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ARTICLE

Combined Effects of Modified Atmosphere Packaging and Organic Acid Salts (Sodium Acetate and Calcium Lactate) on the Quality and Shelf-life of Hanwoo Ground Beef Patties

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Abstract

The present study investigated the combined effects of modified atmosphere packaging (MAP) and organic acid salts on the quality and shelf-life of Hanwoo ground beef patties. The ground beef containing 500 ppm of ascorbic acid was prepared with air-packaging (Air-P), high oxygen-MAP (70% O_2 + 30% CO_2/OxyMAP), and nitrogen-MAP (100% N_2/NitroMAP), in combination with organic acid salts (1500 ppm of sodium acetate and 500 ppm of calcium lactate). The samples were stored for 11 d at 5°C. The pH value of ground beef patties decreased during storage in all the treatments. The ground beef patties with organic acid salts showed relatively higher level of pH during storage compared with non-added patties ($p<0.05$). Lipid oxidation was accelerated in OxyMAP while it was delayed in NitroMAP treated with organic acid salts. Nitro-MAP treated with organic acid salts was effective in stabilizing the color characteristics of lightness (CIE L*) and redness (CIE a*) during storage. Oxygen content in MAP was shown to be a more important factor affecting color stability and lipid oxidation of ground beef than organic acid salts. The aerobic and anaerobic bacterial counts were reduced both in OxyMAP and NitroMAP ($p<0.05$), and the lactic acid bacteria was inhibited by Oxy-MAP ($p<0.05$). Coliform bacteria decreased during storage as pH value was decreased in all treatments. According to the sensory evaluation, the ground beef patties in NitroMAP showed the best quality among all treatments during storage. Therefore, Hanwoo ground beef patties added with sodium acetate and calcium lactate and packed with NitroMAP showed better quality characteristics than other treatments. This packaging method is recommended and could be utilized for packaging hanwoo ground beef patties for improving quality and extending shelf-life.

Key words: modified atmosphere packaging, ground beef patty, sodium acetate, calcium lactate

Introduction

Meat color is one of the most important quality parameters that determine the consumer acceptance of meat and meat products (Liu *et al.,* 1995; Mancini *et al.,* 2006). The red cherry color in fresh meat and red or purple color in ground beef are associated with the freshness of products for consumers. Therefore, the prevention of metmyoglobin formation is the prerequisite for merchandising meat products (Judge *et al.,* 1989).

Shelf-life is defined as the period from the packaging time until the consumption of products while the acceptable quality in terms of appearance, microbiology, and nutritional value is maintained (McMillin, 2008; Singh and Singh, 2005). Shelf-life of products can be extended by the manipulation of the microenvironment in the packaged meat (Hotchkiss, 1989). Vacuum and modified atmosphere packaging (MAP) techniques are used in the food industry to extend the shelf-life of products. High oxygen atmosphere preserves the bright red color of meat and increases shelf-life by suppressing microbial growth. Beef packaged in a high oxygen-modified atmosphere typically retains a shelf-life of 10 to 14 d for ground beef and 12 to 16 d for whole-muscle beef cuts (Belcher, 2006). Carbon dioxide is well known as an antibacterial gas in MAP. Smith *et al.* (1990) demonstrated that 20-60% CO_2 in MAP was required to retard aerobic spoilage effectively. Low CO_2 concentration (20%) was better than high concentration (60%) in preservation of color and odor of fresh sausages (Martinez *et al.,* 2005). Different results were shown by Renerre and Labadie (1993) in

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which CO_2-MAP inhibited microbial growth in fresh red meat, but had no effect on color stability.

In order to protect lipid and pigment oxidation in meat, meat manufactures are currently using different kinds of food additives and organic acid salts. Some organic acid salts used in meat as an antioxidant include ascorbic acid, sodium lactate, sodium acetate, rosemary extract, chitosan etc. Ascorbic acid has been known as an effective antioxidant to inhibit myoglobin oxidation and brown color development on the surface of ground beef (Lee *et al.,* 1999; Sanchez-Escalante *et al.,* 2001). Sodium salts of the low molecular weight organic acids such as acetic acid, lactic acid, and citric acid have been used to control the microbial growth and to improve the color stability, sensory attributes, and shelf-life in ground beef patties (Maca *et al.,* 1997; Sallam and Samejima, 2004). Sallam (2007) reported that sodium lactate and sodium acetate could delay the lipid oxidation and microbial growth in sliced salmon. Sodium acetate improved the color stability in enhanced pork (Livingston *et al.,* 2004). Sodium acetate combined with potassium lactate showed a synergistic effect on improving color stability in pork (Jensen *et al.,* 2003) and beef steaks (Knock *et al.,* 2006).

Lactates exhibit antimicrobial properties against pathogenic (Miller and Acuff, 1994) and non-pathogenic bacteria (Chen and Shelef, 1992), and the lactate anion promote color stability (Seyfert *et al.,* 2007). Calcium lactate with phosphate treatment significantly minimized lipid oxidation and had higher redness (a^*) value in fresh beef in highly oxidizing condition (Kim *et al.,* 2009). Enhanced beef steaks with a solution containing calcium lactate increased color stability and decreased metmyoglobin formation (Lawrence *et al.,* 2004) as did potassium lactate (Mancini *et al.,* 2005). However, the use of potassium lactate often darkened meat appearance by decreasing lightness (L*) value (Knock *et al.,* 2006; Mancini *et al.,* 2005).

