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Effects of Irradiated Phytic Acid on Antioxidation and Color Stability in Meat Models

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Lipid oxidation and color stability of meats treated with irradiated phytic acid were investigated during storage for 2 weeks at 4 °C. The phytic acid in deionized distilled water (DDW) was degraded by irradiation at 10 and 20 kGy, and the irradiated phytic acid showed a strong antiradical activity. For measuring the antioxidant effects of irradiated phytic acid in food models, beef and pork were prepared with DDW (control), irradiated (10 and 20 kGy) or non-irradiated phytic acid, and ascorbic acid as a model system. Irradiated phytic acid significantly inhibited the lipid oxidation in meats compared to the control and ascorbic acid treated samples during storage ($P < 0.05$). The redness of the meats treated with phytic acid had a higher value than did the control and ascorbic acid treated samples, but a significant difference was not observed in the samples treated with phytic acid regardless of irradiation treatment. Irradiated phytic acid was also effective in inhibiting the loss of heme iron and metmyoglobin formation during storage. Results indicated that irradiation might be helpful for improving the antioxidant activity of phytic acid in meats.

KEYWORDS: Irradiation; phytic acid; meat; antioxidation; color

INTRODUCTION

The appearance of fresh retail meat is a major determinant of its appeal to consumers and, consequently, sales of the product. The color of fresh meat and meat products is a strong indicator of quality. An oxidative process in meat leads to the degradation of lipids and proteins, which, in turn, contributes to the deterioration of flavor, texture, and color of fresh meat (*1*). These biochemical changes in meat limit the shelf life of fresh meat. Synthetic antioxidants, including butylhydroxytoluene (BHT) and butylhydroxyanisole (BHA), can inhibit lipid oxidation. However, these antioxidants have limited applications because of their low water solubility, toxic properties, and inability to penetrate into intact muscles (*2*, *3*). Therefore, natural antioxidants have been suggested as a safe alternative to synthetic antioxidants to retard oxidative processes and to improve the quality of meat during distribution or storage. Most studies have investigated the use of ascorbate and tocopherol as additives (*4*). However, the direct application of ascorbate to fresh meat is banned, and the potential benefit of a dietary supplement of ascorbic acid to animals, as a means of improving the oxidative stability of meat, is questionable (*5*). Many researches have reported that natural antioxidants, such as phytic acid, carnosine, quercetin, resveratrol, and others, were effective in inhibiting lipid oxidation (*6*−*9*).

Phytic acid (*myo*-inositol hexaphosphate, IP_6) is historically considered to be an antinutrient. Structurally, phytic acid contains phosphate, and it binds minerals such as calcium, iron, and zinc, causing a decrease of their bioavailability in human and animal models (*10*). However, recently, phytic acid has been reported to be an antioxidant (*11*), anticarcinogenic (*12*), and hypoglycemic or hypolipidemic (*13*). Phytic acid is considered to be an antioxidant agent, because it is a potent inhibitor of iron-catalyzed hydroxyl radical formation by chelating the free iron and then blocking its coordination site (*11*). Epidemiological studies have shown lower incidence of colon cancer in populations consuming a vegetarian-type diet; however, the mechanism of action is still unclear (*12*). Furthermore, lower inositol phosphates, such as IP_4 and IP_3, may play roles in mediating cellular responses and have been noted as having a function in second-messenger transduction systems (*14*).

Ahn et al. (*15*) reported that the degradation of phytic acid occurred by γ-irradiation, and the increase of the antioxidant and antiradical activities was observed in irradiated phytic acid in an aqueous model system. In this manner, the previous study was performed to investigate the antioxidant activity of irradiated phytic acid, even in a degradation by γ-rays (*15*). Recently, a

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new trial for the application of reducing toxic or hazardous compounds such as volatile *N*-nitrosamines (*16*), residual nitrite (*17*), biogenic amines (*18*), or food allergens (*19*), has been reported, besides those for sanitary purposes. This study was designed to investigate the antioxidant effects of irradiated phytic acid in real foods, compared to ascorbic acid. Accordingly, this study is expected to give useful information on the use of irradiation in a new field.

The objective of the present study was to investigate the antioxidant effects of irradiated phytic acid on lipid oxidation and the color in beef and pork model systems during refrigerated storage.

