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ARTICLE

Meat Quality Changes in Aged Pork Loin using Jeju Volcanic Scoria Earthenware

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Abstract This study aimed to investigate changes in the quality of meat aged using Jeju scoria earthenware. Water-holding properties, pH, color, tenderization, fatty acid composition, and free amino acid characteristics of aged pork loin were evaluated to determine the effects of wet and dry (normal and Jeju Scoria) aging methods and aging time (0, 10, 20, 30, and 40 days) on meat quality. The aging methods altered pH and CIE L* after 10 days of aging. However, the aging method did not alter the pH and CIE L* of the aged pork loin after 10 days of aging. The shear force was significantly lower in the Scoria aging method than in the wet aging method after 10 and 20 days of aging. Both the normal and Scoria aging methods increased aging loss compared to the wet aging method, which could be attributed to longer air exposure times of the two non-packaged aging methods than in the packaged aging method. The scoria aging method had significantly higher contents and ratios of saturated (SFA) to mono-unsaturated fatty acids but lower ratios of poly-unsaturated fatty acids to SFA than the wet aging method. The content of most free amino acids significantly increased with aging time, especially those related to the sweet, and umami categories. In summary, this study suggests that the Scoria aging method provides positive aspects of eating quality, such as improvement of meat tenderness and taste, including umami, with minimum changes in the overall meat quality.

Keywords meat quality, aged pork, Jeju volcanic scoria earthenware

Introduction

Meat quality is generally characterized by tenderness, juiciness, flavor, and color (Smith, 1976), and it is also generally accepted that aging is considered one of the best ways to improve meat quality (Ngapo et al., 2013). In addition, aging is a centuries-old practice used to preserve meat, involving biochemical muscle metabolism and enzymatic actions that improve consumer palatability, such as tenderness and flavor of meat (Pearson, 1986). Meat aging is categorized as dry aging and wet aging according to the aging conditions. Dry aging, in which unpackaged meat is exposed to air, has been reported to improve palatability and flavor characteristics but leads to considerable trim loss and poses hygiene-related risk in the meat industry and distribution (Cho et al., 2018; Kim et al., 2018). Dry aging is an ancient process, which is regaining interest nowadays from high-end consumers desiring meat with the unique flavor characteristics and tenderness of aged meat, especially in the beef industry (Dashdorj et al., 2016). Wet aging involves the aging of packaged meat at a low temperature to increase production yield and reduce oxidative meat deterioration (Hwang et al., 2018). In the context of mass production of meat and food safety, wet aging is a more suitable meat aging application, although recent consumers tend to prefer traditional dry aging (Kim et al., 2019).

Scoria is a vesicular volcanic rock, typically dark in color, which is a low-priced natural resource that is widely distributed in the parasitic volcanic zone (Lee et al., 2018). Most scoria is mainly used as a raw material in concrete, structural fill, pavement material, and construction materials as a light-weight aggregate, infiltration barrier, and underground void filler (Anwar Hossain, 2004).

However, there are few studies on developing meat products and applications on meat products using raw Jeju scoria or Jeju scoria-applied products. We aimed to develop meat products that reflect the unique geographical and historical characteristics which may contribute to competitive advantage and economic value added in meat products and meat industry by using Jeju scoria earthenware.

Therefore, we investigated whether dry aging with Jeju scoria earthenware affects meat quality. The present study evaluated the effects of dry and wet aging methods and aging time on meat quality—the water-holding properties, meat pH, color, tenderization, fatty acid composition, and free amino acid (FAA) characteristics of aged pork loin.

Materials and Methods

Sample preparation

All pork loin cuts (*M. longissimus thoracis et lumborum,* crossbreed of Landrace×Yorkshire×Duroc) were purchased randomly at 24 h post mortem from a Jeju local meat supplier. The pigs utilized in this study were within an average slaughter age range of 170 to 180 days. Furthermore, gender and grade distinctions were not taken into consideration, and commercially available products were used, explicitly excluding sow and boar. The pork loins procured for the experiment were left intact and underwent the aging process without any cutting.

Aging method

Visible fat and connective tissue were trimmed off. Aging was performed as detailed in Table 1. We used normal Korean earthenware (normal) and Jeju volcanic scoria earthenware (scoria) to age pork loins via dry aging method. Pork loins in the normal and scoria aging method groups were stored and analyzed after 10 days, 20 days, 30 days, and 40 days (only scoria) at 2℃ to 4℃. For wet aging, pork loins were vacuum-packed and stored at 2℃ to 4℃ for 10 days, 20 days, and 30 days and used after removing excess fat and connective tissue. The normal and Scoria earthenware were produced in JeJu Onggi Village, Hangyeong-myeon. The scoria earthenware was made using the traditional Jeju earthenware-making method by uniformly applying a 7:3 mixture of Jeju-scoria powder and water to the inner and outer surfaces of the earthenware before the firing step. Both normal and scoria earthenware were glazed at 1,300℃ before use in this study.

