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Flavour differences of cooked longissimus muscle from Chinese indigenous pig breeds and hybrid pig breed (Duroc × Landrace × Large White)

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Abstract

The objectives of this study were to investigate the flavour quality and volatile aroma compounds of cooked longissimus muscle from five typical Chinese indigenous pig breeds: Lantang (LT), Dahuabai (HB), Laiwu (LW), Rongchang (RC), Tongcheng (TC) and typical hybrid pig breed Duroc × Landrace × Large White (DLW). The chemical compositions of the main meat flavour precursors of the longissimus muscle from all six breeds were also examined. Distinct differences in amino acid composition and fatty acid composition of longissimus muscle, between the breeds, were observed. Among all six breeds, LW and RC had the highest intramuscular fat content and the lowest crude protein content; DLW had the lowest longissimus muscle fat content and the highest crude protein content. One-way analysis of variance showed that 23 volatile compounds were significantly affected by breed. Sensory analysis indicated that cooked longissimus muscle from DLW had the lowest pork flavour intensity and flavour-liking, compared with the Chinese indigenous breeds. LW and HB showed the highest pork flavour intensity and flavour-liking in cooked longissimus muscle.

Keywords: Chinese indigenous pig breeds; Duroc × Landrace × Large White; Longissimus muscle; Flavour quality; Volatile aroma compounds

1. Introduction

Flavour is a very important component of the eating quality of meat and there has been much research aimed at determining those factors, during the production and processing of meat, which influence flavour quality (Mottram, 1998). Intramuscular lipid in pork has been reported to positively influence flavour quality (Wood, 1993). Berry et al. (1980) found that the degree of marbling of the muscle was significantly related to flavour intensity, and meat with a desirable flavour tended to have higher levels of intramuscular fat and more intense marbling. Usually, intramuscular fat constitutes 0.5–2.5% of muscle wet weight in the pork longissimus muscle (Wood, 1993). Breed is considered to be one of the factors directly influencing the intramuscular fat content (Insausti, Goñi, Petri, Gorraiz, & Beriain, 2005). In comparison with hybrid pigs (Duroc × Landrace × Large White), Chinese indigenous breed pigs have lower growth rate and longer growth period; hence they have fatter carcasses at maturity. In China, it is often assumed, by most Chinese consumers, that Chinese indigenous breed pigs have better flavour than hybrid pigs (Duroc × Landrace × Large White). However, as far as we know, studies on the flavour quality and volatile aroma compounds of cooked pork from Chinese indigenous breed pigs are absent.

Therefore, the objectives of this paper are to investigate the flavour quality and volatile aroma compounds of cooked longissimus muscle from five typical Chinese indigenous pig breeds (Lantang, Dahuabai, Laiwu, Rongchang, Tongcheng) and a typical hybrid pig breed Duroc × Landrace × Large White. At the same time, the chemical compositions of the main meat flavour precursors of the

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longissimus muscle from all the six breeds, such as amino acid composition, fatty acid compositions of intramuscular phospholipids and neutral lipids, are also examined.

2. Materials and methods

2.1. Breeds and sampling

Five Chinese indigenous pig breeds (Lantang, Dahuabai, Laiwu, Rongchang, Tongcheng) in different regions across China and a typical hybrid pig breed Duroc × Landrace × Large White were studied. Different breed pigs, from their own production systems represent the combined effects of genotype, nutrition and management, and all these factors can affect the meat quality and flavour. However, from the consumer's view, only the overall effects on meat quality and flavour are of interest. Therefore, the overall effects were investigated and different breed pigs, from their own production system, were studied. Six barrows per breed were selected at their marketed weight and analyzed. Lantang (LT), one of the representative indigenous breeds in southern China, was obtained from the Breed Pig Farm of Banling, Dongguan city, Guangdong province. The Breed Pig Farm of Banling also provided Dahuabai (HB), one of the representative indigenous breeds in middle China. The breed of Tongcheng (TC), provided by the Farming Bureau of Tongcheng Town, Hubei province, also belonged to the indigenous breeds of middle China. The Farming Bureau of Laiwu City, Shandong province, offered the breed Laiwu (LW), one indigenous breed of northern China. Rongchang (RC), obtained from the Farming Bureau of Chongqing City, is one of the representative indigenous breeds of south-western China. Duroc × Landrace × Large White (DLW) pigs were obtained from Huadu Swine Farm, Beijing.

The animals were transported to the nearby slaughterhouse a day prior to slaughter, allowed to rest overnight with access to water and slaughtered using captive bolt stunning, followed by exsanguination. The facilities of the slaughterhouse met the requirements of the Institute of Animal Care and Use Committee. At 24 h *post-mortem*, the longissimus muscle of the left side carcass was sampled and immediately vacuum-packed. All the pork samples were put into an ice-box and transported immediately to the laboratory of China Agriculture University, Beijing, then frozen at −20 °C prior to analysis.

