

Meat Quality and Volatile Flavor Traits of Duroc, Berkshire and Yorksire Breeds

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Abstract

The present study evaluated the difference in objective and subjective meat quality properties among the pure-breed boars of Duroc, Berkshire and Yorkshire. Ten *longissimus lumborum* (LD) muscles were collected from each breed after 24 h slaughtering. The breed type showed a significant effect on intramuscular fat content, moisture ($p<0.01$), pH, sarcoplasmic protein solubility and color ($p<0.05$), whereas cooking loss and Warner Blazer shear force (WBSf) did not differ among the breeds. The Yorkshire breed showed significant ($p<0.05$) lower sarcoplasmic protein solubility, pH and CIE a* value when compared with other breeds. The sensory panels identified Duroc as having greater overall acceptability and higher rating values than other breeds. The oleic acid content was significantly lower in the Berkshire (29.85 %) than in the Duroc (40.19 %) and Yorkshire breeds (38.18 %, $p<0.05$). The Yorkshire breed showed the most desirable ratio of polyunsaturated and saturated fatty acids (0.31) than the Berkshire (0.16) and Duroc breeds (0.15, $p<0.05$). 40 volatile compounds have been identified and quantified, while aldehydes were the most abundant among flavor substances. Aldehydes were negatively correlated with oleic acid content ($p<0.05$). Current data indicated that each breed had their own merits and deficiencies in terms of meat quality. The Yorkshire breed showed a greater number of weak points. Furthermore, this study indicated that individual fat-driven flavor components were greatly influenced by fatty acid composition. The polyunsaturated fatty acids did not show any negative effects on meat flavor if cooked meats were consumed soon after cooking.

Key words: breed, fatty acids, flavor, pork, volatiles

Introduction

The eating quality introduction of pork is a complex term consisting of multi-attributes of consumer acceptance and palatability such as tenderness, flavor and juiciness (Crawford *et al.*, 2010). The studies have identified a number of intrinsic and extrinsic factors affecting eating quality of pork including breed (Brewer, 2002; Laack *et al.*, 2001), intramuscular fat content (Bejerholm and

Aaslyng, 2003) and pH (Cho *et al.*, 2009; Huff-Lonergan *et al.*, 2002).

There are number of studies have attempted to identify the best premium pig breed in terms of productivity, carcass and eating quality (Newcom *et al.*, 2004; Wood *et al.*, 1996; Yang *et al.*, 2009). The breed, Berkshire showed a higher pH than other commercial pig breeds. These characteristics were consequently attributed to higher overall liking score (Wood *et al.*, 2004, 1996) and more acceptable likeness compared to European commercial pork breeds (Ellis *et al.*, 1996). In addition, purebred Duroc tended to have higher redness than Landrace (Cameron *et al.*, 1990; Newcom *et al.*, 2004). Edwards *et al.* (2003) found that no significant difference in color

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within the same sire lines of Duroc, Chinese, and Pietrain breeds. Our previous study (Park *et al.*, 2007) reported that a higher redness of Korean native pig compared with Landrace, was related to a higher content of myosin heavy chain (more an oxidative fiber type). In addition, it has been received a great attention that pig breed have different fatty acid profile (Wood *et al.*, 2004) because the ratio of polyunsaturated and saturated fats are important viewpoint of healthy food (Leong *et al.*, 2010; Warnants *et al.*, 1998).

The threshold value (2-3%) of intramuscular fat content was required for optimal tenderness of pork (Jeremiah and Miller 1998), but Eikelenboom *et al.* (1996) reported that pH was more important than intramuscular fat content for quality. The pH of meat has a great effect on objective meat quality and palatability (Savell *et al.*, 2005) through its effects on water-holding capacity (Bryhni *et al.*, 2002; Huff-Lonergan *et al.*, 2005), protein solubility and surface reflectance of meat (Hwang *et al.*, 2003; Joo *et al.*, 1999). Scheffler *et al.* (2007) reported that subnormal low pH cause denaturation of sarcoplasmic and myofibrillar proteins, resulting in pale color and reduced water-holding capacity. The higher pH had superior quality on the pork compared to lower pH, and the higher pH also showed stability of meat color significantly (Graziotti *et al.*, 2011; Holmer, 2009; Obi *et al.*, 2010). On the other hand, in terms of flavor aspect, the higher level of polyunsaturated fatty acids negatively affect on meat flavor (Cameron *et al.*, 2000).