Monitoring temperature and humidity

We recorded the core temperature of pork loins, as well as the temperature and humidity in the refrigerator's chamber and

Table 1. Conditions for meat aging

Variable	Jeju scoria earthenware	Normal Korean earthenware	Wet-aging
Aging condition	Aging in air flow type refrigerator (2℃ to 4℃)		Aging in direct cooling type refrigerator (2℃ to 4℃)
Aging period	10, 20, 30, and 40 d		
Packaging	Non packaged		Vacuum packaged

in the normal and scoria earthenware, using a multi-use temperature and humidity data logger (RC-61, Elitech Technology, San Jose, CA, USA) during the aging period. The temperature of the refrigerator's chamber was controlled at an average of 0.7℃ during the aging period. The minimum and maximum temperatures of the refrigerator's chamber were –1.7℃ and 4.0℃, respectively. The average RH in the refrigerator was 74.5% and was maintained between 65% and 85% during the aging period. Aging conditions inside both normal and scoria earthenware were controlled at a temperature of 0.5℃ and RH of 80%–85%. The core temperature of the loins was monitored during the aging period; the average value was 0.7℃.

pH and color

After completion of the aging period, the loin pH was measured using a spear-type pH meter (206-pH2, Testo, Lenzkirch, Germany). The meat color was measured after exposing the surface of the meat to air for 30 min using a Minolta chromameter (CR-300, Konica Minolta, Osaka, Japan). The average of quintuplicated measurements was recorded, and the results were expressed as CIE L*, CIE a*, and CIE b*.

Water-holding properties

Aging loss

Aging loss was expressed as the percentage difference between initial and final weights relative to the initial weight.

Cooking loss

After the aging period, the loins were cut into a rectangular shape (2 cm×4 cm×6 cm), tightly wrapped in a polyethylene bag, and then heated to 85℃ in a water bath (KMC-1205W1, Vision, Mukilteo, WA, USA). When the core temperature reached 75℃, the samples were cooled in cold water for 20 min. After removing the surface moisture, the cooking loss was calculated as the percentage difference between the initial and final weights relative to the initial weight.

Shear force

Three-centimeter-thick loins were tightly wrapped in a polyethylene bag and heated to 85℃ in a water bath (KMC-1205W1, Vision). When the core temperature of the loins reached 80℃, the samples were cooled in cold water for 20 min. After the cooling step, a 13-mm diameter steel borer (Cork borer No.6, Sigma-Aldrich, St. Louis, MO, USA) was used to collect cylindrical samples, which were first cut into a thickness of 1 cm in the direction perpendicular to the muscle fiber and then sheared using a texture analyzer (Texture Analyzer CT3, Brookfield, New York, NY, USA). The shear force of the sample—representing its toughness—was expressed in Newton (N) and corresponded to the maximum force applied by the machine to shear the sample. The conditions for measuring the shear force using an Instron machine are as follows: the target value is set at 20.0 mm, the trigger load is 10 g, and the test is conducted at a speed of 1.00 mm/s. The measurement involves a single cycle, using a TA52 probe and a TASBA fixture.

Texture profile analysis (TPA)

TPA was performed using a Texture Analyzer (CT3, Brookfield). TPA measurements were hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess, and chewiness. The TPA test is based on simulating the biting action of the mouth using a two-cycle compression series (Barbut, 2015). After cutting the pork loin into 3-cm-thick pieces, the samples were tightly wrapped in a polyethylene bag and cooked at 85℃ in a water bath. When the core temperature of the samples reached 75℃, the samples were cooled in cold water for 20 min. After cooling, six subsamples of 2.5 cm×2.5 cm×2.5 cm size were prepared and subjected to TPA. The probe moved downwards at a constant speed of 2.0 mm/s (pre-test), 1.0 mm/s (test), and 4.5 mm/s (post-test). The probe continued downward until it penetrated a predetermined percentage of the sample thickness (75%), retracted to the initial point of contact with the sample, and stopped for a set time period (2 s) before the initiation of the second compression cycle.