MATERIALS AND METHODS

Preparation of Phytic Acid. Phytic acid sodium salt (Sigma Chemical Co., St. Louis, MO) and l-ascorbic acid (Sigma) were dissolved in deionized distilled water (DDW) to final concentrations of 500 μg/mL, respectively. Phytic acid solution was transferred into a glass tube, and the solution was irradiated in a cobalt-60 irradiator (Nordion International, Ottawa, ON, Canada). The source strength was ~100 kCi with a dose rate of 5 kGy h^{-1} at 14 ± 0.5 °C. Dosimetry was performed using 5-mm-diameter alanine dosimeters (Bruker Instruments, Rheinstetten, Germany), and the free radical signal was measured using a Bruker EMS 104 EPR Analyzer. The absorbed doses were 0, 10, and 20 kGy, and the actual doses were within ±2% of the target dose.

Phytic Acid Determination and DPPH Scavenging Effects. After irradiation, the degradation of phytic acid was determined according to the method of Latta and Eskin (*20*). A phytic acid solution (3 mL) was transferred to 15-mL conical tubes, and 1 mL of a modified Wade reagent (0.03% $FeCl_3 \cdot 6H_2O$ and 0.3% sulfosalicylic acid in distilled water) was added. The solution was mixed with a vortex mixer for 5 s, and the mixture was centrifuged at 3000 rpm for 10 min. The supernatant was read at 500 nm by using a spectrophotometer (model UV-1601PC; Shimadzu Co., Tokyo, Japan).

The free radical scavenging effect of irradiated phytic acid was estimated according to the method of Blois (*21*) with some modification. The sample (1 mL) was added into the 0.2 mM 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical (Sigma-Aldrich Co., St. Louis, MO; 1 mL). The mixture was shaken and left to stand for 30 min at room temperature and measured at 517 nm with a spectrophotometer (model UV-1601PC, Shimadzu Co.). The DPPH radical scavenging capacity was estimated from the difference in absorbance with or without samples and expressed as a percentage of DPPH scavenging during storage for 2 weeks at 4 °C.

Preparation of Meat Models. The longissimus dorsi muscle from cows and pigs was obtained 24 h after slaughter from three different local meat packers and ground twice through a 9-mm plate. Meat samples (180 g) were blended with 20 mL of distilled water, phytic acid (irradiation at 0, 10, and 20 kGy), and ascorbic acid prepared, respectively. The sample prepared with distilled water was used as a control. Half of the samples were then vacuum packaged (75 cmHg pulled) in oxygen-impermeable nylon bags (2 mL of O_2/m^2/24 h at 0 °C; 20 cm × 30 cm; Sunkyung Co. Ltd., Seoul, Korea) by a vacuum-packaging machine (Leepack, Hanguk Electronic, Kyungi, Korea), and the other half were aerobically packaged by flushing air into the bag without sealing. After packaging, all of the samples were stored in a 4 °C refrigerator for 2 weeks.

Lipid Oxidation. Lipid oxidation of meat samples was determined as a 2-thiobarbituric acid-reactive substance (TBARS) value by using a spectrophotometer (Shimadzu) as described by Ahn et al. (*22*). The development of the lipid oxidation was recorded as TBARS value. The amounts of TBARS were expressed as milligrams of malondialdehyde per kilogram of meats.

Color Measurement. The Hunter red color value (a^*) was determined with a Color Difference Meter (spectrophotometer CM-3500d, Minolta Co., Ltd., Osaka, Japan). The light source is pulsed xenon arc lamps, and a D65 with a 10° standard observer was used as an illuminant. The instrument was calibrated to standard black and white tiles before analysis. Readings were taken directly from samples in Petri dishes.

Heme Iron. Heme iron contents were analyzed using the method of Hornsey (*23*). A sample (2 g) was transferred into a 50-mL polypropylene conical tube, and 9 mL of acid acetone (90% acetone + 8% distilled water + 2% HCl) was added. The sample was macerated with a glass rod and allowed to stand for 1 h in a dark cabinet at room temperature (21 °C). The extract was filtered with Whatman filter paper no. 42, and the absorbance was read at 640 nm against the acid acetone blank. Total pigments, as acid hematin, were calculated, and the heme iron was calculated according to the method of Clark et al. (*24*).