The flavor intensity and volatile species are necessary for cooked meats. The flavor properties of raw meat is meaty or bloody note, but numerous volatile components are generated during cooking through the Maillard reactions of amino acids with reducing sugars, thermal degradation of fatty acids, vitamin degradation and interaction between the intermediates of Maillard reaction with lipid-degraded products during cooking (Mottram, 1994). The dimethyl sulphide, 2-butanone, ethyl acetate, 2- and 3-methylbutanal, 2-heptanone, dimethyl trisulphide and nonanal were detected as key flavor of cooked meats (Leong *et al.*, 2010; Machiel *et al.*, 2003). On the other hand, our model study revealed that fatty acid composition and protein degradation by postmortem proteolysis activity had a great effect on amount and flavor component (Ba *et al.*, 2010). This result suggested that breed and fatty composition generate different flavor species such as free amino acids/peptides, fatty acids, reducing sugars in meats greatly affect ultimate flavor notes through their effects on the reactions, oxidation and deg-

radation processes on heating (Elmore *et al.*, 2004). Hence, our experiments are designed to find differences of meat quality by using different purebred pigs and to provide information about correlations of meat quality, fatty acid and flavor for selecting boars.

Materials and Methods

Animals and sampling

A total of thirty purebred boars (Duroc n=10, Berkshire n=10, Yorkshire n=10) were sampled from a commercial breeding farm and weighed about 101 ± 0.35 kg. The animals were transported to a commercial abattoir within 100 km with minimum handling-stress and laired overnight with drinking water. The carcasses were chilled overnight at a 4°C in cold room, and graded by a meat grader according to the Korean grading standard (NLCF, 2004). *M. longissimus lumborum* (LD) was separated from the right side of the carcasses and moved to the meat science Laboratory of the Chonbuk National University. These LD sample was divided to each analysis, the contents was packed with vacuum, stored at -20°C until analysis.

Objective and subjective quality

The pH was measured using a portable pH meter (301, Orion, USA). The 1 g of muscle sample was homogenized twice with 10 mL KCl solution (5 mM iodoacetate KCl; w/v) for 30 sec at 11,000 rpm with 15 sec break using the Ultraturrax T25B (IKA works, Malaysia) and pH was measured at 25°C.

The meat color, cooking loss and Warner Blazer share force (WBSf) were analyzed as the protocols of Cho *et al.* (2009). The frozen samples were thawed overnight at 4°C and trimmed and cut 5 mm thickness of top to expose fresh surface. The objective meat color (CIE L*, a*, b*; lightness, redness, yellowness) was measured after a 30 min blooming at 4°C (CM-2500d, Konica Minolta, Japan). For cooking loss and WBSF measurements, approximately 350 g (5×6×7 cm) of meat blocks were trimmed and cooked in 70°C water bath for 60 min until the sample block reached 70°C. The cooked samples were cooled in 18°C running water for 30 min. WBSf was determined from an average of 6 cores from the cooked sample block using an Instron (3342, Instron, USA), and the measurement condition was 400mm/min head speed, 40 kg load cell. The weight loss before and after cooking was expressed as a percentage weight of the initial cooking block and used as a cooking loss.