2.2. Intramuscular fat content and fatty acid analysis

Fat content of the muscle was analyzed, following the method of the Association of Official Analytical Chemists (AOAC, 1990). Intramuscular lipids were extracted according to the method of Bligh and Dyer (1959). Pure fractions of intramuscular phospholipids and neutral lipids were prepared with silica-acid chromatography by the method of Juaneda and Rocquelin (1985). The pure phospholipids and neutral lipids were methylated with boron fluoride–methanol according to the procedures described by Morrison and Smith (1964). The fatty acid methyl esters were analyzed by a 6890 series Gas Chromatograph (Agilent Technologies, Wilmington, USA) equipped with a flame ionization detector. Fatty acid methyl esters were injected in split mode (20:1) onto a DB-23 capillary column (60 m × 0.25 mm, 0.25 μm I.D. film thickness, J&W Scientific). Duplicate analyses were performed on all six samples in each breed.

2.3. Crude protein content and amino acid analysis

Crude protein content of the muscle was analyzed by the method of the Association of Official Analytical Chemists (AOAC, 1990). The wet muscle samples were cut into slices and dried in a vacuum-freeze dryer, allowed to equilibrate with atmospheric moisture for 24 h, and then finely ground to pass a 60-mesh sieve. Amino acid composition of the muscle powder was analyzed using ion-exchange chromatography with an automatic amino acid analyzer (L-8800 Hitachi Automatic Amino Acid Analyzer, Tokyo, Japan) after hydrolyzing with 6 N HCl at 110 °C for 24 h. Methionine, cystine and tryptophan were partly destroyed under acid hydrolysis. Tryptophan was determined after alkaline hydrolysis with 4 N NaOH for 22 h at 110 °C. Methionine and cystine were analyzed after cold formic acid oxidation for 16 h before acid hydrolysis. Duplicate analyses were performed on all six samples in each breed.

2.4. Aroma analysis

2.4.1. Cooking

The longissimus muscle, trimmed of visible fat, was cut into rectangular pieces with a combined weight of 10 g. The pieces were placed in a 100 ml borosilicate glass reagent bottle fitted with an air-tight PTFE-lined screw top, and cooked in an autoclave at 130 °C for 45 min.

2.4.2. Analysis of volatile aroma compounds

Aroma analysis was performed on muscles from six animals in each breed. According to the method described by Elmore, Mottram, Hierro (2000), volatile aroma compounds of the cooked muscles were immediately extracted by solid-phase microextraction (SPME) and analyzed by gas chromatography–mass spectrometry (GC–MS). When the cooked muscle was cooled to ambient temperature, aroma compounds of the cooked muscle were extracted by a fused-silica fibre with a 75 μm layer of Carboxen-Polydimethylsiloxane (CAR/PDMS). CAR/PDMS fibre should be conditioned by heating in a gas chromatography injector port at 250 °C for 30 min before extraction. The screw top used in the cooking process was replaced by a similar top containing one drilled hole when SPME analysis was performed. The stainless needle of CAR/PDMS fibre was placed through the hole and penetrated the liner. After equilibration at 60 °C for 5 min, the fibre was exposed to

the headspace above the sample for 45 min. After extraction, the SPME device was removed from the sample bottle and inserted into the injector port of the GC–MS.

Identification and quantification were performed on an Agilent (Agilent Technologies, Wilmington, USA) 5973 n mass spectrometer, fitted with an Agilent 6890 gas chromatograph and a G1701DA Chemstation. A split/splitless injector port, held at 250 °C, was used to thermally desorb the aroma components from the fibre onto a non-polar deactivated fused-silica retention gap (5 m × 0.25 mm I.D.; J&W Scientific). The retention gap contained five small loops in a coil, which were cooled in solid carbon dioxide contained in a 250 ml breaker. The retention gap was connected to an HP-5 low bleed/MS fused-silica capillary column (5% phenyl/95% PDMS; 60 m × 0.25 mm I.D., 0.25 μm film thickness; J&W Scientific). The injector port was in splitless mode; the splitter was opened after 3 min. During desorption, the oven was at 40 °C. After desorption, the solid carbon dioxide contained in the breaker was removed from the oven, and the oven was maintained at 40 °C for a further 2 min and then the temperature was raised at 4 °C/min to 280 °C. Immediately before desorption, 0.1 μl of an internal standard (100 ng/μl of 1,2-dichlorobenzene in methanol) was injected into the gas chromatograph. Helium, in a flow of 1.0 ml/min at 40 °C, was used as the carrier gas. A series of *n*-alkanes (C_5–C_{25}) were run under the same conditions to obtain the linear retention index (LRI) values for the aroma compounds.

The mass spectrometer was operated in electron impact mode with an electronic energy of 70 eV and an emission current of 50 μA. The ion source was maintained at 170 °C. The mass spectrometer scanned from m/z 29 to m/z 400 at 1.9 scan/s. Aroma compounds were identified by first comparing their mass spectra with those contained in the National Institute of Standards and Technology (NIST)/US Environmental Protection Agency (EPA)/National Institute of Health (NIH) Mass Spectral Databases or in previously published literature; then they were confirmed by comparison of LRI value with published values. Approximate quantities of the aroma compounds were estimated by comparison of their peak areas with that of the 1,2-dichlorobenzene internal standard, obtained from the total ion chromatograms, using a response factor of 1.

