ELECTROSTATIC SPRAYING OF ANTIOXIDNAT AND REDUCING AGENT TO REDUCE OXIDATIVE QUALITY CHANGES IN GROUND BEEF

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***Abstract*—To prevent oxidative quality changes of ground beef with disintegrated muscle structure, a few selected additives (antioxidants, reducing agent) were electrostatically sprayed. Spraying of ascorbic acid at 500 ppm was the most effective in controlling discoloration of ground beef during the storage by retarding met-myoglobin formation, which was induced by maintaining lower oxidation-reduction potential of meat. Other phenolic compounds (tocopherol, sesamol, rosemary oleoresin) had little effects on stabilizing the color of ground beef. Spraying of ascorbic acid was also effective in reducing TBARS and volatile aldehydes (hexanal, heptanal). Sesamol at 100 ppm showed potent antioxidant activities as ascorbic acid at 500 ppm did. Therefore, electrostatic spray of ascorbic acid on the surface of ground beef can be an efficient and economical way to control the antioxidative quality changes of ground beef.**

***Index Terms*—electrostatic spraying, reducing agent, antioxidative quality, ground beef.**

I. INTRODUCTION

Ground beef is the most susceptible meat product to oxidative deterioration due to the structural disintegration and the increased surface of meat particles. Color is a prime quality parameter determining consumer acceptance of meat. Liu, Lanari & Schaefer (1995) indicated that the loss of value due to discoloration in beef at the retail level in the U.S. could be over 700 million dollars per year. Therefore, prevention of oxidative quality changes from ground beef is the most demanding.

To prevent oxidative quality changes in meat and meat products, food additives such as antioxidants and reducing agents can be added (Xiong, Decker, Robe & Moody, 1993). Food antioxidants are used in fresh and further processed meat to prevent oxidative rancidity and improve color stability. Some phenolic antioxidants such as vitamin E have free radical-scavenging properties and terminate free-radical reactions in meat during storage (Gray, Gomaa & Buckley, 1996). Ascorbic acid is a reducing agent, which inhibits myoglobin oxidation and brown color development in beef (Wheeler, Koohmaraie & Shackelford, 1996). The combinations of phenolic antioxidants such as gallate, sesamol, and tocopherol, were effective in reducing the oxidative reactions and the production of sulfur volatiles in irradiated pork by scavenging free radicals produced by irradiation (Nam & Ahn, 2003). Conventionally, the antioxidant and reducing agent are directly added to meat or dietary supplemented for live animals. However, direct addition of additives to meat can result in excessive residue of additives because large amounts of additives can be distributed in even inner part of meat. In general, oxidative deterioration of meat is more serious at outer part of meat product rather than inside core one, as the outer part can contact more with oxidative initiators such as oxygen and light in the air. Therefore, spraying of additives can be an efficient way for food additives to be incorporated in the mainly outer part of meat products.

Electrostatic spraying has been mainly used for food or food processing equipment to spray disinfectants or for fruits and vegetables to spray pesticides and agrichemicals (Russell, 2003; Adams & Palmer, 1989). Electrostatic spraying utilizes electrically charged spray droplets which can be easily attached to food surface where uniform or hidden areas are placed (ESS MaxCharge, INC., 2010). Even though the oxidative quality changes of ground beef are important and imperative, no work has been performed to control the oxidative quality changes using electrostatic spraying system. Therefore, the objective of this study was to determine the effect of electrostatic spraying of selected food antioxidant and reducing agent on the lipid oxidation, color, and oxidative volatiles of ground beef during the storage.

II. MATERIALS AND METHODS

A. Sample preparation

Beef loins (*Longissimus dorsi*) obtained from 4 different carcasses was ground separately through a 3-mm plate and beef patties (each approximately 50g) were formed. Based on the preliminary study, a few antioxidants and a reducing agent were selected and their solutions were prepared to be sprayed on the surface of beef patties. Ascorbic acid solution dissolved in distilled water was sprayed on beef patties using an electrostatic spray (Model ESS XT-3; ESS MaxCharge Inc., Watkinsville, GA, USA) at 30 psi air pressure and 40 micron drop size. The final concentration of ascorbic acid in beef patty was 500 ppm. Antioxidants (α-tocopherol, γ-tocopherol, sesamol, or rosemary oleoresin) were also electrostatically sprayed on beef patties at 100 ppm. In case of tocopherol which is not water-soluble, an emulsion was prepared consisting of 0.8g tocopherol, 4g corn oil, 35.2g water, and 20mg lecithin. Therefore, 7 different treatments were prepared: 1) no-additive control, 2) ascorbic acid at 500 ppm, 3) α-tocopherol at 100 ppm, 4) γ-tocopherol at 100 ppm, 5) sesamol at 100 ppm, 6) rosemary oleoresin at 100 ppm, and 7) ascorbic acid at 500 ppm + α-tocopherol at 100 ppm. Beef patties were was individually packaged in oxygen-permeable bag (polyethylene, 4 x 6, 2 MIL, Associated Bag Company, Milwaukee, WI, USA) and stored at 4°C for 8 days. Color, met-myoglobin, oxidation-reduction potential, lipid oxidation, and volatiles of samples were determined during the storage.

