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ARTICLE

Effect of Dietary Supplementation with Processed Sulfur on Meat Quality and Oxidative Stability in *Longissimus dorsi* of Pigs

Ji-Han Kim, Ha-Young Noh[1], Gyeom-Heon Kim[1], Go-Eun Hong, Soo-Ki Kim[1]*, and Chi-Ho Lee*

Department of Food Science & Biotechnology of Animal Resources, Konkuk University, Seoul 143-701, Korea
[1]Department of Animal Science & Technology, Konkuk University, Seoul 143-701, Korea

Abstract

The effects of dietary supplementation of processed sulfur in pigs according to the level provided during the fattening phase were examined. The pigs were divided into three groups: control (CON), non-sulfur fed pigs; T1, 0.1% processed sulfur fed pigs; T2, 0.3% processed sulfur fed pigs. Physicochemical and sensory properties, as well as meat quality and oxidative stability of the *Longissimus dorsi* muscle were investigated. The feeding of processed sulfur did not affect moisture and protein contents ($p>0.05$). However, the crude fat content of T2 was significantly decreased compared to CON ($p<0.05$), while the pH value of T2 was significantly higher than those of both CON and T1 ($p<0.05$). Cooking loss and expressible drip of T2 were also significantly lower than that of CON ($p<0.05$). The redness of meat from T1 was significantly higher than both CON and T2 ($p<0.01$). During storage, lipid oxidation of the meat from sulfur fed pigs (T1 and T2) was inhibited compared to CON. Examination of omega-3 polyunsaturated fatty acids revealed T2 to have significantly higher content than CON ($p<0.05$). In the sensory test, the juiciness and overall acceptability of T2 recorded higher scores than CON. This study demonstrated that meat from 0.3% processed sulfur fed pigs had improved nutrition and quality, with extended shelf-life.

Keywords: sulfur, polyunsaturated fatty acids, meat quality, lipid oxidation

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Introduction

Recently, high-quality meat products containing high-quality protein, fatty acid compositions, vitamins and minerals have been considered as an important parameter of consumer preference (Pethick *et al*., 2011; Scollan *et al*., 2006). Improvement of meat quality upon the feeding of natural food additives to animals for the development of sensory and nutritional properties has been noted, while increment of the oxidative stability of meat has also been examined in the meat industry (Kim *et al.*, 2013; Rossi *et al*., 2013). Some researchers indicated that mineral supplementation resulted in enhancement of enzyme activities, connected with metabolic processes, as well as increased growth performance and high meat quality (Pogge *et al*., 2013a; Pogge *et al*., 2013b; Ruiz *et al*., 2008; Skrivan *et al*., 2000).

Sulfur, an essential mineral, has also been examined for therapeutic applications in the treatment of metabolic diseases (Jacob, 2006; Parcell, 2002). The transsulfuration pathway is well known as one of the most important metabolic pathways, related to both the synthesis of sulfur-containing amino acids and the oxidative stress defense system (Mosharov *et al*., 2000; Persa *et al*., 2004). Truong *et al*. (2006) and Pogge *et al*. (2013a) found that excess sulfur caused decrease in glutathione, and could increase the amount of antioxidant enzymes, such as superoxide dismutase, catalase, and glutathione peroxidase, in beef and rat. Multiple antioxidant metabolisms, including glutathione peroxidase and Reactive Oxygen Species (ROS) scavenging, are associated with elemental sulfur (Battin *et al*., 2009). Various roles of sulfur have been recognized, such as inclusion in amino acids, in addition to the activities of sulfur-related enzymes and biomolecule metabolism (Komarnisky *et al*., 2003). Though sulfur should be processed to remove its toxicity, In *et al.* (2012) developed and validated a method for detoxification through animal experiment.

