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Abstract

We studied effects of aging methods and temperature on the physical, chemical, and amino acid composition of pork belly from Berkshire and Landrace × Yorkshire × Duroc (LYD) swine. Pork belly samples were assigned randomly to breed groups (Berkshire and LYD), aging temperature groups (0 ℃ and 9 ℃), and aging method groups. One samples of vacuum-packaged hanging pork bellies were hung in a refrigerated cooler with 83±2.0 % humidity, while the other samples were immersed in a 3.5 % salt solution in a vacuum package and subsequently stored in the same cooler for 2 weeks. LYD pork had lower pH and purge loss and higher lightness values than those of Berkshire pork ($p<0.05$). Moreover, thiobarbituric acid reactive substances and hardness values of LYD pork were lower than those of Berkshire pork after aging ($p<0.05$). Berkshire pork had a higher level of flavorful amino acids than LYD pork did during aging ($p<0.05$). Bellies aged at elevated temperatures for two weeks had higher volatile basic nitrogen. However, significantly higher percentages of flavorful and sweet taste amino acids were observed in bellies aged at 9 °C compared to those aged at 0 °C for 2 weeks. Moisture content was higher in immersed samples than hanging samples after two weeks of aging ($p<0.05$). Hanging pork bellies exhibited higher texture profiles than immersed pork bellies at two weeks ($p<0.05$). We concluded that breeds, aging temperature, and methods affected most quality attributes of pork belly.

Key words: aging methods, temperature, meat quality, Berkshire, Landrace × Yorkshire × Duroc , pork belly

Introduction

Pork is one of the most preferred meats in south Korea and its consumption is limited to specific cuts such as the belly and the neck. Pork belly has been a favorite cut among Korean meat consumers for years because of its flavor and high fat content, and consequentially, is more expensive than other cuts of meat (Korea Meat Trade Association, 2018).

Each breed of swine has unique characteristics. The Berkshire breed has higher levels of amino acids, tender meat, better water-holding capacity (WHC), darker meat color, and lower cooking loss and drip loss compared with other breeds (Lee et al., 2012). Crossbreeding in swine is focused on improving the total efficiency and enhancing meat quality (Edwards et al., 2003). In Korea, commercial pork is currently three-way crossbred as Landrace × Yorkshire × Duroc (LYD), which have a faster growth rate, higher yield and litter size than other crossbreeds (Lim et al., 2014). Previous studies found that LYD pigs had lower values in texture, cooking loss, and drip loss but had increased WHC compared with other crossbreeds (Kim et al., 2006; Poldvere et al., 2015). Although LYD pigs are widely bred commercially, differences in meat quality between Berkshire pigs and LYD pigs are unknown. Furthermore, previous work on the comparison of meat quality between purebred and LYD crossbreds has mostly been done for pork loins (Choi et al., 2016). Thus, it is vital to compare the meat quality of belly parts from Berkshire and LYD pigs.

Salting improves the texture and flavor and extends the shelf life of meat (Graiver et al., 2006). Brine is used to soak muscle meat (Jin et al., 2014), however no literature is available on impacts of wet aging using brine on the quality of pork bellies in vacuum packaging.

Aging improves meat quality by enhancing meat characteristics such as tenderness, juiciness, and flavor (Sitz et al., 2006; Koutsidis et al., 2008). Unlike the beef industry, dry or vacuum-aging techniques have not achieved the same popularity in pork industry. Aging regimes, such as methods, time, and temperature, that affect meat quality, have not been reported in the pork industry because they increase production costs (Frenzel et al., 2014). Aging is generally categorized as either vacuum or dry aging. Vacuum aging is a commonly used technology for meat, the meat with a bloody and metallic flavor (Campbell et al., 2001) is stored in a sealed barrier package in a refrigerated cooler (Smith et al., 2008). It also inhibits weight loss caused by moisture evaporation, resulting in microorganism proliferation and improved juiciness and tenderness in pork (Juárez et al., 2011). Unlike dry aging, controlled humidity and air velocity are not required for wet aging (Frenzel et al., 2014). Research on immersed wet-aging of pork is rarely done because it can result in excess water loss and higher lipid rancidity compared to beef, owing to high concentrations of polyunsaturated fatty acids. In addition, positive effects of aging on pork quality might be influenced by the fat content of the carcass, which is related to genotypes in pigs (Juárez et al., 2011). The shelf-life of vacuum-packaged meat depends on temperature because microbial growth is highly related to temperature (Zamora and Zaritzky, 1985). Although previous studies have compared effects of wet and dry aging on the quality of beef (Campbell et al., 2001; Sitz et al., 2006; Stenström et al., 2014) and pork (Jin and Yim, 2020), no study has compared effects of hanging and immersed pork belly in a vacuum package on physicochemical traits. Thus, we aimed to determine effects of two aforementioned aging methods and temperature (0 ℃ and 9 ℃) on physical traits, chemical composition, and amino acid composition of pork belly from Berkshire and crossbred Landrace × Yorkshire × Duroc (LYD) pigs.

Materials and Methods

Sample preparation and aging conditions

Belly cuts from swine, an offspring of a Landrace/Yorkshire sow with a Duroc boar cross-bred, were taken from six carcasses. Same cuts from purebred Berkshire pigs were evaluated to compare meat quality traits with LYD pigs. The average live weight of the pigs was 109 kg. Bellies were obtained from a meat processing plant and moved to the experimental facility by cold transport (2±1 °C). Pork belly cuts between the fifth and the last ribs with consistent thickness of lean and fat layers were obtained from 10 right pork sides at 8-h postmortem. Thereafter, belly muscles were sliced into three pieces of 15 cm thickness, and bellies were trimmed to remove excess fat and bone, after which were grouped into two aging treatments, hanging and immersed pork belly in a vacuum package. Both vacuum-packaged samples were assigned to and stored at 0 ℃ and 9 ℃ at 83±2.0 % humidity for one of the following periods: 0, 1, or 2 weeks. Hanging pork belly samples were hung vacuum-packaged in presence of air in a refrigerated cooler, where temperatures and humidity were monitored and recorded using a temperature probe (175-H2; Testo, Lenzkirch, Germany). Immersed samples were vacuum-packaged, immersed in a brine solution with 3.5 % sodium chloride and then stored inside a refrigerated cooler. All samples were transferred for and aged for 0 (non-aged), 1 and 2 weeks for subsequent analysis.

