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ARTICLE

Lotus (*Nelumbo nucifera*) Rhizome as an Antioxidant Dietary Fiber in Cooked Sausage: Effects on Physicochemical and Sensory Characteristics

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Abstract

The objective of this study was to determine the physicochemical and sensory properties of cooked emulsion sausages containing different levels of lotus rhizome powder (0, 1, 2, and 3%, based on total weight). Lotus rhizome powder had no significant ($p>0.05$) impact on pH, moisture, protein, or ash content of sausage. However, fat content was slightly but significantly ($p<0.05$) decreased when the level of lotus rhizome powder was increased in the sausages. The addition of lotus rhizome powder to sausages at over 1% resulted in significantly ($p<0.05$) darker and less red color of cooked sausage compared to control. Increase in lotus rhizome level slightly improved the emulsion stability and apparent viscosity. Significant ($p<0.05$) reduction in cooking loss was observed when more than 1% of lotus rhizome powder was added to sausages. The textural properties of sausages were unaffected by the inclusion of lotus rhizome except for springiness and chewiness. On the manufacture day, control sausage had significantly ($p<0.05$) higher TBARS value than treatments. Regarding sensory characteristics, increased levels of lotus rhizome powder decreased ($p<0.05$) color and juiciness scores. However, cooked sausages exhibited similar overall acceptability regardless of the level of lotus rhizome powder added to sausages. Therefore, lotus rhizome powder, an antioxidant dietary fiber, could be used as an effective natural ingredient in meat products for the development of healthier and functional food.

Keywords antioxidant, dietary fiber, emulsion sausage, lipid oxidation, lotus rhizome

Introduction

With growing interest in human well-being, consumers are increasingly demanding healthier and functional meat and meat products (Jiménez-Colmenero *et al*., 2001). In this regard, the meat industry has been attempting not only to directly reduce potentially harmful additives (e.g., sodium chloride, nitrites/nitrates, and synthetic additives), but also to substitute those ingredients with food ingredients derived from natural sources (Arihara, 2006).

As one practically effective strategy, antioxidant dietary fiber derived from plant origin which primarily contains high amounts of dietary fiber and natural antioxidants has been extensively used to improve technological properties and extend shelf life by retarding lipid oxidation (López-López *et al*., 2009; Sáyago-Ayerdi *et al*., 2009; Verma *et al*., 2013). In general, dietary fiber has the functional characteristics of water/oil absorption capacity, texture modifying, and stabilizing prop-

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erties, which could enhance water-holding capacity and yield and modify textural properties of meat products (Thebaudin *et al*., 1997). Natural antioxidants obtained from various plant sources, which mainly contain polyphenolic compounds, have been used to prevent nutritional loss and toxic compound formation, thereby inhibiting oxidative deterioration of lipid and protein (Falowo *et al*., 2014). According to Saura-Calixto (2011), dietary fiber could play an important role in the transportation of natural antioxidants (particularly polyphenolic compounds) in human body. Thus, antioxidant dietary fiber can be used as non-meat ingredient to develop functional meat products by providing physiologically benefits on human health and improving physicochemical properties and shelf life of processed meat products.

Lotus (*Nelumbo nucifera*) is an aquatic plant that grows naturally in South-East Asia. Its rhizome, petal, and leaf have been consumed as common food ingredients. It is also extensively used as a traditional herb medicine (Huang *et al*., 2011; Jung *et al*., 2011). In particular, lotus rhizome contains several biological active compounds such as polyphenolic compounds (kaempferol, quercetin, and isoquercetin) and oligomeric procyanidines. In addition, it contains abundant dietary fiber consisting of non-carbohydrate components (Moro *et al*., 2013; Zhao *et al*., 2014). Moreover, lotus rhizome has been reported to have multiple physiological efficacies, including anti-inflammatory, antioxidaive, and anti-hypercholesterolemia activities (Hu and Skibsted, 2002; Lee *et al*., 2006; Tsuruta *et al*., 2011). In processed meat products, the utilization of lotus rhizome has been attempted to improve functional and quality characteristics and a strong antioxidant effect of lotus rhizome has been found (Huang *et al*., 2011; Jung *et al*., 2011; Lee *et al*., 2012). However, in previous studies conducted by Huang *et al*. (2011) and Lee *et al*. (2012), it was difficult to determine the effect of lotus rhizome as a dietary fiber source on processed meat product because it was used in a form of extract. Jung *et al*. (2011) have determined the impact of 0.5% dried lotus rhizome powder on quality characteristics of pork patty. However, the added amount (0.5%) might be insufficient to expect obvious effects of antioxidant dietary fiber because competent results of other antioxidant dietary fibers have been observed at higher addition levels (López-López *et al*., 2009; Sáyago-Ayerdi *et al*., 2009).