2.5. Sensory evaluation

Sensory evaluation was preformed by a 10-member trained panel. According to the guidelines for sensory evaluation of the American Meat Science Association (AMSA, 1995), 10 assessors were selected and trained. Muscle samples were thawed overnight at ambient temperature before cooking. The longissimus muscle, trimmed of visible fat, was cut into 10 portions of similar size and weight, placed in a 250 ml borosilicate glass reagent bottle fitted with an air-tight PTFE-lined screw top, and cooked in an autoclave at 130 °C for 45 min. The panellists were asked to evaluate the following two attributes: pork flavour intensity and flavour-liking. These two attributes were scored by an 8-point scale where 1 = extremely weak, dislike extremely to 8 = extremely strong, like extremely. All the samples ($6 \times 6 = 36$) were assessed by each of the 10 panellists. Six samples from different breeds were served to the panellists randomly in each session, and in each session the panellists received the samples from the six different breeds in different order.

2.6. Statistical analysis

One-way analysis of variance of SAS was carried out on the data for each muscle fatty acid and amino acid, each compound identified in the analysis of volatile aroma compounds, and sensory attributes, in order to determine the differences of the meat flavour and the meat flavour precursor from different breeds. Significance was defined at $P < 0.05$.

3. Results and discussion

3.1. Intramuscular fat content and fatty acids

Intramuscular fat content of wet muscle and fatty acid compositions of the neutral lipids in longissimus muscle from the different breeds are shown in Table 1. The fatty acid compositions of phospholipids in longissimus muscle from the different breeds are shown in Table 2. LW and RC had higher intramuscular fat contents than had the other breeds, and their intramuscular fat contents in longissimus muscle were 5.91% and 5.77%, respectively. DLW had the lowest longissimus muscle fat content in all the breeds investigated, and its fat content in longissimus muscle was 1.98%. The continuing emphasis on selecting and producing pigs with a lower subcutaneous fat content may have contributed to the lowest level of intramuscular fat content in DLW. Pigs reared in a traditional system exhibit higher intramuscular lipid content (Gandemer, 2002). There were significant differences between breeds, both in the fatty acid compositions of neutral lipids and phospholipids in longissimus muscle. In neutral lipids, higher contents of C14:0 and C16:0 were observed in Chinese indigenous breed pigs. Wood et al. (2004) found that British traditional breeds, Berkshire and Tamworth, had higher concentration of C14:0 and C16:0 in neutral lipids than had the modern breeds, Duroc and Large White. Wood et al. (2004) thought that C14:0 and C16:0 were synthesized fatty acids and were expected to be higher in fatter pigs. C18:2 reached a much higher level in DLW breed pigs, and DLW had a significantly higher polyunsaturated fatty acids (PUFA) content in the neutral lipids than Chinese indigenous breed pigs. RC had the lowest PUFA content in the neutral lipids among all the breeds. In phospholipids, DLW and TC had higher PUFA contents. LW had the lowest PUFA content in all the breeds.

Table 1
Intramuscular fat content and fatty acid compositions of neutral lipids in longissimus muscle from different breeds[A]

Items	Breeds[B]						SEM	P[C]
	DLW	LW	TC	HB	LT	RC		
Intramuscular Fat content (% of wet muscle)	1.98c	5.91a	2.66bc	4.16b	3.00bc	5.77a	0.56	***
Fatty acid (% total fatty acids)								
C14:0	1.22c	1.70a	1.88a	1.46b	1.78a	1.81a	0.08	***
C14:1	0.02c	0.11a	0.04c	0.07b	0.10a	0.03c	0.01	***
C16:0	22.3d	25.2c	28.8a	25.3c	27.0b	28.5a	0.57	***
C16:1	2.70d	4.56ab	4.99a	2.77d	3.65c	3.65c	0.21	***
C18:0	11.5c	10.9c	11.5c	15.5a	15.5a	13.3b	0.32	***
C18:1	41.9d	50.0a	45.5bc	47.5ab	43.3cd	45.9bc	1.00	***
C18:2	13.9a	4.86b	4.93b	3.61b	4.09b	3.59b	0.65	***
C18:3	1.22bc	0.68cd	0.21d	1.66b	2.44a	0.20d	0.24	**
C20:0	0.27bc	0.22c	0.31b	0.34ab	0.41a	0.32b	0.27	***
C20:1	3.34a	1.07b	1.26b	1.28b	1.09b	1.41b	0.12	**
C20:2	0.65a	0.39b	0.27b	0.41b	0.41b	0.24b	0.06	***
C20:3	0.52a	0.15b	0.16b	0.13b	0.18b	0.15b	0.03	***
C20:4	0.24a	0.05bc	0.05bc	0.03c	0.03c	0.07b	0.01	***
C22:0	0.29a	–	0.08b	–	–	0.13b	0.02	NS
C22:1	0.03a	0.02ab	0.02b	0.02ab	0.02b	0.02ab	–	***
C24:1	0.13a	–	0.04b	–	–	0.03bc	0.01	***
SFA[D]	35.6c	38.1b	42.6a	42.5a	44.7a	44.1a	0.72	***
MUFA	47.9c	55.8a	51.8b	51.7b	48.2c	51.7b	0.90	***
PUFA	16.5a	6.14bc	5.62bc	5.84bc	7.17b	4.25c	0.70	

[A] Data are means of six replicates; values in the same row with different letters were significantly different ($P < 0.05$ or $P < 0.01$).
[B] DLW, Duroc × Landrace × Large White; LW, Laiwu breed; TC, Tongcheng breed; HB, Dahuabai breed; LT, Lantang breed; RC, Rongchang breed.
[C] NS, not significantly different ($P > 0.05$); * significant at the 5% level; ** significant at the 1% level; *** significant at the 0.1% level.
[D] SFA, total saturated fatty acids; MUFA, total monounsaturated fatty acids; PUFA, total polyunsaturated fatty acids.