Physicochemical analysis

The pH value was measured using a pH meter (MP 230, Mettler Toledo, Switzerland). Approximately 5 g of raw meat was mixed with 45 mL of deionized water and then homogenized (IKA T25, ULTRATURAX, Staufen, Germany) for 50 s at 17,000 × g. Moisture content was determined by calculating the weight difference between pre-dried and post-dried meat samples after drying at 104 °C for 12 h. WHC was estimated according to the modified method suggested by Joo (2018). WHC (%) was calculated as follows: WHC (%) = (Damp filter paper and plastic film weight) - (filter paper and plastic film weight) / meat sample weight × 100. Drip loss was estimated by calculating the difference between the final weight and initial weight of the drippings collected in a bag. Purge loss was calculated as the difference in the final weight of sausages compared to their initial weight after two and four weeks of storage in a vacuum bag. Water and fat loss was expressed as the ratio of the released water (or fat) volume (mL) and raw batter weight (g).

Lipid oxidation was measured according to the method described by Yang et al. (2009). thiobarbituric acid reactive substances (TBARS) was determined as milligrams of malondialdehyde per kilogram of meat. Volatile basic nitrogen (VBN) was obtained as described by Conway (1950). For the microbial count analysis, 10 g of each sample was aseptically obtained and homogenized with 90 mL of sterile 0.85% sodium chloride solution for three min using a stomacher (lab blender 400, Seward, London, UK). Microorganisms were analyzed for total plate counts according to standard procedures (APHA, 1992). Samples for total plate count and coliform analysis were incubated at 37 ℃ for 72 h and 24 h, respectively. Microbiological data were shown as the log of colony forming unit (CFU)/g. The color was measured using a colorimeter (Minolta CR-400, Minolta Co., Tokyo, Japan) and a white plate was used for standardization (Y=93.5, X=0.3132, y=0.3198) before calculation. The color parameters are shown as L* (lightness), a* (redness), and b* (yellowness). The chroma (*C**) and hue angle were calculated as $(a^{*2} + b^{*2})^{1/2}$ and $\tan^{-1}(b^*/a^*)$, respectively (Fernández-López et al., 2000). Sliced samples, 25 mm in diameter, were analyzed using a texture analyzer (TA-XT2i, Stable Micro System, Surrey, UK), and their hardness, cohesiveness, springiness, gumminess, chewiness, and adhesiveness were measured. The free amino acid content was determined using a modified high-performance liquid chromatography technique, as described by Bidlingmeyer et al. (1984).

Statistical analysis

Calculations based on the general linear model were analyzed using an analysis of variance using the SAS 8.3 software program (SAS Institute Inc., USA) with three replications, and results were reported as mean values with standard error of the means. A *t*-test was used to compare results between the two groups. Significance was determined using Duncan's multiple range test. Differences were considered significant at $p<0.05$.

Results and Discussion

Effects of the two aging methods and temperature on physicochemical properties of pork bellies from Berkshire and crossbred (LYD) pigs are depicted in Table 1. Regardless of treatment, the pH decreased with aging. Our results agree with those of Hwang et al. (2018), who report similar findings in wet-aged pork. pH values of pork belly were higher for Berkshire pigs than for LYD pigs at 0 and 1 week ($p<0.05$), which was in line with a previous report (Subramaniyan et al., 2016). The variation in pH could be due to effects of crossbreeding (Choi et al., 2016). Aging pork bellies at 9 ˚C resulted in lower pH values than aging at 0 ˚C in samples at 2 weeks. Hanging pork had higher pH values than immersed samples in brine at 1 week ($p<0.05$), and our results were consistent with those of Lee et al. (2010). The increase in basic free amino acids caused by microorganisms may be the primary reason for the rising pH in hanging pork (Lee et al., 2016).

Hanging samples had lower moisture content than immersed samples in brine at one and two weeks ($p<0.05$). The reduced moisture content of meat during hanging aging could be due to higher evaporation loss (Kim et al., 2019). Juárez et al. (2011) also noted that hanging pork muscle decreased the moisture content. The WHC of all samples increased in the 1st week and decreased in the 2nd week ($p<0.05$). The WHC of pork bellies was not significantly affected by the aging method until 14 days of aging in our study. Regardless of the treatment sample, drip loss decreased with aging. Purge loss was higher in Berkshire pigs than in LYD pigs at one and two weeks ($p<0.05$). Hanging samples showed lower purge loss than immersed samples at one week ($p<0.05$). Water and fat loss in all samples decreased until one week of aging and then increased for two weeks ($p<0.05$). Aging pork bellies at 9 ˚C resulted in higher water and fat loss than aging at 0 ˚C did in samples at 2 weeks ($p<0.05$).

Effects of the two aging methods and temperature on TBARS, VBN, and microbiological properties of pork bellies from Berkshire and crossbred (LYD) pigs are presented in Table 2. The TBARS values for all samples increased until one week of aging and then decreased for two weeks ($p<0.05$). TBARS values of pork belly were higher for Berkshire pigs than for LYD pigs, regardless of aging time ($p<0.05$). This could be due to the high fat content in Berkshire breeds compared to other breeds (Lee et al., 2012). Previous study showed that fat contents of dry-cured ham were higher in Berkshire than in LYD (Yim et al., 2019). Analyses of fatty acid levels in pork belly muscles from Berkshire meat had higher unsaturated fatty acid contents compared to those from LYD during storage (data not shown), potentially leading to effects on lipid oxidation. There was no overall difference in TBARS values according to the storage temperature (0, 9℃), but there was a slight difference only in the first week. Differences in lipid oxidation between hanging and immersed pork belly were not confirmed in our study. The VBN of the belly parts increased as the aging time increased ($p<0.05$). Elevating aging temperature from 0 ˚C to 9 ˚C increased the VBN content in the samples ($p<0.05$). Aging at 9 ˚C resulted in higher total plate counts than aging at 0 ˚C did in samples at one week ($p<0.05$). Coliform counts of the belly increased as the aging time increased ($p<0.05$) and were lower in Berkshire pigs than in LYD pigs at 2 weeks ($p<0.05$). Counts of total aerobic bacteria and coliforms were similar for hanging and immersed pork belly samples. A similar result was reported in a previous study where hanging pork did not influence total aerobic bacteria (Lee et al., 2016).