In the animal industry, the positive and negative effects

*Corresponding author: Chi-Ho Lee, Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 143-701, Korea. Tel: +82-2-450-3681, Fax: +82-2-453-1948, E-mail: leech@konkuk.ac.kr; Soo-Ki Kim, Department of Animal Science and Technology, Konkuk University, Seoul 143-701. Korea, Tel: +82-2-450-3728, Fax: +82-2-458-3728, E-mail: sookikim@konkuk.ac.kr

of sulfur have gained much attention, with examination of dietary sulfur fed pigs, cattle and chicks for improvement of meat quality and growth performance (Kim *et al*., 2014a; Kim *et al*., 2014b; Park *et al*., 2003). In addition, the supplementation of dietary sulfur to pigs and cattle displayed increase in the ratio of polyunsaturated fatty acid to saturated fatty acid, as well as sulfur-containing antioxidants contents such as methionine and cysteine (Lee *et al*., 2009; Lee *et al*., 2013; Richter *et al*., 2012; Song *et al*., 2013). A few reports have shown the effects of feeding diets containing plentiful sulfur content to cattle on the shelf life and tenderness of meat (Depenbusch *et al*., 2009; Koger *et al*., 2010).

The objective of the present study was to investigate the effectiveness of processed sulfur supplementation to pig for improvement of the physicochemical properties, meat quality and shelf life of *Longissimus dorsi* (LD) muscle. Sensory evaluation of cooked pork was also conducted to determine the influence of dietary processed sulfur on sensory attributes.

Materials and Methods

Animals and experimental design

A total of 90 three-way crossbred pigs with an average live weight of 93.2±0.14 kg at the age of 144 d were randomly assigned to one of three treatment groups on the basis of weight, so that each treatment had 30 pigs arranged in three replicates of 10 pigs for 30 d (n=10 in each pen, three replicate pens per treatment). A commercial composition (Dongaone, Co.) was used as the experimental basal diet. The chemical composition of the diets was analyzed using the AOAC methods (1995), and listed in Table 1. Processed sulfur used in the T1 and T2 diets was prepared as a powder and mixed with the basal diet. The experimental diets were designed to complete the nutrient requirements for all breeding phases (NRC, 1998), and were given to the pigs ad libitum. The three dietary treatments were made up as follows: 1) the control group (CON), fed the basal diet; 2) the T1 group, fed basal diet with processed sulfur at 1 g/kg feed; 3) the T2 group, fed basal diet with processed sulfur at 3 g/kg feed. Experimental treatments were fed during the fattening phase, for 30 d before slaughter. The sulfur was processed for detoxification according to the method of In *et al*. (2012). The processed sulfur, purchased from Jungmin Co., Ltd (Korea), contained 97.93% elemental sulfur, a registered single ingredient at the Korea Feed Ingredients Association (KFIA). The animals were cared for following the guidelines of the animal policy of Konkuk University (Korea). The pigs of the three treatments were slaughtered at the live weight of 120±9 kg. All pigs were slaughtered on day 174 at the abattoir of the Yang-ju Federation of Livestock Cooperatives in the Republic of Korea. The carcass traits of the experimental pigs were recorded as follows: average daily gain (ADG), 0.86±0.07 kg; average daily feed intake (ADFI), 32.56±0.72 kg; carcass weight, 101.01±6.34 kg (Kim *et al*., 2014a). Following the 24 h chilling process, the *longissimus dorsi* muscle of all pigs was removed from the carcass (n=90). The collected *longissimus dorsi* were then transported on ice back to the laboratory at Konkuk University. The proximate compositions, pH, cooking loss, expressible drip, color and TBARS were measured immediately upon arrival. The other separated muscles were stored in vacuum packaging at -20°C until analyzed for fatty acid and free

Table 1. Formula and chemical compositions of basal diets in fattening pigs (% DM basis)

Ingredients	Basal diet[1)]
Corn	40.92
Wheat	28
Rice bran	2
Soybean meal	17.1
Rapeseed meal	3
Corn germ meal	2.5
Animal fat and oil	2.07
Molasses	2
Limestone	0.99
Calcium phosphate	0.19
Salt	0.3
Lysine 25% (liquid)	0.44
Threonine 98% (powder)	0.04
Choline chloride 50% (powder)	0.1
Vitamin/Mineral/etc[2)]	0.35
Total	100
Chemical composition (%)	
Crude protein	16.0
Crude fat	4.48
Crude fiber	3.99
Crude ash	4.03
Calcium	0.40
Phosphorus	0.80
Total lysine	0.86
DE (Mcal/kg)[3)]	3.45

[2)]Vitamin/Mineral/etc, supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se, 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, and 12 mg antioxidant.
[3)]Digestible energy.

amino acid composition.