Therefore, the objective of this study was to evaluate the physicochemical and sensory properties of cooked emulsion sausages formulated with various levels of lotus rhizome powder (0, 1, 2, and 3%) to determine the optimal level of lotus rhizome powder as an antioxidant dietary fiber. Results from this study will provide relevant information to the meat industry on the development of functional meat products using lotus rhizome.

Materials and Methods

Raw materials and emulsion sausage manufacture

Dried lotus rhizome powder was purchased from Joeunyeon Food Co. (Korea). Fresh pork hams (*M. biceps femoris, semitendinosus,* and *semimembranosus*) and back fats were purchased from a local retailer at 24 h postmortem. Subcutaneous fat and visible connective tissues were removed from fresh pork ham muscles. Four treatments of pork emulsion sausages were manufactured with different levels (0, 1, 2, and 3%) of lotus rhizome powder. Ham and back fat were ground through an 8 mm plate and reground through 3 mm plate using a meat grinder (PM-70, Mainca, Spain). Raw materials, additives (1.2% nitrite pickling salt (NPS), 0.1% sodium tri-polyphosphate, 0.05% $_L$-ascorbic acid, 0.9% sugar, 0.1% pepper, 0.3% onion powder, 0.3% garlic powder, and 0.2% ginger powder), and lotus rhizome powder were emulsified with in a silent cutter (MSK 760-II, Mado, Germany). The temperature of ingredients during emulsification was maintained below 10ºC. The emulsified meat batter was stuffed into edible collagen casings (approximately 25 mm in diameter; #240, NIPPI Inc., Japan) using a hand stuffer (IS-8, Sirman, Italy). These raw sausages were heated at 75°C for 30 min in a water bath. The cooked sausages were then cooled and stored at 4°C until analysis.

Total dietary fiber measurements

The lotus rhizome powder was analyzed for total dietary fiber in triplicated using the method of Lee *et al*. (1992) including enzymatic hydrolysis with α-amylase, protease, and amyloglucosidase. Triplicate of samples (1 g) were suspended in Mes-Tris buffer (40 mL) and submitted to an enzymatic hydrolysis process. After enzymatic hydrolysis procedure, the sample was filtered in fritted glass crucibles, with glass wool as a filtration agent. The crucibles containing the residue were dried in a 105°C dry oven, cooled in a desicator, and weighed.

Proximate composition

Proximate composition of cooked sausage was evaluated in triplicates according to the AOAC methods (2007); moisture content (oven air-drying method, 950.46B), protein content (Kjeldahl method, 981.10), fat content (Soxhlet method, 960.69), and ash contents (muffle furnace method, 920.153). All results were expressed as g/100g of cooked sausage.

pH measurement

The pH values of meat batter and cooked sausage (5 g of sample : 20 mL of distilled water) were determined in triplicates using an electronic pH meter (Model 340, Mettler-Toledo GmbH, Switzerland).

Instrumental color evaluations

Colors of meat batter and cooked sausages were measured with CIE LAB system using a colorimeter (Minolta Chroma meter CR-210, Japan; illuminate C, calibrated with white plate, CIE L* = +97.83, CIE a* = -0.43, CIE b* = +1.98). CIE L* (lightness), CIE a* (redness), and CIE b* (yellowness) of cooked sausages were recorded from five random locations (cross-section) per each sample.

Cooking loss

Cooking loss was determined according to weight difference between raw and cooked sausages using the following formula; cooking loss (%) = [(weight of raw sample (g) – weight of cooked sample (g)) / weight of raw sample (g)] × 100.

Emulsion stability

The emulsion stability of meat batter was determined in duplicates according to the method of Bloukas and Honikel (1992) described by Choi *et al*. (2010). The released water and fat were measured in milliliters and calculated as percentages of the original weight of the batter. Total expressible fluid was measured by the sum of released water and fat.