Table 3 describes meat color measurements of pork belly from Berkshire and crossbred (LYD) pigs as a consequence of the two aging methods and temperature. With respect to meat color, pork belly samples had increased L*, b*, and h values during aging and decreased in a* and c values ($p<0.05$). This was similar to a previous study, which indicated that pork muscle demonstrated increased L* and b* values, and decreased a* values with increasing aging time (Hwang et al., 2018). The lower a* values could be explained by the oxidation of myoglobin, which was clearly reflected in the increasing levels of metmyoglobin during aging. The redness decreased, which was in line with previous studies (Hansen et al., 2004). Juárez et al. (2011) also reported an increase in lightness with aging. L* values were significantly lower in Berkshire pork bellies than in LYD pork bellies at 0 and 1 week of aging. A similar result was seen in the Berkshire breed with lower L* values than the LYD breed (Yim et al., 2019). This may be attributed to the discrepancy in muscle composition between the two breeds (Seong et al., 2014). Higher pH values in Berkshire pigs may decrease the L* values of muscle (Choi et al., 2016), which this finding coincides with the one from our study. CIL a* values in LYD pork bellies were significantly lower than those in Berkshire pork bellies, which was consistent with the literature (Subramaniyan et al., 2016) where LYD pork had a lower color a* compared with Berkshire pork. Aging pork bellies at 9 ˚C resulted in higher L* values than aging at 0 ˚C in samples at two weeks ($p<0.05$). Hanging samples had lower L* values than immersed samples in brine at one week ($p<0.05$). The higher L* values for immersed bellies may be due to the higher water content of immersed samples. Aging at 9 ˚C resulted in higher a* values than aging at 0 ˚C in samples at one week ($p<0.05$). Hanging samples showed higher a* values than immersed samples at one week ($p<0.05$). Aging at 9 ˚C resulted in higher W values than aging at 0 ˚C in samples at 2 weeks ($p<0.05$). Our results indicated that aging methods did not negatively affect color.

Table 4 describes texture profiles of pork belly from Berkshire and crossbred (LYD) pigs as a consequence of the two aging methods and temperature. Hardness values in Berkshire pork bellies were significantly higher than those in LYD pork bellies at one and two weeks of age. Aging temperature did not adversely affect the texture profile, and elevated aging temperatures could shorten aging periods. Hanging samples showed higher hardness values than immersed samples at two weeks ($p<0.05$). Cohesiveness values in Berkshire pork bellies were significantly higher than those in LYD pork bellies at 0 week. Effects of the two aging methods until one week of aging ($p>0.05$) did not significantly differ. However, hanging samples showed higher hardness, cohesiveness, gumminess, and adhesiveness values than immersed samples at 2 weeks ($p<0.05$).

Amino acid composition in the belly parts of Berkshire and crossbred (LYD) pigs as a result of the two aging methods and temperature are presented in Table 5. With the exception of a few amino acids, differences in amino acid composition between Berkshire and crossbred (LYD) pigs were significant in the belly cuts. The free amino acid carnosine had the highest concentration in the pork belly, with taurine, glutamic acid, alanine, leucine, and carnosine were the most abundant free amino acids in pork belly. LYD pigs had higher percentages of essential amino acids, sweet tasting amino acids, aromatic amino acids, and bitter amino acids in bellies compared to Berkshire samples at 0 week ($p<0.05$). Berkshire pigs had a higher percentage of flavorful amino acids than LYD samples during aging ($p<0.05$). Although aging at 9 ˚C resulted in a higher percentage of flavorful amino acids and sweet tasting amino acids than aging at 0 ℃ in samples at one and two weeks ($p<0.05$), the mechanism responsible for this phenomenon was investigated further. Expectedly, the free amino acid content of pork bellies was not significantly affected by the aging method; however, those of belly muscles increased as the aging period increased ($p<0.05$). Moya et al. (2001) also reported that samples of pork loin contained higher amounts of free amino acids after aging. Free amino acids are potent flavor precursors that may contribute characteristic taste through the Maillard reaction in meat (Koutsidis et al., 2008). Although several amino acids contribute to an unpleasant taste, free amino acids are vital contributors to the pleasant flavor of cooked meat (Koutsidis et al., 2008). Our study concluded that the free amino acid content of pork bellies was affected by pig genotypes, and aging temperature. However, it should be further examined how aging temperature affect the free amino acid.

Conclusions

Quality traits of pork belly were influenced by breed, temperature, and aging method. In particular, pig breed affected meat quality and amino acid composition. It is plausible that bellies from LYD pork present relatively desirable meat quality parameters with regard to lower pH, lipid oxidation, hardness, drip and purge loss, as well as higher lightness values. Our study showed that application of elevated aging temperatures could shorten aging time, while not negatively affecting meat quality, except for a higher VBN content in the bellies aged at 9 °C. The aging method did not adversely influence the meat quality of pork bellies. In conclusion, both methods may be utilized for aging. Further studies are needed to establish optimal aging conditions for pork bellies to ensure high quality, feasibility, and consumer benefits.

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Table 1.