Proximate composition

The moisture and ash of all samples were measured using official methods (AOAC, 1995). Crude fat was measured by Soxhlet extraction (AOAC, 1995), while crude protein content was determined by Kjeldahl's method (AOAC, 1995).

pH, cooking loss and expressible drip

The pH of the samples was measured with a pH meter (pH 900, Precisa Co, Switzerland). For measurement, 2 g samples were homogenized with 18 mL of distilled water for 90 sec using a Bag mixer 400 (Interscience Co, St Nom la Bretêche, France).

For determination of cooking loss, a fresh 30-mm-thick slice from each sample was weighed (50±5 g), placed in a plastic bag and cooked to an internal temperature of 70°C for 1 h. Cooked samples were allowed to cool for 30 min before blotted dry and weighed. Cooking loss of the meat was calculated using the following equation:

Cooking loss (%) = (weight of raw sample – weight of cooked sample) / weight of raw sample × 100

The measurement of expressible drip was carried out according to the method of Schilling *et al.* (2000), with slight modifications. Weighed samples (A) were first sandwiched between Whatman No. 1 filter papers. A 0.5 g weight was then placed on top within 30 min and held there for 2 min. The refrigerated samples were placed at room temperature (25°C) for 20 min, and then pressed at 100 tons/m^2 using a hydraulic press (Ilshintech. Co., LTD, Korea). Finally, the samples were removed and weighed (B), and the drip under pressure was determined as [(A − B) / A] × 100 (Hasegawa, 1987).

Determination of Thiobarbituric Acid Reactive Substances (TBARS)

TBARS values of the LD muscles stored for different periods of time (0, 2, 5 and 7 d) were determined according to a method modified from Witte *et al*. (1970). Briefly, 2 g samples were homogenized with 10 mL of 10% trichloroacetic acid for 60 sec. The homogenized samples were then mixed with 10 mL distilled water. The mixture was filtrated through Whatman No. 1 filter paper, and then 5 mL of 2-thiobarbituric acid was added to the supernatant. After heating for 10 min, the absorbance was recorded at 532 nm using a spectrophotometer (Optizen 2120 UV, Mecasys, Korea). TEP (1,1,3,3-Tetraethoxypropane) was used as a positive control for construction of the standard curve. The TBARS values were calculated as malondialdehyde (MDA) mg/kg.

Measurement of Color

After placement of all samples at room temperature (25 °C) for 30 min, the color of the meat was measured using a colorimeter (NR-300, Nippon Denshoku, Japan). The machine was calibrated with a white plate (CIE L*= +94.48, a*=-0.67, b*=+3.31). Values of CIE L* (lightness), CIE a* (redness), and CIE b* (yellowness) were expressed.

Fatty acids

The fatty acid analysis was conducted using the method presented in AOAC (1995). Lipid extraction was performed following the method of Folch *et al.* (1957), with slight modifications. In brief, 25 mg 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 at 0.3 mg/mL, as an internal standard, was added 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 um) was used with a flame ionization detector.

Free amino acids

Analysis of the free amino acids in the meat was carried out by the method of Mikami *et al.* (1994). Each sample (5 g) was homogenized with distilled water (90 mL) for 1 min. After centrifugation for 20 min at 10,000 g at 0°C, the supernatant was filtered through Whatman No. 5 and the samples were diluted 1:1 with 4 % trichloroacetic acid. The diluted samples were incubated at 37°C for 30 min, and then filtered again with Whatman No. 5, repeatedly. The filtrate was then subjected to a final filtration with a 0.45 um Millipore filter. Each of the filtered samples was analyzed using a fully automated amino acid analyzer, HIT-ACHI L-8800A (Hitachi Ltd., Japan).

Sensory evaluation

Panelists (n=13) were selected from a descriptive panel with previous experience in sensory analysis studies. After placement of the refrigerated raw meat at room temperature (2°C) for 20 min, the color and marbling score of the meat was tested. The raw meat was then cooked for 30 min to a core temperature of 70°C and allowed to cool for 30 min before serving to the panel. The samples were cut into cube shapes (1.5 cm × 1.5 cm) for each panel. The trained panelists (n=13) performed the analysis following the method of Mur and Yuste (2003). The sensory test progressed in two trials per panel, resulting in the collection of a total of 26 responses. In the quantitative response scale test (ISO 4121: 2003E), each sensory trait was assessed on a 9-point hedonic scale, including evaluation of color (1 = very undesirable to 9 = like extremely), marbling (1 = extremely low content to 9 = extremely high content), juiciness (1 = extremely dry to 9 = extremely juicy), flavor (1 = dislike extremely to 9 = like extremely) and overall acceptability (1 = dislike extremely to 9 = like extremely).

