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ARTICLE

Effect of Substitution of Fermented King Oyster Mushroom By-Products Diet on Pork Quality during Storage

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Abstract

This study was carried out to investigate the effects of substitution of fermented king oyster mushroom (*P. eryngii*) by-products diet on pork meat quality characteristics, during the storage. A mixture of 40% king oyster mushroom by-products, 28% soybean meal and 20% corn was fermented for 10 d, and the basal diet was then substituted by the fermented diet mixture of up to 20, 50 and 80%, respectively. A total of 96 pigs were fed experimental diet (8 pigs per pen × 4 diets × 3 replication), and eight *longissiumus* (LD) per treatment were collected, when each swine reached to 110 kg of body weight. The Warner-Bratzler shear forces and cooking loss were significantly lowered in the treatments, while crude protein content and water holding capacity significantly (p<0.05) increased in the treatments than in the control group. The volatile basic nitrogen (VBN), at 1 d of storage, was lower in the treatments, while texture profiles and sensory evaluation did not differ between the control and the treatments (p>0.05). The pH, thiobarbituric acid reactive substances (TBARS), VBN and meat color in all treatments were increased as storage increased. Fermented king oyster mushroom by-products diet effects on lightness (CIE L*), yellowness (CIE b*) and chroma were determined, when LD muscles in T2 and T3 treatments were higher (p<0.05), up to 7 d (p<0.05). Therefore, the results indicate that the substitution of the fermented king oyster mushroom by-products diet to swine diet influenced the quality of the meat and it may be an economically valuable ingredient.

Key words: by-products, fermented diet, king oyster mushroom, meat quality, swine

Introduction

Due to increased health conscious consumers in food market, rapid development in mushroom industry is performed and mushroom is produced up to 1.90 million ton per year in Korea (Kim *et al*., 2007). The amount of mushroom by-products has also been sharply increased, and many mushroom planters tried to find a way to dispose mushroom by-products right after cultivation. It may generate problems in near future. Therefore, the use of mushroom by-products must be considered. The media used for mushroom cultivation mainly contain cotton waste, corn cob and rice straw with a small amount of rice bran, wheat bran, beet pulp and dried okara (Bae *et al*., 2006). These can be considered as dietary ingredients due to available nutrients. According to a paper conducted by Williams *et al*. (2001), the mushroom cultivation media contain approximately 80% available nutrients because the mushroom uses only 20% of the nutrients in the cultivation media. However, the mushroom by-products can easily be contaminated by fungi and bacteria (Kim *et al*., 2007), and such deterioration is due to high content of moisture in mushroom cultivation media (Kwak *et al*., 2008). Enhanced storage condition for mushroom by-products must be supplied, the use of mushroom by-products in Korea will be limited.

Fermentation is a relatively cost-effective and a low energy preservation process, ensuring the shelf-life and microbiological safety of the products (Liu *et al*., 2011). Fermented diet has been subjected to the actions of the microorganism or enzyme, so desirable biochemical changes can be generated. Steinkraus (1996) reported that fermentation has played at least five different roles including i)

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enrichment of the diet through development of a diversity of flavors, aromas and textures in substrates; ii) preservation through lactic acid, alcoholic, acetic acid and alkaline fermentations; iii) biological enrichment of substrates with proteins, essential amino acids, essential fatty acids and vitamins; iv) detoxification during fermentation processing and v) decrease in cooking times and fuel requirements. Lactic acid bacteria (LAB) are the most common microorganism in the fermented diet, and their crucial function is mainly associated with their physiological features, including substrate utilization, metabolic capabilities and pro-biotic properties (Liu *et al*., 2011). Therefore, the LAB (e.g. *Lactobacillus plantarum*) was selected as a microorganism applied to this experiment.