Effects of two aging methods and temperature on physico-chemical traits of pork bellies from Berkshire and crossbred (LYD) pigs during aging

	Weeks	Breed		Temperature(℃)		Aging method	
		Berkshire	LYD	0	9	Hanging	Immersed in brine
pH	0	6.51±0.10^{Aa}	6.29±0.02^{Ba}	6.40±0.14^{a}	6.40±0.14^{a}	6.40±0.14^{a}	6.40±0.14^{a}
	1	6.36±0.22^{Ab}	6.17±0.08^{Bb}	6.33±0.24^{a}	6.20±0.07^{b}	6.36±0.21^{Aa}	6.18±0.09^{Bb}
	2	5.95±0.16^{c}	5.96±0.15^{c}	6.09±0.10^{Ab}	5.82±0.03^{Bc}	5.98±0.18^{b}	5.93±0.12^{c}
Moisture (%)	0	49.06±1.05^{a}	49.67±0.49^{a}	49.36±0.88^{a}	49.36±0.88^{a}	49.36±0.88^{a}	49.36±0.88^{b}
	1	48.65±1.98^{a}	47.37±6.62^{ab}	47.74±3.35^{a}	48.74±5.53^{a}	44.29±3.61^{Bb}	51.43±2.48^{Aa}
	2	45.05±3.63^{b}	44.45±1.42^{b}	44.78±2.39^{b}	44.72±3.11^{b}	43.32±2.01^{Bb}	46.18±2.64^{Ac}
WHC (%)	0	60.66±0.84^{Bb}	62.49±2.04^{Aa}	61.57±1.83^{ab}	61.57±1.83^{b}	61.57±1.83^{ab}	61.57±1.83^{b}
	1	72.25±2.21^{Aa}	66.58±7.19^{Ba}	65.40±8.39^{Ba}	72.04±2.47^{Aa}	66.28±8.54^{a}	71.76±3.36^{a}
	2	55.08±6.53^{c}	46.60±13.82^{b}	57.11±8.74^{Ab}	44.57±10.52^{Bc}	55.22±12.62^{b}	46.45±8.46^{c}
Drip loss (%)	0	3.06±0.50^{Aa}	2.06±0.20^{Ba}	2.56±0.65^{a}	2.56±0.65^{a}	2.56±0.65^{a}	2.56±0.65^{a}
	1	0.63±0.14^{b}	0.56±0.12^{b}	0.59±0.11^{b}	0.63±0.15^{b}	0.64±0.14^{b}	0.57±0.12^{b}
	2	0.38±0.14^{b}	0.41±0.14^{c}	0.40±0.17^{b}	0.39±0.12^{b}	0.36±0.14^{b}	0.43±0.13^{b}
Purge loss(%)	0	0.00±0.00^{c}	0.00±0.00^{c}	0.00±0.00^{c}	0.00±0.00^{c}	0.00±0.00^{b}	0.00±0.00^{c}
	1	10.19±3.32^{Aa}	6.43±1.69^{Ba}	7.24±1.66^{a}	9.82±4.11^{a}	6.42±2.01^{Ba}	10.25±3.60^{Aa}
	2	7.78±2.15^{Ab}	4.41±2.68^{Bb}	5.17±3.61^{b}	7.02±1.82^{b}	7.19±3.75^{a}	5.00±1.22^{b}
Water and fat loss (%)	0	19.29±0.11^{Aa}	18.62±0.83^{Bb}	18.96±0.69^{a}	18.96±0.69^{b}	18.96±0.69^{a}	18.96±0.69^{b}
	1	13.33±0.86^{Bb}	15.85±3.11^{Ab}	16.08±3.23^{b}	13.85±1.67^{c}	14.94±3.57^{b}	14.52±2.06^{c}
	2	20.03±4.19^{a}	23.79±5.87^{a}	19.01±4.07^{Ba}	24.80±4.98^{Aa}	19.35±5.83^{Ba}	24.47±3.39^{Aa}

$^{A-B}$ Means with different superscripts in the same row and section significantly differ at $p<0.05$.

$^{a-c}$ Means with different superscripts in the same column significantly differ at $p<0.05$.

Table 2.

Effects of two aging methods and temperature on TBARS, VBN, microbiological traits of pork bellies from Berkshire and crossbred (LYD) pigs during aging

Items	Weeks	Breed		Temperature (℃)		Aging method	
		Berkshire	LYD	0	9	Hanging	Immersed in brine
TBARS (mg MA/kg)	0	0.22±0.00^{Ac}	0.14±0.00^{Bc}	0.18±0.04^{c}	0.18±0.04^{c}	0.18±0.04^{c}	0.18±0.04^{c}
	1	0.36±0.11^{Aa}	0.29±0.02^{Ba}	0.37±0.10^{Aa}	0.28±0.03^{Ba}	0.33±0.10^{a}	0.32±0.07^{a}
	2	0.27±0.03^{Ab}	0.24±0.02^{Bb}	0.26±0.04^{b}	0.25±0.02^{b}	0.25±0.02^{b}	0.26±0.04^{b}
VBN (mg%)	0	6.11±0.07^{c}	6.11±0.07^{c}	6.11±0.07^{c}	6.11±0.07^{c}	6.11±0.07^{c}	6.11±0.07^{c}
	1	6.97±0.73^{b}	7.00±0.56^{b}	6.32±0.28^{Bb}	7.57±0.16^{Ab}	6.88±0.73^{b}	6.99±0.66^{b}
	2	8.72±1.24^{a}	8.97±1.58^{a}	7.50±0.14^{Ba}	10.19±0.34^{Aa}	8.82±1.37^{a}	8.87±1.48^{a}
TPC (log10 CFU)	0	3.79±0.01^{A}	3.53±0.07^{Bb}	3.66±0.15	3.66±0.15^{b}	3.66±0.15^{b}	3.66±0.15^{b}
	1	3.82±0.48	4.27±0.37^{a}	3.77±0.44^{B}	4.27±0.27^{Aa}	4.26±0.47^{a}	3.82±0.40^{ab}
	2	3.59±0.32^{B}	4.05±0.11^{Aa}	3.89±0.13	3.75±0.45^{b}	3.68±0.39^{b}	3.96±0.21^{a}
Coliform (log10 CFU)	0	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}
	1	3.27±1.07^{a}	2.79±0.34^{b}	2.95±0.35^{a}	3.25±1.17^{a}	3.34±0.56^{a}	2.90±1.04^{a}
	2	3.15±0.46^{Ba}	3.59±0.07^{Aa}	3.17±0.49^{a}	3.57±0.51^{a}	3.32±0.45^{a}	3.42±0.34^{a}

$^{A-B}$ Means with different superscripts in the same row and section significantly differ at $p<0.05$.

$^{a-c}$ Means with different superscripts in the same column significantly differ at $p<0.05$.

Table 3.

