

Changes of Physicochemical and Sensory Properties of Fermented Sausage from Sulfur-fed Pork

Min-Gu Ju, Ji-Han Kim, Hyun-Joo Jang, Su-Jung Yeon, Go-En Hong,
Woojoon Park, Han Geuk Seo, and Chi-Ho Lee*

Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea

Abstract

This study was performed to evaluate the quality of fermented sausages manufactured with processed sulfur-fed pigs. The fermented sausages were divided into two groups; one was manufactured with non sulfur-fed pigs (NP), the other one was made with processed sulfur-fed pigs (SP). No differences were found in moisture and fat contents ($p>0.05$) between NP and SP, but the protein and ash contents of SP were significantly higher than those of NP ($p<0.05$). The pH of SP was significantly lower than that of NP, and the water activity (a_w) of SP was significantly higher than that of NP after 14 and 21 d ($p<0.05$). The TBA (Thiobarbituric acid reactive substance) value of SP was significantly lower than that of NP ($p<0.05$). The lightness and yellowness of NP were significantly higher than those of SP, whereas the redness of NP was lower than SP ($p<0.05$). The total plate count of SP was lower than that of NP ($p<0.05$). There was no significant difference in TPA (Texture profile analysis) between the two samples. SP showed significantly increased monounsaturated fatty acid ($p<0.05$) and decreased saturated fatty acid. Umami taste and richness in SP were significantly higher than in NP ($p<0.05$). Therefore, it is suggested that processed sulfur fed pigs may play a key role in enhancing the quality of meat products.

Keywords: processed sulfur-fed pigs, lipid oxidation, free amino acid, umami

Received June 9, 2016; Revised October 21, 2016; Accepted October 31, 2016

Introduction

Sulfur is a major inorganic element and essential for the entire biological field because of its incorporation into amino acids, proteins, enzymes, vitamins, and other biomolecules, and unlike humans and monogastric animals, plants can use inorganic sulfur and can synthesize sulfur-containing amino acids such as methionine and cysteine (Lioudmila *et al.*, 2003). Organic sulfur compound such as MSM (methylsufonylmethane) is the representative non-toxic sulfur compound and is extracted from plants involved in the formation of sulfur-containing amino acids, such as methionine, cysteine and taurine (Total Health, 1998). These sulfur compounds are quickly evacuated from the body and caused no problems in toxicity tests with rats over a period of 90 d, even at 1.5-2.0 g/kg (Magnuson *et al.*, 2007).

Researchers that study meat science have often attempted to increase meat quality (Kim *et al.*, 2015; Lee *et al.*, 2009). One of the most important factors for improving

meat quality is reducing lipid oxidation. Meat products manufactured with dietary sulfur fed animals are well known to possess significant antioxidant effects (Kim *et al.*, 2015; Lee *et al.*, 2009). Song *et al.* (2013) reported that pigs that ate feed containing a high concentration of sulfur had a lot of antioxidants in their body. Additionally, supplementation with dietary sulfur is known to decrease saturated fatty acid and increase polyunsaturated fatty acid (Danielle *et al.*, 2014). Kim *et al.* (2015) reported that the ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (SFA) is an important indicator for cardiovascular disease prevention.

Dry-cured sausages are some of the oldest and most famous meat products in southern Europe because of the dry climate in areas such as Spain, Italy and France. However, these meat products have high fat contents (20-40% lard in dry-cured sausage formulation). Thus, they are more susceptible to lipid oxidation than other meat products, and are not recommended for health management (Utrilla *et al.*, 2014). Moreover, saturated fatty acid and cholesterol, which increase the rate of cardiovascular disease, are highly distributed in fermented sausages (USDA, 2000). Processed sulfur-fed pork can decrease saturated fatty acids and increase polyunsaturated fatty acids in

*Corresponding author: Chi-Ho Lee, Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea. Tel: +82-2-450-3681, Fax: +82-2-453-1948, E-mail: leech@konkuk.ac.kr

© This is an open access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

meat products (Kim *et al.*, 2015). Also, meat products manufactured from processed sulfur-fed pork have higher moisture contents and water-holding capacity than general meat products (Kim *et al.*, 2015; Lee *et al.*, 2009).

Meanwhile, electronic tongue (E-tongue), taste sensing system, is an instrument that evaluates the taste by electronic techniques (Latha and Lakshmi, 2012). Their sensing system could represent the specific taste to the figures. Recently, E-tongue is used for evaluating the quality of meat product. Especially, it is necessary for aging meat products because this system could measure richness and umami taste which are important to these products (Nodake *et al.*, 2013). Thus, representing the taste quality of aging meat products using E-tongue might be increasingly valuable.

In our previous study, dry-cured ham by using 0.3% processed sulfur-fed pigs showed relatively a higher meat quality and shelf life extension than with the dry-cured ham made from pigs fed 0.1% processed sulfur (Kim *et al.*, 2015). Thus, the object of this study was to find out the physicochemical and sensory properties of the fermented sausages made with processed sulfur-fed pigs.