Fermented by-products diet sources were used, such as oyster mushroom by-products (Song *et al*., 2007), co-products of apple (Lee *et al*., 2009) and agro by-products (Kang *et al*., 2010). King oyster mushroom (*P. eryngii*), a major mushroom produced in Korea, is rich, thereby, the use of by-products production due to increased King oyster mushroom cultivation must be considered. Commonly, the king oyster mushroom by-product diet fermented by *L. plantarum* and *Saccharomyces cerevisiae*, improved the crude protein (CP) content and total calorie at the end of fermentation as compared to that of initial fermentation. In spite of this, the fermented diet decreased the growth performance of swine and economically unacceptable (Song et al., 2011). Due to a study conducted by Chu *et al*. (2011), the fermented diet improved carcass grade in swine, and it seems that the fermented diet is now economically valuable. Therefore, this study was conducted to investigate the effects of fermented king oyster mushroom (*P. eryngii*) by-product diet on the pork meat quality characteristics during 1 and 7 d of storage.

Materials and Methods

Animal and diet

Pigs at the age of 130 d and average body weight (BW) of 73.15±6.77 kg were used, and total 96 pigs were randomly assigned to four different treatments based on BW and gender ($8 \times 3 \times 4 =$ pigs × replication × treatments; 4 female and 4 barrow per treatment). In order to provide a fermented king oyster mushroom by-products diet, 40.0% king oyster mushroom (*P. eryngii*) by-products, 28.0% soybean meal, 20.0% corn, 9.82% rice bran, 1.0% sugar, 1.0% corn oil, 0.08% cellulose and 0.1% probiotics were mixed. For the 0.1% probiotics addition, 3.0×10^7 CFU lactic acid bacteria (*L. plantarum*), 2.0×10^7 CFU *Enterococcus faecium* and 2.0×10^7 CFU yeast (*S. cerevisiae*) per gram were used. After 24 h of the mixing process, the mixture was transferred to anaerobic plastic containers and then fermented at room temperature for 10 d.

All pigs were fed with a basal diet (Control, C) containing 33.5% corn, 30.0% wheat and 12.5% soybean meal, and a diet substituted a basal diet to 20 (T1), 50 (T2) and 80% (T3) fermented king oyster mushroom by-products, respectively (Table 1). All pigs were slaughtered when they were reached at 110 kg at the end of feed trial. During the experiment, all actions were approved by the Committee on Animal Experimentation of Gyeongnam National University of Science and Technology and conducted in compliance with the Guide lines for the Care and Use of Laboratory Animals. Total 8 *longissiumus* (LD) (6th to 13th rib) from each treatment was collected and used for the determination of chemical composition and sensory evaluation. Additionally, to determine the pH, thiobarbituric acid reactive substances (TBARS), volatile basic nitrogen (VBN) and parameters of meat color, every

Table 1. Composition of experimental diet

Ingredient	Percentage (%)
Corn	33.50
Wheat	30.00
Soybean meal	12.50
Tallow	4.20
Wheat bran	4.00
Molasses	4.00
Rapeseed meal	3.00
Cotton seed meal	3.00
Palm kernel meal	2.00
Rice bran	1.00
Limestone	1.45
Calcium phosphate, tribasis	0.60
Sodium chloride	0.30
L-lysine hydrochloric acid	0.20
Vitamin premix[1)]	0.10
Trace mineral premix[2)]	0.10
Phytase	0.05
Chemical composition[3)]	
Crude protein	15.50
ME, Mcal/kg	3.22
Lysine	0.87
Calcium	0.70
Total phosphorus	0.50

[1)]Supplied per kilogram of diet: 4000 IU vitamin A, 3800 IU vitamin D, 1500 IU vitamin E, 150 mg vitamin K, 320 mg vitamin B_{12}, 11.0 mg niacin, 16.0 mg thiamin, 2.0 mg pantothenic acid, 8.0 mg riboflavin and 0.02 mg Biotin

[2)]Supplied per kilogram of diet: 100 mg Zn, 175 mg Fe, 90 mg Mn, 30 mg Cu, 0.50 mg Co, 0.20 mg Se and 0.30 mg I

[3)]Calculated values

sample was vacuum packaged, stored at 4°C and then used on day 1 and 7 of storage.

Determination of crude protein content, backfat surface color, water holding capacity and cooking loss

The Kjeldhal method (#984.13) of AOAC (1995) was used for crude protein determination. Approximately, 1 g of ground LD was weighed, added to a digestion flask, and a series of sample digestions and distillations was conducted. Each sample was then titrated with a sodium hydroxide and expressed as a percent (%).