Table 2
Fatty acid compositions of phospholipids in longissimus muscle from different breeds[A]

Fatty acid (% total fatty acids)	Breeds[B]						SEM	P[C]
	DLW	LW	TC	HB	LT	RC		
C14:0	0.34c	3.41a	0.52bc	3.58a	3.09a	1.06b	0.24	***
C14:1	0.27d	3.27a	0.44d	3.11a	2.69b	1.00c	0.17	***
C16:0	26.4a	20.8bc	21.3bc	21.3bc	22.2b	20.3c	0.65	***
C16:1	0.65d	1.65bc	1.48c	1.38c	1.88ab	1.97a	0.10	***
C18:0	10.8abc	11.5a	9.24c	10.0abc	9.34bc	11.2ab	0.68	NS
C18:1	9.55d	19.7a	14.7c	15.7bc	17.5b	19.4a	0.71	***
C18:2	38.3a	28.0d	40.0a	31.9bc	33.0b	29.8cd	1.20	***
C18:3	0.84a	0.60bcd	0.47d	0.63bc	0.71b	0.55d	0.05	***
C20:0	0.06c	0.22b	0.18b	0.19b	0.20b	0.36a	0.04	**
C20:1	0.18c	0.40a	0.23bc	0.39a	0.33ab	0.33ab	0.04	*
C20:2	0.84bc	1.40ab	0.56c	1.48a	1.09abc	0.60c	0.23	***
C20:3	0.32a	–	0.02b	–	0.01b	0.06b	0.03	***
C20:4	9.48b	8.85bc	9.15b	10.09ab	7.70c	10.85a	0.47	***
C20:5	–	0.17a	–	0.16a	0.27a	–	0.05	***
C22:0	0.74b	0.04c	0.54bc	0.05c	0.08c	1.34a	0.23	NS
C22:1	–	0.04	0.02	0.05	0.02	–	0.02	*
C24:0	0.08abc	0.14a	0.11ab	0.05abc	0.04bc	–	0.03	***
C24:1	0.81a	–	0.89a	–	–	1.25a	0.23	***
C22:6	0.51a	–	0.25b	–	–	0.07c	0.05	**
SFA[D]	38.4a	36.1ab	31.9c	35.2b	35.0b	34.2bc	0.85	***
MUFA	11.3e	25.1a	17.7d	20.6c	22.4bc	23.9ab	0.75	***
PUFA	50.3a	39.0c	50.4a	44.2b	42.8b	41.9bc	1.18	

[A] Data are means of six replicates; values in the same row with different letters were significantly different ($P < 0.05$ or $P < 0.01$).
[B] DLW, Duroc × Landrace × Large White; LW, Laiwu breed; TC, Tongcheng breed; HB, Dahuabai breed; LT, Lantang breed; RC, Rongchang breed.
[C] NS, not significantly different ($P > 0.05$); * significant at the 5% level; ** significant at the 1% level; *** significant at the 0.1% level.
[D] SFA, total saturated fatty acids; MUFA, total monounsaturated fatty acids; PUFA, total polyunsaturated fatty acids.

3.2. Crude protein content and amino acids

Crude protein content and amino acid composition of longissimus muscle from all the six breeds are shown in Table 3. Chinese indigenous breeds, LW and RC, which had higher intramuscular fat content, had lower crude protein content. DLW had the highest crude protein content. Apart from histidine, all the other amino acids were significantly affected by breeds. Because of higher crude protein content in DLW, almost all of the amino acids were at higher levels in DLW.

3.3. Volatile aroma compounds

Ninety-five compounds were identified in the headspace of at least one breed at a concentration above 2 ng/100 g of cooked longissimus muscle (Table 4). These compounds included 18 alkanes, 1 terpenoid, 23 aldehydes, 7 alcohols, 20 ketones, 9 furans, 6 nitrogen-containing compounds, 7 sulfur-containing compounds and 4 unknown compounds.