Material and Methods

Animal experiment

The sample used in the present study was obtained from a population of pigs fed the same basal diet composition described by Kim *et al.* (2015). A total of 60 three-way crossbred pigs (Duroc × Landrace × Yorkshire) from Yang-Ju Livestock Federation in the Republic of Korea were raised for 174 d. The animal experiment was managed by the animal care committee of Konkuk University of Seoul, Republic of Korea. Non-processed sulfur-fed pigs (NP) were fed a basal diet; 0.3% processed sulfur-fed pigs (SP) were fed a mixed diet until 121.01±1.26 kg Body weight without a significant difference between NP and SP. The elemental sulfur concentration was 97.9% processed sulfur according to the Korea Feed Ingredients Association. The feeding system and watering processes were managed by automatic circulation. Slaughter was performed at slaughter house in Pocheon Nongchucksan by knocking, the carcasses were chilled at 1°C for 24 h and loin muscles were obtained from the carcasses. The samples were transported to Konkuk University for this experiment as soon as they were obtained.

Preparation of fermented sausages

The fermented sausages were produced according to a

Table 1. Formulation of fermented sausages

	Formulation
Pork sirloin (%)	60
Pork Back Fat (%)	40
Total	100
Water (%)	10
Salt (%)	2
Black pepper (%)	0.05
Sodium ascorbate (%)	0.05
Sodium nitrite (%)	0.015
Glucose (%)	1
<i>Staphylococcus carnosus</i> (%)	0.125
<i>Lactobacillus plantarum</i> (%)	0.125

slight modification of the recipe described by Kim *et al.* (2014). Pork meat was trimmed to remove visible fats and connective tissue. Pork meat and pork back fat were ground separately using a grinder with a 5 mm plate. After grinding, basic ingredients were added to the meat and fat. The formulation of fermented sausage is presented in Table 1. Also, starter culture, *Staphylococcus carnosus* and *Lactobacillus plantarum* (10^7 CFU/g), was added at the same time as the basic ingredients. The ingredients were mixed manually for 5 min. Finally, the mixtures were filled with collagen casing and hung in a room for 30 d with a humidifier and air conditioner capable of adjusting the temperature. The ripening conditions on the first day consisted of a respective temperature and RH of 20±2°C and 90±5%. The drying conditions on subsequent days, the temperature and RH were 12±2°C and 75±5%. The pH and water activity of the fermented sausage were measured during the drying and ripening processes. After the manufacturing process, the proximate composition, physicochemical and microbiological experiments were analyzed for meat quality.

Proximate composition of fermented sausages

Moisture, crude protein, crude fat and ash contents of fermented sausages were determined according to the AOAC (1995).

Water activity (a_w) and pH measurement

Water activity was measured at 25°C using a water activity device (Aqua Lab CX-2, Decagon Device Inc., Germany).

pH was measured using a suspension homogenized 2 g sample and 18 mL distilled water for 1 min with a pH meter device (pH 900, Precisa Co., Switzerland).

Color measurement

Color was measured using Handy colorimeter 9 (NR-

300, Nippon Denshoku, Japan). The machine was calibrated with a white square plate (CIE $L^* = +94.48$, $a^* = -0.67$, $b^* = +3.31$). Values for CIE L^* (lightness), CIE a^* (redness), and CIE b^* (yellowness) were determined at 30 d.

TBARS (Thiobarbituric acid reactive substance)

Lipid oxidation was determined according to the TBA (2-thiobarbituric acid) method from Witte *et al.* (1977). First, 2 g of sample was homogenized at 12,000 rpm for 1 min with 10 mL of 10% TCA (trichloroacetic acid) and 10 mL of distilled water. After homogenizing, the solution was filtered through a filter paper (Whatman No. 1, Whatman Inc., USA). 5 mL of the filtered solution was mixed with 5 mL of TBA (2-thiobarbituric acid 2.88 g/L) and then, the mixed solution was placed in a 90°C water bath for 10 min. After cooling for 30 min, the absorbance of the solution was measured with a spectrophotometer (UV/Vis Spectrophotometer, Mecasys Co., Korea) at 532 nm. Thiobarbituric acid reactive substance (TBARS) values were determined from a standard curve of malondialdehyde.

Microbial analysis

2 g of sample was homogenized in 18 mL distilled water for 90 s and the supernatant was diluted for inoculation onto petrifilm and MRS agar. Total aerobes were inoculated onto petrifilm to count the total aerobic bacteria (3M Petrifilm, USA) for 24 h at 35°C. Lactic acid bacteria were cultured on MRS agar (Oxoid, England) at 30±3°C for 72 h.

Fatty acid composition

The fatty acid analysis was performed according to the AOAC (1995). Briefly, 25 mg of samples were mixed with potassium hydroxide (KOH) in methanol and heated. After cooling, 1 mL of isooctane solution and saturated sodium chloride (NaCl) were mixed with the solution. Chromatographic conditions were as follows: initial oven temperature, 100°C (held for 4 min); ramping at 3°C/min to 240°C (held for 15 min). The injector and detector were maintained at 225°C and 285°C, respectively. The flow rate of helium was 0.75 mL/min, and 1 µL of solution was injected in split mode (200:1). Nonadecanoic acid methyl ester, as an internal standard, was added at 0.3 mg/mL to the samples prior to fat extraction and methylation. The isooctane layer was dehydrated with anhydrous sodium sulfate and analyzed by gas chromatography (GC) (5,890, Agilent Technologies, USA). An SP-2560 column (100 m × 0.25 mm × 0.2 µm) (Sigma-Aldrich, USA) was used with a flame ionization detector.