Fat and meat color of LD were evaluated on freshly cut surface (3 cm thick slice) using a Chroma Meter CR-300 (Minolta, Osaka, Japan) after 20 min of blooming at the room temperature (RT). Five color measurements were carried out across individual sample surface, and the average was expressed as CIE L^*, CIE a^*, CIE b^*, Chroma and Hue angle. The Chroma Meter CR-300 was calibrated against a white tile (L^*=93.30, a^*=0.32 and b^*=0.33) based on a daily basis. Chroma (saturation) and Hue angle were calculated as $(a^{*2}+b^{*2})^{1/2}$ and arctan b^*/a^* (Wyszcecki and Stiles, 1982).

Both water holding capacity (WHC) and cooking loss were determined as described by Honikel (1998). Samples were cut (2.0 cm × 0.4 cm × 0.4 cm), weighed and placed in tubes with a filter to separate the meat from the expelled liquid in the bottom of the tubes. The samples were centrifuged (Combi-514R, Hanil, Incheon, Korea) at 40 *g* for 1 h at 4°C, and then the loss was calculated as the difference in weight before and after centrifugation. For the cooking loss, 80 g of 1.5 cm thick LD was placed in a polyethylene bag. The packages were then kept in a water bath (DS-23S, Dasol, Hwaseong, Korea) at 75°C for 1 h and cooled at RT for 30 min. The cooking loss percentage was determined using the muscle weight that was taken before and after cooking.

Determination of fatty acid composition

For the determination of fatty acids composition, total lipid was extracted using a modified Folch method as described by Ways and Hanahan (1964), and then saponification and esterification was conducted using a 0.5 N potassium hydroxide in methanol and 14% boron trifluoride methanol solution. Finally, the fatty acid methyl esters (FAME) in the hexane were injected to a gas chromatography (Agilent 6890+, Agilent HP, USA) fitted with a capillary column (HP-5MS capillary GLC column, 30 m × 0.32 mm i.d. 0.25 mm film thickness, Agilent HP, USA) and a mass spectrometry detector (G1530A, Agilent HP, USA). The mass spectrometry interface and injector temperature were fixed at 270°C and 260°C, respectively, and oven temperature was instituted to 160°C at 2.5 min, 160 to 260°C at 4°C per min and then 260°C at 5 min. Each fatty acid was identified by comparing their retention times with those of FAME standard (FAME Mix C8-C24, Supelco, PA, USA) and expressed as a percentage of standards.

Determination of WBSF, TPA and sensory evaluation

Warner-Bratzler shear force (WBSF) was determined as described by Honikel (1998). Each LD was prepared into a cube of 4 cm × 2.5 cm × 1.5 cm (length × width × height) and then cooked and cooled. The WBSF was measured using an Instron 3343 (US/MX50, A&D Co., USA) equipped with a Warner-Bratzler shearing device providing a 100 mm/min crosshead speed. The average shear force value from each treatment was calculated and expressed as kg/cm^2.

Texture profile analysis (TPA) of eight samples (2 cm × 2 cm × 2 cm) from each treatment was assessed using an Instron 3343 (US/MX50, A&D Co., USA) equipped with a cylindrically shaped plunger (5-mm diameter) and a 500-N load cell (Bourne, 1978; Szczceniak, 1963; Texture Technologies, 2003). To determine texture parameters including brittleness, hardness, cohesiveness, springness, gumminess, chewiness and adhesiveness, each cube sample was equilibrated to a room temperature and compressed twice to 50% of its original thickness at a constant speed of 60 mm/min. Texture profile parameters were calculated from the force deformation curves as follows: hardness (kg f; force necessary to attain a given deformation, maximum force), cohesiveness (dimensionless, ratio; ratio of the positive force area during the second compression to that during the first compression excluding the areas under the decompression portion of each cycle), springness (ratio; ratio of distances that the samples recover after the first compression), gumminess (kg f; simulated energy required to disintegrate a semisolid food to a steady state, hardness × cohesiveness) and chewiness (kg f; hardness × cohesiveness × springness).