The protein solubility was determined by dissolving 1 g of muscle tissue in 10 mL of ice-chilled potassium phosphate buffer (pH 7.2) according to the method described by Warner *et al.* (1997). Briefly, 1 g of meat sample was homogenized with 20 mL of extraction buffer by an ultra Turrax T25B (IKA, Malaysia) at 11,000 rpm with 4 s burst and 10 s break. The homogenate were kept overnight in ice and centrifuged at 1500 g at 4°C for 20 min. 1 mL of supernatant was taken and protein concentration of the supernatant was determined, and it was expressed as mg/g tissue. The myofibrillar protein solubility was calculated as the difference between total and sarcoplasmic protein solubility. Moisture content was analyzed using the HR 73 halogen moisture analyzer (Mettler-Toledo, Switzerland). The crude fat content was analyzed using the Soxhlet extraction method with petroleum ether (AOAC, 2006). 5 g of sample was minced and placed in an extraction thimble, dried at 102°C for 5 h, cooled in a desiccator at room-temperature, and extracted using Soxhlet extractor by petroleum ether for 6 h. Crude fat content was expressed as weight percentage of wet muscle weight.

Sensory evaluation was performed following method of Hwang *et al.* (2008). Sensory panels were recruited from a university group, consisting of 48 male and female students. A total of 288 sensory samples were randomly allocated in 12 sets of four sessions; each session had 12 panelists and each panelist evaluated 6 samples. A total of twelve thin slices (30×30×4 mm) for each sensory samples was cut parallel to fiber direction. Samples were again vacuum-packed and stored in the freezer set at -20°C until analysis. Samples allotted for session were thawed for 30 min before the scheduled sensory panel. The vacuum-packed meats were opened only when the samples are about to be cooked. Cooking was done on open tin-coated grill (surface temperature: 240-250°C). Two sets of grill were used where each grill was set to cook 6 strips of samples. The twelve cooked samples were immediately served to designated panelists. Panelists rated tenderness, juiciness and flavor using 10 cm unstructured line scale with verbal anchors based on quantitative descriptive analysis was used, where the left anchor represented scoring of either tough, dry, extremely dislike the flavor or sample is extremely unacceptable. After evaluating each sample, the panelists were asked to refresh their mouth with the provided distilled drinking water and salt-free crackers.

Fatty acid analysis

Fatty acid composition was determined by the procedure developed by Rule (1997). The meat samples were pulverized after freeze dried for 48 h. 500 mg of pulverized meat sample was placed into a 20 mL headspace vial with silicone-lined cap, and 2 mL of 14% borontrifluoride in methanol was added. The mixture was vortex-mixed every 5 min for 2 h at 80°C, then 3 mL of distilled water and 3 mL of hexane were added. The mixture was cooled, capped and vortex-mixed for 15 min. One mL of the upper hexane phase was transferred to GLC auto-sampler vials after centrifugation at 1000 g for 5 min and stored at -20°C until analysis. Fatty acid analysis was performed by a gas chromatography (GC-MS Agilent 6890N equipped with Fused silica capillary column 30 m×0.25 mm×0.25 µm film thickness with helium carrier gas and split ratio of 100:1) at the total running time of 35 min. Sample inlet and oven chamber temperatures were 250°C. A linear elevation of oven temperatures were programmed as 50°C for 1 min, 200°C at the rate of 25°C per min, 230°C at the rate of 3°C/min. Detector temperature was 280°C. Individual fatty acid peaks were identified by comparing the retention times with known standards of fatty acid and composition expressed as percentage of the total fatty acid methyl esters (Supelco F.A.M.E, Mix C8-C24).

Volatile compounds analysis

For volatile flavor components, 1 g of sample was powdered in liquid nitrogen and placed in a 40 mL headspace vial sealed with PTFE-faced silicone septum (Supelco Co., USA) and heated in an autoclave at 132°C for 30 min. The sample was immediately cooled in an ice bath for 10 min to avoid further aroma development, thereafter equilibrated at 60°C for 10 min. Water bath temperature was monitored by a temperature data logger (TR-52, T & D, Japan). The SPME needle (Carboxen/PDMS, 75 µm, Supelco Co., USA) was inserted into the PTFE/silicone septum and the fiber was exposed after the 10 min-equilibration period. The extraction process for volatiles was carried out at 60 min (Moon and Li Chan, 2004). A DB-5MS capillary column (30 m×0.25 mm i.d.×0.25 µm film thickness, Agilent J & W Scientific, Model No. 122-5532, USA) was aged overnight at 230°C. The SPME fiber was desorbed at 250°C for 5 min. Carrier gas, split ratio, split flow and flow rate were helium, 10:1 and 10 mL/min and 1.0 mL/min, respectively. Oven temperatures were programmed as 40°C with 5 min, 250°C at the rate of 25°C/min, and 250°C at 31.25°C min (Ba *et al.*, 2010; Schilling *et al.*, 2009). The area of each peak was integrated using the ChemStation software (Agilent Technologies, USA),