Fatty acid composition

Gas chromatography (GC) analysis was performed using a GC–Flame Ionization Detector. The GC-column was an SPR®-2560 (Sigma-Aldrich) of 100 m length, 0.25 mm internal diameter, and 0.2 μm film thickness. Twenty-five milligrams of sample were extracted, methylated by adding 14% of BF_3-methanol, and diluted with 1 mL of isooctane. The operating conditions were as follows: a nitrogen gas flow rate of 0.8 mL/min, the flame ionization detector set at 285℃, the injector set at 240℃, and a split ratio of 100:1. The individual fatty acid peaks were identified by comparing the retention times with known mixtures of standard fatty acids (Supelco 37 Component FAME Mix, Sigma-Aldrich) run under the same operating conditions.

Free amino acid (FAA) analysis

Two hundred milligrams of the sample were mixed with 30 mL of 6 N HCl, hydrolyzed at 130℃ for 24 hours, and filtered through a 0.45 μm aqueous syringe filter. After mixing 20 μL of the hydrolyzed sample with 20 μL of diluent, FAA analysis was performed on the mixture using GC with flame ionization detection. The column was a ZB-AAA (Phenomenex, Torrance, CA, USA), 10 m×0.25 mm. The carrier gas was nitrogen, 1.5 mL/min; the injector temperature was 250℃; the detector temperature was 320℃; and the split ratio was 5:1. Identification and quantification of the standard amino acid solution (Phenomenex, Aschaffenburg, Germany) were based on retention time and peak area integration of the reference amino acids.

Statistical analysis

A completely randomized design was adopted to analyze the main effects of the aging method and aging period. The significance of the model was determined by analysis of variance (ANOVA), and Duncan's multiple range test was performed when the main factors were significant ($p<0.05$). All statistical analyses were performed using SAS software v.9.4 (SAS Institute, Cary, NC, USA).

Results and Discussion

The degree of spoilage in the samples, excluding the aging of the volcanic scoria, became pronounced after a period of 30 days, rendering them unsuitable for experimental use. Furthermore, to identify distinct aspects of aging volcanic scoria, we extended the aging process up to 40 days.

pH and color

Table 2 shows the pH and color changes in pork loin with the three aging methods during the indicated aging periods. The pH after 10 days of aging was significantly higher with the wet aging method than with the other two aging methods. While there was no significant difference between the pH after 40 days of aging and the initial pH with the normal aging method, the pH after 40 days of aging was higher with this method than the other groups. For both dry aging methods unlike the wet aging method, the pH tended to increase after 10 days of aging. With the wet aging method, the pH value first increased and then decreased over 10 days of aging. The increase in the pH of meat during the aging process may be due to the formation of nitrogen compounds by proteolysis of endogenous proteins (Aksu et al., 2005). In this study, the scoria aging method showed the lowest pH on the 10th day and the highest pH on the 40th day of aging. It is generally accepted that meat with a low pH value (<5.2) is pale, soft, and exudative (PSE), whereas meat with a high ultimate pH (>6.2) is dark, firm, and dry (DFD). In

Table 2. pH and meat color of aged pork loin by aging methods during the aging period

Variable	0 d	10 d	20 d	30 d	40 d	LS
pH						
Wet	5.41^{b}±0.04	5.57^{Aa}±0.06	5.51^{a}±0.06	5.48^{ab}±0.02	NA	*
Normal	5.41±0.04	5.29^{B}±0.06	5.34±0.15	5.49±0.35	NA	NS
Scoria	5.41^{b}±0.04	5.33^{Bb}±0.15	5.41^{b}±0.14	5.44^{b}±0.10	5.77^{a}±0.10	***
LS	NS	*	NS	NS	-	
CIE L*						
Wet	50.64^{a}±2.67	45.87^{Cb}±2.32	49.43^{a}±2.50	49.96^{a}±2.76	NA	**
Normal	50.64±2.67	49.61^{B}±3.22	51.61±2.56	51.13±4.15	NA	NS
Scoria	50.64^{ab}±2.67	51.89^{Aa}±2.64	51.40^{ab}±3.30	49.49^{b}±4.10	52.13^{a}±2.75	*
LS	NS	***	NS	NS	-	
CIE a*						
Wet	6.17±1.86	6.52±1.14	6.71^{AB}±0.96	6.67±0.85	NA	NS
Normal	6.17±1.86	7.04±1.13	6.24^{B}±0.79	7.42±2.20	NA	NS
Scoria	6.17±1.86	6.65±1.35	7.50^{A}±1.23	6.90±1.68	7.56±2.02	NS
LS	NS	NS	**	NS	-	
CIE b*						
Wet	2.44^{a}±0.91	1.52^{Bb}±0.70	1.99^{Cab}±0.95	2.68^{Ba}±0.48	NA	*
Normal	2.44^{b}±0.91	2.52^{Ab}±1.05	2.98^{Bb}±1.07	5.18^{Aa}±1.82	NA	***
Scoria	2.44^{b}±0.91	3.21^{Aab}±0.93	4.05^{Aa}±1.29	3.83^{Ba}±1.57	3.52^{a}±1.11	**
LS	NS	***	***	**	-	