The effect of MAP and organic acid salts in Hanwoo (Korean native cattle) ground beef patties has not been investigated yet. Therefore, the present study was conducted to evaluate the combined effects of MAP and organic acid salts (sodium acetate and calcium lactate) on the physical, chemical, and microbial properties of Hanwoo ground beef patties containing ascorbic acid.

Materials and Methods

Sample preparation and experimental design

Fresh Hanwoo beef (<3 d *postmortem*) were purchased from a local retailer. Top round part of beef was ground through 3 mm plates using a meat grinder (DFG 450, Daehan Food Machine Co., Ltd., Korea). The ground meat contains 22.6% of crude protein, 3.5% of crude fat, and 1.1% of ash. Hanwoo ground beef was mixed with 500 ppm of ascorbic acid (Sigma Chemical Co., St. Louis, USA). Ground beef was then divided into two groups, one for the control and the other for the addition of sodium acetate and calcium lactate (Aldrich Chemical Co., Milwaukee, USA). Experimental design for the preparation of samples is shown in Table 1. Three hundred grams of ground beef patty was placed on a barrier foam tray (O_2 transmission rate=0.1 cc/cm^2 at 23°C, 0% RH; water vapor transmission rate=7.87 mg/ 24 h-cm^2 at 38°C, 100% RH, Cryovac Sealed Air Corp., USA) for the following packaging methods. Each tray with ground beef patty inside was sealed with O_2 barrier film (O_2 transmission rate=0.39 mg/24 h-cm^2 at 4.4°C, 100% RH; Lid 1050, Cryovac Sealed Air Corp., USA). The trays were filled with air in different composition by using MAP machine (Hypervac, Korea) equipped with the gas mixture (MAP Mix 9001 ME, PBI Dansensor, Denmark). Oxygen, carbon dioxide, and nitrogen were obtained from a local gas supplier (Baeklyung Specialty Gas Co., Korea). A hundred-ninety-six packs (6 packs in each treatment) of Hanwoo ground beef patties were stored for 11 d at 5°C the dark condition. Six packs from each group were opened on 1, 3, 5, 7, 9, and 11 d for subsequent analysis for each formulation. Three packs were used for microbial analysis, while the remaining 3 packs were used for sensory, instrumental color, and chemical analysis.

Gas composition measurement

On 1, 3, 5, 7, 9, and 11 d of storage, six trays from each treatment were allocated for the gas analysis. Before opening the packs, the gas composition in the headspace of pack was measured using a gas analyzer (DK Checkmate 9900, PBI Dansensor, Denmark) to check O_2 and

Table 1. Experimental design

Treatments	Gas composition	Org. acid salts (ppm)	
		Sodium acetate	Calcium lactate
Control	Air packaging	0	0
OxyMAP	70% O + 30% CO	0	0
NitroMAP	100% N	0	0
OxyMAP+Org. acid salts	70% O + 30% CO	1500	500
NitroMAP+Org. acid salts	100% N	1500	500

CO_2 composition.

pH determination

For the pH determination, 10 g of sample was added with 100 mL of distilled water and then homogenized at 10,000 rpm for 60 s using a homogenizer (PH91, SMT Co., Ltd., Japan). The pH value of the homogenized sample was measured using a pH meter (SevenEasy pH, Mettler-Toledo GmbH, Switzerland). Measurements were performed on duplicates in every sample (3 trays in each treatment).

2-Thiobarbituric acid reactive substance (TBARS) value analysis

The TBARS value was measured according to Sinnhuber and Yu (1977). Briefly, 0.5 g of sample was mixed with 3 drops of antioxidant solution, 3 mL of TBA solution, and 17 mL of 25%(w/v)+Trichloroacetic acid. The mixture was heated at 100°C for 30 min and centrifuged at 3,500 rpm for 30 min. An absorbance of supernatant was measured at 532 nm using a spectrophotometer (UV-mini-1240, Shimadzu, Japan). The results were calculated as mg of malonaldehyde (MA) per kg of sample.

Instrumental color measurement

Color changes on the surface of Hanwoo ground beef patties were monitored by measuring the CIE lightness (L*) and redness (a*) using a color difference meter (CR-400, Konica Minolta Sensing Inc., Japan) and an illuminant C. The color instrument was calibrated using white plate (Y=93.6, x=0.3134, and y=0.3194). Color measurements were directly performed on the surface of samples immediately after the packs were opened. The color of ground beef patties surface was measured 30 times in each pack at different locations.

Hardness analysis

Hardness analysis was carried out using a texture analyzer (TA-XT2*i* version 6.06, Stable Micro Systems Ltd., UK). Thirty two grams of ground beef patties sample was placed in petridish with Ø60 mm × 15 mm depth (SPL Life Science, Korea). The sample was first formed by using a petridish and the hardness was measured by using a Ø5 mm cylindrical probe. The measurements were performed on triplicates in every sample. Hardness is expressed as kgf.