Effects of two aging methods and temperature on meat color of pork bellies from Berkshire and crossbred (LYD) pigs during aging

Items	Weeks	Breed		Temperature(℃)		Aging method	
		Berkshire	LYD	0	9	Hanging	Immersed in brine
L*	0	47.23±0.85^{Bb}	51.05±1.41^{Ab}	49.14±2.31^{b}	49.14±2.31^{b}	49.14±2.31^{b}	49.14±2.31^{c}
	1	47.40±5.46^{Bb}	52.49±4.78^{Ab}	51.64±4.44^{b}	47.87±6.37^{b}	46.50±3.03^{Bb}	52.72±5.96^{Ab}
	2	65.19±4.40^{a}	63.80±3.44^{a}	61.65±1.70^{Ba}	67.34±3.42^{Aa}	65.16±4.73^{a}	63.83±2.99^{a}
a*	0	18.59±0.45^{Aa}	12.66±0.44^{Ba}	15.62±3.13^{a}	15.62±3.13^{a}	15.62±3.13^{a}	15.62±3.13^{a}
	1	13.45±3.19^{b}	12.21±3.31^{a}	11.46±2.79^{Bb}	14.28±3.05^{Aa}	15.00±2.43^{Aa}	11.16±2.38^{Bb}
	2	8.35±2.01^{c}	8.74±1.63^{b}	9.16±1.64^{c}	7.94±1.81^{b}	8.30±1.22^{b}	8.80±2.27^{b}
b*	0	3.34±0.51^{Ab}	2.22±0.72^{Bb}	2.78±0.86^{b}	2.78±0.86^{b}	2.78±0.86^{b}	2.78±0.86^{b}
	1	2.08±0.99^{Bc}	4.75±3.13^{Aa}	3.77±3.51^{ab}	2.77±1.01^{b}	2.71±1.24^{b}	3.44±3.17^{ab}
	2	4.78±1.21^{a}	5.09±0.95^{a}	4.72±0.85^{a}	5.14±1.27^{a}	5.26±1.07^{a}	4.60±1.02^{a}
W	0	37.21±1.14^{Bb}	44.40±0.84^{Aa}	40.81±3.89^{b}	40.81±3.89^{b}	40.81±3.89^{b}	40.81±3.89^{b}
	1	41.16±7.30^{b}	38.24±9.22^{b}	40.32±9.34^{b}	39.55±7.18^{b}	38.38±4.81^{b}	42.39±10.09^{b}
	2	50.87±3.71^{a}	48.53±3.51^{a}	47.48±3.09^{Ba}	51.92±2.96^{Aa}	49.37±3.60^{a}	50.02±3.98^{a}
c	0	18.89±0.52^{Aa}	12.87±0.50^{Ba}	15.88±3.19^{a}	15.88±3.19^{a}	15.88±3.19^{a}	15.88±3.19^{a}
	1	13.63±3.28^{b}	13.57±2.64^{a}	12.59±2.42^{b}	14.57±3.09^{a}	15.27±2.58^{Aa}	12.08±2.33^{Bb}
	2	9.72±1.83^{c}	10.17±1.52^{b}	10.35±1.53^{c}	9.54±1.75^{b}	9.90±0.96^{b}	9.99±2.20^{b}
h	0	10.15±1.30^{b}	9.86±3.07^{c}	10.00±2.36^{b}	10.00±2.36^{b}	10.00±2.36^{b}	10.00±2.36^{c}
	1	8.55±2.70^{Bb}	21.98±16.39^{Ab}	18.18±17.64^{b}	11.07±3.68^{b}	9.81±3.43^{b}	16.87±14.95^{b}
	2	30.34±8.51^{a}	30.58±6.13^{a}	27.66±5.78^{a}	33.26±7.71^{a}	32.59±7.58^{a}	28.33±6.53^{a}

$^{A\text{-}B}$ Means with different superscripts in the same row and section significantly differ at $p<0.05$.

$^{a\text{-}c}$ Means with different superscripts in the same column significantly differ at $p<0.05$.

Table 4.

Effects of two aging methods and temperature on texture profile of pork bellies from Berkshire and crossbred (LYD) pigs during aging