For sensory evaluation, a total of 35 panelists were participated and conducted in duplicate on each sample. Training of panelists was performed according to a sensory evaluation guideline (Meilgaard *et al*., 1991). The meat samples were cooked to an internal temperature of 74°C in a water bath and then the samples were cut into 10 × 3 × 25 mm^3 pieces, placed on white plastic trays covered with aluminum foil and served immediately to each

panelist. The cooked meat samples were evaluated for color (1 = very unacceptable; 9 = very acceptable), off-flavor (1 = very weak; 9 = very strong), juiciness (1 = very dry; 9 = very juicy), flavor (1 = very unacceptable; 9 = very acceptable), tenderness (1 = very tough; 9 = very tender) and total acceptability (1 = very unacceptable; 9 = very acceptable).

Determination of pH, TBARS, VBN and meat color during storage

To determine the pH value, a 10 g sample was homogenized with a 90 mL of double distilled water (DDW) for 20 s at 13,500 rpm (T25B, IKA Sdn. Bhd., Malaysia). The pH meter (Hanna HI 9025, Woonsocket, RI, USA) with an Orion 8163 glass electrode (Berverly, MA, USA) was used, and duplicate reading per sample was performed. Prior to record the pH value, the pH meter was calibrated daily basis using standard buffers at pH 4.0 and 7.0.

The TBARS analysis described by Huang and Miller (1993) was performed to determine the degree of lipid oxidation. Three grams of each meat sample were weighed and mixed with a 57 mL phosphate buffer (pH 7.0). The mixtures were then homogenized at 12,000 *g* for 1 min (T25B, IKA Sdn. Bhd., Malaysia). The homogenized samples were incubated, cooled and centrifuged at 2,000 rpm for 15 min. The supernatants were collected, read, calculated and expressed as mg malonaldehyde/kg of LD muscle tissue.

The VBN analysis was conducted as described to Pearson (1976) and expressed as mg VBN/100 g of sample. Briefly, 1 g of sample and a few drops of phenolphthalein indicator were mixed with a 3.5 mL 20% sodium hydroxide solution in a distillated flask. The apparatus was tightly sealed, and steam distillate was collected in a flask containing a 20 mL 4% boric acid and a few drops of methyl red and methylene blue. The steam distillate was continuously collected until a 250 mL distillated flask was filled. The solution obtained was then titrated using a 0.01 M hydrochloric acid, and titration was stopped when the green color changed to gray. The final VBN calculation was accomplished based on a VBN value from a blank containing 6% perchloric acid steam distillation.

Statistical Analyses

For general data of LD from each treatment, data were analyzed with one-way ANOVA, and significant differences among diet types and sex were determined using Fisher's LSD method. Additionally, to determine data collected during storage, the changes in pH, TBARS, VBN and meat color were analyzed using a two-way ANOVA, and the model included sex, diet type and storage period. Significant differences were determined using Fisher's LSD method as well. All analyses were conducted using the General Linear Model (GLM) procedure of SAS (1999) and significant differences among the means were determined using the Duncan's Multiple Range Test method ($p<0.05$).

Results

Crude protein content, backfat surface color, cooking loss and water holding capacity

Crude protein content was not influenced due to the gender but affected by the diet (Table 2), and CP content was significantly increased in T2 and T3 than in C and T1 ($p<0.05$).

The substitution of fermented king oyster mushroom by-products diet to swine diet showed an influence on the lightness (CIE L^*) and the hue angle (Table 2), and the lightness was significantly higher in T3 as compared to that of others ($p<0.05$). Hue angel values were significantly higher in treatments than in C and were not different between treatments.

The substitution of fermented king oyster mushroom by-products diet had an effect on both cooking loss and WHC (Table 2). Cooking loss was significantly lowered when both T2 and T3 diets were fed to pigs, in contrast, WHC showed higher values in T2 and T3 treatments than in C and was significantly higher in T3 than C and T1 ($p<0.05$).