Sensory evaluation

Panel consisting of 6 trained-faculty members and students evaluated the ground beef patties on the visual color, flavor, oxidation odor, and sour odor at 1, 3, 5, 7, 9, and 11 d of storage. The visual color evaluation was conducted directly from the trays after gas composition analysis. For flavor, oxidation odor, and sour odor, 15 g of sample was placed into a petridish with Ø60 mm × 15 mm depth. The petridish was opened just before the panelist performed the sensory evaluation. The panelist scored the visual color, and flavor in scales: 9=extremely like, 7=like, 5=moderate like, 3=dislike, and 1=extremely dislike, while the scores for oxidation odor and sour odor were 9=extremely strong, 7=strong, 5=medium, 3=weak, and 1=none.

Microbial analysis

Ten grams of meat sample was placed into the autoclaved bag (Nasco Co., Ltd., USA) and added with 90 mL of 0.1%(w/v) peptone solution. Each sample was homogenized using a Stomacher Lab Blender 400 (Seward Laboratory, UK) for 3 min. Serial 10-fold dilution was performed by mixing 1 mL of solution with 9 mL of peptone solution. Three different medium agars were prepared for four different microbial analyses; aerobic and anaerobic bacterias (Plate Count Agar, Difco, USA), coliform (Violet Red Bile Agar, Difco , USA) and lactic acid bacteria (Lactobacilli MRS Agar, Difco, USA). Agar plates were prepared according to the manufacturer's instruction. One milliliter of sample was taken from the peptone dilution and put it on petridish. Samples were incubated for 48 h at 35°C. Three replications were made in each sample. Microbial populations were counted and expressed as Log CFU/g sample.

Statistical analysis

All data were analyzed using SPSS 14.0 for Windows Evaluation Version (2005). The data was analyzed by one way analysis of variance, with treatments (packaging method and organic acid salts combination) as variable. Means of data in every day of storage were compared using Duncan's multiple range tests with examination for significant differences ($p<0.05$).

Results and Discussion

Gas composition measurement

The level of oxygen was found to be 0% during the storage in NitroMAP. This result is in agreement with Lund *et al.* (2007a) who showed 0% oxygen throughout the entire chill storage period of beef patties in 100% N_2

packaging with and without additives. The level of oxygen in OxyMAP both in control ground beef patties and organic acid salts treatment increased until 3 d and then decreased from 3 d until the end of storage, while in Air-P the oxygen level decreased during storage period (Fig. 1). The increase in oxygen level until 3 d of storage in OxyMAP might be attributed to meat respiration via muscle enzyme and microorganism metabolism, as described in Kropf (2000).

The level of carbon dioxide was increased during the storage in all treatment groups as compared with Air-P. The increase in carbon dioxide might be caused by microbial growth in the packs. Lund *et al.* (2007a) noticed the increase in carbon dioxide level indicating microbial growth in meat. The changes in gases head space composition (CO_2 concentration) in MAP are results of microbial growth (Jackson *et al.,* 1992). The addition of sodium acetate and calcium lactate decreased oxygen level of OxyMAP and increased carbon dioxide level of OxyMAP and NitroMAP. It showed that the organic acid salts system also played role in reducing microbial growth. Similar results have previously been shown by Lund *et al.* (2007a) in beef patties.

pH value

The pH value decreased as the storage time increased in treatment groups (Table 2). The pH value of Hanwoo ground beef patties added with organic acid salts was generally higher than non-added counterparts (p<0.05). The pH value in Air-P was the lowest compared to other treatments from 7 d until the end of storage. The pH values in OxyMAP with organic acid salts were higher (p< 0.05) than other treatments from 3 d until the last day of

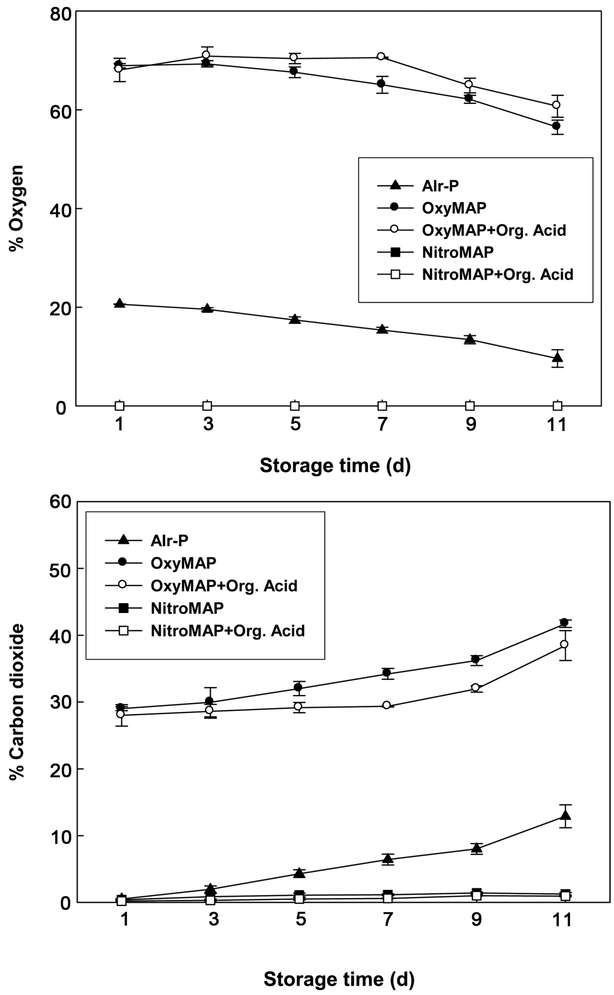

Fig. 1. Combined effects of modified atmosphere packaging and organic acid salts on the gas composition (%) of Hanwoo ground beef patties.