Apparent viscosity

The apparent viscosity of meat batter was determined in triplicates using a rotational viscometer (HAKKE Viscotester®500, Thermo Electron Corporation, Germany) set at 10 rpm for 30 s (Choi *et al*., 2010). Apparent viscosity values were measured in centipoises.

Texture profile analysis (TPA)

Texture profile analysis of cooked sausage was performed using a spherical probe (diameter approximately 6 mm) attached to a texture analyzer (TA-XT2*i*, Stable Micro Systems, England) at room temperature. A total of six samples per treatment were prepared from the central portion of different cooked sausages and equilibrated to room temperature (20°C for 3 h). Texture profile analysis was conducted as following conditions: pre-test speed 2.0 mm/s, post-test speed 5.0 mm/s, maximum load 2 kg, head speed 2.0 mm/s, distance 8.0 mm, and force 5 g. The TPA values of hardness (kg), springiness, cohesiveness, gumminess (kg), and chewiness (kg) were determined by graphing a curve using force and time plots according to Bourne (1978).

Sensory evaluation

Sensory characteristics of cooked sausages were determined according to quantitative descriptive analysis (QDA) described by Latoch and Stasiak (2015) and Santana *et al*. (2015). The evaluation scale was unstructured within 100 mm. It was converted to numerical scale from 0 to 10 units. Definition and scale terms for sensory attributes used for evaluation were as follows: cured/cooked meat color (intensity of cured/cooked red color; 1 = less intense and 9 = very intense), cooked meat flavor (intensity of cooked meat flavor; 1 = none and 9 = very strong), another flavor (different or nonspecific flavor; 1 = very intense and 9 = less intense), hardness (hardness in the first bite; 1 = none and 9 = much), juiciness (the sensation after chewing; 1 = dry and 9 = juicy), and overall acceptability (attribute of total appearance and quality; 1 = undesirable and 9 = desirable). Emulsion sausages were randomly served to panelists (consisted of 11 members from the department of food sciences and biotechnology of animal resources at Konkuk University in Korea). Each sample was coded with a randomly selected 3-digit numbers and kept at room temperature for 1 h before serving. Panelists were instructed to cleanse their palates between samples using water.

2-Thiobarbituric acid reactive substances (TBARS) value

Lipid oxidation was assessed in triplicate using the 2-thiobarbituric reactive substance (TBARS) method of Tarladgis *et al*. (1960) with minor modifications as described by Kim *et al.* (2016). The TBA values were expressed as malondiadehyde (MDA) per kilogram of sample (mg MDA/kg sample).

Statistical analysis

The experimental design of this study was a completely randomized block with three independent replicates. Data were analyzed with one-way analysis of variance (ANOVA) using SPSS 18.0 software (SPSS Inc., USA) to determine the significance of a main effect (treatment). Duncan's multiple range tests was performed to determine differences between means at significance level of 95%.

Results and Discussion

Proximate composition

The proximate compositions of cooked sausages formulated with different levels of lotus rhizome powder (0, 1, 2, and 3%) are shown in Table 1. The addition of lotus rhizome powder slightly increased the moisture and ash contents of cooked sausages (p>0.05). However, it decreased protein content, although the decrease was not statistically significant. Fat content of cooked sausages was decreased (p<0.05) with increasing amount of lotus rhizome powder. Fat contents of the control and treatments were 21.42 g/100 g and 20.38-20.56 g/100 g, respectively. Similarly, Jung *et al*. (2011) have reported that the addition of 0.5% of lotus rhizome has increased moisture and ash contents but decreased fat and protein contents of cooked pork patty. In general, previous studies have also reported that the addition of dietary fiber to emulsified meat products has increased moisture content but decreased fat content due to high water absorption ability of dietary fiber (Fernández-Ginés *et al*., 2004; Lee *et al*., 2008).

pH and color characteristics

The pH and color characteristics of meat batter and cooked sausages formulated with different levels of lotus rhizome powder are shown in Table 2. The addition of lotus rhizome powder did not alter the pH value of meat batter or cooked sausage (5.99-6.05 and 6.04-6.11, p> 0.05). Similarly, Jung *et al*. (2011) have reported that the inclusion of 0.5% lotus rhizome has no effect on pH of cooked pork patty. Huang *et al*. (2011) have also noted that the inclusion of 3% lotus rhizome extract does not change the pH of cooked ground pork. In addition, the slightly increased pH value after cooking might be due to exposure of imidazolium moiety in basic amino acids such as histidine (Choi *et al*., 2008).