One-way analysis of variance showed that 23 compounds were affected by breed, including 6 alkanes, 1 terpenoid, 4 alcohols, 6 ketones, 2 furans, 1 nitrogen-containing compound, 2 sulfur-containing compounds and 1 unknown compound. These six alkanes were 4-methylheptane, 2,4-dimethyl-1-heptene, 2,3-dimethylheptane, 4-methyloctane, 2,6-dimethylnonane and dodecane. Aliphatic and alicyclic hydrocarbons are not particularly odiferous and have high odour threshold values, so they did not contribute significantly to meat flavour. The terpenoid, limonene, was at higher levels in HB. Alcohols have higher odour thresholds, and generally are not thought of as important flavour contributors to meat products (Drumm & Spanier, 1991), but the flavour intensity of the alcohols increased with extension of the carbon chain (Forss, 1972). Four alcohols, 1-heptanol, 2-ethyl-1-hexanol, 1-octanol and butylated hydroxytoluene, were significantly influenced by breed. 1-Heptanol and 2-ethyl-1-hexanol were present at higher levels in LW; 1-octanol increased in DLW and LW. Butylated hydroxytoluene was at a higher level in HB. Forss (1972) found that many ketones have a green note. There were significant differences in the concentrations of 2,4-pentanedione, 2-butanone, 2-methyl-2-hepten-4-one, 2-pentadecanone, 2,5-cyclohexadiene-1,4-dione and 1-hydroxy-2-propanone between the breeds. 2-Butanone and 1-hydroxy-2-propanone, formed from the Maillard reaction, were present at significantly lower levels in DLW than in Chinese indigenous breeds. 2-Butanone has been reported to impart chocolate, buttery notes to cooked beef (Machiels, Istasse, & van Ruth, 2004). 2,4-Pentanedione was exclusively present in LT; 2-methyl-2-hepten-4-one was exclusively present in HB and 2-pentadecanone was exclusively present in DLW. 2,5-Cyclohexadiene-1,4-dione was at higher levels in HB. Furanones were formed from Maillard reactions and alkylfurans were the products of lipid oxidation (Elmore, Mottram, Enser, & Wood, 2000). Dihydro-2-methyl-3(2H)-furanone was present at very low level in DLW, and 2-methoxymethylfuran was not present in DLW, LW and HB. Heterocyclic nitrogen and sulfur compounds, originating from Maillard reactions, have higher aroma significance with low odour threshold values (Mottram, 1998). The

Table 3
Crude protein content and amino acid composition in longissimus muscle from different breeds[A]

Items	Breeds[B]						SEM	*P* Value[C]
	DLW	LW	TC	HB	LT	RC		
Crude protein content (% of wet muscle)	22.0a	18.5c	22.0a	21.0b	20.3b	19.1c	0.3	***
Amino acid (g/100 g meat powder)								
Asparagine	7.63a	6.28cd	7.40ab	6.75bc	7.00ab	5.85d	0.20	***
Threonine	3.70a	3.05bc	3.52ab	3.62a	3.43ab	2.80c	0.15	***
Serine	3.03a	2.52bc	2.92a	2.88ab	2.77ab	2.34c	0.12	*
Glutamine	8.44a	7.22bc	7.97ab	8.33a	8.04ab	6.34c	0.32	**
Alanine	4.43a	3.58c	4.26ab	3.82bc	3.77bc	3.42c	0.16	**
Glycine	3.89a	3.23bc	3.92a	3.65ab	3.56abc	3.13c	0.14	*
Cysteine	1.14a	0.98b	1.04a	1.10a	1.08ab	0.85[c]	0.03	***
Valine	3.79a	3.28bc	3.76a	3.66ab	3.68ab	3.03c	0.13	**
Methionine	3.03a	2.14c	2.70ab	2.39bc	2.38bc	2.11c	0.11	***
Isoleucine	3.92a	3.22bc	3.97a	3.69a	6.58ab	3.13c	0.14	**
Leucine	7.24a	5.61c	7.06ab	6.35bc	6.19c	5.56c	0.25	**
Tyrosine	2.75ab	2.41bc	3.05a	2.76ab	2.68bc	2.35c	0.11	**
Phenylalanine	3.94ab	3.15c	4.07a	3.47bc	3.44bc	3.27c	0.16	**
Lysine	7.70ab	6.69c	7.06bc	7.18bc	8.14a	5.57d	0.29	***
Histidine	3.68	3.25	3.25	3.49	3.09	2.94	0.25	NS
Arginine	5.17a	4.09cd	4.86ab	4.62abc	4.37bcd	0.38d	0.19	**
Proline	1.60a	1.28cd	1.47b	1.35bc	1.34bc	1.18d	0.04	***
Tryptophan	0.58b	0.78a	0.74a	0.80a	0.85a	0.47b	0.04	***

[A] Data are means of six replicates; values in the same row with different letters were significantly different ($P < 0.05$ or $P < 0.01$).
[B] DLW, Duroc × Landrace × Large White; LW, Laiwu breed; TC, Tongcheng breed; HB, Dahuabai breed; LT, Lantang breed; RC, Rongchang breed.
[C] NS, not significantly different ($P > 0.05$); * significant at the 5% level; ** significant at the 1% level; *** significant at the 0.1% level.