TPA (Texture profile analysis)

Texture profile analysis (TPA) of the fermented sausages was performed at 4±1°C with a Texture Analyzer (CT3-1000, Brookfield Engineering Laboratories, Inc., USA) to measure hardness, springiness, cohesiveness, gumminess and chewiness. TPA was performed following a slight modification of the method described by Claus (1995). A 1 cm sample was cut from the fermented sausages. The cut sample was compressed to 70% of its original height with a cylindrical probe of 10 cm diameter at a compression load of 15 kg and cross-head speed of 20 cm/min. Values for hardness, springiness, cohesiveness, gumminess, and chewiness were determined as described by Bourne (1978).

Electronic tongue

Extraction of meat was conducted by the modified method introduced by Escudero *et al.* (2012). 5 g of meat and 20 mL of 0.01 N HCl were homogenized using a bag mixer for 8 min. The homogenized sample was centrifuged at 10,000 g for 20 min at 4°C. The centrifuged sample was filtered through a whatman No. 1 filter paper to remove impurities. Then, the extracts were stored at -80°C until analysis. The standard compounds, namely MgSO₄ (bitterness), HCl (sourness), NaCl (saltiness), and MSG (umami), were prepared to check the cross-selectivity of the sensors. All standard compounds were the same concentration (0.01 mol/L). Electronic tongue analysis was performed using an Electronic tongue machine (Taste sensing system SA 402B, Insent Intelligent Sensor Technology, Inc., Japan). The chemical sensor of E-tongue machine has various taste receptors. The sensor immersed in the extract sample, then transferred the signal to the computer. The computer depicted the E-tongue value of bitterness, sourness, saltiness and Umami.

Free amino acid composition

The free amino acid composition in fermented sausages was followed as described by Henderson *et al.* (2000). Briefly explaining the pretreatment of sample, samples were put into the 75% ethanol and extracted for 1 h by ultrasonication, and stored 24 h at room temperature. After extraction, they were filtered by 0.2 µm filter and analyzed using Dionex Ultimate 3000 HPLC system (Dionex, USA). Used column for analysis was VDSpher 100 C18-E (4.6 mm × 150 mm, 3.5 µm/VDS optilab, Germany), and mobile phase A was 40 mM sodium phosphate dibasic (pH 7), and mobile phase B was acetonitrile:MeOH:distilled water=45:45:10(v/v/v). Amino acid standard (Agilent tech., USA), borate buffer (Agilent tech., USA), and OPA (ortho-phthalaldehyde) reagent (Agilent tech., USA) were

used as reagent for analysis.

Statistical analysis

This experiment was designed as two treatments (NP and SP) and six storage periods (0, 1, 7, 14, 21 and 30 d). The data was expressed as mean and standard error of means (SEM). ANOVA (one way analysis of variance) was performed to determine significant difference in pH and water activity during the storage periods and an independent *t* test of the results from proximate composition, TBARS, pH, water activity, color (CIE L*, CIE a* and CIE b*), total plate count, lactic acid bacteria, fatty acid, free amino acid compositions, texture analysis and electronic tongue was used to determine the significant difference between NP and SP after ripening process at 30 d. $p < 0.05$ was considered significant, and a trend was noted at $p < 1.0$.

Results and Discussion

Proximate compositions

Proximate compositions of the fermented sausages are shown in Table 2. The moisture and fat contents of SP and NP were not significantly different ($p > 0.05$) in this study. The protein and ash contents of SP were higher than those of NP ($p < 0.05$). Similar result for ash contents was reported by Kim *et al.* (2014). Researchers reported that meat products made with sulfur-fed pork or cattle had higher moisture contents and lower fat contents than meat products made with normal pork or cattle (Kim *et al.*, 2015; Lee *et al.*, 2009). However, there were no significant differences in moisture and fat contents in this study ($p > 0.05$).

pH and water activity (a_w)

Fig. 1 shows the changes in water activity (a_w) and pH during the manufacturing process. The a_w in both samples

Table 2. Proximate composition and TBARS of fermented sausages

Composition	NP	SP	SEM	<i>p</i> -value
Moisture (%)	25.54	23.16	0.21	0.17
Protein (%)	22.59	23.53	2.34	0.04
Fat (%)	36.75	38.66	1.28	0.46
Ash (%)	4.23	5.20	0.20	0.01
TBARS ²⁾	1.94	0.96	0.05	0.01

All values are the means of three replicates.