Metmyoglobin. Percent metmyoglobin was determined using the method of Kryzywicki (*25*). Meat (5 g) was placed into a 50-mL polypropylene conical tube, and a 25 mL of ice-cold phosphate buffer (pH 6.8, 40 mM) was added. The mixture was homogenized for 10 s using a homogenizer (DIAX 900, Heidolph, Schwabach, Germany). The homogenized sample was allowed to stand for 1 h at 4 °C and centrifuged at 5000 rpm for 30 min at 4 °C. The supernatant was filtered through Whatman no. 1 filter paper, and the absorbance was read at 700, 572, and 525 nm with a spectrophotometer (model UV-1601PC; Shimadzu Co., Tokyo, Japan).

$$\% \text{ metmyoglobin} = \{1.395 - [(A_{572} - A_{700})/(A_{525} - A_{700})]\} \times 100$$

Statistical Analysis. Experiments were designed as 5 (treatment) × 2 (packaging) × 3 (storage) factorials. The study, from sample preparation to analysis, was done in triplicate, and the data were then analyzed by SAS software (SAS Institute, Cary, NC). The general linear model procedure was processed, and Duncan's multiple-range test was used to compare the mean values at $P < 0.05$. Mean values and pooled standard errors of the mean (SEM) were recorded.

Table 1. Degradation (Percent) and DPPH Radical Scavenging Capacity (Percent) of Irradiated Phytic Acid Used in Meat Models[a,b]

	irradiation dose			
	0 kGy	10 kGy	20 kGy	SEM[c]
degradation	0.0b	3.1a	5.5a	0.12
DPPH	0.0c	72.2b	79.6a	1.34

[a] Values with different letters (a–c) within a row differ significantly ($P < 0.05$). [b] Phytic acid (500 μg/mL) in DDW was irradiated, and then analyzed. [c] Standard error of the mean ($n = 9$).

RESULTS AND DISCUSSION

Radiolysis of Phytic Acid. After γ-irradiation, the radiolysis and DPPH radical scavenging effects of phytic acid dissolved in DDW were observed (**Table 1**). It was previously found that phytic acid in an aqueous model system showed increased antioxidant and antiradical activity after γ-irradiation, and irradiated phytic acid at a 100 μg/mL level was degraded by >70% by 5-kGy irradiation (*15*). The percent degradation of phytic acid (500 μg/mL) used in this study was 3−5%. Accordingly, the degree of degradation by irradiation was significantly different from the concentration of phytic acid, and these results indicated that the concentration of the materials has a great effect on the degree of radiolysis. Results also indicated that the radicals produced during irradiation may abstract phosphorus in the phytic acid structure and, consequently, the reduction of the phytic acid content was determined according to the method of Latta and Eskin (*20*).

The stable DPPH radical scavenging ability by irradiated phytic acid was stronger than that with ascorbic acid at the same concentration. The DPPH radical scavenging capacity of ascorbic acid at a 500 μg/mL level was 67% (data not shown). Therefore, irradiated phytic acid is expected to increase the

Table 2. TBARS Value of Beef and Pork Model Systems Prepared with Irradiated Phytic Acid during Storage at 4 °C[a]

storage (weeks)	packaging	sample[b] control	PA0	PA10	PA20	AA	SEM[c]
		Beef System					
0	aerobic	0.31ax	0.26b	0.17c	0.18c	0.29b	0.014
	vacuum	0.24ay	0.20b	0.22b	0.21b	0.28a	0.023
	SEM[d]	0.018	0.021	0.008	0.019	0.040	
1	aerobic	1.96ax	1.02bx	1.16bx	0.96bx	1.15bx	0.074
	vacuum	0.82ay	0.67by	0.66by	0.64by	0.71aby	0.029
	SEM[d]	0.030	0.036	0.092	0.035	0.062	
2	aerobic	2.74ax	1.39cx	1.24cdx	1.02dx	1.64bx	0.059
	vacuum	1.26ay	0.59by	0.58by	0.48cy	0.63by	0.075
	SEM[d]	0.055	0.090	0.102	0.119	0.130	
		Pork System					
0	aerobic	0.34a	0.30a	0.21b	0.28ab	0.30a	0.030
	vacuum	0.37a	0.34a	0.24b	0.29b	0.35a	0.036
	SEM[d]	0.047	0.013	0.005	0.040	0.038	
1	aerobic	0.58a	0.33b	0.35b	0.30b	0.32b	0.115
	vacuum	0.50a	0.33bc	0.27cd	0.25d	0.39b	0.019
	SEM[d]	0.051	0.021	0.006	0.024	0.025	
2	aerobic	0.72a	0.30b	0.29by	0.25b	0.37b	0.033
	vacuum	0.63a	0.40b	0.42bx	0.33b	0.43b	0.061
	SEM[d]	0.086	0.123	0.018	0.025	0.057	