Table 4
Mean concentrations of volatile aromas of cooked longissimus muscle from different breeds in headspace by SPME

Compound [*m*/*z* (relative intensity)]	Mean concentration in headspace (ng/100 g)[A]						SEM	*P*[B]	LRI[C]	Method of identification[D]
	DLW	LW	TC	HB	LT	RC				
Alkanes	313	1707	590	2472	723	1398				
Heptane	24	66	5	37	11	25	22	NS	700	ms + lri
4-Methylheptane	0	86bc	29c	243a	47bc	128b	28	***	761	ms
Toluene	41	160	103	160	100	57	41	NS	771	ms + lri
Octane	85	409	119	101	101	127	86	NS	800	ms + lri
2,4-Dimethylheptane	0	0	0	37	0	138	58	NS	810	ms
1,3-Octadiene	0	9	5	13	0	4	5	NS	828	ms
2,4-Dimethyl-1-heptene	4c	324bc	176bc	901a	263bc	571ab	120	**	841	ms
2,3-Dimethylheptane	0	11bc	0	44a	5bc	26ab	7	**	856	ms
4-Methyloctane	0	156b	46b	330a	85b	94b	46	**	864	ms
1,3-Dimethylbenzene	13	37	0	32	15	10	9	NS	876	ms + lri
Styrene	0	20	0	9	0	3	8	NS	898	ms + lri
Nonane	9	22	5	3	0	6	7	NS	900	ms + lri
Decane	9	114	0	30	26	0	25	NS	1000	ms + lri
2,6-Dimethylnonane	0	172b	64b	521a	67b	206b	62	**	1016	se
Undecane	17	13	3	0	0	3	4	NS	1100	ms + lri
Dodecane	23ab	29a	8bc	11abc	0	0	6	*	1200	ms + lri
Tridecane	22	16	3	0	0	0	6	NS	1300	ms + lri
Pentadecane	66	63	24	0	3	0	18	NS	1500	ms + lri
Terpenoid	51	197	105	286	45	75				
Limonene	51b	197ab	105b	286a	45b	75b	50	*	1034	ms + lri
Aldehydes	2410	4244	2906	1920	1750	1468				
2-Methylpropanal	0	0	33	10	0	44	21	NS	533	ms + lri
3-Methylbutanal	0	0	5	14	29	0	9	NS	656	ms + lri
2-Methylbutanal	0	0	0	13	10	8	6	NS	665	ms + lri
Pentanal	20	84	49	9	8	0	19	NS	709	ms + lri
(E)-2-pentenal	0	0	0	5	0	0	2	NS	774	ms + lri
3-Methyl-2-butenal	0	0	2	2	8	9	4	NS	791	ms + lri
Hexanal	518	1111	1229	537	417	497	248	NS	804	ms + lri
(E)-2-Hexenal	4	0	0	0	0	0	2	NS	860	ms + lri
Heptanal	90	217	107	19	50	78	54	NS	900	ms + lri
3-(Methylthio)propanal	7	12	8	7	0	3	6	NS	914	ms
(E)-2-Heptenal	55	27	22	7	6	12	12	NS	962	ms + lri
Benzaldehyde	707	1302	839	1022	808	380	350	NS	971	ms + lri
Octanal	184	345	137	64	113	114	96	NS	1006	ms + lri
Benzeneacetaldehyde	31	30	20	21	19	50	19	NS	1054	ms + lri
(E)-2-Octenal	61	47	25	6	8	0	16	NS	1062	ms + lri
Nonanal	409	809	341	147	220	203	168	NS	1100	ms + lri
(E)-2-Nonenal	31	32	4	0	0	9	11	NS	1163	ms + lri
Decanal	75	81	39	37	46	23	16	NS	1209	ms + lri
(E)-2-Decenal	5	63	10	0	0	22	24	NS	1265	ms + lri
(E,E)-2,4-Decadienal	15	20	0	0	0	16	12	NS	1319	ms + lri
2-Undecenal	29	30	0	0	0	0	17	NS	1367	ms + lri
Dodecanal	12	0	0	0	0	0	3	NS	1400	ms + lri
Hexadecanal	157	34	36	0	8	0	51	NS	1825	ms + lri
Alcohols	237	1214	346	716	231	393				
1-Pentanol	40	41	58	0	32	39	21	NS	773	ms + lri
1-Hexanol	0	18	10	11	14	5	5	NS	876	ms + lri
1-Heptanol	29ab	40a	20b	0	3c	0	5	***	971	ms + lri
2-Ethyl-1-hexanol	80c	1001a	167c	504b	145c	342bc	81	***	1032	Ms
1-Octanol	58a	58a	31ab	0	0	7b	15	*	1071	ms + lri
(E)-2-Octen-1-ol	11	2	0	0	2	0	4	NS	1071	ms + lri
Butylated hydroxytoluene	19b	54b	60b	201a	35b	0	16	***	1510	ms
Ketones	372	709	685	885	973	583				
2-Butanone	8c	122bc	106bc	209ab	322a	108bc	50	*	602	ms + lri
2,3-Pentanedione	82	67	81	84	56	50	36	NS	703	ms + lri
2-Pentanone	0	0	0	13	0	4	6	NS	704	ms + lri
2-Methyl-3-pentanone	0	0	0	0	0	4	2	NS	705	ms
1-Hydroxy-2-propanone	71b	124b	195b	214b	417a	217b	47	**	714	ms + lri
3-Hydroxy-2-butanone	0	65	73	84	27	71	25	NS	742	ms + lri
2,4-Pentanedione	0	0	0	0	13a	0	3	*	788	ms

Table 4 (*continued*)