B. Analysis

CIE color values of ground beef were measured on the surface of meat samples using a LabScan colorimeter (Hunter Associated Labs. Inc., Reston, VA, USA) with an illuminant A and a 1.225-cm aperture. Met-myoglobin content was determined by the modified method of Krzywicki (1982). The ORP values of meat samples were determined using a pH/ion meter (Accumet 25; Fisher Scientific, Fair Lawn, NJ, USA) equipped with a platinum electrode filled with an electrolyte solution (4 M KCl saturated with AgCl). Lipid oxidation was determined using a TBARS method. Volatiles of samples were analyzed using a Solatek 72 Multimatrix-Vial Autosampler/Sample Concentrator 3100 (Tekmar-Dohrmann, Cincinnati, OH, USA) connected to a GC/MS (Model 6890/5973, Hewlett-Packard Co., Wilmington, DE, USA) according to the method of Ahn, Nam, Du & Jo (2001).

C. Statistical analysis

A completely randomized design with 7 treatments and 4 replications was used. Data were analyzed using the generalized linear model procedure of SAS software. Student-Newman-Keul's multiple range test was used to determine significant differences between the mean values of treatments. Mean values and standard error of the means (SEM) were reported. Significance was defined at $P< 0.05$.

III. RESULTS AND DISCUSSION

The CIE color L*, a*, and b* values of ground beef significantly decreased during the aerobic storage, and especially the a* values were drastically decreased. Therefore the color deterioration of ground beef at 5 days was organoleptically unacceptable to consumers. Among additives eletrostatically sprayed on meat samples, ascorbic acid was very effective in preventing the discoloration of ground beef during the storage. The a*-values of ground beef sprayed with ascorbic acid maintained at 5 days and they were significantly higher than the control at 8 days. At 8 days, spraying of ascorbic acid could maintaine the a*-values of ground beef up to 68~71% of the 1 day, while the control had only 34. Addition of ascorbic acid had no effect on the L* values of ground beef during the storage. Although a few phenolic compounds (α-tocopherol and rosemary oleoresin) showed effects to maintain a*-values of ground beef at 5 days, they did not at 8 days. Addition of ascorbic acid with α-tocopherol was also effective in maintaining the a*-values, but the results were mainly attributed to ascorbic acid because there was no synergistic effect by the addition of α-tocopherol. Thus the spray of ascorbic acid was more effective in stabilizing beef color than any other antioxidants, but the combined spray of ascorbic acid with antioxidant would be more beneficial in controlling lipid oxidation as well as color oxidation during storage.

The discoloration of ground beef during storage could be attributed to the generation of met-myoglobin. After 5 days of storage, more than 80% of color pigment present in ground beef was oxidized myoglobin, responsible for the unacceptable brownish gray color. Ascorbic acid-sprayed ground beef had lower met-myoglobin percentage than the control after 5 days of storage. It can be concluded that spraying of ascorbic acid on the surface of ground beef retarded the formation of met-myoglobin. Spraying of ascorbic acid with or without α-tocopherol significantly lowered the ORP values of ground beef from the early stage of storage. The ORP values of ground beef with ascorbic acid with tocopherol were not much different from that of ascorbic acid-sprayed, indicating that the decrease of ORP in ground beef was caused by only ascorbic acid. The lowered ORP values by ascorbic acid could keep heme pigments in ferrous status from being oxidized, resulting in stabilizing the color of ground beef. Ascorbic acid accelerated met-myoglobin reduction by donating electrons to the ferric state of heme (Judge, Aberle, Forrest, Heddrick & Merkel, 1989) and facilitated the conversion of ferrimyoglobin to ferrous myoglobin (Anderson & Skibsted 1992). The ORP values of ground beef containing ascorbic acid gradually increased as storage time increased, but they were always significantly higher than the control or other antioxidant-sprayed ones. The discoloration of ground beef could be related with the loss of reducing power of meat and could be reverted to desirable red color by the reducing power of ascorbic acid.

Ground beef was very susceptible to lipid oxidation during the aerobic storage. The TBARS values of ground beef at 8 days increased as about 2-times compared with at 1 day. Ascorbic acid, tocopherol, sesamol, and rosemary oleoresin sprayed on ground beef showed significant antioxidant activities during the storage. Especially ascorbic acid and sesamol showed the strongest antioxidant activities in ground beef. The TBARS values of ground beef sprayed with ascorbic acid was 76~80% lower than that of the control at 8 days. The results are consistent with the previous studies showing the antioxidant effects of ascorbic acid in beef products (Shivas, Kropf, Hunt, Kastner, Kendall & Dayton, 1984; Craig, Bower, Wang & Seib, 1996), where ascorbic acid was simply mixed with meat samples.