Mean±SD.
$^{A–C}$ Means with different superscripts in the same column significantly differ.
^{a,b} Means with different superscripts in the same row significantly differ.
* p<0.05; ** p<0.01; *** p<0.001.
Wet, wet-aging; Normal, dry-aging in normal Korean earthenware; Scoria, dry-aging in Jeju scoria earthenware; LS, level of significance; NS, not significant; NA, not available.

summary, none of the aging methods showed any abnormal pH (<5.2 or >6.2) during the aging period. Meat color is closely related to its water-holding capacity (WHC) and pH (Hughes et al., 2014; Tornberg, 1996). Muscles with high pH have a higher WHC, larger muscle fiber diameters, and longer distances between myofilaments, allowing more transmitted light into the interior structure and causing the meat to appear dark (Hughes et al., 2017; Swatland, 2008).

In this study, CIE L* and CIE b* had the lowest values ($p<0.05$) on the 10th day of aging with the wet aging method compared to the two dry aging methods. In contrast, CIE a* showed no significant difference during the 10-day aging period with any of the methods.

However, with the normal aging method, only CIE b* showed the highest value on the 30th day of aging; there were no differences in CIE L* and CIE a* during the 30-day aging period. Thus, the scoria aging method exhibited the highest CIE L* after 10 days of aging. However, the normal aging method showed a significantly lower CIE a* than other two aging methods after 20 days of aging. There were significant differences in the CIE b* for the three aging methods at 10, 20, and 30 days of aging. The highest value of CIE b* was observed on the 10th day of aging with the wet aging method, on the 20th day of aging with scoria aging method, and on the 30th day of aging with the normal aging method.

Aging loss, cooking loss, and shear force

The results of aging loss, cooking loss, and shear force of aged meat by the wet, normal, and scoria aging methods are shown in Table 3. Aging loss was significantly higher with the normal and scoria aging methods (both non-packaged aging methods) than with the wet aging method during the aging period. However, unlike the normal aging method, aging time did

Table 3. Aging loss, cooking loss, and shear force of aged pork loin by aging methods during the aging period

Variable	0 d	10 d	20 d	30 d	40 d	LS
Aging loss (%)						
Wet	-	0.83^{Bb}±0.17	2.14^{Bab}±0.72	2.99^{Ba}±1.03	NA	*
Normal	-	4.17^{Ab}±0.03	8.59^{Aa}±3.31	10.16^{Aa}±2.40	NA	*
Scoria	-	4.92^{A}±1.34	7.50^{A}±1.13	7.58^{A}±2.15	9.53±4.63	NS
LS	-	**	*	**	-	
Cooking loss (%)						
Wet	21.03^{b}±0.40	20.84^{b}±2.86	23.34^{ab}±2.55	25.95^{a}±0.59	NA	*
Normal	21.03±0.40	22.27±2.36	25.79±3.15	24.33±4.58	NA	NS
Scoria	21.03^{ab}±0.40	18.05^{b}±2.68	22.98^{a}±3.84	24.64^{a}±2.94	21.38^{ab}±3.23	**
LS	NS	NS	NS	NS	-	
Shear force (kg)						
Wet	9.31^{a}±2.43	5.54^{Ab}±1.33	5.53^{Ab}±1.52	4.69^{c}±0.95	NA	***
Normal	9.31^{a}±2.43	5.19^{Ab}±0.89	5.93^{Ab}±1.90	4.20^{c}±1.21	NA	***
Scoria	9.31^{a}±2.43	4.44^{Bb}±0.83	4.52^{Bb}±1.07	4.27^{b}±0.94	3.34^{c}±0.72	***
LS	NS	***	***	NS	-	

Mean±SD.
A,B Means with different superscripts in the same column significantly differ.
a–c Means with different superscripts in the same row significantly differ.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.
Wet, wet-aging; Normal, dry-aging in normal Korean earthenware; Scoria, dry-aging in Jeju scoria earthenware; LS, level of significance; NA, not available; NS, not significant.

not affect aging loss in the scoria aging method. Previously, several studies had shown that in both wet and dry aging, meat tenderness is improved by proteolysis of the myofibrillar protein and degradation of structural proteins, and the meat flavor is developed by changing the concentrations of peptides and FAAs (Aaslyng and Meinert, 2017; Dashdorj et al., 2016; Laville et al., 2009). Cooking loss also increased with the aging time, although there were no differences between the aging methods. The shear force decreased with the aging time in all three aging methods. However, after 10 days of aging, the scoria aging method showed a significantly lower shear force value than the other two aging methods. In this study, the aging process showed improved meat tenderness during the aging period in all three aging methods. In particular, the tenderness was enhanced to a greater extent over 10 and 20 days of aging with the scoria aging method than with the other two aging methods. In addition, after 40 days of aging, the shear force decreased by 64.1% compared to the shear force on the 0th day of aging with the scoria aging method.