Items	Weeks	Breed		Temperature(℃)		Aging method	
		Berkshire	LYD	0	9	Hanging	Immersed in brine
Hardness (kg)	0	0.44 ± 0.02^{Bb}	0.49 ± 0.02^{Aa}	0.46 ± 0.03^{a}	0.46 ± 0.03	0.46 ± 0.03	0.46 ± 0.03^{a}
	1	0.52 ± 0.04^{Aa}	0.41 ± 0.07^{Bb}	0.48 ± 0.07^{a}	0.47 ± 0.08	0.45 ± 0.08	0.49 ± 0.07^{a}
	2	0.47 ± 0.09^{Aab}	0.40 ± 0.03^{Bb}	0.41 ± 0.05^{b}	0.46 ± 0.09	0.47 ± 0.09^{A}	0.40 ± 0.03^{Bb}
Surface hardness(kg)	0	0.44 ± 0.02^{Bb}	0.46 ± 0.03^{Aa}	0.45 ± 0.02^{ab}	0.45 ± 0.02	0.45 ± 0.02	0.45 ± 0.02^{a}
	1	0.51 ± 0.05^{Aa}	0.41 ± 0.07^{Bb}	0.48 ± 0.07^{a}	0.45 ± 0.08	0.45 ± 0.08	0.47 ± 0.07^{a}
	2	0.47 ± 0.09^{Aab}	0.40 ± 0.03^{Bb}	0.41 ± 0.05^{b}	0.46 ± 0.09	0.47 ± 0.09^{A}	0.40 ± 0.03^{Bb}
Cohesiveness(%)	0	0.56 ± 0.01^{Aa}	0.52 ± 0.00^{B}	0.54 ± 0.02	0.54 ± 0.02^{a}	0.54 ± 0.02	0.54 ± 0.02^{a}
	1	0.55 ± 0.03^{a}	0.61 ± 0.24	0.66 ± 0.24	0.52 ± 0.04^{ab}	0.66 ± 0.24	0.52 ± 0.05^{ab}
	2	0.52 ± 0.03^{b}	0.52 ± 0.06	0.54 ± 0.05	0.50 ± 0.04^{b}	0.54 ± 0.05^{A}	0.49 ± 0.03^{Bb}
Springiness (mm)	0	1.00 ± 0.00	1.02 ± 0.03^{b}	1.01 ± 0.02^{b}	1.01 ± 0.02	1.01 ± 0.02^{b}	1.01 ± 0.02
	1	1.01 ± 0.02	1.19 ± 0.41^{a}	1.26 ± 0.47^{a}	1.01 ± 0.02	1.27 ± 0.47^{a}	1.00 ± 0.01
	2	1.01 ± 0.02	1.04 ± 0.06^{ab}	1.03 ± 0.06^{ab}	1.01 ± 0.02	1.04 ± 0.06^{b}	1.01 ± 0.02
Gumminess (kg)	0	0.24 ± 0.01^{Bb}	0.25 ± 0.01^{A}	0.25 ± 0.01^{b}	0.25 ± 0.01	0.25 ± 0.01	0.25 ± 0.01^{a}
	1	0.28 ± 0.03^{a}	0.26 ± 0.13	0.31 ± 0.11^{a}	0.24 ± 0.05	0.30 ± 0.12	0.26 ± 0.05^{a}
	2	0.25 ± 0.05^{Ab}	0.21 ± 0.03^{B}	0.22 ± 0.04^{b}	0.23 ± 0.06	0.26 ± 0.05^{A}	0.20 ± 0.02^{Bb}
Chewiness (kg,mm)	0	0.25 ± 0.01^{b}	0.26 ± 0.01	0.25 ± 0.01^{b}	0.25 ± 0.01	0.25 ± 0.01^{b}	0.25 ± 0.01^{a}
	1	0.28 ± 0.02^{a}	0.35 ± 0.34	0.44 ± 0.33^{a}	0.25 ± 0.05	0.42 ± 0.34^{a}	0.26 ± 0.05^{a}
	2	0.25 ± 0.05^{b}	0.22 ± 0.05	0.23 ± 0.05^{b}	0.23 ± 0.06	0.27 ± 0.05^{b}	0.20 ± 0.02^{b}
Adhesiveness(kgf)	0	0.06 ± 0.01^{Bb}	0.09 ± 0.02^{Aa}	0.08 ± 0.02	0.08 ± 0.02	0.08 ± 0.02	0.08 ± 0.02^{ab}
	1	0.09 ± 0.02^{Aa}	0.07 ± 0.02^{Bb}	0.08 ± 0.01	0.08 ± 0.03	0.08 ± 0.03	0.08 ± 0.01^{a}
	2	0.08 ± 0.01^{b}	0.07 ± 0.01^{b}	0.07 ± 0.01	0.07 ± 0.01	0.08 ± 0.01^{A}	0.07 ± 0.01^{Bb}

$^{A\text{-}B}$ Means with different superscripts in the same row and section significantly differ at $p<0.05$.

$^{a\text{-}c}$ Means with different superscripts in the same column significantly differ at $p<0.05$.

Table 5. Effects of two aging methods and temperature on amino acid composition of pork bellies from Berkshire and crossbred (LYD) pigs during aging