Ascorbic acid-sprayed beef had significantly lower TBARS values than the control or other antioxidants. The spraying of ascorbic acid at 500 ppm on ground beef was very effective in preventing lipid oxidation as well as discoloration during the aerobic storage. If the ascorbic acid is just added throughout the whole part of meat sample, more amounts of ascorbic acid would be needed to show equal activities compared with the use of electrostatic spraying. Therefore, the spray of ascorbic acid was an efficient and economical way to control the antioxidative quality changes of ground beef. Among the other sprayed antioxidants, sesamol at 100 ppm showed as strong antioxidant activities as ascorbic acid at 500 ppm did. Tocopherols and rosemary extract also had antioxidant effects but they were less stronger than ascorbic acid or sesamol.

As storage time progressed, a few volatiles compounds increased in ground beef. Most of volatiles detected in ground beef at 8 days were hydrocarbons and carbonyls. Although a few ketones (2-propanone, 2-butanone, and 2,3-butadione) were the predominant volatiles in ground beef, lipid oxidation-related compounds (volatile aldehydes) were the most characteristic volatiles in stored ground beef. As Shahidi and others (1975) reported that hexanal was a good indicator of lipid oxidation, it was the most predominant aldehyde compound. The amount of hexanal was drastically increased during the storage and a considerable amount of hexanal was produced at 8 days. Spraying of ascorbic acid and sesamol was very effective in reducing the hexanal production as shown in lipid oxidation of ground beef. Heptanal and 1-pentanol were also significantly increased during the storage, and ascorbic acid and sesamol was effective in reducing them.

IV. CONCLUSION

Ground beef has disintegrated muscle structure and is more susceptible to oxidative quality changes such as lipid oxidation, brown color formation, and production of aldehydes volatiles. To control the antioxidative quality problems in ground beef, a few additives can be added by simple mixing during the processing. Electrostatic spraying, which is used to spray minimal content of additives, can be applied to meat products to coat or envelop more uniformly using charged droplets. Among antioxidants and reducing agent applied to ground beef using electrostatic spraying method, ascorbic acid was the most effective in reducing lipid oxidation as well as preventing discoloration. Ascorbic acid effectively reduced TBARS values and volatile aldehydes (hexanal, heptanal), and reduced the formation of met-myoglobin by maintaining lower oxidation-reduction poteintial. As spraying of ascorbic acid on the surface of meat products can reduce the used amount, it can be an more industrially applicable way to retard oxidative quality changes of ground beef compared with the conventional simple mixing.

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Table 1. Met-myoglobin percentage of ground beef sprayed with different additives during aerobic storage at 4 °C

Treatment	1 day	5 day	8 day	SEM
	---------------- (*%*) --------------			
Control	45.2ay	82.0ax	85.2ax	2.3
Ascorbic acid	28.7bz	52.8dy	62.8bx	2.4
α-Tocopherol	41.7ay	80.2abx	84.4ax	2.6
γ-Tocopherol	37.6aby	82.8ax	85.0ax	2.3
Sesamol	40.5abz	69.5cy	86.7ax	1.8
Rosemary oleoresin	35.6abz	74.5bcy	86.1ax	1.7
Ascorbic acid + α-Tocopherol	35.4abz	49.8dy	59.0bx	2.5
SEM	2.8	2.0	2.0	

(a-d) Values with different letters within a column are significantly different ($P < 0.05$).
(x-z) Values with different letters within a row are significantly different ($P < 0.05$).

Table 2. ORP values of ground beef sprayed with different additives during aerobic storage at 4 °C

Treatment	1 day	5 day	8 day	SEM
	---------------- (*mV*) --------------			
Control	144.8abz	219.7ay	235.5ax	2.4
Ascorbic acid	107.3cz	140.0cy	163.9bx	3.5
α-Tocopherol	139.7bz	198.8by	213.2bx	1.9
γ-Tocopherol	153.6ay	205.8bx	214.2bx	2.8
Sesamol	146.8abz	202.9by	211.8bx	2.7
Rosemary oleoresin	145.3aby	210.5bx	211.4bx	2.7
Ascorbic acid + α-Tocopherol	106.2cy	141.5cx	154.6cx	4.7
SEM	2.3	3.1	3.8	

(a-c) Values with different letters within a column are significantly different ($P < 0.05$).
(x-z) Values with different letters within a row are significantly different ($P < 0.05$).

Table 3. TBARS values of ground beef spayed with different additives during aerobic storage at 4 °C

Treatment	1 day	5 day	8 day	SEM
	------ (*mg MDA/kg meat*) ------			
Control	1.57ay	2.69ax	3.20ax	0.19
Ascorbic acid	0.72cy	0.99bx	0.75cy	0.05
α-Tocopherol	1.50ay	2.57ax	2.65bx	0.22
γ-Tocopherol	1.22by	2.67ax	2.73bx	0.13
Sesamol	0.35dy	0.26cy	0.56cx	0.04
Rosemary oleoresin	1.13bz	2.23ay	2.68bx	0.11
Ascorbic acid + α-Tocopherol	0.55c	0.55bc	0.65c	0.08
SEM	0.06	0.18	0.12	

(a-c) Values with different letters within a column are significantly different ($P < 0.05$).
(x-z) Values with different letters within a row are significantly different ($P < 0.05$).