Fatty acid composition

The palmitic acid, stearic acid and linolenic acid composition were similar across treatments, while composition of myristic acid, oleic acid, linoleic acid and arachidonic acid were affected due to the substitution of fermented king oyster mushroom by-products diet (Table 3). It seems that high myristic acid was composed when fermented king oyster mushroom by-products diet was supplied to diet and then fed to pigs, however, lower composition was determined as fermented king oyster mushroom by-products diet was supplied to pigs for 52 d ($p<0.05$). Additionally, it appears that linoleic acid composition was not highly arranged but tended to compose more arachidonic acid in LD muscle as fermented king oyster mushroom by-products diets were fed to pigs ($p<0.05$). More saturated fatty acid (SFA) and less unsat-

Table 2. Crude protein content, backfat surface color, cooking loss and water holding capacity of swine *longissimus dorsi* muscle fed with different levels of fermented king oyster mushroom by-products diet

Items	Treatment[1)]				SEM[4)]	p	
	C	T1	T2	T3		Sex	Diet
Proximate Composition							
Crude protein (%)	21.13[b]	22.67[ab]	23.13[a]	23.07[a]	0.77	–	*
Backfat surface color[2)]							
Lightness (CIE L*)	78.82[b]	79.65[b]	79.53[b]	81.48[a]	1.82	–	*
Redness (CIE a*)	0.80	0.43	0.45	0.49	0.45	–	–
Yellowness (CIE b*)	8.89	8.21	8.35	8.51	0.80	–	–
Chroma	8.92	8.25	8.41	8.79	0.70	–	–
Hue angle	87.00[b]	93.81[a]	94.91[a]	93.58[a]	4.97	–	*
Physical property							
Cooking loss (%)	26.82[a]	23.74[ab]	22.93[b]	21.99[b]	4.02	–	*
WHC[3)] (%)	62.90[c]	63.49[bc]	67.42[ab]	68.32[a]	0.76	–	*

[1)]The basal diet was substituted by the fermented king oyster mushroom by-products diet: C, no substitution; T1, 20%; T2, 50% and T3, 80%.
[2)]Chroma, $(a^{*2}+b^{*2})^{1/2}$ and hue angle, b^*/a^*
[3)]Water Holding Capacity
[4)]Standard error of the means and * stands for $p<0.05$
[a,b,c]Mean values within a row followed by the same letter are not significantly different ($p>0.05$).
Each data point represents the mean of 8 observations (4 female and 4 barrow).

Table 3. Fatty acid profiles of swine *longissimus dorsi* muscle fed with different levels of fermented king oyster mushroom by-products diet

Items	Treatment[1)]				SEM[5)]	p	
	C	T1	T2	T3		Sex	Diet
C14:0	10.26[b]	14.46[ab]	22.43[a]	11.53[ab]	4.72	-	*
C16:0	22.82	22.54	21.03	21.76	1.15	-	-
C18:0	9.12	9.88	8.91	9.55	0.48	-	-
C18:1	41.33[a]	36.66[b]	33.89[b]	30.51[c]	3.94	-	*
C18:2	13.13[ab]	12.69[b]	10.09[b]	19.87[a]	5.31	-	*
C18:3	0.25	0.29	0.15	0.29	0.26	-	-
C20:4	3.10[b]	3.52[b]	3.50[b]	6.49[a]	1.33	-	*
SFA[2)]	42.20[b]	46.89[ab]	52.32[a]	42.85[b]	4.16	-	*
UFA[3)]	57.80[a]	53.11[ab]	47.62[b]	57.15[a]	4.16	-	*
EFA[4)]	13.35[b]	12.98[b]	10.24[b]	20.16[a]	7.12	-	*
UFA/SFA	1.37	1.16	0.93	1.34	0.16	-	-

[1)]The basal diet was substituted by the fermented king oyster mushroom by-products diet: C, no substitution; T1, 20%; T2, 50% and T3, 80%.
[2)]Saturated Fatty Acid = C14:0 + C16:0 + C18:0
[3)]Unsaturated Fatty Acid = C18:1 + C18:2 + C18:3 + C20:4
[4)]Essential Fatty Acid = C18:2 + C18:3
[5)]Standard error of the means and * stands for $p<0.05$
[a-c]Mean values within a row followed by the same letter are not significantly different ($p>0.05$).
Each data point represents the mean of 8 observations (4 female and 4 barrow).

urated fatty acid (UFA) were determined in T1 and T2 than those in C and T3 ($p<0.05$), and essential fatty acid composition was only differed in T3 ($p<0.05$).