In raw meat batter, an increase in lotus rhizome powder decreased the CIE L* (lightness) and CIE a* (redness) values but increased CIE b* (yellowness) value (p<0.05).

Table 1. Proximate composition of cooked sausages formulated with lotus rhizome powder

Traits (g/100 g)	Control (0%)	Adding levels of lotus rhizome powder			SEM[1)]	Lotus rhizome powder[2)]
		1%	2%	3%		
Moisture	60.34	60.40	60.48	60.61	0.124	6.91±0.36
Protein	13.62	13.58	13.57	13.59	0.179	7.84±1.11
Fat	21.42[a]	20.56[b]	20.40[b]	20.38[b]	0.149	1.06±0.30
Ash	2.08	2.06	2.15	2.17	0.042	5.14±0.02
Total dietary fiber	-[3)]	-	-	-	-	11.85±0.03

[1)]SEM, the standard error of the means.
[2)]Mean±standard deviation (n=3).
[3)]Not measured.
[a,b]Means sharing different letters in the same row are significantly different (p<0.05).

Table 2. pH and color characteristics of meat batter and cooked sausages formulated with lotus rhizome powder

Traits	Control (0%)	Adding levels of lotus rhizome powder			SEM[1)]
		1%	2%	3%	
Meat batter (uncooked)					
pH	6.05	5.99	6.00	5.96	0.021
CIE L* (lightness)	71.49[a]	71.15[ab]	69.95[bc]	69.42[c]	0.258
CIE a* (redness)	9.71[ab]	10.01[a]	9.38[bc]	8.77[c]	0.093
CIE b* (yellowness)	13.09[b]	13.93[a]	14.16[a]	14.19[a]	0.114
Cooked sausage					
pH	6.11	6.07	6.05	6.04	0.017
CIE L* (lightness)	71.44[a]	70.35[b]	68.56[c]	67.92[c]	0.225
CIE a* (redness)	6.48[a]	5.26[b]	5.04[b]	5.33[b]	0.193
CIE b* (yellowness)	9.31	9.32	9.40	9.35	0.123

[1)]SEM, the standard error of the means.
[a-c]Means sharing different letters in the same row are significantly different (p<0.05).

However, the differences in the color parameters between treatments were numerically negligible. Such color changes of meat batter could be related to the original color of lotus rhizome powder added. The lightness, redness, and yellowness of lotus rhizome powder were 78.31, 3.80, and 18.42, respectively (data not shown). Thus, the addition of lotus rhizome powder might have directly changed the color of meat batter, resulting in darker and yellower meat batter. Regarding color characteristics of cooked sausages, lower ($p<0.05$) lightness and redness were also observed for cooked sausages formulated with lotus rhizome powder compared to control sausage. However, there was no significant ($p>0.05$) difference in yellowness of cooked sausages. According to Jung *et al*. (2011), white lotus rhizome contains 0.204 mg/g of flavonoids such as quercetin and kaempferol. Some parts of yellow and water-soluble flavonoids could be released from meat emulsion during thermal process as a form of cooking drip. This might have contributed to the similar yellowness of cooked sausage. Thus, our result showed that lotus rhizome powder at over 1% resulted in slightly darker but less red color of cooked sausage compared to control sausage.

Emulsion stability and cooking loss

The effects of lotus rhizome powder on emulsion stability and cooking loss of meat emulsion are shown in Table 3. Although there was no significant difference, an increase in lotus rhizome level resulted in decreased total, fat, and water releases. Such decrease implies that lotus rhizome powder could contribute to the stabilization of meat emulsions. In addition, cooking loss was decreased with increasing lotus rhizome levels ($p<0.05$). Cooking loss of lotus rhizome treatments (5.89-6.25%) was significantly lower than that of control sausage (7.31%). It has been well documented that the inclusion of dietary fiber could increase cooking yield of cooked meat product, thereby improving water and fat binding abilities (Cofrades *et al*., 2000). Those abilities of dietary fiber could form a stable complex with emulsified meat products (Cofrades *et al*., 2008). Thus, the decrease in cooking loss could be attributed to dietary fiber in the lotus rhizome powder (11.85 g/100 g, Table 1), suggesting that the addition of least 1% lotus rhizome powder could reduce the cooking loss of cooked sausage. Previously, Jung *et al*. (2011) have reported that cooking yield and moisture/fat retention of pork patty are not influenced by 0.5% lotus rhizome addition. Such discrepancy in results indicates that the effect of lotus rhizome on water/fat retention in meat products could be dependent upon the amount of lotus rhizome added and/or the type of meat product applied.