Statistical analysis

Statistical analyses of all data were conducted using SPSS (SPSS/PC Statistics 18.0 SPSS Inc., 2009). In addition, orthogonal polynomials were used to determine the linear and quadratic effects of processed sulfur concentration. The pen was provided as the experimental unit in the analyses. Values were expressed as mean±standard deviation of each pork loin batch. Differences between the groups regarding proximate compositions, pH, water activity, color, cooking loss, expressible drip, TBARS, free amino acids, fatty acids of mean and sensory evaluation were tested using Tukey's test ($p<0.05$), and trends were declared at $p<0.1$. In addition, differences in the mean TBARS values between time periods were tested for using Tukey's test ($p<0.05$).

Results and Discussion

Physicochemical properties

The effects of the processed sulfur diets on proximate composition, pH, cooking loss, expressible drip, and color of the meat are summarized in Table 2. Significant differences were not detected in moisture and protein contents among CON, T1, and T2 ($p>0.05$). However, the crude fat content of T2 was significantly lower than that of CON, while the ash of T2 was significantly higher than that of CON ($p<0.05$). A similar observation of decreased lipid content in meat due to diet sulfur was reported in chicks (Park *et al*., 2003). Moreover, Kim *et al.* (2014a) reported higher moisture content and lower fat content of dry cured ham from sulfur fed pigs compared to pigs fed a basal diet.

The pH differences of meat are based on various factors, including different muscles and diet composition. The pH of meat is determined by lactic acid accumulation, generated from postmortem glycolysis (Monin *et al*., 1987; Sales *et al*., 1996). The pH plays important roles in determining the water holding capacity and tenderness of the meat (Bouton *et al*., 1971). Herein, T2 was found to have a significantly higher pH than both CON and T1 ($p<0.05$). The cooking loss and expressible drip of T2 were also significantly lower than those of CON ($p<0.05$). The diet processed sulfur also appeared to influence the water holding capacity of the meat. Improvement of the water holding capacity of sulfur fed pigs was reported by Lee *et al*.

Table 2. Changes in proximate composition and physiochemical properties of pork loin from pigs fed processed sulfur

Contents	Treatment			P-value	
	CON	T1	T2	Linear	Quadratic
Proximate compositions (%)					
Moisture	71.54±0.98	71.59±0.47	71.81±0.44	0.50	0.61
Crude protein	24.84±1.07	25.52±1.06	23.46±1.54	0.20	0.17
Crude fat	4.41±1.33^{a}	2.81±0.59^{ab}	2.45±0.22^{b}	0.06	0.34
Ash	1.20±0.03^{b}	1.19±0.01^{b}	1.25±0.01^{a}	0.01	0.03
Item					
pH	5.52±0.05^{b}	5.71±0.04^{a}	5.72±0.07^{a}	0.03	0.05
Cooking loss (%)	32.70±0.60^{a}	32.91±0.44^{ab}	31.90±0.35^{b}	0.09	0.12
Expressible drip (%)	37.86±1.46^{a}	35.31±1.21^{b}	35.04±0.27^{b}	0.02	0.19
CIE L*	58.15±2.99	56.36±0.55	53.49±2.51	0.37	0.05
CIE a*	6.92±0.56^{c}	9.25±0.60^{a}	8.06±0.28^{b}	0.03	0.003
CIE b*	8.31±0.65	8.51±1.23	7.07±1.07	0.18	0.29

[1)]CON, commercially formulated feed; T1, control diet+0.1% processed sulfur; T2, control diet+0.3% processed sulfur.
[a-c]means within a row with different letters are significantly different at $p<0.05$.

(2009).