Texture profile analysis (TPA)

TPA tests are widely applied to evaluate the texture of meat and meat products. The TPA parameters include hardness, springiness, adhesiveness and cohesiveness, gumminess, chewiness, and resilience (Novaković and Tomašević, 2017). This study analyzed TPA to test the effects of the aging time and aging method (Table 4). The hardness increased with the aging time in the wet aging method. In contrast, the hardness in the normal and scoria aging methods showed a tendency to first increase with the aging time and then decrease.

After 30 days of aging, the hardness value was the lowest with the normal method compared to the other two aging methods. Increased WHC, as measured by the swelling ratio in cooked meat, is known to influence the tenderness of cooked beef (Gault, 1985). Our results showed that WHC tended to decrease with aging, indicating that the increase in hardness with aging might be due to a decrease in the WHC of the aged meat. In this study, WHC decreased in all three aging methods, resulting in increased aging loss and hardness during the aging period. Adhesiveness showed a significant difference with the aging time only in the scoria aging method, and in the 40 days of aging, adhesiveness in the scoria aging method was not different from that on the 0th day of aging. The adhesiveness was the lowest on the 10th and 20th days of aging with the normal aging method compared to the other two aging methods. The resilience of the wet aging method decreased after 10 days of aging, whereas that of the scoria aging method showed the highest value at 40 days of aging. After 20 days of aging, the resilience of the normal aging method was the highest of all three aging methods. Cohesiveness tended to decrease after 10 days of aging in the normal and scoria aging methods, while it was the highest on the 30th day of aging in the normal aging method compared to the other two methods. The scoria aging method showed the lowest springiness on the 20th day of aging compared to the other aging methods. However, there was no difference in gumminess and chewiness during the aging period in any of the three aging methods.

Fatty acid composition

The results of fatty acid composition analyses of the wet, normal, and scoria aging methods with aging time are shown in Table 5. In this study, the major fatty acids—C18:1 (oleic acid), C16:0 (palmitic acid), C18:0 (stearic acid), and C18:2n-6 (linoleic acid)—were the most abundant fatty acids in the experimental groups. The content of C16:0 and C18:0, which are saturated fatty acids (SFA), was significantly higher in the normal and scoria aging methods than in the wet aging method. In the case of unsaturated fatty acids (UFA), the content and ratio of C18:1 were significantly higher in the normal and scoria aging methods than in the wet aging method. However, while the content of C18:2n-6 was significantly higher in the normal and

Table 4. Texture profile analysis on aged pork loin by aging methods during the aging period