and peaks were identified by Kovats index calculated by applying a series of standard alkanes C8-C20 (Fluka, Cat. No. 04070, New Zealand).

Statistical analysis

Least square means for the breed effects were stated using the general linear models of SAS program (SAS, 2007), and significant difference between means were examined at 5% threshold. Pearson's correlation coefficient were evaluated using Corr. procedure to describe the relationships between breeds, pH and meat quality traits.

Results and Discussion

Effects of breed on objective and subjective meat quality traits

Least square means and their significant level as a function of the breed on objective meat quality and sensory traits are presented in Tables 1 and 2. Initially, most factors related to meat carcass and meat quality were greatly influenced by breed in that intramuscular fat content, sarcoplasmic protein solubility, pH, meat color, overall acceptability of consumer panels were particularly significant ($p < 0.05$). There are several studies demonstrated that level of intramuscular fat content greatly influence on eating quality (Wood *et al.*, 1996). In this study, intramuscular fat content of different breed showed a significant difference ($p < 0.001$), where Duroc *longissimus* muscle contained the highest level of intramuscular fat content with the lowest of water level among breeds (Table 1). Similar to the other study (Wood *et al.*, 1996), the higher concentration of intramuscular fat improved ($p < 0.05$) eat-

Table 1. Breed effect on objective meat quality traits of *longissimus lumborum* muscle from Duroc, Berkshier and Yorkshire

Trait	Breed			P value
	Duroc	Berkshire	Yorkshire	
Intramuscular fat content (%)	3.28±0.89 ^a	2.17±0.77 ^b	2.13±0.56 ^b	0.001
Moisture (%)	71.28±1.42 ^c	72.08±0.59 ^b	72.69±1.0 ^a	0.001
Sarcoplasmic protein solubility (mg/g)	39.13±0.71 ^a	39.42±2.28 ^a	37.96±1.65 ^b	0.02
pH	5.71±0.11 ^a	5.69±0.17 ^a	5.58±0.22 ^b	0.003
CIE L* ²⁾	52.09±1.70 ^a	49.77±2.59 ^b	53.76±3.66 ^a	0.001
CIE a* ²⁾	4.24±1.26 ^a	3.77±1.68 ^a	2.65±1.25 ^b	0.004
CIE b* ³⁾	12.29±0.88	11.56±1.40	11.97±1.48	ns
Cooking loss (%)	17.48±2.31	17.26±1.36	17.59±2.36	ns
WBSF(N) ⁴⁾	21.72±1.55	21.54±1.03	21.29±1.19	ns
df ⁵⁾				2/30

^{a-c}Mean±SE in the same row with different superscript differed significantly ($p < 0.05$)

ns, not significant ($p > 0.05$)

¹⁾CIE L*, lightness

²⁾CIE a*, redness

³⁾CIE b*, yellowness

⁴⁾WBSF, Warner-Bratzler shear force

⁵⁾df, Numerator/Denominator degree of freedom

Table 2. Breed effect on sensory properties of *longissimus lumborum* muscle from Duroc, Berkshier and Yorkshire

Items ²⁾	Breed			P value
	Duroc	Berkshire	Yorkshire	
Tenderness	56.15±8.08	60.32±10.11	53.55±10.69	ns ¹⁾
Juiciness	64.26±9.27	58.99±12.48	62.76± 9.57	ns
Flavor	63.00±7.27	62.35± 8.14	61.85± 6.27	ns
Overall acceptability	64.57±5.98 ^a	56.82±10.66 ^b	55.35± 5.77 ^b	0.04
Overall rating	2.31±0.35 ^a	2.02± 0.45 ^b	1.80± 7.50 ^b	0.05
df ³⁾				2/30

^{a-c}Mean±SE in the same row with different superscript differed significantly ($p \leq 0.05$).