storage. Comparing the pH value of the same packaging methods both in OxyMAP and in NitroMAP, addition of

Table 2. Combined effects of modified atmosphere packaging and organic acid salts on the pH value of Hanwoo ground beef patties

Storage time (d)	Air-P[1)]	OxyMAP[2)]		NitroMAP[3)]	
		None	Org. acid salts[4)]	None	Org. acid salts
0	6.11±0.00^{aA}	6.11±0.00^{aA}	6.01±0.01^{bA}	6.11±0.00^{aA}	6.02±0.01^{bA}
1	6.06±0.02^{aA}	6.07±0.00^{aA}	6.01±0.01^{aA}	6.03±0.01^{aA}	5.91±0.11^{bA}
3	5.07±0.19^{cB}	5.28±0.26^{bcB}	5.96±0.06^{aA}	4.99±0.11^{cB}	5.54±0.16^{bB}
5	4.72±0.03^{cCD}	4.85±0.07^{bcC}	5.55±0.21^{aB}	4.80±0.07^{cC}	5.05±0.08^{bC}
7	4.75±0.04^{dC}	4.88±0.10^{dC}	5.62±0.10^{aB}	5.01±0.05^{cB}	5.15±0.01^{bC}
9	4.60±0.06^{dD}	4.73±0.02^{cC}	4.94±0.04^{aC}	4.70±0.03^{cC}	4.82±0.07^{bD}
11	4.37±0.00^{dE}	4.47±0.05^{bcD}	4.64±0.01^{aD}	4.43±0.01^{cdD}	4.52±0.02^{bE}

$^{a-d}$Values within each row with different superscripts are significantly different (p<0.05).
$^{A-E}$Values within each column with different superscripts are significantly different (p<0.05).
1)Air-P: Air-packaging.
2)OxyMAP: 70% O_2 + 30% CO_2.
3)NitroMAP: 100% N_2.
4)Org. acid salts: 1500 ppm of sodium acetate 500 ppm of calcium lactate.

sodium acetate and calcium lactate resulted in higher pH value ($p<0.05$) from 3 d of storage until the end of storage. This result is consistent with those of previous reports. Kim *et al.* (2009) reported an increase in the pH of lactate-enhanced beef. Suman *et al.* (2010) reported that the pH value of lactate-treated beef patties was higher compared with the control (non-treated sample). However, other researchers reported no differences in pH value due to lactate treatment, such as in ground beef (Seyfert *et al.,* 2007) and in steaks (Lawrence *et al.,* 2003; Mancini *et al.,* 2009).

The higher pH value in organic acid salts treatments might be due to the antimicrobial activity of sodium acetate and calcium lactate to reduce the population of lactic acid bacteria. This result agreed with the microbial analysis results. Lower lactic acid bacteria population resulted higher pH value. Lactates exhibit antimicrobial properties against pathogenic (Miller and Acuff, 1994) and non-pathogenic bacteria (Chen and Shelef, 1992), while sodium salts have been used to control microbial growth in beef patties (Maca *et al.,* 1997).

TBARS value

Lipid oxidation can be determined by TBARS methods. TBARS is a strong objective predictor of the perception of rancidity (McMillin, 2008). TBARS values of NitroMAP in both with or without organic acid salts were lower ($p<0.05$) than those of OxyMAP and Air-P (Fig. 2). Similarly, Lund *et al.* (2007a) showed that 100% N_2-MAP significantly lower the TBARS value with or without organic acid salts in beef patties. These results are also in agreement with those of Cayuela *et al.* (2004), John *et al.* (2005), and McMillin (2008) who showed that high oxygen packaging resulted higher lipid oxidation, compared with vacuum packaging or low oxygen packaging in meat. The addition of sodium acetate and calcium lactate lowered the lipid oxidation in OxyMAP until 7 d of storage ($p<0.05$), while on 9 and 11 d of storage no effect on TBARS value was observed ($p>0.05$). In agreement with our results, Lund *et al.* (2007b) showed that additives lowered TBARS value in both high oxygen and low oxygen packaging in porcine *longisimus dorsi*. Sallam (2007) reported that sodium lactate and sodium acetate can delay the lipid oxidation in sliced salmon. Calcium lactate with phosphate treatment significantly minimized lipid oxidation in fresh beef under highly oxidizing condition was also noticed (Kim *et al.,* 2009). In NitroMAP, the addition of sodium acetate and calcium lactate gave no oxidative effect in Hanwoo ground beef patties ($p>0.05$).