Compound [*m/z* (relative intensity)]	Mean concentration in headspace (ng/100 g)[A]						SEM	*P*[B]	LRI[C]	Method of identification[D]
	DLW	LW	TC	HB	LT	RC				
2-Methyl-2-hepten-4-one	0	0	0	95	0	0	20	*	830	ms
1-Acetyloxy-2-propanone	20	35	63	24	51	42	18	NS	879	ms
2-Cyclopentene-1,4-dione	0	0	0	18	6	12	8	NS	890	ms
2-Heptanone	20	78	19	35	19	33	16	NS	891	ms + lri
2,3-Octanedione	4	51	65	0	0	0	18	NS	983	ms + lri
1-Octen-3-ol	123	112	69	46	30	42	27	NS	983	ms + lri
6-Methyl-5-hepten-2-one	0	0	9	0	21	0	7	NS	989	ms
3-Octanone	7	6	0	7	0	0	5	NS	990	ms + lri
Acetophenone	9	0	5	0	0	0	4	NS	1072	ms + lri
2-Nonanone	4	20	0	0	0	0	6	NS	1092	ms + lri
2-Decanone	0	25	0	0	0	0	10	NS	1194	ms + lri
2,5-Cyclohexadiene-1,4-dione	4b	4b	0	56a	11b	0	7	**	1470	ms
2-Pentadecanone	20a	0	0	0	0	0	2b	***	1702	ms + lri
Furans	340	706	225	288	388	495				
2-Methylfuran	0	17	0	104	0	0	43	NS	602	ms + lri
2-Ethylfuran	6	0	0	0	0	0	2	NS	702	ms + lri
Dihydro-2-methyl-3(2H)-furanone	5c	12bc	28bc	39abc	70a	42ab	11	*	812	ms + lri
2-Methoxymethylfuran	0	0	14c	0	43b	69a	5	***	835	ms
Furfural	54	126	70	51	82	86	37	NS	837	ms + lri
2-Furanmethanol	13	110	34	38	95	218	53	NS	867	ms + lri
1-(2-Furanyl)ethanone	0	0	0	0	12	33	8	NS	915	ms
2-Pentylfuran	251	441	79	56	86	47	134	NS	993	ms + lri
2-Heptylfuran	11	0	0	0	0	0	3	NS	1194	ms + lri
Nitrogen-containing	49	314	126	297	141	145				
Pyrazine	0	25	13	17	12	24	9	NS	739	ms + lri
Methylpyrazine	30	177	46	111	85	63	58	NS	829	ms + lri
2,5 and 2,6-Dimethylpyrazine	11	112	50	67	25	21	49	NS	917	ms + lri
Ethylpyrazine	0	0	9	7	5	11	4	NS	921	ms + lri
2-Ethyl-6-methylpyrazine	8	0	3	20	6	26	9	NS	1002	ms + lri
2-Butylpyrroline 83, 55 (33), 69 (24), 41 (13), 168 (9), 111 (7) 125 (4), 97 (4), 29 (4)	0	0	5b	75a	8b	0	6	***	1068	se
Sulfur-containing	44	152	30	277	19	49				
Dimethyl disulfide	0	0	0	11	0	0	4	NS	740	ms + lri
2-Methylthiophene	5	52	0	88	0	26	33	NS	775	ms + lri
2-Furanmethanethiol	2	0	0	0	0	0	1	NS	914	ms
Dimethyl trisulfide	0	10bc	23b	46a	19b	19b	5	**	982	ms + lri
2-Thiophenecarboxaldehyde	0	70	0	128	0	0	42	NS	1011	ms + lri
2-Acetylthiazole	32	0	0	0	0	0	3	***	1024	ms
3-Methyl-2-thiophenecarboxaldehyde	5	20	7	4	0	4	5	NS	1089	ms
Unknown										
Unknown A 116, 46 (62), 74 (30), 41 (24), 42 (22), 39 (14), 88 (7), 59 (6)	9	24	18	49	29	31	12	NS	988	
Unknown B 43, 56 (90), 70 (69), 85 (56), 111 (20), 29 (16), 154 (9), 127 (7), 99 (6)	0	0	0	84	74	0	48	NS	1024	
Unknown C 69, 43 (78), 57 (58), 83 (55), 111 (44), 97 (16), 125 (15), 29 (15), 154 (7)	62b	93b	0	337a	32b	49b	52	**	1307	
Unknown D 69, 43 (83), 57 (62), 85 (59), 111 (50), 29 (16), 97 (15), 154 (10), 125 (7)	10	184	24	238	17	39	108	NS	1317	

[A] Data are means of six replicates; values in the same row with different letters were significantly different ($P < 0.05$ or $P < 0.01$). DLW, Duroc × Landrace × Large White; LW, Laiwu breed; TC, Tongcheng breed; HB, Dahuabai breed; LT, Lantang breed; RC, Rongchang breed.

[B] NS, not significantly different ($P > 0.05$); * significant at the 5% level; ** significant at the 1% level; *** significant at the 0.1% level.

[C] Linear retention index on a HP-5 low bleed/MS column.

[D] ms + lri, mass spectrum identified using NIST/EPA/NIH Mass Spectral Database and LRI agrees with literature value (Elmore, Mottram, Hierro, 2000; Elmore, Mottram, Enser et al., 2000; Elmore et al., 2005); ms, mass spectrum agrees with spectrum in NIST/EPA/NIH Mass Spectral Database; se, tentative identification from structure elucidation of mass spectra.