¹⁾NP, group, processed fermented sausage with non-sulfur fed pork; SP, group, processed fermented sausage with processed sulfur-fed pork. ²⁾TBARS (Thiobarbituric acid reactive substance), malondialdehyde mg/kg. ³⁾SEM, standard error of the means.

decreased significantly during the dry-curing process ($p < 0.05$). The a_w of the samples showed no significant difference ($p > 0.05$) between 0 and 7 d. However, the a_w of SP was significantly higher than the a_w of NP on 14 and 21 d ($p < 0.05$). At the end of the process (30 d), there was no significant difference between NP and SP. The results on 14 and 21 d may be explained by the higher water holding capacity of processed sulfur fed pigs (Lee *et al.*, 2009).

The pH value showed a significant decrease until 21 d in all samples ($p < 0.05$). However, between 21 and 30 d, the pH values of the samples were slightly increased or remained stable. This pH evolution is similar to the change in other fermented sausages (Fernández-López *et al.*, 2007). These results are because of the microbial activity of lactic acid bacteria, which metabolize sugar in meat to produce lactic acid (Fernández-López *et al.*, 2007). The pH value of the two samples had no significant differences on 0, 1 and 7 d ($p > 0.05$), whereas the pH value of SP was significantly lower than that of NP on 14 and 21 d ($p < 0.05$). Generally, a high pH value in meat and meat product is due to the hydrolysis of urea and accumulation of ammonia, sulphides, indole and amines (Hernández-Jover

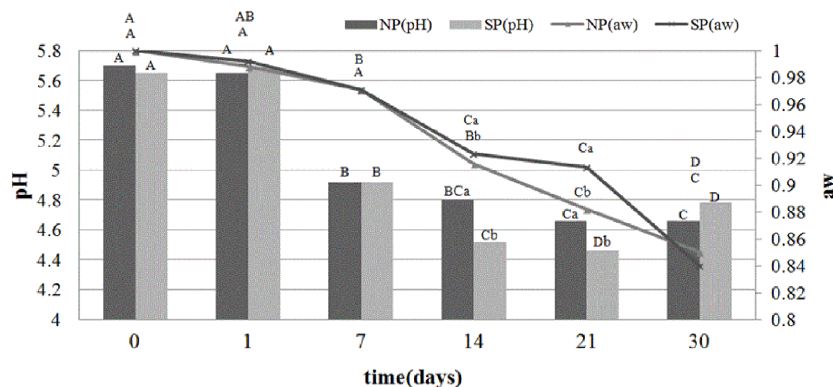


Fig. 1. pH and water activity of fermented sausages.

et al., 1996). On the other hand, a low pH value in meat product can inhibit pathogenic microorganisms and decrease biogenic amines (Suzzi *et al.*, 2003).

Lipid oxidation

The TBA values of the final products are shown in Table 2. The TBA value of NP was significantly higher than that of SP ($p < 0.05$). Komarnisky *et al.* (2003) reported that sulfur-containing compounds such as cysteine, glutathione and lipoic acid protect against oxidative stress through the scavenging and reduction of various oxidants in biological systems. Some researchers found that glutathione, which is an important antioxidant that prevents damage caused by free radicals, peroxides and lipid peroxides (Pompella *et al.*, 2003), was formed from the transsulfuration pathway during the consumption of sulfur-containing feeds (Kim *et al.*, 2015; Song *et al.*, 2013). Song *et al.* (2013) demonstrated that sulfur-containing antioxidants such as glutathione enzyme, methionine and taurine were increased as fed high sulfur-containing diet to pigs. Similar results showed an antioxidant effect from sulfur-fed pork applied to meat products. (Cho *et al.*, 2015; Kim *et al.*, 2015). Also, the higher value of TBA meat products have, rancid odor increased, the sensory quality of meat product might be negatively affected (Younathan and Watts, 1959).

Changes in color

Table 3 shows the color of the final products. The lightness value (CIE L*) of NP was significantly higher than that of SP ($p < 0.05$), whereas the redness value (CIE a*) was significantly lower than that of SP at the end of the processing period ($p < 0.05$). The yellowness value of the NP was significantly higher than that of SP ($p < 0.05$). Lactic acid bacteria metabolize carbohydrates, generating a red color in fermented sausages (Van Schalkwyk *et al.*, 2011). The higher redness value in SP might be explained by higher lactic acid bacteria activity at the lower pH of SP. According to Rosenstein *et al.* (2009), cysteine, which is a representative sulfur-containing amino acid, is an essential amino acid necessary for the growth of *Staphylococcus carnosus*. *S. carnosus* is a color fixing strain responsible for the typical red color of fermented sausages (Neubauer *et al.*, 1999). The yellowness increased when lipid oxidation was increased during processing (Kim *et al.*, 2015). Therefore, the lower yellowness value of SP could be related to lower lipid oxidation in fermented sausages.

Microbial properties

The microbial properties of fermented sausages are

shown in Table 3. The total plate counts (TPC) of SP were significantly lower than those of NP ($p < 0.05$). The lactic acid bacteria (LAB) counts of SP and NP showed no significant differences in the finished products ($p > 0.05$). Microorganisms damage lipids and this process is usually called lipid oxidation (Kohen *et al.*, 2002). Sahoo and Anjaneyulu (1997) proved the positive correlation between microbiology population and TBARS. Similar results of lower TPC with sulfur-fed pork were reported by Kim *et al.* (2014). In general, TPC can be used as a parameter for evaluating the deterioration of meat products (Ciuciu *et al.*, 2011). Hence, these results indicate that fermented sausages processed with sulfur-fed pork can prevent spoilage by microorganisms.