Instrumental color

Surface color measurements showed that the L* value of non-treated ground beef patties packaged under OxyMAP was higher ($p<0.05$) than other treatments from 3 d of storage (Fig. 3). Both in OxyMAP and in NitroMAP, the addition of sodium acetate and calcium lactate significantly lowered the L* value over the storage ($p<0.05$), in other words, the use of organic acid salts resulted in darker color in ground beef patties. The darkening effect of lactate in ground beef also was reported by Lawrence *et al.* (2003) and Kim *et al.* (2006). In addition, Maca *et al.* (1999) showed that L* values decreased with the addition of sodium lactate in beef top rounds. Mancini *et al.*

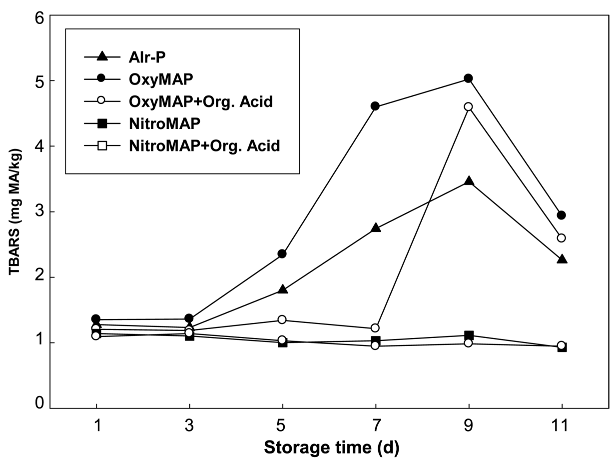

Fig. 2. Combined effects of modified atmosphere packaging and organic acid salts on the TBARS value (mg MA/kg) of Hanwoo ground beef patties.

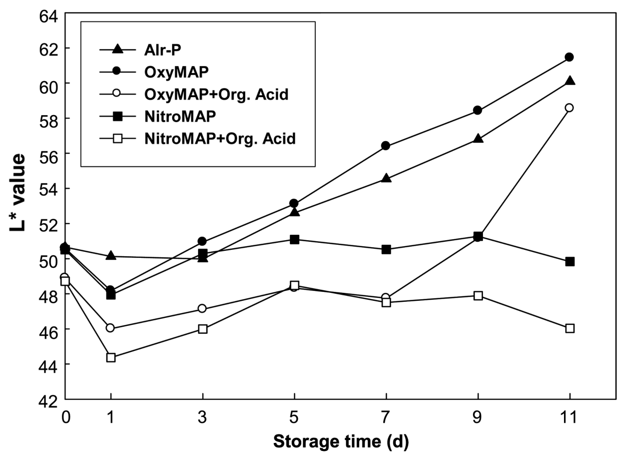

Fig. 3. Combined effects of modified atmosphere packaging and organic acid salts on the L* value of Hanwoo ground beef patties.

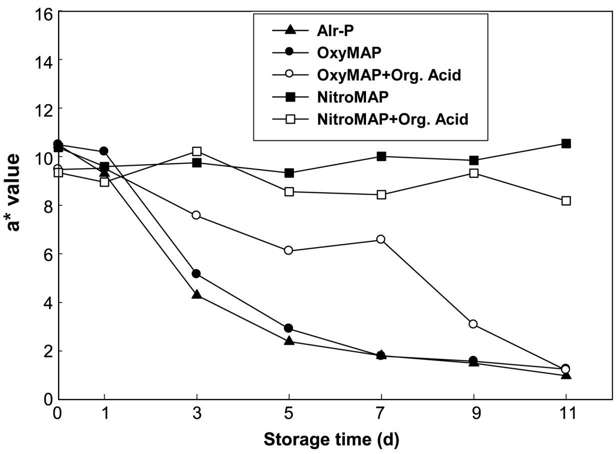

Fig. 4. Combined effects of modified atmosphere packaging and organic acid salts on the a* value of Hanwoo ground beef patties.

(2005) showed that L* value decreased with the addition of potassium lactate in beef *longissimus*. The difference in packaging methods also affected the L* value. In ground beef patties without organic acid salts, L* value in OxyMAP was higher than in NitroMAP from 5 d of storage ($p<0.05$), while ground beef patties with organic acid salts showed higher values from 9 d of storage ($p<0.05$). In contrast, results reported by Suman *et al.* (2010) noticed L* values for lactate patties in carbon monoxide-MAP and high oxygen-MAP were not significantly different.

The redness (a*) value in NitroMAP was higher ($p<0.05$) and more stable compared to other packaging methods by 3 d of storage (Fig. 4). The effect of packaging methods was different from several previous researches. High oxygen packaging extended the redness of beef (Houben *et al.,* 2000), and maintained a bright red color for 10 d in ground beef (Jayasingh *et al.,* 2002). This difference might be due to the meat characteristics in scavenging oxygen as well as oxidize oxymyoglobin from myoglobin. Hunt *et al.* (2004) noted that each muscle differs in their ability to scavenge oxygen and to reduce ferric heme iron. This process is related to the formation of oxymyoglobin.

The treatment of organic acid salts in NitroMAP lowered a* value during the storage compared to non organic acid salts ($p<0.05$), except on 3 d, while in OxyMAP a* value of organic acid salts ground beef was higher from 3 to 9 d compared to the control ($p<0.05$). It showed that the color preservation activity of sodium acetate and calcium lactate was different according to the packaging methods. Suman *et al.* (2010) noted that the color-stabilizing effect of lactate on ground beef depends on packaging. The difference in color preservation activity of sodium acetate and calcium lactate might be due to the different combined effect of packaging method and organic acid salts. Sanchez-Escalante *et al.* (2001) showed that ascorbic acid alone can improve the redness, and with the presence of other antioxidants can enhance the ability of ascorbic acid in beef patties.