Apparent viscosity

Changes in apparent viscosity of meat batter containing different levels of lotus rhizome powder for 30 s are shown in Fig. 1. Apparent viscosity is a useful indicator to predict meat emulsion stability without thermal process (Choi *et al*., 2010). On initial time, apparent viscosity of meat batters formulated with lotus rhizome powder was obviously higher than that of control meat batter. However, the apparent viscosity values of lotus rhizome powder contained treatments were similar to each other. As rotation time passed, the apparent viscosity was continuously decreased. This is a feature of non-Newtonian thixotropic fluids which generally shows a decrease in viscosity with time-dependent under constant shear rate (Choi *et al*., 2010). Most previous studies have reported that the inclusion of dietary fiber could increase apparent viscosity of meat emulsion (Choi *et al*., 2010; Claus and Hunt, 1991; Kim *et al*., 2016; Lee *et al*., 2008). Water binding capacity and increased solid content due to dietary fiber addition might have contributed to the increase of apparent viscosity of meat emulsion.

Texture profile analysis

The textural properties of cooked sausages formulated with different levels of lotus rhizome powder are shown in Table 4. Hardness, cohesiveness, and gumminess of

Table 3. Emulsion stability and cooking loss of meat emulsions formulated with lotus rhizome powder

Traits		Control (0%)	Adding levels of lotus rhizome powder			SEM[1)]
			1%	2%	3%	
Emulsion stability (%)	Total expressible fluid	9.22	8.89	8.72	8.38	0.253
	Fat separation	1.02	0.96	0.87	0.79	0.059
	Water separation	8.19	7.93	7.85	7.59	0.207
Cooking loss (%)		7.31[a]	6.25[b]	6.13[b]	5.89[b]	0.107

[1)]SEM, the standard error of the means.

[a,b]Means sharing different letters in the same row are significantly different ($p<0.05$).

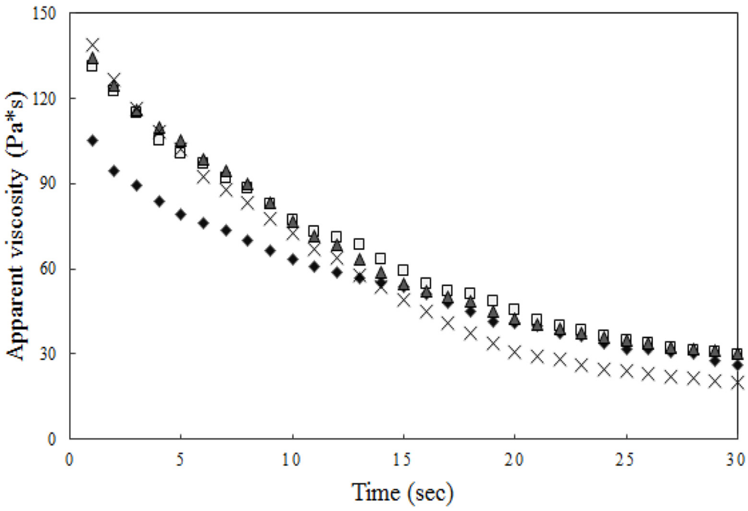

Fig. 1. A Change in apparent viscosity of meat batter containing different levels of lotus rhizome powder for 30 s. (◆) meat batter without lotus rhizome powder; (□) meat batter with 1% lotus rhizome powder; (▲) meat batter with 2% lotus rhizome powder; (×) meat batter with 3% lotus rhizome powder.