Variable	0 d	10 d	20 d	30 d	40 d	LS
Hardness						
Wet	2,487.40^{c}±873.64	3,332.87^{b}±681.75	3,446.20^{ab}±1,052.25	3,873.31^{Aa}±574.27	NA	***
Normal	2,487.40^{c}±873.64	3,706.65^{a}±674.42	3,300.29^{ab}±830.20	3,179.10^{Cb}±757.39	NA	***
Scoria	2,487.40^{c}±873.64	3,395.00^{a}±606.49	3,646.86^{a}±860.97	3,519.47^{Ba}±794.72	2,885.92^{b}±732.40	***
LS	NS	NS	NS	***	-	
Adhesiveness						
Wet	1.13±0.85	1.79^{AB}±1.39	2.14^{A}±2.02	1.70±1.17	NA	NS
Normal	1.13±0.85	1.17^{B}±0.56	1.12^{B}±0.94	1.01±0.54	NA	NS
Scoria	1.13^{b}±0.85	2.04^{Aa}±1.56	1.46^{ABab}±1.53	1.32^{b}±1.36	1.28^{b}±1.25	**
LS	NS	*	*	NS	-	
Resilience						
Wet	0.12^{a}±0.03	0.10^{b}±0.02	0.10^{Bb}±0.02	0.10^{Bb}±0.02	NA	*
Normal	0.12±0.03	0.10±0.02	0.13^{A}±0.03	0.17^{A}±0.19	NA	NS
Scoria	0.12^{a}±0.03	0.10^{a}±0.03	0.11^{Ba}±0.04	0.11^{Ba}±0.11	0.14^{a}±0.11	**
LS	NS	NS	**	**	-	
Cohesiveness						
Wet	0.49±0.23	0.33±0.12	0.51±0.88	0.33^{B}±0.06	NA	NS
Normal	0.49^{a}±0.23	0.33^{c}±0.06	0.43^{ab}±0.09	0.41^{Ab}±0.08	NA	***
Scoria	0.49^{a}±0.23	0.35^{b}±0.08	0.35^{b}±0.12	0.35^{Bb}±0.08	0.40^{b}±0.08	***
LS	NS	NS	NS	***	-	
Springiness						
Wet	6.21±1.74	6.38±1.39	6.24^{A}±0.74	6.09±0.57	NA	NS
Normal	6.21±1.74	5.98±0.90	6.00^{AB}±0.97	5.95±0.80	NA	NS
Scoria	6.21^{a}±1.74	6.08^{ab}±1.37	5.61^{Bb}±1.29	5.86^{ab}±0.75	5.96^{ab}±0.78	*
LS	NS	NS	**	NS	-	
Gumminess						
Wet	1,143.90±426.03	1,091.37±412.42	1,290.44±433.54	1,281.85±301.39	NA	NS
Normal	1,143.90±426.03	1,221.77±275.87	1,396.04±322.96	1,292.70±401.76	NA	NS
Scoria	1,143.90±426.03	1,184.78±385.55	1,236.88±415.71	1,234.73±359.48	1,116.96±319.57	NS
LS	NS	NS	NS	NS	-	
Chewiness						
Wet	72.92±48.02	72.49±44.94	79.40±28.17	77.61±23.97	NA	NS
Normal	72.92±48.02	71.83±20.67	82.19±23.67	76.62±27.92	NA	NS
Scoria	72.92±48.02	72.13±28.52	70.05±32.27	71.92±25.44	66.07±21.84	NS
LS	NS	NS	NS	NS	-	

Mean±SD.
$^{A–C}$ Means with different superscripts in the same column significantly differ.
$^{a–c}$ Means with different superscripts in the same row significantly differ.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.
Wet, wet-aging; Normal, dry-aging in normal Korean earthenware; Scoria, dry-aging in Jeju scoria earthenware; LS, level of significance; NA, not available; NS, not significant.

Table 5. Fatty acids compositions (contents and ratio) of aged pork loin by aging method

Variable	Contents (g/100g)				Percentage (%)			
	Wet	Normal	Scoria	LS	Wet	Normal	Scoria	LS
C12:0	0.0028[b]	0.0040[ab]	0.0051[a]	**	0.15	0.14	0.14	NS
C14:0	0.0275[b]	0.0492[a]	0.0626[a]	**	1.45[b]	1.57[ab]	1.64[a]	*
C15:0	0.0012[b]	0.0017[a]	0.0020[a]	**	0.07	0.06	0.06	NS
C16:0	0.4609[b]	0.7965[a]	1.0018[a]	**	24.07[b]	25.44[a]	26.21[a]	***
C16:1	0.0652[b]	0.1168[ab]	0.1483[a]	**	3.31	3.59	3.89	NS
C17:0	0.0056[b]	0.0092[a]	0.0113[a]	**	0.30	0.31	0.32	NS
C18:0	0.2466[b]	0.4106[a]	0.5002[a]	**	13.16	13.47	13.28	NS
C18:1	0.7573[b]	1.3195[a]	1.6729[a]	**	39.43[b]	41.26[ab]	42.60[a]	*
C18:2n-6	0.2134[b]	0.2647[ab]	0.2943[a]	*	11.62[a]	9.71[b]	8.46[b]	**
C18:3n-3	0.0057	0.0076	0.0085	NS	0.31[a]	0.24[ab]	0.21[b]	*
C18:3n-6	0.0018	0.0021	0.0023	NS	0.10[a]	0.08[b]	0.06[b]	***
C20:0	0.0038[b]	0.0058[a]	0.0072[a]	**	0.20	0.20	0.20	NS
C20:1n-9	0.0147[b]	0.0235[a]	0.0286[a]	**	0.78	0.76	0.75	NS
C20:2n-6	0.0076[b]	0.0096[ab]	0.0118[a]	*	0.41	0.34	0.34	NS
C20:3n-3	0.0012[b]	0.0020[a]	0.0023[a]	**	0.07[a]	0.06[ab]	0.05[b]	*
C20:3n-6	0.0086	0.0085	0.0093	NS	0.47[a]	0.33[b]	0.28[b]	***
C20:4n-6	0.0599	0.0514	0.0495	NS	3.39[a]	2.08[b]	1.44[b]	***
C20:5n-3	0.0014	0.0015	0.0015	NS	0.08	0.07	0.06	NS
C21:0	0.0012	0.0019	0.0021	NS	0.06	0.05	0.05	NS
C22:0	0.0015	0.0011	0.0011	NS	0.08[a]	0.04[b]	0.03[b]	**
C22:1n-9	0.0072	0.0056	0.0059	NS	0.40[a]	0.22[b]	0.15[b]	***
C24:1	0.0026	0.0025	0.0022	NS	0.15[a]	0.10[b]	0.06[c]	***
Total	1.8970[b]	3.0921[a]	3.8200[a]	**				
SFA	0.7506[b]	1.2794[a]	1.5932[a]	**	39.51[b]	41.27[a]	41.93[a]	**
UFA	1.1455[b]	1.8113[ab]	2.2253[a]	**	60.43[a]	58.69[b]	58.04[b]	**
MUFA	0.8399[b]	1.4602[a]	1.8424[a]	**	43.67[b]	45.63[ab]	47.04[a]	*
PUFA	0.3066	0.3525	0.3844	NS	16.82[a]	13.10[b]	11.03[b]	***

