loin of Berkshire and LYD, which is considered normal quality. High moisture content, pH, and water-holding capacity in Berkshire were confirmed. Additionally, it was confirmed that Berkshire have more intense redness and higher SFA than LYD. As a result of conducting a correlation analysis between variables that determine pork quality characteristics, SFA was closely related to fat content, and PUFA was closely related to moisture content, and two hypotheses could be derived. First, an increase in SFA leads to an increase in fat content, which leads to an increase in cooking loss, and it can be hypothesized that L* and b* may increase because of an increase in fat content. Second, an increase in PUFA leads to an increase in moisture content and an increase in drip loss. As a result of the factor analysis, the main factors were SFA, MUFA, and PUFA, and a PLS model was generated using SFA and PUFA except for MUFA. As a result, SFA and PUFA have high variable explanatory power. In conclusion, the effect of pig breeds caused differences in several measurement parameters, and these differences were closely related to fatty acid composition, especially SFA and PUFA.

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