Fatty acid composition

The fatty acid composition of the fermented sausages is shown in Table 5. The SFA (saturated fatty acids) content of SP was lower than that of NP, while the MUFA (monounsaturated fatty acids), especially oleic acid, in SP was significantly higher than that in NP ($p < 0.05$). However, the PUFA/SFA ratio was not significantly different between SP and NP. Yang *et al.* (2015) demonstrated that basal diet supplementation with 0.3% processed sulfur increased MUFA in pigs. Also, children who eat foods containing lots of MUFA have healthier serum lipid profiles (Sanchez-Bayle *et al.*, 2009). According to Lunt and Smith (1991), meat products that have more oleic acid were evaluated to have better taste and flavor in a sensory test. Cameron and Enser (1991) also reported better taste in meat when MUFA was higher and PUFA was lower. Therefore, dry-cured sausage made from 0.3% processed sulfur pigs might enhance the nutritional balance needed for health.

TPA (texture profile analysis)

Table 4 shows the texture profile analysis (TPA) results

Table 3. Physicochemical and microbial properties of fermented sausages

Parameter	NP	SP	SEM	<i>p</i> -value
Microbial properties (Log CFU/g)				
Total plate count	6.49	6.05	0.07	0.02
Lactic acid bacteria	8.14	8.06	0.04	0.31
Color measurement				
CIE L*	54.40	47.56	0.33	0.004
CIE a*	7.92	12.64	0.50	0.004
CIE b*	21.34	15.37	0.72	0.008

All values are the means of three replicates.

¹)NP, group, processed fermented sausage with manufactured with non sulfur-fed pork; SP, group, processed fermented sausage with processed sulfur-fed pork. ²)SEM, standard error of the means.

Table 4. Textural properties of fermented sausages

Parameter	NP	SP	SEM	<i>p</i> -value
Hardness (kg)	6.01	7.59	0.15	0.95
Springiness (mm)	2.37	2.62	0.22	0.24
Cohesiveness	0.25	0.25	0.01	0.28
Gumminess (kg)	1.99	1.68	0.27	0.18
Chewiness (mJ)	45.63	42.57	5.84	0.41

All values are the means of three replicates.

¹)NP, group, processed fermented sausage with non sulfur-fed pork; SP, group, processed fermented sausage with processed sulfur-fed pork. ²)SEM, standard error of the means.

Table 5. Fatty acid composition of fermented sausages (%)

	NP	SP	SEM	<i>p</i> -value
C14:0	1.62	1.08	0.28	0.42
C16:0	23.56	23.99	0.19	0.27
C18:0	12.33	11.28	0.58	0.27
C20:0	0.19	0.12	0.04	0.36
C16:1n7	2.42	2.47	0.17	0.12
C18:1n9	43.51	46.34	0.69	*
C20:1n9	1.04	1.01	0.01	0.06
C18:2n6	12.13	12.03	0.16	0.69
C20:2n6	0.53	0.18	0.09	0.18
C18:3n3	0.67	0.66	0.01	0.40
C20:3n3	0.08	0.10	0.09	0.90
ΣSFA	37.78	36.46	0.44	0.16
ΣMUFA	46.96	49.82	0.70	*
ΣPUFA	13.59	12.96	0.28	0.23
Σw6	12.83	12.21	0.26	0.18
Σw3	0.75	0.76	0.08	0.98
w6/w3	17.30	16.58	1.69	0.78
PUFA/SFA	0.36	0.35	0.01	0.80
MUFA/SFA	1.24	1.37	0.02	*

All values are the means of three replicates.

¹)NP, group, processed fermented sausage with non sulfur-fed pork; SP, group, processed fermented sausage with processed sulfur-fed pork. ²)SEM, standard error of the means. **p*<0.05

for the fermented sausages. There were no significant differences in TPA (*p*>0.05) between SP and NP. Texture profile analysis (TPA) is the most commonly used technique for measuring the textural properties of foods (Herrero *et al.*, 2008). Hardness, cohesiveness, gumminess and chewiness are related to water activity and moisture contents (Lorenzo *et al.*, 2014). When the water activity and moisture contents of sausages decrease, the hardness, cohesiveness, gumminess and chewiness of the sausages increase.