[a] Values with different letters (a–d) within a row differ significantly ($P < 0.05$). Values with different letters (x, y) within a column differ significantly ($P < 0.05$). [b] Control (distilled water); PA0, PA10, PA20 (phytic acid irradiated at 0, 10, and 20 kGy, respectively); AA (ascorbic acid). [c] Standard error of the mean ($n = 15$). [d] Standard error of the mean ($n = 6$).

Table 3. Hunter Red Color Values (a^*) of Beef and Pork Model Systems Prepared with Irradiated Phytic Acid during Storage at 4 °C[a]

storage (weeks)	packaging	sample[b] control	PA0	PA10	PA20	AA	SEM[c]
		Beef System					
0	aerobic	7.45	8.11	7.55	7.74	7.31	0.243
	vacuum	6.57b	7.43a	7.23a	7.30a	6.87ab	0.107
	SEM[d]	0.274	0.175	0.082	0.158	0.198	
1	aerobic	6.43cy	8.02b	8.41ax	8.36ax	7.83bx	0.186
	vacuum	6.63bx	7.32a	7.37ay	7.56ay	6.03by	0.188
	SEM[d]	0.016	0.133	0.261	0.172	0.245	
2	aerobic	5.78c	7.44ab	7.37ab	7.97a	7.04bx	0.260
	vacuum	6.25b	6.82ab	7.42a	7.41a	6.04by	0.221
	SEM[d]	0.289	0.147	0.379	0.173	0.113	
		Pork System					
0	aerobic	1.58	1.54	1.72	1.79x	1.57x	0.197
	vacuum	0.78	0.89	0.71	0.72y	0.70y	0.165
	SEM[d]	0.193	0.159	0.220	0.177	0.149	
1	aerobic	1.65b	1.69b	1.65b	2.03a	1.72bx	0.318
	vacuum	1.18c	2.39a	1.83b	1.84b	0.88dy	0.080
	SEM[d]	0.365	0.136	0.086	0.319	0.087	
2	aerobic	1.36c	1.61by	1.64b	2.19ay	1.80b	0.157
	vacuum	2.69b	3.33ax	3.37a	3.49ax	2.85b	0.469
	SEM[3]	0.311	0.085	0.450	0.177	0.524	

[a] Values with different letters (a–d) within a row differ significantly ($P < 0.05$). Values with different letters (x, y) within a column differ significantly ($P < 0.05$). [b] Control (distilled water); PA0, PA10, PA20 (phytic acid irradiated at 0, 10, and 20 kGy, respectively); AA (ascorbic acid). [c] Standard error of the mean ($n = 15$). [d] Standard error of the mean ($n = 6$).

antioxidant activity in a food system compared to ascorbic acid or phytic acid alone.

Lipid Oxidation. The TBARS values of the beef and pork model systems prepared with distilled water (control), phytic acid, and ascorbic acid during storage are shown in **Table 2**.

In the beef model, a statistically significant difference was observed, and phytic acid irradiated at 20 kGy was most effective in preventing lipid oxidation in beef during storage for 2 weeks ($P < 0.05$). The antioxidation effect of irradiated phytic acid was higher than that of ascorbic acid, the commercially used antioxidant. Thus, the packaging effects were also observed, and a vacuum condition could be helpful in inhibiting lipid oxidation. Ahn et al. (*15*) reported that irradiated phytic acid was effective in inhibiting lipid oxidation of soybean oil emulsion, but at a higher concentration (400 μg/mL), irradiated phytic acid showed no difference compared to the non-irradiated one. However, in this study, irradiated phytic acid at a 500 μg/mL level effectively inhibited the oxidation in the lipids of beef. Thus, the disruption of the muscle membrane by homogenization might alter the compartmentalized cellular systems and facilitate the formation of free radicals, which catalyze the peroxidation process. Therefore, the meat models might be more complex systems than oil emulsion during the process of lipid oxidation, causing a different effect by antioxidants. The development of off-flavor in meats results from lipid oxidation, and transition metals are important in this reaction (*26*). Phytic acid has antioxidant functions by virtue of forming a unique iron chelate, and it suppresses iron-catalyzed oxidative reactions (*11*). Consequently, such actions of phytic acid may be involved in the inhibitory effects of lipid oxidation. Lee and Hendricks (*27*) reported that phytic acid inhibited lipid peroxidation effectively and dose-dependently in beef homogenates. Lee et al. (*6*) reported that antioxidant activity of carnosine and phytic acid was more effective than other antioxidants such as α-tocopherol and BHT, and especially, the inhibition of lipid oxidation by phytic acid was stronger than with carnosine at the same concentrations. An inhibitory effect on lipid oxidation was observed in the pork models; however, irradiated phytic acid did not show a statistically significant difference in the samples treated with antioxidants. Thus, the packaging effect was not observed. The present study indicated that the lipid in beef was more susceptible to oxidative changes than pork, and these results agree well with those of Kim et al. (*28*).