Texture

The addition of sodium acetate and calcium lactate in OxyMAP, significantly delayed the hardening ($p<0.05$) compared to the control meat from 3 to 9 d of storage (Table 3). In addition, NitroMAP added with of organic acid salts comparatively decreased the hardness from 5 to 7 d. On the last day of storage, no difference was found among the treatments ($p>0.05$). Comparing the packaging methods, the Air-P and OxyMAP without organic acids showed a higher compared with other treatments until 9 d of storage. Different results were recorded by Sorheim *et al.* (2004) who showed no difference in hardness of the ground beef in different packaging methods and storage condition. Few reports mentioned that high oxygen atmosphere decreased tenderness of porcine *longissimus dorsi* (Lund *et al.,* 2007b) and beef (Seyfert *et al.,* 2005).

Table 3. Combined effects of modified atmosphere packaging and organic acid salts on the hardness properties (kgf) of Hanwoo ground beef patties

Storage time (d)	Air-P	OxyMAP		NitroMAP	
		None	Org. acid salts	None	Org. acid salts
1	4.01±1.26^{aD}	3.52±0.45^{abE}	3.28±0.33^{abD}	3.42±0.32^{abC}	3.03±0.39^{bC}
3	4.70±1.18^{abD}	4.89±0.91^{aD}	3.88±0.16^{bCD}	4.48±0.46^{abB}	3.85±0.15^{bC}
5	8.42±0.9^{aB}	8.91±1.13^{aB}	5.44±0.68^{cCD}	7.91±0.95^{aA}	6.01±0.69^{bB}
7	8.39±0.25^{bB}	9.23±0.83^{aB}	6.75±0.65^{cC}	8.03±0.57^{bA}	6.83±0.39^{cB}
9	9.69±1.19^{abA}	10.73±1.51^{aA}	6.61±1.45^{cA}	8.48±0.81^{bA}	8.31±1.12^{bA}
11	6.33±0.50^{C}	6.58±1.61^{C}	6.35±1.14^{B}	6.80±1.26^{B}	6.28±0.80^{B}

$^{a-d}$Values within each row with different superscripts are significantly different ($p<0.05$).
$^{A-E}$Values within each column with different superscripts are significantly different ($p<0.05$).

Table 4. Combined effects of modified atmosphere packaging and organic acid salts on the sensory evaluation of Hanwoo ground beef patties

Storage time (d)		Air-P	OxyMAP		NitroMAP	
			None	Org. acid salts	None	Org. acid salts
Visual color	1	8.7±0.5^{aA}	8.4±0.5^{aA}	8.9±0.3^{aA}	6.3±1.1^{bA}	6.0±1.2^{bA}
	3	5.5±1.0^{cB}	6.8±0.4^{bB}	8.8±0.5^{aA}	6.3±1.1^{bcA}	6.3±1.1^{bcA}
	5	1.1±0.4^{dC}	1.3±0.5^{dCD}	3.4±1.4^{cB}	4.2±0.4^{aB}	3.7±0.9^{bA}
	7	1.0±0.0^{dC}	1.0±0.0^{dD}	3.4±1.8^{cB}	4.1±1.1^{aBC}	3.9±1.6^{bB}
	9	1.0±0.0^{cC}	1.0±0.0^{cD}	2.2±1.4^{bC}	3.5±0.6^{aCD}	2.7±0.7^{bC}
	11	1.0±0.0^{cC}	1.0±0.0^{cD}	1.0±0.0^{cD}	3.3±0.5^{aD}	2.3±0.5^{bC}
Flavor	1	8.4±0.9^{aA}	7.6±1.4^{bA}	7.9±0.7^{abA}	8.0±1.0^{abA}	8.6±0.6^{aA}
	3	4.3±0.5^{cB}	4.3±1.0^{cB}	6.0±0.4^{bB}	7.1±0.5^{aA}	7.1±0.5^{aB}
	5	2.3±0.9^{cC}	1.3±0.5^{dC}	2.7±0.6^{cC}	5.1±1.1^{bB}	5.9±0.9^{aC}
	7	1.2±0.4^{cD}	1.2±0.4^{cC}	2.3±1.1^{bC}	4.4±1.5^{aBC}	4.1±1.6^{aD}
	9	1.0±0.0^{cD}	1.0±0.0^{cC}	1.7±0.0^{cD}	4.5±1.3^{bBC}	5.4±1.3^{aC}
	11	1.0±0.0^{cD}	1.0±0.0^{cC}	1.0±0.0^{cE}	4.4±1.3^{aC}	3.0±1.3^{bE}
Oxidation Odor	1	1.0±0.0^{E}	1.0±0.0^{D}	1.0±0.0^{E}	1.0±0.0^{D}	1.0±0.0^{C}
	3	5.6±0.5^{aD}	5.9±0.7^{aC}	3.6±0.7^{bD}	2.3±0.5^{cC}	2.3±0.5^{cB}
	5	7.3±0.9^{bC}	8.6±0.5^{aB}	5.8±1.2^{cC}	2.7±1.2^{dBC}	2.4±1.4^{dB}
	7	8.2±1.7^{aB}	8.4±1.2^{aAB}	6.8±0.9^{bB}	3.4±1.4^{cB}	2.8±1.2^{cB}
	9	9.0±0.0^{aA}	9.0±0.0^{aA}	8.5±0.6^{aA}	5.6±1.1^{bA}	5.0±1.2^{cA}
	11	9.0±0.0^{aA}	9.0±0.0^{aA}	9.0±0.0^{aA}	6.0±1.7^{bA}	5.3±2.1^{bA}
Sour Odor	1	1.0±0.0^{E}	1.0±0.0^{C}	1.0±0.0^{D}	1.0±0.0^{D}	1.0±0.0^{E}
	3	3.8±1.6^{aD}	3.8±1.9^{aB}	2.3±1.9^{bC}	2.3±1.1^{bC}	2.3±1.1^{bD}
	5	4.0±1.0^{aD}	4.4±1.2^{aB}	2.2±0.7^{cC}	3.1±0.6^{bBC}	3.1±0.7^{bCD}
	7	5.1±1.4^{aC}	4.1±0.5^{abB}	3.1±1.1^{bC}	3.5±1.9^{bB}	3.7±2.2^{bC}
	9	6.3±2.4^{aB}	4.6±1.7^{bB}	5.6±1.5^{abB}	5.5±1.1^{abA}	4.7±1.1^{bB}
	11	7.5±0.5^{aA}	7.0±1.7^{bA}	7.3±1.9^{aA}	5.0±2.0^{bA}	7.5±1.6^{aA}