Table 4. Textural properties of cooked sausages formulated with lotus rhizome powder

Traits	Control (0%)	Adding levels of lotus rhizome powder			SEM[1)]
		1%	2%	3%	
Hardness (kg)	0.60	0.54	0.56	0.58	0.015
Cohesiveness	0.43	0.43	0.42	0.42	0.002
Springiness (ratio)	0.82[b]	0.83[b]	0.87[a]	0.87[a]	0.004
Gumminess (kg)	0.26	0.23	0.23	0.26	0.006
Chewiness (kg)	0.21[ab]	0.19[b]	0.20[ab]	0.22[a]	0.005

[1)]SEM, the standard error of the means.
[a,b] Means sharing different letters in the same row are significantly different (p<0.05).

cooked sausages were unaffected (p>0.05) by the addition of lotus rhizome powder. However, as the amount of lotus rhizome powder added to sausage was increased, springiness of cooked sausages was significantly increased (p<0.05). The cooked sausage formulated with 3% lotus rhizome powder had the highest (p<0.05) chewiness. Similar results have been reported by Jung *et al*. (2011) showing that the addition of 0.5% lotus rhizome powder has resulted in increased springiness and chewiness but no impact on hardness or cohesiveness. In general, the impact of dietary fiber source on texture of meat emulsion is greatly associated with the amount and type of dietary fiber added (Cofrades *et al*., 2000). Álvarez and Barbut (2013) have reported that the inclusion of β-glucan (one of water-soluble non-starch polysaccharides) has decreased both primary texture parameters (hardness, springiness, and cohesiveness) and secondary parameters (gumminess and chewiness) of cooked meat batter in spite of increased water-holding capacity. On the other hand, Choi *et al*. (2014) have indicated that insoluble fiber extracted from *makgeolli* lees has increased the hardness, cohesiveness, gumminess, and chewiness of pork frankfurter. According to Bai and Guan (2007), dietary fiber extracted from lotus rhizome has 66.34% of total dietary fiber with 6.05% of water-soluble dietary fiber, which signifies that dietary fiber contained in lotus rhizome could be predominantly composed of insoluble fiber. Thus, the textural properties of cooked sausages prepared with lotus rhizome powder might be mostly affected by insoluble fiber rather than water-soluble fiber.

Sensory characteristics

The sensory properties of cooked sausages formulated with different levels of lotus rhizome powder are shown in Table 5. The intensity of cured/cooked meat color generally presented as evident pink-red color by nitrosilmyo-

Table 5. Sensory properties of cooked sausages formulated with lotus rhizome powder

Traits[1)]	Control (0%)	Adding levels of lotus rhizome powder			SEM[2)]
		1%	2%	3%	
Cured/cooked meat color	8.07[a]	7.53[b]	7.13[bc]	6.93[c]	0.094
Cooked meat flavor	7.60	7.47	7.53	7.53	0.089
Another flavor	8.17	8.23	8.20	8.40	0.099
Hardness	7.53	7.53	7.43	7.13	0.082
Juiciness	7.93[a]	7.77[a]	7.53[ab]	7.20[b]	0.093
Overall acceptability	7.60	7.40	7.63	7.50	0.084

[1)]Cured/cooked meat color (intensity of cured/cooked red color; 1 = less intense and 9 = very intense), cooked meat flavor (intensity of cooked meat flavor; 1 = none and 9 = very strong), another flavor (different or nonspecific flavor; 1 = very intense and 9 = less intense), hardness (hardness in the first bite; 1 = none and 9 = much), juiciness (the sensation after chewing; 1 = dry and 9 = juicy), and overall acceptability (attribute of total appearance and quality; 1 = undesirable and 9 = desirable).
[2)]SEM, the standard error of the means.
[a-c]Means sharing different letters in the same row are significantly different ($p<0.05$).