Lightness (CIE *L**) showed a decreasing tendency with increasing levels of dietary processed sulfur. The meat of sulfur fed pigs was reported to have increased absorption of Fe, while the lightness of the meat displayed a negative correlation with iron content (Lee *et al.*, 2009; Zembayashi *et al.*, 1999). The redness (CIE *a**) of the meat from processed sulfur fed pigs (T1 and T2) was significantly higher than that of CON ($p<0.01$). Mortimer *et al*. (2014) suggested that the redness of meat also had a relationship with iron content. Therefore, providing dietary sulfur to pigs may influence the heme-Fe binding in myoglobin. Nevertheless, the redness of T2 was significantly lower than that of T1. When sulfur atoms bind to myoglobin under the place of oxygen, green-pigmented sulfmyoglobin is formed (Nichol *et al*., 1970). Pogge *et al*. (2013a) reported that increasing the sulfur content in the diet induced sulfmyoglobin formation in the blood of steers. Yellowness (CIE *b**) showed no significant differences among the three groups (CON, T1 and T2, $p>0.05$). The color of meat is known to be determined by factors such as the reaction between myoglobin and oxygen, enzymes, temperature, and pH, and is dependent on the diet composition (Dugan, 1999; Lawrie, 1985).

Lipid oxidation

Changes in the TBARS values of the samples during refrigerated storage at 4°C are shown in Table 3. The TBARS values of all groups increased significantly during storage ($p<0.001$), although T1 and T2 had significantly lower values compared to CON ($p<0.001$) after 5 and 7 d. Several studies demonstrated the inhibition of lipid oxidation in meat from sulfur fed pigs during storage (Kim *et al*., 2014a; Lee *et al*., 2009). According to Mcbean (2011), glutathione, a powerful antioxidant enzyme, was formed in such cases via the transsulfuration pathway. Hydroperoxide is formed from a free radical chain mechanism in the presence of oxygen, and the TBA value was reported to have a positive correlation with the amount of breakdown products from hydroperoxide, such as volatiles compounds, alcohols and ketones (Ahn *et al*, 1999; Frankel, 1980). Inhibition of the chain reaction of lipid oxidation due to the formation of methionine sulfoxide from the reaction between sulfur atom of methionine and hydroperoxide was also reported previously (Natake *et al*., 1973; Slump *et al*., 1973). This result could be related to the antioxidant effect in the meat from sulfur fed pigs. Besides, sulfur compounds are also well known for increasing radical scavenging ability (Laggnera *et al*., 2005; Nuutila *et al*., 2003). Therefore, the lipid oxidation of pork from sulfur fed pigs would be retarded during storage.

Free amino acids

The free amino acid composition of pork from pigs fed processed sulfur is shown in Table 4. Free amino acids are typically evaluated as prospective biochemical indicators of the quality of the pork (Flores *et al*., 2000), as they play important roles in the determination of specific tastes. The generation of free amino acids mostly occurs through post-mortem protein degradation by protease activities (Nishimura *et al*., 1988; Toldra *et al*., 2000). In particular, tyrosine and phenylalanine showed tendencies of inclination along with the levels of dietary processed sulfur provided. Tyrosine and phenylalanine are well known aromatic amino acids with high heat stability (Gatellier *et al*., 2009). According to Pogge *et al*. (2013b), increasing dietary sulfur contributed to the revitalization of protease activities, such as troponin T degradation and *u*-Calpain autolysis. In the current study, the addition of processed sulfur to diets (T1 and T2) tended to increase the total free amino acids. Nishimura *et al.* (1988) suggested that total free amino acids can be considered as an important component determining taste in meat. Wu *et al*. (2003) also indicated that increase of free amino acids

Table 3. Changes in TBARS of pork loin from pigs fed processed sulfur, occurring during cold storage at 4°C (unit : malondialdehyde mg/ kg)

Period (d)	Treatment[1)]			P-value	
	CON	T1	T2	Linear	Quadratic
0	0.036 ± 0.01^{D}	0.031 ± 0.01^{D}	0.033 ± 0.01^{D}	0.60	0.54
2	0.045 ± 0.01^{C}	0.034 ± 0.01^{C}	0.036 ± 0.01^{C}	0.30	0.39
5	0.131 ± 0.01^{aB}	0.075 ± 0.02^{bB}	0.055 ± 0.02^{cB}	<0.001	0.015
7	0.182 ± 0.01^{aA}	0.104 ± 0.01^{bA}	0.054 ± 0.01^{cA}	<0.001	0.020
P-value	<0.001	<0.001	<0.001		

[1)]CON, commercially formulated feed; T1, control diet +0.1% processed sulfur; T2, control diet+0.3% processed sulfur.
[a-c]means within a row with different letters are significantly different at $p<0.05$.
[A-D]means within a column with different letters are significantly different at $p<0.05$.