Free amino acid composition

The free amino acid composition of fermented sausages is shown in Table 6. The Glutamic acid, Asparagines, Histidine, Glycine, Arginine, Alanine, Taurine, Tyrosine, Valine, Tryptophan, Isoleucine and Leucine contents of SP

Table 6. Free amino acid composition of fermented sausages (g/100g)

	NP	SP	SEM	<i>p</i> -value
Aspartic acid	9.94	9.40	0.12	0.49
Glutamic acid	811.69	886.42	8.41	0.02
Asparagines	152.77	175.49	4.01	0.02
Serine	34.93	42.06	1.73	0.12
Glutamine	201.47	229.11	3.15	0.01
Histidine	112.01	122.79	1.62	0.03
Glycine	229.39	285.74	2.31	0.01
Threonine	268.52	249.61	9.01	0.39
Arginine	99.38	116.50	4.16	0.05
Alanine	894.52	1018.24	8.89	0.01
Taurine	1859.19	1940.78	6.89	0.01
GABA	28.41	30.58	2.12	0.60
Tyrosine	47.19	72.80	1.60	0.01
Valine	304.24	351.79	3.31	0.02
Methionine	152.46	181.15	10.07	0.13
Tryptophane	26.32	37.90	0.69	0.01
Phenylalanine	247.44	249.84	6.54	0.81
Isoleucine	290.84	312.04	2.10	0.03
Leucine	555.02	627.23	10.38	0.01
Lysine	285.59	310.71	7.66	0.16
Proline	246.59	223.77	3.52	0.02

All values are the means of three replicates.

¹)NP, group, processed fermented sausage with non sulfur-fed pork; SP, group, processed fermented sausage with processed sulfur-fed pork. ²) SEM, standard error of the means.

were significantly higher than those of NP (*p*<0.05). However, the Aspartic acid, Serine, Glutamine, Threonine, GABA, Methionine, Phenylalanine and Lysine contents showed no significant differences between SP and NP. The processed sulfur supplementation positively affected on protein degradation of dry cured loin during the manufacture and free amino acid composition was considered as an indicator of sensory quality (Kim *et al.*, 2015). The free amino acids in fermented meat have a significant role of generating flavor and taste (Zhao *et al.*, 2016). During the ripening process for fermented sausages, proteins are degraded into large peptides, and the large peptides are degraded into oligopeptides, which are finally degraded into free amino acids (Domínguez *et al.*, 2016). Among these amino acids, glutamic acid has a synergy effect with salt in increasing Umami taste (Nishimura and Kato, 1988).

Electronic tongue

Fig. 2 shows the differences in electronic tongue values between SP and NP. Bitterness and Saltiness in the two samples had no significant differences (*p*>0.05) but NP had a significantly higher sourness value than SP. However, the Umami and Richness values of the SP were significantly higher than those of NP (*p*<0.05). Recently, ins-

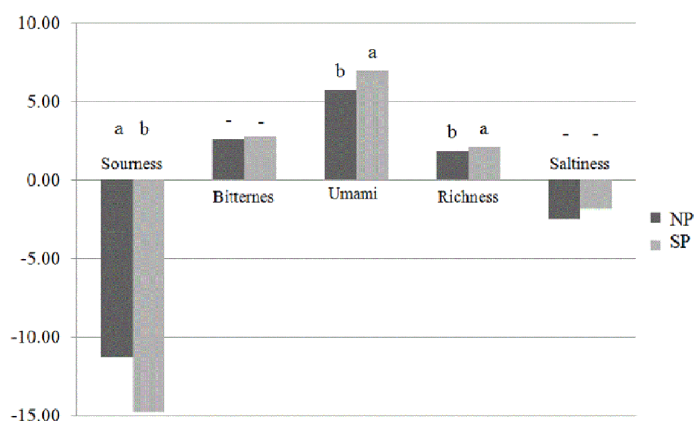


Fig. 2. Electronic tongue results for of fermented sausages.

stead of human sensory evolution, which is depend on daily mental and physical conditions, analytic sensory system (electronic tongue) is often used for evaluating foods taste because of objectivity (Nodake *et al.*, 2013). Umami has a 'savory' or 'delicious' meaning derived from Japanese and important taste of fermented meat (Sentandreu *et al.*, 2003; Zhao *et al.*, 2016). Researchers concluded that Umami taste is related to glutamate-like taste from high amounts of glutamic acid and hydrophilic amino acid residues (Aristoy and Toldra, 1995; Dang *et al.*, 2015). Also, Kobayashi *et al.* (2010) reported that richness is Umami after-taste. Therefore, we could suppose the sensory values of SP were better than that of NP because of the amount of free amino acids in SP.

Conclusion

This study reports that the dry-cured sausages made from 0.3% processed sulfur-fed pork demonstrated better storage stability and meat quality than those made from normal pork. According to the result of electronic tongue analysis, umami and richness of the SP group were better than those of the NP group because the SP group had more free amino acids contents. The dry cured sausage form the 0.3% processed sulfur supplementation showed higher redness compared to the basal diet supplementation. In conclusion, the supplementation of pig feed with 0.3% processed sulfur improves oxidative stability, the nutritional quality and sensory properties of fermented sausages.

Acknowledgments

This study was conducted with support of the Technology Commercialization Support Program, IPET (Korea

Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry, and Fisheries) and support from the Ministry of Agriculture, Food, and Rural Affairs, Republic of Korea.