Table 4. WBSF, texture profiles and sensory evaluation of swine *longissimus dorsi* muscle fed with different levels of fermented king oyster mushroom by-products diet

Items	Treatment[1)]				SEM[4)]	p	
	C	T1	T2	T3		Sex	Diet
WBSF[2)] (kg/cm^2)	4.41[a]	4.06[ab]	3.96[bc]	3.82[c]	0.47	-	*
Texture profile analysis							
Hardness	1.07	1.16	1.13	1.11	0.17	-	-
Surface hardness	1.00	1.10	1.08	1.11	0.17	-	-
Cohesiveness	0.37	0.46	0.39	0.40	0.09	-	-
Springness	1.00	1.14	1.08	1.12	0.11	-	-
Gumminess	0.39	0.56	0.43	0.45	0.14	-	-
Chewiness	0.39	0.64	0.47	0.52	0.20	-	-
Adhesiveness	0.20	0.20	0.15	0.17	0.05	-	-
Sensory evaluation[3)]							
Color	4.33	4.35	3.30	4.13	1.51	-	-
Aroma	4.23	4.10	4.48	4.27	0.89	-	-
Flavor	4.37	4.30	4.08	4.20	1.44	-	-
Tenderness	4.83	4.83	4.18	4.37	1.05	-	-
Texture	4.90	4.73	4.70	4.70	1.55	-	-
Overall acceptability	4.88	4.64	4.13	4.70	1.26	-	-

[1)]The basal diet was substituted by the fermented king oyster mushroom by-products diet: C, no substitution; T1, 20%; T2, 50% and T3, 80%.
[2)]Warner-Bratzler shear force
[3)]Sensory evaluation were scored on 9 point scale based on 1 (extremely bad) to 9 (extremely good).
[4)]Standard error of the means and * stands for $p<0.05$.
[a-c)]Mean values within a row followed by the same letter are not significantly different ($p>0.05$).
Each data point represents the mean of 8 observations (4 female and 4 barrow).

WBSF, Texture profile and sensory evaluation

The WBSF was significantly lowered in T2 and T3 than in C and had a lower value in T3 than in C and T1 (Table 4) ($p<0.05$). However, the partial substitution of fermented king oyster mushroom by-products diet to the swine diet did not affect texture profile and sensory evaluation of LD muscles (Table 4).

Changes of pH, TBARS and VBN during storage

The pH and TBARS at day 1 and 7 of storage were not affected due to the diet (Table 5) ($p>0.05$). However, the VBN at 1 d was significantly influenced by the substitution of fermented king oyster mushroom by-products diet, while VBN at 7 d was not affected. The VBN at day 1 of storage was significantly lowered in treatments than in C

Table 5. pH, TBARS and VBN of swine *longissimus dorsi* muscle fed with different levels of fermented king oyster mushroom by-products diet

Items	Storage periods	Treatment[1)]				P	
		C	T1	T2	T3	Sex	Diet
pH	1	4.62±0.02^{B}	4.69±0.15^{B}	4.79±0.17^{B}	4.56±0.14^{B}	–	–
	7	5.10±0.32^{A}	5.14±0.14^{A}	5.28±0.23^{A}	5.17±0.09^{A}	–	–
	p	*	*	*	*		
TBARS[2] (mg malonaldehyde/kg)	1	0.31±0.03^{B}	0.29±0.01^{B}	0.30±0.01^{B}	0.30±0.01^{B}	–	–
	7	0.36±0.02^{A}	0.36±0.08^{A}	0.35±0.02^{A}	0.32±0.02^{A}	–	–
	p	*	*	*	*		
VBN[3)] (mg/100g)	1	11.95±2.95^{aB}	6.40±0.27^{bB}	6.52±0.74^{bB}	6.72±1.96^{bB}	–	*
	7	34.33±5.13^{A}	40.40±4.75^{A}	40.25±7.01^{A}	35.07±1.10^{A}	–	–
	p	*	*	*	*		

[1)]The basal diet was substituted by the fermented king oyster mushroom by-products diet: C, no substitution; T1, 20%; T2, 50% and T3, 80%.
[2)]Thiobarbituric Acid Reactive Substances
[3)]Volatile Basic Nitrogen
[a-c]Mean values within a column followed by the same letter are not significantly different ($p>0.05$).
[A-C]Mean values within a row followed by the same letter are not significantly different ($p>0.05$).
Data represent the mean ± SD of 8 observations (4 female and 4 barrow).