Table 4. Free amino acid composition of pork from pigs fed processed sulfur (mg/ 100 mL)

Item	Treatment			P-value	
	CON	T1	T2	Linear	Quadratic
Aspartic acid	2.12±0.47	2.18±0.17	2.09±0.27	0.95	0.77
Threonine	1.08±0.29	1.21±0.07	1.27±0.10	0.47	0.83
Serine	0.98±0.26	0.79±0.28	1.08±0.07	0.34	0.18
Glutamic acid	2.89±0.72	2.89±0.06	2.88±0.71	0.54	0.28
Proline	0.84±0.23	1.14±0.09	1.22±0.39	0.25	0.57
Glycine	0.93±0.15	1.03±0.09	1.03±0.05	0.48	0.57
Alanine	1.08±0.13	1.23.0.08	1.24±0.16	0.31	0.49
Cysteine	0.34±0.05	0.32±0.05	0.27±0.04	0.20	0.73
Valine	0.97±0.18	1.06±0.03	1.16±0.03	0.17	0.98
Methionine	0.64±0.03^{a}	0.57±0.04^{ab}	0.52±0.03^{b}	0.18	0.02
Isoleucine	0.93±0.21	1.09±0.07	1.17±0.04	0.15	0.70
Leucine	1.72±0.34	2.00±0.30	2.21±0.15	0.16	0.86
Thyrosine	0.72±0.20	0.93±0.10	1.05±0.18	0.13	0.20
Phenylalanine	0.86±0.15	1.08±0.09	1.18±0.26	0.16	0.68
Histidine	1.03±0.19	1.14±0.03	1.10±0.07	0.53	0.38
Lysine	1.93±0.34	2.22±0.15	2.30±0.13	0.19	0.52
Arginine	1.35±0.34	1.62±0.04	1.64±0.06	0.22	0.43
Total free amino acids	20.42±3.98	24.15±4.99	23.48±0.76	0.09	0.77

[1)]CON, commercially formulated feed; T1, control diet+0.1% processed sulfur; T2, control diet+0.3% processed sulfur.
[a-c]means within a row with different letters are significantly different at $p<0.05$.

and peptides due to protein hydrolysis had a positive correlation with antioxidant properties. However, in spite of the processed sulfur supplementation, the amount of methionine in T2 was significantly lower than that of CON ($p<0.05$). In addition, cysteine content also showed a declining tendency according to the increase in sulfur supplementation. Therefore, the feeding of processed sulfur to pigs seems to interfere with the metabolism of sulfur-containing amino acids.

Fatty acid composition

The fatty acid composition of pork from pigs fed processed sulfur is shown in Table 5. No significant differences in saturated fatty acids (SFA) were found among the three groups ($p>0.05$). However, the total monounsaturated fatty acids (MUFA) was significantly higher in T2 than in CON ($p<0.05$). In particular, the groups fed processed sulfur showed lower levels of palmitoleic acid (C 16:1n7) and oleic acid (C18:1n9). The decreases in these two fatty acids were associated with suppression of desaturase activity, which prevented the formation of MUFA (Ayerza *et al*., 2002). Hence, the desaturase activity of T1 and T2 may have been inhibited due to the dietary processed sulfur provided to the pigs. Moreover, the total polyunsaturated fatty acid (PUFA) content showed an increasing tendency with increasing levels of processed sulfur ($p<0.1$). Furthermore, T2 had significantly higher amounts of omega 3 polyunsaturated fatty acid than CON ($p<0.05$). According to Lorgeril and Salen (2012), the intake of omega 3 fatty acid confers anticancer effects, while also displaying reduction of cardiovascular disease. Likewise, the ratio of PUFA to SFA is considered as an indicator of the nutritional quality of meat. Both processed sulfur fed pigs (T1 and T2) showed higher ratios (0.26-0.33) compared to the control group (0.24). The Department of Health (1994) recommended that higher intake ratio of PUFA to SFA could reduce the risk of disease.