chrome formation was decreased ($p<0.05$) with increasing levels of lotus rhizome powder. This might be due to the direct influence of original lotus rhizome color. Lightness and redness values on instrumental color measurement were also decreased with increasing levels of lotus rhizome powder added to sausages. The addition of lotus rhizome resulted in similar scores on cooked meat flavor, another flavor, and hardness ($p>0.05$), indicating that lotus rhizome powder had little or no impact on typical flavor or texture of cooked sausages. However, an increase in lotus rhizome level decreased ($p<0.05$) the juiciness score of cooked sausage. Cooked sausage formulated with 3% lotus rhizome powder had a significantly lower juiciness score than control sausage. Fernández-Ginés *et al*. (2004) have found that the addition of dietary fiber extracted from lemon albedo has resulted in a significantly decreased juiciness of bologna sausages. They have suggested that such reduction in juiciness could be due to decreased fat content, which could support our result. Thus, the relatively reduced fat content by adding lotus rhizome powder might have decreased the juiciness perception of cooked sausage. Despite the difference in cured/cooked meat color, all treatments exhibited similar ($p>0.05$) overall acceptability of sausages regardless of the addition level of lotus rhizome powder. Huang *et al*. (2011) have reported that 3% lotus rhizome extract can alter the color of cooked pork homogenate without changing the overall acceptability, since the changed color might be acceptable to sensory panels. Consequently, although the addition of lotus rhizome powder decreased the intensity of cured/cooked meat color, less than 2% of lotus rhizome had no adverse impacts on the flavor, hardness, juiciness, or the overall acceptability of cooked sausage.

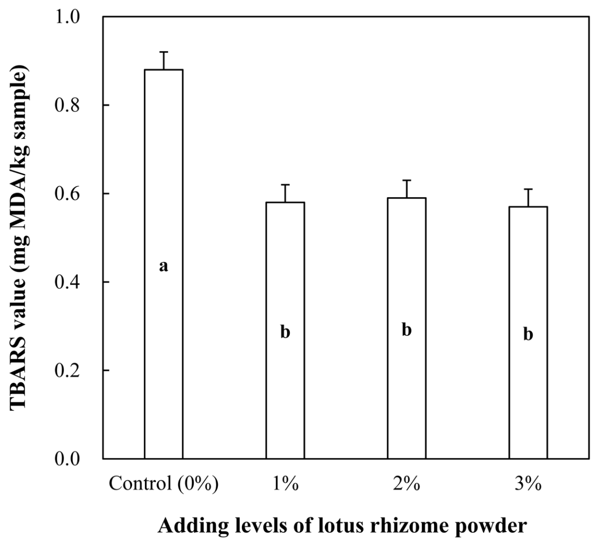

Fig. 2. 2-Thiobarbituric acid reactive substances (TBARS) value of cooked sausage formulated with different level of lotus rhizome powder after cooking. [a,b]Means with different letters are significantly different ($p<0.05$).

2-Thiobarbituric acid reactive substances (TBARS)

The TBARS values of cooked sausages prepared with different levels of lotus rhizome powder are shown in Fig. 2. Control sausage (0.88 mg MDA/kg sample) had a significantly higher TBARS value than treatments (0.57-0.59 mg MDA/kg sample). However, there was no significant ($p>0.05$) difference in TBARS value among treatments. Numerous previous studies have indicated that lotus rhizome has a strong antioxidant effect which can prevent the initial and further extent of lipid oxidation of meat products during storage (Huang *et al*., 2011; Jung *et al*., 2011). Huang *et al*. (2011) have reported that cooked pork homogenate containing 3% lotus rhizome extract had higher free radical scavenging ability and reducing activity than control sample without any of the extract. Recently, Deng *et al*. (2013) have found strong antioxidant capacities of lipophilic fraction in lotus rhizome and suggested that gallic acid is one of the main phenolic compounds. This finding suggests that lotus rhizome could be used as a potential antioxidant in processed meat products susceptible to lipid oxidation due to high fat content. Volf *et al*. (2014) have reported that the degradation of gallic acid during cooking at 80ºC for 50 min is below 5%. Such thermal stability of gallic acid might have contributed to the stable antioxidant capacity of lotus rhizome in cooked meat product during further storage, although the progress of lipid oxidation of cooked sausage was not investigated in this current study. In fact, Huang *et al*. (2011) have reported that the TBARS value of cooked pork homogenate prepared with 3% lotus rhizome extract was unchanged during 10 d of refrigerated storage. To confirm the practical application of lotus as a natural antioxidant, further studies are warranted to determine its impact on lipid oxidation stability of meat product under several storage conditions (different packaging material, temperature, and/or light) with different types of processed meat products.

Conclusions

Our results revealed that addition of lotus rhizome powder up to 3% had positive impacts on cooking loss, texture (mainly springiness), and TBARS value of cooked sausages without adverse impacting its overall acceptability. Our results suggest that lotus rhizome powder, an antioxidant dietary fiber, could be used as a natural ingredient to further develop healthier and functional meat products.

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