¹⁾ns, not significant ($p > 0.05$)

²⁾Tenderness, 0 (not tender) to 100 (very tender); juiciness, 0 (not juicy) to 100 (very juicy); flavor, 0 (dislike extremely) to 100 (like extremely); overall acceptability, 0 (dislike extremely) to 100 (like extremely); overall rating was subjective grade, 1(lowest grade) to 4(highest grade)

³⁾df, Numerator/denominator degree of freedom

ing quality (Table 2) in that Duroc breed received significantly ($p < 0.05$) higher scores on overall acceptability and overall ratings than other two breeds. Brewer *et al.* (2002) reported that 1% difference of fatty acid content in pork altered different flavor intensity on panel test, however, in our result, there was not significant difference on flavor score with difference intramuscular fat contents between Duroc and other breeds meats.

The pH of meat has great influence on objective meat quality and palatability through its effects on water-holding capacity, protein solubility and surface reflectance of meat (Hwang *et al.*, 2003; Joo *et al.*, 1999). Scheffler *et al.* (2007) reported that abnormal low pH causes denature of sarcoplasmic and myofibrillar proteins, and it was resulting in pale color and reduced water-holding capacity. In particular, when the rate of postmortem glycolysis was faster and glycolysis activity under slow chilling regime was greater than normal, meats are more susceptible to a higher extent of protein denature (Choi *et al.*, 2010). In the current study, all animals were handled and slaughtered by standard commercial procedures. However, Yorkshire showed significantly ($p < 0.05$) lower pH than two other breeds. Duroc showed the highest pH with 5.71 even though that did not a significant differences from Berkshire ($p > 0.05$). The pH result was reflected on sarcoplasmic protein solubility where Yorkshire LD muscle had significantly ($p < 0.05$) lower solubility than other breeds. This mirrors that Duroc and Berkshire have similar traits in postmortem glycolytic regime, although Duroc meat contained significantly ($p < 0.5$) higher intramuscular fat content than Berkshire.

It has been identified that meat with low pH uses less oxygen due to decreased activity and/or inactivation of enzymatic oxygen consumption systems (Lindhahl *et al.*, 2006). Joo *et al.* (1999) reported that sarcoplasmic protein solubility negatively correlated with CIE L^* , a^* and b^* for meat color, and our study also showed negative relationship between sarcoplasmic protein solubility and meat color.

According to Hwang *et al.* (2005)'s report, Berksire had more oxidative fiber type than Yorkshire, it was reflects higher redness on Berkshire meat. The high redness for Duroc and Berkshire is likely confounded by fiber type and ultimate pH and which are consequently reflected on protein solubility. Low pH of meat resulted in increased free water at the muscle cell surface, and effected increased reflectance giving the meat a lighter appearance (Rees *et al.*, 2003), but Berkshire showed the lowest lightness ($p < 0.05$) with significantly higher pH

than Yorkshire. Current study not measured oxidation of myoglobin, but it is well known that decreased redness was a result of oxidation of myoglobin, clearly reflected in increasing levels of MetMb and a simultaneous decrease in MbO₂ levels (Lindhahl *et al.*, 2006; Kim *et al.*, 2010). The current data of unexplainable lightness value might be confounded by the different characteristics of myoglobin oxidation between breeds. On the other hand, sarcoplasmic protein solubility showed a significant simple correlation with CIE L^* values ($r = -0.45$, data not shown).

WBSF and cooking loss were not differed between the breeds. The results was particularly of interest because the current data showed significant effect of breeds on intramuscular fat content and ultimate pH which in general have significant effect on water-holding capacity and tenderness (Aaslyng *et al.*, 2003). Crawford *et al.* (2010) reported that Berkshire was tender than Landrace. The authors noted that higher collagen might force, the more water out from the muscle as a function of shrinkage during cooking, and thus may indicate a breed-specific relationship of meat quality, even though the relationship depends on genetics.