Free amino acid	Weeks	Breed		Temperature(℃)		Aging method	
		Berkshire	LYD	0	9	Hanging	Immersed in brine
Taurine	0	5.24±0.00^{Ba}	7.86±0.00^{Aa}	6.55±1.51	6.55±1.51^{a}	6.55±1.51^{a}	6.55±1.51
	1	4.40±0.89^{Bab}	5.94±1.15^{Ab}	5.62±1.51	4.73±0.95^{ab}	5.00±0.75^{ab}	5.34±1.74
	2	3.85±0.82^{Bb}	5.32±0.20^{Ab}	4.83±0.94	4.34±1.06^{b}	4.44±1.14^{b}	4.74±0.89
Aspartic acid	0	1.36±0.00^{Aa}	1.25±0.00^{Ba}	1.31±0.06^{a}	1.31±0.06^{a}	1.31±0.06^{a}	1.31±0.06^{a}
	1	0.63±0.23^{b}	0.72±0.28^{b}	0.86±0.19^{Ab}	0.49±0.09^{Bb}	0.64±0.26^{b}	0.71±0.25^{b}
	2	0.36±0.16^{c}	0.38±0.31^{b}	0.49±0.20^{c}	0.24±0.20^{c}	0.36±0.08^{c}	0.37±0.34^{b}
Threonine	0	0.81±0.00^{Bc}	0.99±0.00^{Ac}	0.90±0.10^{c}	0.90±0.10^{c}	0.90±0.10^{c}	0.90±0.10^{c}
	1	1.36±0.20^{b}	1.48±0.23^{b}	1.25±0.09^{Bb}	1.59±0.14^{Ab}	1.42±0.26^{b}	1.42±0.19^{b}
	2	2.01±0.44^{a}	2.03±0.34^{a}	1.71±0.12^{Ba}	2.33±0.20^{Aa}	2.13±0.43^{a}	1.92±0.31^{a}
Serine	0	0.76±0.00^{Bc}	0.84±0.00^{Ac}	0.80±0.05^{c}	0.80±0.05^{c}	0.80±0.05^{c}	0.80±0.05^{c}
	1	1.54±0.11^{b}	1.66±0.23^{b}	1.49±0.09^{b}	1.71±0.18^{b}	1.55±0.17^{b}	1.65±0.20^{b}
	2	1.97±0.17^{a}	2.02±0.14^{a}	1.92±0.11^{a}	2.07±0.15^{a}	2.01±0.13^{a}	1.98±0.18^{a}
Asparagine	0	0.28±0.00^{b}	0.28±0.00^{c}	0.28±0.00^{c}	0.28±0.00^{b}	0.28±0.00^{b}	0.28±0.00^{c}
	1	0.62±0.09^{a}	0.66±0.09^{b}	0.57±0.06^{Bb}	0.71±0.04^{Aa}	0.62±0.09^{a}	0.66±0.09^{b}
	2	0.69±0.12^{a}	0.84±0.13^{a}	0.73±0.02^{a}	0.80±0.21^{a}	0.72±0.16^{a}	0.82±0.12^{a}
Glutamic acid	0	1.43±0.00^{Ac}	1.39±0.00^{Bb}	1.41±0.02^{b}	1.41±0.02^{c}	1.41±0.02^{b}	1.41±0.02^{c}
	1	2.85±0.09^{b}	2.44±0.44^{b}	2.47±0.47^{a}	2.82±0.11^{b}	2.70±0.39^{ab}	2.58±0.39^{b}
	2	4.22±1.15^{a}	3.79±1.39^{a}	3.01±0.59^{Ba}	5.01±0.63^{Aa}	4.20±1.64^{a}	3.82±0.78^{a}
Glycine	0	2.06±0.00^{A}	1.75±0.00^{Bb}	1.91±0.18	1.91±0.18^{b}	1.91±0.18^{b}	1.91±0.18^{b}
	1	2.30±0.32	2.17±0.26^{a}	2.04±0.25^{B}	2.44±0.12^{Aa}	2.37±0.23^{a}	2.11±0.29^{ab}
	2	2.41±0.32	2.33±0.12^{a}	2.20±0.16^{B}	2.54±0.14^{Aa}	2.30±0.25^{a}	2.44±0.22^{a}
Alanine	0	4.29±0.00^{Bb}	5.32±0.00^{Ab}	4.81±0.59	4.81±0.59^{b}	4.81±0.59^{b}	4.81±0.59^{b}
	1	5.31±0.42^{Ba}	6.39±0.45^{Aa}	5.55±0.62	6.15±0.74^{a}	5.98±0.60^{a}	5.72±0.88^{ab}
	2	5.67±0.51^{Ba}	6.67±0.36^{Aa}	5.82±0.68	6.52±0.53^{a}	6.20±0.86^{a}	6.14±0.56^{a}
Citrulline	0	0.25±0.00^{Bc}	0.44±0.00^{Ab}	0.35±0.11^{b}	0.35±0.11^{b}	0.35±0.11^{c}	0.35±0.11^{b}
	1	0.54±0.26^{b}	0.47±0.19^{b}	0.52±0.21^{b}	0.50±0.25^{b}	0.63±0.18^{b}	0.39±0.19^{b}
	2	0.88±0.08^{a}	0.85±0.05^{a}	0.83±0.07^{a}	0.90±0.03^{a}	0.90±0.06^{a}	0.83±0.06^{a}
Valine	0	0.96±0.00^{Bc}	0.97±0.00^{Ac}	0.97±0.01^{c}	0.97±0.01^{c}	0.97±0.01^{c}	0.97±0.01^{c}
	1	1.69±0.13^{b}	1.72±0.26^{b}	1.57±0.13^{Bb}	1.85±0.12^{Ab}	1.71±0.27^{b}	1.70±0.11^{b}
	2	2.50±0.54^{a}	2.42±0.48^{a}	2.07±0.18^{Ba}	2.84±0.31^{Aa}	2.58±0.62^{a}	2.33±0.32^{a}
Cystine	0	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{b}
	1	0.14±0.22^{b}	0.16±0.20^{ab}	0.27±0.22^{ab}	0.04±0.07^{b}	0.13±0.22^{b}	0.17±0.20^{ab}
	2	0.47±0.21^{a}	0.39±0.28^{a}	0.42±0.31^{a}	0.44±0.18^{a}	0.50±0.16^{a}	0.36±0.29^{a}
Methionine	0	0.40±0.00^{c}	0.40±0.00^{b}	0.40±0.00^{b}	0.40±0.00^{c}	0.40±0.00^{b}	0.40±0.00^{b}
	1	0.96±0.08^{b}	1.04±0.19^{a}	1.03±0.19^{a}	0.96±0.08^{b}	0.93±0.07^{b}	1.07±0.17^{a}
	2	1.62±0.48^{a}	1.26±0.43^{a}	1.20±0.34^{a}	1.68±0.50^{a}	1.65±0.60^{a}	1.23±0.19^{a}
Isoleucine	0	0.60±0.00^{Ac}	0.56±0.00^{Bc}	0.58±0.02^{c}	0.58±0.02^{c}	0.58±0.02^{c}	0.58±0.02^{c}
	1	1.26±0.09^{b}	1.17±0.13^{b}	1.15±0.13^{b}	1.28±0.05^{b}	1.18±0.17^{b}	1.24±0.04^{b}
	2	2.00±0.39^{a}	1.69±0.45^{a}	1.59±0.30^{a}	2.10±0.40^{a}	2.01±0.58^{a}	1.69±0.13^{a}
Leucine	0	1.16±0.00^{Ac}	1.11±0.00^{Bc}	1.14±0.03^{c}	1.14±0.03^{c}	1.14±0.03^{c}	1.14±0.03^{c}
	1	2.35±0.17^{b}	2.15±0.27^{b}	2.09±0.23^{b}	2.41±0.12^{b}	2.25±0.32^{b}	2.25±0.17^{b}
	2	3.47±0.69^{a}	3.14±0.75^{a}	2.80±0.37^{Ba}	3.82±0.54^{Aa}	3.50±0.97^{a}	3.12±0.29^{a}
Tyrosine	0	0.79±0.00^{B}	0.83±0.00^{A}	0.81±0.02^{b}	0.81±0.02^{a}	0.81±0.02	0.81±0.02
	1	0.89±0.68	0.82±0.41	1.31±0.22^{Aa}	0.40±0.20^{Bb}	0.76±0.54	0.96±0.57
	2	1.08±0.70	0.95±0.53	1.45±0.37^{Aa}	0.58±0.35^{Bab}	1.25±0.53	0.78±0.58
Phenylalanine	0	1.14±0.00^{Bc}	1.18±0.00^{Ab}	1.16±0.02^{c}	1.16±0.02^{c}	1.16±0.02^{c}	1.16±0.02^{c}
	1	1.78±0.09^{b}	1.66±0.22^{b}	1.64±0.20^{b}	1.80±0.09^{b}	1.76±0.13^{b}	1.68±0.21^{b}
	2	2.42±0.44^{a}	2.42±0.49^{a}	2.10±0.28^{Ba}	2.74±0.29^{Aa}	2.47±0.61^{a}	2.38±0.25^{a}
Lysine	0	1.09±0.00^{B}	1.18±0.00^{A}	1.14±0.05^{c}	1.14±0.05^{ab}	1.14±0.05	1.14±0.05
	1	1.35±0.64	1.73±0.50	1.78±0.12^{b}	1.30±0.77^{a}	1.34±0.67	1.75±0.44
	2	1.25±1.09	1.51±0.97	2.26±0.13^{Aa}	0.50±0.30^{Bb}	1.30±1.13	1.46±0.94
Histidine	0	0.21±0.00^{Bc}	0.26±0.00^{Ab}	0.24±0.03^{c}	0.24±0.03^{c}	0.24±0.03^{c}	0.24±0.03^{c}
	1	0.53±0.07^{b}	0.55±0.10^{a}	0.47±0.02^{Bb}	0.61±0.04^{Ab}	0.55±0.10^{b}	0.53±0.07^{b}
	2	0.71±0.15^{a}	0.69±0.12^{a}	0.59±0.03^{a}	0.81±0.07^{a}	0.74±0.15^{a}	0.66±0.11^{a}
Carnosine	0	71.02±0.00^{Aa}	67.63±0.00^{Ba}	69.32±1.96^{a}	69.32±1.96^{a}	69.32±1.96^{a}	69.32±1.96^{a}
	1	64.32±2.02^{b}	61.27±2.28^{b}	63.28±2.50^{b}	62.31±2.93^{b}	62.70±1.97^{b}	62.89±3.40^{b}
	2	55.48±2.49^{c}	52.17±4.48^{c}	55.39±0.89^{c}	52.26±5.13^{c}	52.33±4.87^{c}	55.32±1.99^{c}
Arginine	0	0.80±0.00^{B}	0.88±0.00^{A}	0.84±0.05^{c}	0.84±0.05	0.84±0.05	0.84±0.05^{b}
	1	1.45±0.27	1.54±0.43	1.54±0.12^{b}	1.45±0.49	1.27±0.29	1.72±0.22^{a}
	2	1.35±0.77	1.34±0.75	1.90±0.07^{Aa}	0.80±0.58^{B}	1.37±0.72	1.32±0.79^{ab}
EAA	0	7.16±0.00^{Bc}	7.53±0.00^{Ac}	7.35±0.21^{c}	7.35±0.21^{c}	7.35±0.21^{c}	7.35±0.21^{c}
	1	12.72±0.49^{b}	13.03±1.31^{b}	12.51±0.65^{b}	13.24±1.11^{b}	12.40±0.47^{b}	13.35±1.09^{b}