Mean±SD.
[a–c] Means with different superscripts in the same row significantly differ.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.
Wet, wet-aging; Normal, dry-aging in normal Korean earthenware; Scoria, dry-aging in Jeju scoria earthenware; LS, level of significance; NS, not significant; SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

scoria aging methods, the ratio of C18:2n-6 was lower in the normal and scoria aging methods than in the wet aging method. Fatty acid compositions in meat are associated with sensory flavor (Wood et al., 2004). The scoria aging method showed a lower ratio of C18:3n-3 than the wet aging method. This negatively affects flavor as linolenic acid reacts with volatile compounds from the cooking process (Campo et al., 2003). However, the content of C18:3n-3 was not significantly different among the three aging methods.

In this study, the normal and scoria aging methods showed higher contents and ratios of SFA, as well as higher content of

UFA than the wet aging method. However, the normal and scoria aging methods showed lower ratios of UFA than the wet aging method. Previously, SFA and monounsaturated fatty acids (MUFA) were positively associated with eating quality traits, whereas polyunsaturated fatty acids (PUFA) were negatively correlated with eating quality (Cameron and Enser, 1991). While the normal and scoria aging methods showed significantly higher contents and ratios of SFA and MUFA but lower ratios of PUFA than the wet aging method, further studies are necessary to demonstrate the relationships among eating quality and SFA and/or UFA changes with scoria aging method.

Free amino acid (FAA)

The results of FAA analysis by aging method and aging time are shown in Table 6. Except for arginine, and taurine, there were no significant differences in FAA content among the three aging methods. The scoria aging method showed higher contents of taurine than the other two aging methods. However, the content of arginine was significantly lower in the scoria aging method than in the wet aging method. The trends of FAA ratios were similar to those of the FAA content. Amino acids are not only essential components of proteins but also affect the synthesis of other components in muscle. Moreover, amino acids are essential for the unique flavor of meat (Khan et al., 2015). In the current study, we classified FAAs into sweet, umami, and savory taste categories. However, the aging method did not affect the FAA contents in the sweet, umami, bitter, and functional categories.