Table 6. Meat color of swine *longissimus dorsi* muscle fed with different levels of fermented king oyster mushroom by-products diet

Items	Storage periods	Treatments[1)]				P	
		C	T1	T2	T3	Sex	Diet
Lightness (CIE L*)	1	53.59±1.44^{aB}	51.44±4.03^{abB}	49.59±2.51^{bB}	51.98±2.42^{ab}	–	*
	7	57.77±2.67^{aA}	55.38±1.46^{aA}	53.74±2.85^{bA}	54.53±2.71^{b}	–	*
	P	*	*	*			
Redness (CIE a*)	1	3.07±1.41	3.04±1.32	3.72±1.25	3.12±1.52	–	–
	7	3.47±0.89	3.58±0.84	3.17±0.97	2.95±1.04	–	–
	p	–	–	–	–		
Yellowness (CIE b*)	1	5.50±0.73^{B}	5.12±1.14^{B}	5.02±0.71^{B}	5.79±1.05	–	–
	7	6.99±0.68^{aA}	6.56±0.67^{aA}	5.77±0.69^{bA}	5.60±0.62^{b}	–	*
	p	*	*	*	–		
Chroma[2)]	1	6.37±1.23^{B}	6.06±1.27^{B}	6.02±1.33	6.32±1.80	–	–
	7	7.82±0.94^{aA}	7.49±0.86^{aA}	6.63±0.89^{b}	6.39±0.74^{b}	–	*
	p	*	*	–	–		
Hue angle[3)]	1	62.32±9.56	59.71±11.45	50.84±16.40^{B}	62.30±12.39	–	–
	7	63.90±4.49	61.69±5.08	61.69±6.87^{A}	62.60±8.75	–	–
	p	–	–	*	–		

[1)]The basal diet was substituted by the fermented king oyster mushroom by-products diet: C, no substitution; T1, 20%; T2, 50% and T3, 80%.
[2)]Chroma = $(a^{*2}+b^{*2})^{1/2}$
[3)]Hue angle = b^{*}/a^{*}
[a-c]Mean values within a column followed by the same letter are not significantly different ($p>0.05$).
[A-C]Mean values within a row followed by the same letter are not significantly different ($p>0.05$).
Data represent the mean ± SD of 8 observations (4 female and 4 barrow).

but did not differ between treatments. The pH and TBARS values were increase when LD muscles from all treatments were stored up to 7 d of storage ($p<0.05$) but significance was not determined between treatments ($p>0.05$).

Change of meat color during storage

The substitution of king oyster mushroom by-products diet affected lightness (CIE L^*) at 1 and 7 d of storage (Table 6) ($p<0.05$). Moreover, the diet affected yellowness (CIE b^*) and chroma at 7 d, while yellowness (CIE b^*) and chroma at 1 d were not influenced. It seems that the substitution of fermented king oyster mushroom by-products diet decreased the lightness (CIE L^*), yellowness (CIE b^*) and chroma as compared to those of LD muscle at day 1 of storage ($p<0.05$). However, the diet effects were not determined in the redness (CIE a^*) and hue angel during storage ($p>0.05$). Due to the effects of storage on LD color, lightness (CIE L^*) and yellowness (CIE b^*) in C, T1 and T2 were highly increased in 7 d than in 1 d ($p<0.05$). The LD muscles from C and T1 treatments had increased chroma values in 7 d of storage as compared to that of LD muscle stored up to day 1, and only hue angel of LD from T2 treatment showed a higher value when LD muscles were stored up to 7 d ($p<0.05$).