The most important aspect of meat quality is eating quality and usually defined as scores given by panelists for tenderness, juiciness and flavor (Wood *et al.*, 2004). Our data revealed that sensory scores for tenderness, juiciness and flavor were not differed among breeds (Table 2), although Pearson's correlation between intramuscular fat content and overall quality of parameters was relatively high. It has been modeled that muscle pH affects the distance between myofilaments through its effect on electrostatic repulsion. In addition, the distance between the myofilaments influences in the distribution of water and strength of water bound to muscle proteins (Aaslyng *et al.*, 2003). However, the significant difference in ultimate pH between breeds was not reflected on sensory juiciness and tenderness, similarly to cooking loss (Table 1). On the other hand, sensory panels identified Duroc was more acceptable overall liking and overall rating than other breeds significantly ($p < 0.05$). In fact, Duroc received numerically higher scores for juiciness and flavor than other breeds, even though there was not significant ($p > 0.05$). Furthermore, Duroc had significantly higher intramuscular fat content and higher pH than other breeds. The significant factors collectively mirrored on higher overall liking and rating significantly ($p < 0.05$).

The fatty acid composition of LD muscle from three different breed pigs was given in Table 3. The predomi-

Table 3. Difference of fatty acid contents of *longissimus lumborum* muscle from Duroc, Berkshier and Yorkshire

Fatty acids	Breed			P value
	Duroc	Berkshire	Yorkshire	
Caprylic acid (C8:0)	0.03±0.02	0.02± 0.01	0.02± 0.01	Ns ¹⁾
Capric acid (C10:0)	0.20±0.06 ^{ab}	0.22± 0.06 ^a	0.17± 0.05 ^b	0.01
Lauric acid (C12:0)	0.17±0.04 ^a	0.18± 0.04 ^a	0.14± 0.03 ^b	0.007
Myristic acid (C14:0)	2.23±0.41 ^a	2.27± 0.50 ^a	1.81± 0.37 ^b	0.002
Palmitic acid (C16:0)	29.49±4.95 ^b	34.80± 7.87 ^a	26.96± 5.88 ^b	0.001
Palmitoleic acid (C16:1)	4.50±1.17	5.13± 2.31	4.33± 1.27	ns
Stearic acid (C18:0)	15.30±3.23 ^{ab}	17.34± 3.83 ^a	14.07± 3.32 ^b	0.01
Oleic acid (C18:1)	40.19±8.43 ^a	29.85±11.37 ^b	38.18± 5.74 ^a	0.001
Linoleic acid (C18:2)	6.65±6.09 ^b	8.21± 7.02 ^b	12.87± 5.87 ^a	0.008
Linolenic acid (C18:3)	0.57±0.22 ^b	0.76± 0.32 ^a	0.59± 0.18 ^b	0.04
Aracidic acid (C20:0)	0.21±0.05	0.21± 0.05	0.19± 0.04	ns
Behenic acid (C22:0)	0.16±0.11 ^b	0.28± 0.16 ^a	0.18± 0.06 ^b	0.002
Eruric acid (C22:1)	0.04±0.02 ^b	0.06± 0.03 ^a	0.05± 0.0 ^{ab}	0.03
Lignoceric acid (C24:0)	0.39±0.34 ^b	0.68± 0.33 ^a	0.47± 0.16 ^b	0.003
SFA ²⁾	48.19±7.85 ^b	56.05±12.21 ^a	44.01± 9.38 ^b	0.001
MUFA ³⁾	44.58±7.44 ^a	35.04±10.45 ^b	42.56± 4.46 ^a	0.001
PUFA ⁴⁾	7.22±6.01 ^b	8.97± 6.68 ^b	13.46±13.46 ^a	0.01
PUFA/SFA	0.15±0.15 ^b	0.16± 0.15 ^b	0.31± 0.31 ^a	0.001
df ⁵⁾				2/30

^{a-c}Mean±SE in the same row with different superscript differed significantly ($p<0.05$).