References

1. AOAC (1995) *Official methods of analysis* (16th ed.) Washington, DC, USA: Association of Official Analytical Chemists.
2. Aristoy, M. C. and Toldrá, F. (1995) Isolation of flavor peptides from raw pork meat and dry-cured ham. *Dev. Food Sci.* **37**, 1323-1344.
3. Bourne M. C. (1978) Texture profile analysis. *Food Technol.* **32**, 62-66.
4. Cameron, N. D. and Enser, M. B. (1991) Fatty acid composition of lipid in longissimus dorsi muscle of Duroc and British landrace pigs and its relationship with eating quality. *Meat Sci.* **29**, 295-302
5. Cho, H. S., Park, W., Hong, G. E., Kim, J. H., Ju, M. G., and Lee, C. H. (2015) Antioxidant activity of *Allium hookeri* root extract and its effect on lipid stability of sulfur-fed pork patties. *Korean J. Food Sci. An.* **35**, 41.
6. Ciuciu, A. M. S., Carballo, J., and Alexe, P. (2011) Microbiological evolution of Dacia sausage, a dry cured Romanian sausage. *Studii si Cercetari Stiintifice-Chimie si Inginerie Chimica, Biotehnologii, Industrie Alimentara* **1**, 215-220.
7. Claus, J. R. (1995) Methods for the objective measurement of meat product texture. In Reciprocal Meat Conference Proceedings. **48**, 96-101.
8. Dang, Y., Gao, X., Ma, F., and Wu, X. (2015) Comparison of umami taste peptides in water-soluble extractions of Jinhua and Parma hams. *LWT-Food Sci. Technol.* **60**, 1179-1186.
9. Danielle, J.P., Steven, M. L., and Stephanie, L. H. (2014) Influence of supplemental vitamin C on postmortem protein degradation and fatty acid profiles of the longissimus thoracis of steers fed varying concentrations of dietary sulfur. *Meat Sci.* **96**, 956-963.
10. Domínguez, R., Munekata, P. E., Agregán, R., and Lorenzo, J. M. (2016) Effect of commercial starter cultures on free