Results indicated that phytic acid, especially, treated with irradiation might inhibit lipid oxidation in raw meats during storage.

Color Stability. The color stability of meats is a very important factor for consumers and is directly related to shelf life. The changes of the red color (a^* value) in the beef and pork models prepared with irradiated phytic acid and ascorbic acid during the refrigerated storage are shown in **Table 3**. The redness of the beef treated with phytic acid both irradiated and non-irradiated was higher than that of the control and ascorbic acid treated beef under a vacuum condition at 0 weeks ($P < 0.05$). After 1 week of storage, a significant difference was observed in the aerobic and vacuum packaging beef, and the beef treated with irradiated phytic acid (10 and 20 kGy) showed higher redness values than the other samples. The red color of the control beef gradually faded during storage. Packaging effects were also observed, and with an aerobic packaging the redness was higher than with vacuum packaging until 1 week. In pork treated with phytic acid (20 kGy), the redness was significantly higher than that of the others. Many factors can influence the stability of a meat's color, and the oxidation of myoglobin by free radicals or the products from lipid peroxidation is predominant (*29*). Several natural antioxidants, such as carnosine, quercetin, and phytic acid, have a metal-chelating ability (*6*, *30*, *31*); therefore, they are helpful for maintaining the meat color and for inhibiting lipid oxidation. Especially, phytic acid is a powerful inhibitor of the iron-related hydroxyl radical formation because it forms an inactive iron chelate (*32*).

Table 4. Heme Iron (Micrograms per Gram) Contents of Beef and Pork Model Systems Prepared with Irradiated Phytic Acid during Storage at 4 °C[a]

storage (weeks)	packaging	sample[b] control	PA0	PA10	PA20	AA	SEM[c]
		Beef System					
0	aerobic	12.2b	13.7b	15.3a	15.5a	16.7a	1.01
	vacuum	12.2b	13.6a	13.7a	13.0a	13.0a	1.18
	SEM[d]	1.69	0.17	0.95	0.74	2.04	
1	aerobic	10.3ab	10.0b	12.2a	10.3ab	8.8b	0.52
	vacuum	8.6	8.3	10.2	10.8	10.9	0.71
	SEM[d]	0.74	0.43	0.41	0.92	0.45	
2	aerobic	8.2b	9.8ab	11.4ab	12.7ax	10.5ab	0.93
	vacuum	7.1	9.9	10.8	9.9y	11.9	2.16
	SEM[d]	3.32	0.57	0.97	0.23	1.22	
		Pork System					
0	aerobic	9.3	5.2	7.9	8.3	7.8	3.41
	vacuum	7.1	8.2	8.0	8.1	8.6	1.48
	SEM[d]	1.53	0.81	1.18	1.08	1.94	
1	aerobic	3.4	3.7	4.9	4.2	4.1	0.73
	vacuum	4.4a	3.3b	4.3a	4.4a	4.0ab	0.50
	SEM[d]	0.53	0.59	0.23	0.15	0.67	
2	aerobic	4.9	4.1	3.6	5.3	3.7	0.62
	vacuum	3.5bc	4.8a	4.6ab	3.7abc	3.0c	0.29
	SEM[d]	0.93	0.36	0.18	0.50	0.31	

[a] Values with different letters (a–c) within a row differ significantly ($P < 0.05$). Values with different letters (x, y) within a column differ significantly ($P < 0.05$). [b] Control (distilled water); PA0, PA10, PA20 (phytic acid irradiated at 0, 10, and 20 kGy, respectively); AA (ascorbic acid). [c] Standard error of the mean ($n = 15$). [d] Standard error of the mean ($n = 6$).