¹⁾ns, not significant ($p>0.05$)

²⁾SFA, saturated fatty acid

³⁾MUFA, mono unsaturated fatty acid

⁴⁾PUFA, poly unsaturated fatty acid

⁵⁾df, Numerator/denominator degree of freedom

nant saturated fatty acids such as palmitic acid was significantly ($p<0.05$) higher (34.85%) in Berkshire while stearic acid was significantly lower (14.1%) in Yorkshire than other breeds. In addition, capric and myristic fatty acids were significantly ($p<0.05$) lower in Yorkshire. Oleic acid content was greatly ($p<0.05$) lower in Berkshire (29.85%) than in Duroc (40.19%) and Yorkshire (38.18%). Even though, we did not tabulate the results because of the limited animal numbers, it was interest to examine correlations between crude fat content and fatty acid concentrations during preliminary data analysis. The results revealed that intramuscular content had significantly positive relation with oleic acid content and significant negative relation with linoleic acid, eruric, behenic and lignoceric contents. The results were in agreement of previous report (Zhang *et al.*, 2007) and indicates that increased intramuscular fat content could increase oleic acid and decrease unsaturated fatty acid content.

On the other hand, the higher level of polyunsaturated fatty acids was observed from Yorkshire (13.46%) than Berkshire (8.97%) and Duroc (7.22%) breeds. The increased linoleic acid was the main driver for Yorkshire (12.87%), Berkshire (8.21%) and Duroc (6.65%) and this

lead to the most desirable PUFA/SFA ratio for Yorkshire (0.31) than Berkshire (0.16) and Duroc (0.15). In 1994, The Department of Health of UK recommended that ratio of PUFA/SFA of higher than 0.4 (Alonso, 2010). Enser *et al.* (2000) presented that meats naturally had PUFA/SFA ratio of around 0.1 can be a main food source, which is the imbalanced fatty acid intake of today's consumers. PUFA/SFA ration of Yorkshire appeared higher than others, and this result showed importance that Yorkshire will be considered great quality of fatty acid source on breeding. The importance of PUFA ratio in fatty acid, was high digestion rate and improving digestibility of saturated fatty acid with emulsifying agents (Park *et al.*, 2009; Warnants *et al.*, 1998). On the other hand, in terms of eating quality aspect, the higher level of polyunsaturated fatty acids will cause undesirable meat flavor (Cameron *et al.*, 2000).

Relationship of volatile flavor compounds and fatty acids

Ba *et al.* (2010) demonstrated that fatty acid composition affected to amount of volatile component from beef, also PUFA generated unpleasant odor, whereas SFA, such

Table 4. Pearson's correlation coefficients between volatile components and total intramuscular fat (IMF) content and unsaturated fatty acids of *longissimus lumborum* muscle from Duroc

Volatile components	IMF	Unsaturated fatty acids				
		C16:1	C18:1	C18:2	C18:3	C22:1
Aldehydes						
Hexanal	-0.48	-0.40	-0.62*	0.13	-0.35	0.35
Heptanal	-0.68*	-0.49		0.42	-0.07	0.43
Octanal	0.54		-0.32	0.68*	-0.01	0.36
2-Octenal	-0.54	-0.41	-0.32	0.67*	0.18	0.60
Decanal	-0.02	0.29	0.24	-0.33	0.64*	-0.59
E-2-Decenal	-0.54	-0.33	-0.31	0.49	-0.04	0.61
E,E,2,4-Decadienal	-0.88	-0.68	-0.71	0.93*	0.7	0.82
Tetradecanal	-0.88	0.81*	-0.85*	0.67	0.13	0.81
Ketones						
2-Propanone	-0.84	0.05	-0.51*	-0.13	-0.52	-0.33
2-Butanone	0.01	0.37	0.47	-0.09	-0.13	-0.03
2-Heptanone	-0.38	-0.49	-0.18	0.23	-0.06	0.41
Alcohols						
1-Pentanol	-0.65	-0.34	-0.49	0.57	0.01	0.05
2-Furanmethanol	-0.52*	-0.40	-0.08	0.50	0.27	0.34
1-Hexanol	-0.48	-0.40	-0.62*	0.13	-0.35	0.35
1-Octen-3-ol	-0.37	-0.53	-0.79*	0.29	-0.06	0.51
1-Octanol	0.57*	-0.5	-0.47	0.70*	0.15	0.70*
Hydrocarbons						
2,5,6-Trimethyloctane	-0.65*	-0.42	-0.28	0.63	0.27	-0.04
3-Ethyl-2-methyl-1,3-hexadiene	0.21	-0.28	-0.03	0.46	0.57	0.08
3-Methylnonane	-0.53	-0.56	-0.74*	0.72*	0.31	0.68