Discussion

The major purpose of this study was to investigate the effects of fermented king oyster mushroom (*P. eryngii*) by-product diet on the pork meat quality characteristics during storage. Substitution of fermented king oyster mushroom by-products diet increased CP content and WHC but decreased lightness (CIE L^*) and cooking loss (Table 2). Typically, the consumption of diet with high energy and fat increased pig backfat thickness (Pettigrew and Moser 1991), and the CP content increased due to decreased crude fat (CF) of meat (Shield *et al*., 1983). The fermented king oyster mushroom by-products diet had low energy (1.77 to 2.86 Mcal/kg ME) and fat (1.66 to 5.22% CF), and it seems that the CP content was affected due to the substitution of fermented king oyster mushroom by-products diet to a pig diet. Therefore, WHC increased and cooking loss decreased when fermented king oyster mushroom by-products diet was supplied to pigs for 52 d, and it is similar to results reported by Lee *et al.* (2009) and Kang *et al.* (2010). Animal breed, sex, age and feed are common factors influencing meat and fat color, and as mentioned, lightness (CIE L^*) of backfat surface was affected when fermented king oyster mushroom by-products diet was substituted up to 80%. It was similar to a result confirmed by Kang *et al.* (2010), and they indicated that high carbohydrate-low fat fermented diet increased lightness (CIE L^*) of meat in fattening pigs.

The 80% substitution of fermented king oyster mushroom by-products diet to basal diet increased the composition of linoleic acid, arachidonic acid and essential fatty acid in LD of fattening pigs (Table 3). Song *et al*. (2007) reported that fermented oyster mushroom by-products diet increased the composition of arachidonic acid in LD of Berkshire pigs, and fatty acid composition of meat is able to be influenced due to the diet (French *et al*., 2000). Therefore, the fermented king oyster mushroom by-products diet could be a reason of increased fatty acid composition including linoleic acid, arachidonic acid and essential fatty acid, respectively. The substitution of fermented king oyster mushroom by-products diet to the swine diet decreased WBSF, but any significant differences were not determined in texture properties and sensory evaluation as studied by Platter *et al*. (2003).

The pH and TBARS were not influenced due to fermented king oyster mushroom by-products diet (Table 5). However, pH and TBARS were affected when LD muscles were stored up to 7 d, and they were increased as storage period was elapsed. The VBN was also increased during storage, and effects of dietary fermented king oyster mushroom by-products diet were observed as LD muscles were kept at 4°C for day 1 of storage, only. The VBN concentration is an important index for estimation of meat freshness because it is increased by the levels of microbial contamination. Meat protein degraded into amino acids by protease and enzymes from microorganisms and amino acids degraded into inorganic nitrogen compounds when levels of microorganism contamination increased (Lee *et al*., 2006). Moreover, the CP content in LD muscle may positively be affected, but CP content did not provide any effects when LD muscles were stored on day 1 of storage, in contrast it seems that CP content was influenced on the generation of inorganic nitrogen compounds. As a result, similar VBN was determined at 7 d of storage.

The lightness (CIE L^*) and yellowness (CIE b^*) in LD of C, T1 and T2 treatments increased by storage, but T3 was not affected at all meat color parameters. The evaluation of meat quality was based on meat color, texture and etc., especially, consumer preference is based on meat color in market than other meat quality parameters

(Risvik, 1994). The change of fresh meat color during storage is affected by many factors, such as pH, storage temperature, oxygen partial pressure, and diet (Lawrie 1985). It seems that fermented king oyster mushroom by-products diet had an influence on lightness (CIE L^*) and yellowness (CIE b^*) when fermented king oyster mushroom by-products diet was substituted to diet more than 50%, and such a result was similar to that of Darmadji and Izumimoto (1994) who found the increased meat lightness and yellowness color when fermented diet was supplied to pigs for 10 d of feeding period.

In conclusion, the results indicate that the fermented king oyster mushroom by-products diet decreased WBSF and cooking loss but increased CP content, WHC and lightness (CIE L^*) of LD muscles in fattening pigs. Substitution of fermented king oyster mushroom by-products diet was not observed on pH, TBARS and VBN but was determined on the lightness and yellowness of LD muscle during 1 or 7 d of storage. Therefore, further investigation is required to clarify the effects of fermented king oyster mushroom by-products diet on the mechanisms of meat quality and its relation to sensory evaluation for meat consumers.

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