Table 5. Metmyoglobin (Percent) Formation of Beef and Pork Model Systems Prepared with Irradiated Phytic Acid during Storage at 4 °C[a]

storage (weeks)	packaging	sample[b] control	PA0	PA10	PA20	AA	SEM[c]
		Beef System					
0	aerobic	36.4ax	31.9bx	33.8ax	35.0a	33.7a	1.37
	vacuum	23.7y	25.5y	22.4y	19.0	22.3	5.38
	SEM[d]	4.64	6.15	5.49	7.64	7.58	
1	aerobic	52.5a	38.1b	34.4b	32.4b	33.4b	4.93
	vacuum	45.2	27.8	30.2	22.5	28.5	5.67
	SEM[d]	6.05	5.92	4.02	4.56	5.73	
2	aerobic	56.6a	40.2b	40.6b	38.5c	35.3c	2.30
	vacuum	48.9	27.7	29.3	23.7	20.4	5.34
	SEM[d]	2.08	2.54	2.98	1.74	4.36	
		Pork System					
0	aerobic	30.6	29.6x	31.4	25.9	27.2x	2.26
	vacuum	28.8a	22.6ay	26.9a	29.6a	15.9by	2.77
	SEM[d]	2.70	1.13	3.44	1.49	3.05	
1	aerobic	42.9	35.1	33.4	28.8	28.9	2.79
	vacuum	28.6	27.8	29.9	27.9	27.7	8.22
	SEM[d]	3.76	6.33	5.76	6.35	5.11	
2	aerobic	56.6a	43.8b	36.0b	35.2b	26.7c	2.99
	vacuum	50.4	34.5	39.8	36.6	37.4	3.76
	SEM[d]	1.93	2.38	5.09	3.40	2.35	

[a] Values with different letters (a, b) within a row differ significantly ($P < 0.05$). Values with different letters (x, y) within a column differ significantly ($P < 0.05$). [b] Control (distilled water); PA0, PA10, PA20 (phytic acid irradiated at 0, 10, and 20 kGy, respectively); AA (ascorbic acid). [c] Standard error of the mean ($n = 15$). [d] Standard error of the mean ($n = 6$).

The contents of the heme iron (micrograms per gram) in the meats during storage are shown in **Table 4**. When the beef was treated with phytic acid and ascorbic acid, the heme iron contents were higher than the control at 0 weeks. With aerobic packaging, phytic acid irradiated at 10 and 20 kGy showed higher contents of heme iron compared to the others. In addition to developing a red color in the meats, heme iron is considered to be nutritionally important as it is higher in bioavailability (>15%) than nonheme iron (< 5%) (*33*). Therefore, irradiated phytic acid, as a meat additive, is more useful for maintaining the heme iron in beef during storage. In a pork model, a significant effect, which is maintaining heme iron contents, was observed in samples treated with phytic acid and ascorbic acid after 2 weeks. Lee et al. (*6*) reported that phytic acid at a 1 or 5 mM level was effective in retaining the heme iron of cooked meat during storage. Although phytic acid is known as an iron chelator, Carpenter and Mahoney (*34*) reported that phytic acid is known to inhibit nonheme iron absorption, but it does not affect heme iron absorption in the intestine. Heme iron is fixed in a complex; therefore, it cannot be converted into an unabsorbable form, indicating that it cannot form complexes with phytic acid that would become unavailable (*35*).

Phytic acid, especially irradiated, was effective in inhibiting metmyoglobin formation in beef with aerobic packaging after storage (**Table 5**). After 2 weeks of storage, beef treated with phytic acid (20 kGy) and ascorbic acid had a lower percentage of metmyoglobin (~50% lower) than the control beef. In a pork system, a statistically significant difference by phytic acid was observed after 2 weeks, which indicated that irradiated phytic acid, which has increased antiradical and antioxidant activities, was effective in retarding the metmyoglobin formation in meats during storage.

In conclusion, these results suggest that irradiation improves the ability of phytic acid such as the antioxidation and color stability, in a meat model. However, for an explanation of the efficiency of the irradiation effects, the structural changes of phytic acid by irradiation should be investigated, and further study is required to provide adequate information on a useful application.

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