*Significance of the difference between two correlation variables ($p < 0.05$)

as linolenic and linoleic acids, developed order acceptability on sensory test (Campo *et al.*, 2003; Wood *et al.*, 2004). As described above, fatty acid composition was different by breed, and/also it had relationship with generation and composition of volatile (Table 3, Table 4). Duroc meat was selected as that contains high levels of intramuscular fat content (3.28%), and monounsaturated fatty acids (44.58%) with 40% of oleic acid and polyunsaturated fatty acid (7.22%). In the current study, 40 volatile compounds were identified in LD muscle of three breeds using the SPME-GC/MS system. The most abundant flavor substances was total of 20 kind of volatile components, followed by 8 hydrocarbons, 3 ketones, 5 alcohols and 4 hydrocarbons compounds (Table 4).

A large number of volatile components were originated from the oxidation of fatty acids during heating and the comparison was made only with the fat-driven components such as aldehydes, ketones, alcohols and hydrocarbons. On the other hand, amino acid-originated component such as sulphur compounds and heterocycles was exempted; the methyl-branched aldehyde (methylbutanal) are produced from degradation of branched amino acids and sul-

fide compounds (dimethyl trisulfide and dimethyl sulfide) are principally formed from the sulfur containing amino acids such as methionine, cysteine and cystine via the Strecker degradation to thiols (Huan *et al.*, 2005). Collectively, it was not the case that the most abundant aldehydes had a negative correlation with oleic acid, while there was positively correlated with linoleic acid. It was been well documented that aldehyde class such as hexanal, heptanal, octanal, E-2-octenal, E-2-decenal, E,E-2,4-decadienal and tetradecanal produces pungent, rancid and fatty odors (Brewer, 2009). The results indicate that meat with a higher level of oleic acid generate less level of aldehydes and consequently less rancid and fatty odors. Furthermore, above mentioned aldehyde species were more likely originated from polyunsaturated linoleic acid. On the other hand, not all the aldehydes were identified in the current study. Tetradecanal was negatively correlated with oleic acid, however there was positive correlation with palmitoleic acid. Furthermore, Decanal, fatty and meaty odors, was positively correlated with linolenic acid. The earlier study (Peterson, 1977) reported that high level of aldehydes contribute undesirable flavor charac-

teristics to the beef rather than desirable beefy flavor notes and more free radicals of oxidized long chain polyunsaturated fatty acids initiate the oxidation process. These indicate that individual fat-driven flavor components are greatly influenced by composition and polyunsaturated fatty acids are not showed negative effects on meat flavor always if cooked meats are consumed soon.

The earlier studies (Elmore *et al.*, 1999; Wood *et al.*, 2004) indentified that some of the aldehydes are more likely to driven from oleic acid and linoleic acid than from linolenic acid. The total fatty acids, ketone 2-propanone (livery off flavor note), alcohols 1-hexanol and 1-octen-3-ol (fruit and roasted meat order) and hydrocarbon 3-methylnonane were negatively correlated with oleic acid. The data indicated that oleic acid content have a great effect on pork flavor. Furthermore, the negative relationship indicates that the meat with high oleic acid generates less fat-driven odor and less alteration to make amino acid driven odor, which in general have more pleasant meat flavor.

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