$^{a\text{-}d}$ Values within each row with different superscripts are significantly different ($p<0.05$).
$^{A\text{-}E}$ Values within each column with different superscripts are significantly different ($p<0.05$).

Sensory evaluation

Color sensory scores of Air-P and OxyMAP without organic acid salts were the lowest among the treatments ($p<0.05$) from 5 d of storage (Table 4). Generally, NitroMAP samples obtained higher color scores compared with Air-P and OxyMAP samples from 5 to 11 d of storage ($p<0.05$). This sensory result was similar with instrumental redness value. The redness of NitroMAP was higher than that of OxyMAP and Air-P. Meat color, especially redness attribute is one of the most important quality parameter that determines the consumer acceptance of meat (Liu *et al.,* 1995; Mancini *et al.,* 2006). In OxyMAP, the color scores of ground beef patties added with sodium acetate and calcium lactate was higher than the sample without organic acid salts from 3 to 9 d ($p<0.05$). However, in NitroMAP, color sensory scores of samples with organic acid salts were lower than those without organic acid salts from 5 d to end of storage ($p<0.05$).

Flavor scores of ground beef patties in NitroMAP were higher than Air-P and OxyMAP ($p<0.05$). Addition of sodium acetate and calcium lactate preserved the flavor in OxyMAP until 7 d of storage. Nevertheless, no significant differences were found for flavor score in NitroMAP regardless the addition of organic acid salts ($p>0.05$). The sensory scores for oxidation and sour odor of ground beef patties in NitroMAP were lower compared to Air-P and OxyMAP from 5 d of storage. Organic acid salts might account for delaying the oxidation and development of sour odor which was, however, only found in OxyMAP until 7 d of storage ($p<0.05$). High oxygen packaging increased lipid oxidation in meat (John *et al.* 2005) and accelerates rancid flavor development in cooked ground beef (Jayasingh *et al.,* 2002).

Microbiology

Sodium acetate and calcium lactate lowered ($p<0.05$) the aerobic and anaerobic bacterial counts in OxyMAP and NitroMAP (Table 5). In OxyMAP, antibacterial effects of organic acid salts on aerobic and anaerobic bacteria was observed until 9 d of storage, while in NitroMAP the

Table 5. Combined effects of modified atmosphere packaging and organic acid salts on the microbial counts (Log CFU/g) of Hanwoo ground beef patties