Sensory evaluation

The results of the sensory evaluation of pork according to the level of processed sulfur provided in the diet are shown in Table 6. Significant differences were not found in the color evaluation among CON, T1 and T2 ($p>0.05$); however, the marbling score of CON was significantly higher than that of both T1 and T2 ($p<0.05$). In the aroma evaluation herein, a tendency of inclination was observed according to the level of sulfur supplementation. The increased aromatic free amino acids (Threonine and tyrosine) could be responsible for improving the aroma evaluations of T1 and T2 (Gatellier *et al*., 2009). The juiciness of T2 was also significantly higher than that of CON ($p<0.05$). When compared to the results of the decreased cooking loss of T1 and T2, the higher juiciness score of the sulfur fed groups could be influenced by the water holding

Table 5. Fatty acid composition of pork from pigs fed processed sulfur

Item	Treatment			P -value	
	CON	T1	T2	Linear	Quadratic
C14:0	1.52±0.24	1.64±0.17	1.36±0.13	0.33	0.19
C16:0	27.12±0.98	27.62±1.07	26.39±0.43	0.35	0.21
C18:0	16.18±1.01	16.04±0.76	16.56±1.68	0.72	0.72
Total SFA	44.82±1.49	45.30±1.96	44.50±1.55	0.82	0.61
C16:1n7	2.70±0.48	2.77±0.12	2.42±0.51	0.44	0.50
C18: 1n9	40.56±0.69	38.84±1.47	36.63±2.90	0.05	0.86
C20: 1n9	0.92±0.15	0.89±0.07	0.95±0.07	0.80	0.57
Total MUFA	44.19±0.81^{a}	42.50±1.53^{ab}	39.99±.2.99^{b}	0.04	0.78
C18:2n6	8.48±0.84	9.15±2.59	11.8±1.68	0.07	0.48
C20: 2n6	0.46±0.03	0.57±0.13	0.59±0.14	0.22	0.58
C20: 4n6	1.30±0.25	1.43±0.50	1.79±0.76	0.33	0.77
Total w6	10.24±1.10	11.14±2.92	14.37±2.85	0.08	0.53
Total w3	0.36±0.03^{b}	0.53±0.16^{ab}	0.58±0.07^{a}	0.03	0.33
Total w6/w3	28.47±3.76	21.30±5.95	25.22±7.12	0.192	0.22
Total PUFA	10.60±1.09	11.68±3.00	14.94±2.81	0.081	0.55
PUFA/SFA	0.24±0.03	0.26±0.08	0.33±0.07	0.099	0.56

[1)]CON, commercially formulated feed; T1, control diet+0.1% processed sulfur; T2, control diet+0.3% processed sulfur.
[a-c]means within a row with different letters are significantly different at $p<0.05$.

Table 6. Sensory characteristics of pork loin from processed sulfur fed pigs

Parameters	Treatment		
	CON	T1	T2
Color	5.56±1.59	4.67±2.60	4.78±1.30
Marbling score	7.11±0.78^{a}	3.78±1.09^{b}	1.66±1.00^{c}
Aroma	4.71±0.76	5.28±1.11	5.57±2.15
Juiciness	3.67±1.5^{b}	4.11±1.69^{ab}	5.67±2.06^{a}
Overall acceptability	4.80±0.83^{b}	5.40±0.89^{ab}	6.20±1.10^{a}

[1)]CON, commercially formulated feed; T1, control diet+0.1% processed sulfur; T2, control diet+0.3% processed sulfur. [a-c]means within a row with different letters are significantly different at $p<0.05$.

capacity. As a result, the overall acceptability score of T2 was significantly higher than that of CON ($p<0.05$).

Conclusion

The feeding of processed sulfur to pigs significantly enhanced the oxidative stability, meat quality and sensory properties. Because the fat content was decreased and the composition of fatty acids was affected by the feeding of processed sulfur to allow higher quality, improvement of the nutritional properties of the pork from processed sulfur fed pigs was obtained. The meat from processed sulfur fed pigs showed lower TBARS throughout the 7 d of storage under the refrigerated condition. Additionally, the expressible drip and cooking loss in T2 were lower than that of the control group. The supplementation with processed sulfur may increase water-holding capacity of meat. In sensory evaluation, T2 had the highest score for juiciness. Consequently, the supplementation with processed sulfur to pigs may be helpful for the meat industry, as well as consumers.

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