Table 6. Free amino acids contents and ratio of aged pork loin by aging method

Variable	Contents (mg/100g)				Percentage (%)			
	Wet	Normal	Scoria	LS	Wet	Normal	Scoria	LS
Alanine	34.5±6.7	33.6±6.2	34.9±7.6	NS	12.22±1.69	12.49±1.69	12.70±3.95	NS
Aminoadipic acid	6.5±11.5	3.5±2.1	2.4±1.2	NS	1.89±2.51	1.25±0.52	0.88±0.30	NS
Arginine	12.3^{a}±3.4	10.8^{ab}±3.0	8.3^{b}±4.0	*	4.15^{a}±0.92	3.98^{ab}±0.78	3.10^{b}±1.43	*
Cystathionine	4.3±9.4	2.3±1.4	2.6±1.2	NS	1.17±2.15	0.78±0.35	0.82±0.29	NS
Ethanolamine	2.0±2.3	1.8±0.9	3.3±4.1	NS	0.63±0.50	0.69±0.18	1.17±1.59	NS
Glutamic acid	42.4±15.8	39.4±11.2	33.8±8.1	NS	14.27±3.05	14.38±1.43	12.26±2.96	NS
Glycine	12.9±4.4	13.0±2.8	13.1±2.7	NS	4.47±1.12	4.83±0.45	4.64±0.41	NS
Histidine	7.5±6.8	5.2±2.2	5.1±1.9	NS	2.23±1.35	1.76±0.34	1.71±0.35	NS
Isoleucine	11.9±4.5	10.8±3.7	11.5±3.8	NS	3.86±0.30	3.85±0.37	3.94±0.56	NS
Leucine	19.4±7.5	18.3±3.7	19.1±6.1	NS	6.29±0.80	6.40±0.77	6.55±0.89	NS
Lysine	15.3±9.8	13.8±5.5	15.9±8.5	NS	4.68±1.83	4.83±0.77	5.32±2.08	NS
Methionine	11.2±4.6	10.3±4.0	11.3±4.4	NS	3.62±0.63	3.70±0.60	3.86±0.76	NS
Ornithine	3.3±3.5	2.8±2.6	2.8±2.1	NS	0.95±0.69	0.93±0.55	0.93±0.50	NS
Phenylalanine	10.9±4.9	10.6±4.4	12.2±4.6	NS	3.48±0.78	3.65±0.67	4.12±0.84	NS
Proline	6.1±3.4	5.1±2.9	4.7±1.7	NS	2.01^{a}±0.42	1.80^{ab}±0.43	1.65^{b}±0.24	*
Sarcosine	4.0±5.7	2.4±0.5	2.2±0.4	NS	1.16±1.24	0.89±0.21	0.82±0.20	NS
Serine	19.9±17.3	14.6±5.4	14.6±4.2	NS	5.97±3.42	5.13±1.88	5.10±0.73	NS
Taurine	15.3^{b}±4.8	15.5^{b}±4.6	19.3^{a}±3.5	*	5.17^{b}±1.23	5.82^{ab}±1.88	6.93^{a}±1.32	*
Threonine	11.8±5.2	10.8±4.0	11.0±3.7	NS	3.81±0.71	3.82±0.42	3.77±0.54	NS

Table 6. Free amino acids contents and ratio of aged pork loin by aging method (continued)

Variable	Contents (mg/100g)				Percentage (%)			
	Wet	Normal	Scoria	LS	Wet	Normal	Scoria	LS
Tyrosine	9.7±2.9	9.5±2.6	10.1±2.5	NS	3.33±0.82	3.50±0.44	3.56±0.49	NS
Urea	26.4±4.9	25.5±10.7	23.1±9.7	NS	9.42±3.27	9.34±2.64	8.18±2.50	NS
Valine	21.4±12.4	18.4±5.0	25.8±4.4	NS	6.79±2.04	6.63±0.56	8.71±0.60	NS
Total amino	303.9±96.7	276.9±80.7	284.9±64.0	NS	-	-	-	-
Sweet	81.8±24.1	77.2±20.7	78.4±15.4	NS	27.3±1.17	28.08±1.17	27.85±3.02	NS
Umami	42.4±15.8	39.4±11.2	33.8±8.1	NS	14.27±1.43	14.38±1.43	12.26±2.96	NS
Bitter	113.9±47.0	102.3±36.3	106.9±32.7	NS	36.56±4.07	36.29±4.07	36.84±4.67	NS
Functional	18.2±6.0	18.4±6.3	22.1±4.7	NS	6.04^{b}±1.67	6.75^{b}±1.67	7.85^{a}±1.05	**

Mean±SD.
^{a,b} Means with different superscripts in the same row significantly differ.
* $p<0.05$; ** $p<0.01$.
Wet, wet-aging; Normal, dry-aging in normal Korean earthenware; Scoria, dry-aging in Jeju scoria earthenware; LS, level of significance; NS, not significant.

Conclusion

The pH and CIE L* of aged pork loin were not significantly affected by the aging method after 10 days, resembling those of normal meat. The scoria aging method exhibited lower shear force values than the wet aging method after 10 and 20 days, indicating superior meat tenderness. Unpackaged aging methods (normal and scoria) led to increased aging loss compared to the wet aging method (packaged aging method), potentially due to prolonged air exposure. The taste profile, as reflected by the increased FAA content, improved with aging, suggesting enhanced eating quality. In summary, the scoria aging method demonstrates favorable aspects in terms of meat tenderness, taste improvement (including umami), and minimal overall changes in meat quality. These findings highlight its potential as a promising meat processing technique for regional specialized industries. However, further research is required to ensure long-term aging process food safety and maintain weight yield in aged meat products.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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