	2	17.33±2.54^{a}	16.49±1.53^{a}	16.21±1.41^{a}	17.60±2.44^{a}	17.73±2.58^{a}	16.08±0.91^{a}
	0	1.43±0.00^{Ac}	1.39±0.00^{Bb}	1.41±0.02^{b}	1.41±0.02^{c}	1.41±0.02^{b}	1.41±0.02^{c}
FAA	1	2.85±0.09^{Ab}	2.44±0.04^{Bb}	2.47±0.17^{Ba}	2.82±0.11^{Ab}	2.70±0.39^{ab}	2.58±0.39^{b}
	2	4.22±0.15^{Aa}	3.79±0.39^{Ba}	3.01±0.59^{Ba}	5.01±0.63^{Aa}	4.20±1.64^{a}	3.82±0.78^{a}
	0	7.92±0.00^{Bc}	8.89±0.00^{Ac}	8.41±0.56^{c}	8.41±0.56^{c}	8.41±0.56^{b}	8.41±0.56^{b}
STAA	1	10.51±0.79^{b}	11.70±1.14^{b}	10.33±0.58^{Bb}	11.88±0.96^{Ab}	11.32±1.05^{a}	10.90±1.29^{a}
	2	12.07±1.25^{a}	13.05±0.88^{a}	11.65±0.75^{Ba}	13.46±0.50^{Aa}	12.64±1.38^{a}	12.47±1.03^{a}
	0	0.40±0.00^{c}	0.40±0.00^{b}	0.40±0.00^{b}	0.40±0.00^{c}	0.40±0.00^{c}	0.40±0.00^{b}
SAA	1	1.10±0.25^{b}	1.20±0.38^{a}	1.30±0.37^{a}	1.00±0.15^{b}	1.06±0.25^{b}	1.24±0.36^{a}
	2	2.09±0.50^{a}	1.65±0.66^{a}	1.62±0.61^{a}	2.12±0.53^{a}	2.16±0.61^{a}	1.58±0.47^{a}
	0	1.93±0.00^{Bb}	2.01±0.00^{Ac}	1.97±0.05^{b}	1.97±0.05^{b}	1.97±0.05^{b}	1.97±0.05^{b}
AAA	1	2.67±0.71^{ab}	2.49±0.23^{b}	2.95±0.40^{Aa}	2.20±0.20^{Bb}	2.52±0.43^{b}	2.63±0.62^{ab}
	2	3.50±0.75^{a}	3.37±0.42^{a}	3.55±0.55^{a}	3.32±0.64^{a}	3.72±0.51^{a}	3.15±0.51^{a}
	0	4.90±0.00^{Bc}	5.08±0.00^{Ac}	4.99±0.10^{c}	4.99±0.10^{c}	4.99±0.10^{c}	4.99±0.10^{c}
BAA	1	8.55±0.71^{b}	8.49±0.62^{b}	8.70±0.65^{b}	8.35±0.62^{b}	8.16±0.28^{b}	8.89±0.68^{b}
	2	11.67±2.31^{a}	10.76±0.98^{a}	10.89±1.25^{a}	11.54±2.24^{a}	12.07±2.06^{a}	10.37±0.83^{a}

[1)] EAA (essential amino acid : Threonine, Valine, Methionine, Isoleucine, Leucine, Phenylalanine, Histidine, Lysine, Arginine), FAA (flavorous amino acid : Glutamic acid), STAA (sweet taste amino acid : Threonine, Serine, Glycine, Alanine), SAA (sulfur-containing amino acid : Cysteine, Methionine), AAA (aromatic amino acid : Tyrosine, Phenylalanine), BAA (bitter amino acid : Valine, Methionine, Isoleucine, Tyrosine, Phenylalanine, Histidine, Arginine).

$^{A\text{-}B}$ Means with different superscripts in the same row and section significantly differ at $p<0.05$.

$^{a\text{-}c}$ Means with different superscripts in the same column significantly differ at $p<0.05$.