Table 5
Sensory attributes of cooked longissimus muscle from different breeds[A]

Items	Breeds[B]						SEM	P[C]
	DLW	LW	TC	HB	LT	RC		
Pork flavour intensity	4.0d	5.7a	4.4c	5.1b	4.3cd	4.3cd	0.12	***
Flavour-liking	3.9d	5.8a	4.3c	5.3b	4.0cd	4.0d	0.12	***

[A] Data are means of six replicates; values in the same row with different letters were significantly different ($P < 0.05$ or $P < 0.01$).
[B] DLW, Duroc × Landrace × Large White; LW, Laiwu breed; TC, Tongcheng breed; HB, Dahuabai breed; LT, Lantang breed; RC, Rongchang breed.
[C] NS, not significantly different ($P > 0.05$); * significant at the 5% level; ** significant at the 1% level; *** significant at the 0.1% level.

tentatively identified nitrogen-containing compound, 2-butyl-pyrroline, was at higher levels in HB. The level of dimethyl trisulfide was significantly higher in HB and 2-acetylthiazole was exclusively present in DLW. Dimethyl trisulfide is derived from sulfur-containing amino acids (Machiels et al., 2004).

Aroma significance of the volatile aroma compounds relies, not only on their concentration, but also their odour threshold value. Therefore, the Maillard reaction products whose concentration differences between the breeds were not significant were also considered in the present study. 2-Methylpropanal and 2-methylbutanal are formed from the Strecker decomposition of valine and isoleucine, respectively. 3-Methylbutanal is the Strecker decomposition product of leucine (Machiels et al., 2004). These three compounds were not present in DLW and LW; even higher levels of valine and leucine were observed in DLW longissimus muscle. Maybe the Strecker decomposition products of amino acids have higher correlations with the contents of free amino acid in muscle. Pyrazine is an important Maillard reaction product. 3-Hydroxy-2-butanone is formed from the decomposition of sugar (Machiels et al., 2004). These two compounds were also not present in DLW.

The total volatile alkanes concentration of DLW was lower than those of the other breeds investigated. This is possibly associated with the lower intramuscular lipid content of DLW; volatile alkanes were mainly formed from the decomposition of lipids. The total volatile aldehydes concentration of DLW was lower than those of LW and TC, but higher than those of the other Chinese indigenous breeds. This was probably due to enhanced oxidation of the more unsaturated lipids of DLW. The total volatile alcohols concentration of DLW was lower than those of LW, TC, HB and RC. The total ketone concentrations of DLW was the lowest among all the breeds. The total concentrations of furans in LW and RC were higher than those in DLW, TC, LT and HB. The total concentrations of nitrogen-containing compounds in LW and HB were higher than those in DLW, TC, LT and RC. The total sulfur-containing compound concentrations were also at higher levels in LW and HB.

3.4. Sensory attributes

Sensory analysis indicated that cooked longissimus muscle from DLW had the lowest pork flavour intensity and flavour-liking, compared with the Chinese indigenous breeds (Table 5). LW and HB showed the highest pork flavour intensity and flavour-liking in cooked longissimus muscle.

The volatile aroma compounds analysis corresponded with the results of sensory analysis. One-way analysis of variance of volatile compounds indicated that many flavour contributors were at higher levels in LW and HB. Those compounds could contribute to produce a different overall flavour by adding their special flavour notes to LW and HB meat. LW and HB had higher levels of total sulfur-containing compounds and nitrogen-containing compounds, and these compounds usually impart meaty aromas to meat. LW and HB had higher levels of total alcohols and ketones, in comparison with the other breeds. Suzuki and Bailey (1985) found that C_6–C_{10} straight-chain fatty acids and certain aldehydes, ketones and hydrocarbons had positive correlations with meat flavour strength. DLW showed the lowest pork flavour intensity and flavour-liking among all the breeds. The volatile aroma analysis indicated that many Maillard reaction products were at lower levels or not present in DLW. The total furans, nitrogen-containing compounds and sulfur-containing compounds were all at lower levels in DLW. All of these may be associated with the lowest pork flavour intensity and flavour-liking in DLW.

4. Conclusions

Distinct differences in amino acid composition and fatty acid composition of longissimus muscle from five Chinese indigenous breed pigs and DLW pigs were observed in this study. Among all the six breeds, LW and RC had the highest intramuscular fat content and the lowest crude protein content; DLW had the lowest longissimus muscle fat content and the highest crude protein content. In neutral lipids, DLW had significantly higher PUFA content, whereas RC had the lowest PUFA content. In phospholipids, DLW and TC had higher PUFA content. LW had the lowest PUFA content. One-way analysis of variance showed that 23 volatile compounds were affected by breed. Many flavour contributors were at higher levels in LW and HB. Many Maillard reaction products were at lower levels, or not present, in DLW. Sensory analysis indicated that cooked longissimus muscle from DLW showed the lowest pork flavour intensity and flavour-liking, compared with

indigenous breeds. LW and HB showed the highest pork flavour intensity and flavour-liking in cooked longissimus muscle.

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