- amino acid, biogenic amine and free fatty acid contents in fermented foal sausage. *LWT-Food Sci. Technol.* **71**, 47-53.
11. Escudero, E., Aristoy, M. C., Nishimura, H., Arihara, K., and Toldrá, F. (2012) Antihypertensive effect and antioxidant activity of peptide fractions extracted from Spanish fermented ham. *Meat Sci.* **91**, 306-311.
 12. Fernández-López, J., Viuda-Martos, M., Sendra, E., Sayas-Barberá, E., Navarro, C., and Pérez-Alvarez, J. A. (2007) Orange fibre as potential functional ingredient for fermented sausages. *Eur. Food Res. Technol.* **226**, 1-6.
 13. Folch, J., Lees, M., and Sloane-Stanley, G. H. (1957) A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **226**, 497-509.
 14. Henderson, J. W., Ricker, R. D., Bidlingmeyer, B. A., and Woodward, C. (2000) Rapid, accurate, sensitive, and reproducible HPLC analysis of amino acids. Amino acid analysis using Zorbax Eclipse-AAA columns and the Agilent. **1100**, 1-10.
 15. Hernández-Jover, T., Izquierdo-Pulido, M., Veciana-Nogués, M. T., and Vidal-Carou, M. C. (1996) Biogenic amine sources in cooked cured shoulder pork. *J. Agr. Food Chem.* **44**, 3097-3101.
 16. Herrero, A. M., De la Hoz, L., Ordóñez, J. A., Herranz, B., de Ávila, M. R., and Cambero, M. I. (2008) Tensile properties of cooked meat sausages and their correlation with texture profile analysis (TPA) parameters and physico-chemical characteristics. *Meat Sci.* **80**, 690-696.
 17. Kim, J. H., Hong, G. E., Pyun, C. W., Park, W., and Lee, C. H. (2015) Enhancement of physicochemical, microbiological and sensory properties of fermented loin by using processed sulfur-fed pigs. *Ani. Prod. Sci.* **56**, 1936-1945.
 18. Kim, J. H., Pyun, C. W., Hong, G. E., Kim, S. K., Yang, C. Y., and Lee, C. H. (2014) Changes in physicochemical and microbiological properties of isoflavone-treated fermented sausage from sulfur-fed pork during storage. *J. An. Sci. Technol.* **56**, 1.
 19. Kobayashi, Y., Habara, M., Ikezaki, H., Chen, R., Naito, Y., and Toko, K. (2010) Advanced taste sensors based on artificial lipids w10 (4th global selectivity to basic taste qualities and high correlation to sensory scores). *Sensors* **10**, 3441-3443.
 20. Kohen, R. and Nyska, A. (2002) Invited review: Oxidation of biological systems: oxidative stress phenomena, antioxidants, redox reactions, and methods for their quantification. *Toxicol. Pathol.* **30**, 620-650.
 21. Komarnisky, L. A., Christopherson, R. J., and Basu, T. K. (2003) Sulfur: its clinical and toxicologic aspects. *Nutrition* **19**, 54-61.
 22. Latha, R. S. and Lakshmi, P. K. (2012) Electronic tongue: An analytical gustatory tool. *J. Adv. Pharmaceut. Technol. Res.* **3**, 3.
 23. Lee, J. I., Min, H. K., Lee, J. W., Jeong, J. D., Ha Y. J., Kwack, S. C., and Park, J. S. (2009) Changes in the quality of loin from pigs supplemented with dietary methyl sulfonyl methane during cold storage. *Korean J. Food Sci. An.* **29**, 229-237.
 24. Lorenzo, J. M. (2014) Changes on physico-chemical, textural, lipolysis and volatile compounds during the manufacture of fermented foal "cecina". *Meat Sci.* **96**, 256-263.
 25. Lunt, D. K. and Smith, S. B. (1991) Wagyu beefs holds profit potential for U.S. feed lot. *Feedstuffs* **19**, 18-22.
 26. Magnuson, B. A., Appleton, J., Ryan, B., and Matulka, R. A. (2007) Oral developmental toxicity study of methylsulfonyl methane in rats. *Food Chem. Toxicol.* **45**, 977-984.
 27. Neubauer, H., Pantel, I., and Götz, F. (1999) Molecular characterization of the nitrite-reducing system of *Staphylococcus carnosus*. *J. Bacteriol.* **181**, 1481-1488.
 28. Nishimura, T. and Kato, H. (1988) Taste of free amino acids and peptides. *Food Rev. Int.*, **4**, 175-194.
 29. Nodake, K., Numata, M., Kosai, K., Kim, Y. J., and Nishiumi, T. (2013) Evaluation of changes in the taste of cooked meat products during curing using an artificial taste sensor. *Anim. Sci. J.* **84**, 613-621.
 30. Pompella, A., Visvikis, A., Paolicchi, A., De Tata, V., and Casini, A. F. (2003) The changing faces of glutathione, a cellular protagonist. *Biochem. Pharmacol.* **66**, 1499-1503.
 31. Rosenstein, R., Nerz, C., Biswas, L., Resch, A., Raddatz, G., Schuster, S. C., and Götz, F. (2009) Genome analysis of the meat starter culture bacterium *Staphylococcus carnosus* TM 300. *Appl. Environ. Microb.* **75**, 811-822.
 32. Sahoo, J. and Anjaneyulu, A. S. R. (1997) Effect of natural antioxidants and vacuum packaging on the quality of buffalo meat nuggets during refrigerated storage. *Meat Sci.* **47**, 223-230.
 33. Sanchez-Bayle, M., Gonzalez-Requejo, A., Pelaez, M. J., Morales, M. T., Asensio-Anton, J., and Anton-Pacheco, E. (2008) A cross-sectional study of dietary habits and lipid profiles. The Rivas-Vaciamadrid study. *Eur. J. Pediatr.* **167**, 149-154.
 34. Sentandreu, M. A., Stoeva, S., Aristoy, M. A., Laib, K., Voelter, W., and Toldra, E. (2003) Identification of small peptides generated in spanish dry-cured ham. *J. Food Sci.* **68**, 64-69.
 35. Song, R., Chen, C., Wang, L., Johnston, L. J., Kerr, B. J., Weber, T. E., and Shurson, G. C. (2013) High sulfur content in corn dried distillers grains with soluble protects against oxidized lipids by increasing sulfur-containing antioxidants in nursery pigs. *J. Anim. Sci.* **91**, 2715-2728.
 36. Suzzi, G. and Gardini, F. (2003) Biogenic amines in dry fermented sausages: A review. *Int. J. Food Microbiol.* **88**, 41-54.
 37. Total Health (1998) "MSM". Feb/Mar, **20**, 30-31.
 38. USDA. US Department of Agriculture-US Department of Health and Human Services (2000) Nutrition and your health: Dietary guidelines for Americans Homes and garden bulletin no. 232. Washington, DC: Government University Press.
 39. Utrilla, M. C., Ruiz, A. G., and Soriano, A. (2014) Effect of partial replacement of pork meat with an olive oil organogel on the physicochemical and sensory quality of dry-ripened venison sausages. *Meat Sci.* **97**, 575-582.
 40. Van Schalkwyk, D. L., McMillin, K. W., Booyse, M., Witthuhn, R. C., and Hoffman, L. C. (2011) Physico-chemical, microbiological, textural and sensory attributes of matured game salami produced from springbok (*Antidorcas marsupialis*), gemsbok (*Oryx gazella*), kudu (*Tragelaphus strepsiceros*) and zebra (*Equus burchelli*) harvested in Namibia. *Meat Sci.* **88**, 36-44.
 41. Yang, F., Kim, J. H., Yeon, S. J., Hong, G. E., Park, W., and Lee, C. H. (2015) Effect of dietary processed sulfur supplementation on water-holding capacity, color, and lipid profiles of pork. *Korean J. Food Sci. An.* **35**, 824-830.
 42. Younathan, M. T. and Watts, B. M. (1959) Relationship of meat pigments to lipid oxidation a, b. *J. Food Sci.* **24**, 728-734.
 43. Zhao, C. J., Schieber, A., and Gänzle, M. G. (2016) Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations-A review. *Food Res. Int.* **89**, 39-47.