Bacteria	Treatments	Storage time (d)					
		1	3	5	7	9	11
AE[1)]	Air-P	5.46±0.11^{aC}	5.76±0.12^{aB}	6.11±0.14^{aA}	5.96±0.07^{aAB}	5.93±0.24^{aAB}	5.85±0.10^{aB}
	OxyMAP	5.37±0.06^{aD}	5.82±0.11^{aB}	6.19±0.15^{aA}	5.85±0.23^{abB}	5.60±0.08^{bC}	5.43±0.03^{bCD}
	OxyMAP+Org.	4.85±0.02^{bD}	5.22±0.08^{cC}	5.67±0.14^{bA}	5.46±0.67^{cB}	5.42±0.05^{cB}	5.41±0.07^{bB}
	NitroMAP	5.40±0.13^{aC}	5.61±0.09^{bB}	6.06±0.17^{aA}	5.72±0.12^{bB}	5.64±0.14^{bB}	5.43±0.07^{bC}
	NitroMAP+Org	4.75±0.15^{bD}	5.24±0.10^{cC}	5.64±0.06^{bC}	5.43±0.09^{cB}	5.20±0.08^{dC}	5.12±0.15^{cC}
AN[2)]	Air-P	5.34±0.07^{aD}	5.72±0.17^{aC}	6.04±0.05^{aA}	5.92±0.04^{aAB}	5.89±0.01^{aAB}	5.82±0.21^{aBC}
	OxyMAP	5.30±0.05^{aD}	5.77±0.04^{aB}	6.03±0.15^{aA}	5.73±0.15^{bB}	5.53±0.06^{bC}	5.36±0.09^{bD}
	OxyMAP+Org.	4.80±0.06^{bC}	5.17±0.08^{cB}	5.54±0.25^{bA}	5.35±0.05^{dB}	5.31±0.02^{cB}	5.29±0.12^{bB}
	NitroMAP	5.32±0.09^{aC}	5.59±0.08^{bB}	6.00±0.14^{aA}	5.58±0.11^{cB}	5.35±0.07^{cC}	5.32±0.14^{bC}
	NitroMAP+Org	4.71±0.20^{bD}	5.21±0.15^{cBC}	5.62±0.16^{bA}	5.33±0.07^{dB}	5.07±0.04^{dC}	4.71±0.33^{cD}
LAB[3)]	Air-P	4.28±0.09^{aC}	4.71±0.22^{aB}	5.30±0.06^{aA}	4.78±0.12^{bB}	4.73±0.15^{aB}	4.67±0.12^{aB}
	OxyMAP	4.23±0.12^{aD}	4.77±0.03^{aBC}	5.38±0.15^{aA}	4.96±0.19^{aB}	4.84±0.08^{aBC}	4.64±0.16^{aC}
	OxyMAP+Org.	3.88±0.11^{bC}	4.34±0.12^{bB}	4.84±0.13^{bA}	4.78±0.15^{bA}	4.73±0.14^{aA}	4.69±0.06^{aA}
	NitroMAP	4.21±0.11^{aB}	4.37±0.08^{bB}	4.81±0.20^{bA}	4.36±0.10^{cB}	4.32±0.05^{bB}	4.26±0.05^{bB}
	NitroMAP+Org	3.83±0.12^{bD}	4.31±0.07^{bBC}	4.73±0.11^{bA}	4.37±0.05^{cB}	4.13±0.05^{cC}	3.84±0.29^{cD}
CO[4)]	Air-P	3.88±0.06^{A}	3.44±0.25^{B}	2.81±0.09^{cC}	ND[5)]	ND	ND
	OxyMAP	3.89±0.06^{A}	3.58±0.15^{B}	3.11±0.12^{bC}	2.58±0.07^{bD}	ND	ND
	OxyMAP+Org.	3.87±0.10^{A}	3.61±0.14^{B}	3.40±0.03^{aB}	3.16±0.14^{aC}	2.69±0.20^{bD}	ND
	NitroMAP	3.89±0.08^{A}	3.63±0.22^{B}	3.44±0.14^{aB}	3.21±0.14^{aC}	2.87±0.05^{aD}	ND
	NitroMAP+Org	3.81±0.14^{A}	3.66±0.07^{A}	3.38±0.10^{aB}	3.13±0.10^{aC}	2.74±0.16^{abD}	ND

$^{a\text{-}d}$Values within each column with different superscripts are significantly different (p<0.05).
$^{A\text{-}D}$Values within each row with different superscripts are significantly different (p<0.05).
[1)]AE: aerobic.
[2)]AN: anaerobic.
[3)]LAB: lactic acid bacteria.
[4)]CO: coliform.
[5)]ND: not detected.

effects remained until the end of storage. It might be due to the strong effect of lactate and acetate, exhibiting inhibitory effect on microbial growth. The antibacterial effect of sodium acetate and calcium lactate on the anaerobic and aerobic bacteria counts is in agreement with Lawrence *et al.* (2003) who reported reduced antimicrobial plate counts in beef *longissimus dorsi* owing to the effect of calcium salts. In addition, Papadopoulas *et al.* (1991) reported that cooked beef containing 3% or 4% sodium lactate had 2 log units reduction in microbial population during storage. Air-P resulted in higher aerobic and anaerobic bacteria from 7 d of storage compared to other treatments (p<0.05). In samples without organic acid salts, NitroMAP resulted lower aerobic bacteria population compared to OxyMAP until 7 d of storage, while in anaerobic bacteria until 9 d of storage (p<0.05).

Sodium acetate and calcium lactates lowered (p<0.05) lactic acid bacteria in OxyMAP until 7 d of storage, while in NitroMAP the antibacterial effects of organic acid salts appeared in the beginning and in the end of storage (1, 9, and 11 d). This result is in agreement with Maca *et al.* (1997), who described the lactic acid bacteria reducing ability of sodium lactate in ground beef patties under vacuum packaging. Sodium acetate also showed inhibitory effects on lactic acid bacteria in the cooked beef under vacuum packaging (Papadopoulas, 1991). Moreover, it was also documented that sodium lactate is most effective against lactic acid bacteria (DeWit and Rombouts, 1990). In the control ground beef patties, NitroMAP resulted a lower lactic acid bacterial count from 2 d until the end of storage compared to the control meat in Air-P and OxyMAP (p<0.05). Coliform counts decreased as the pH decrease in all the treatments. Addition of sodium acetate and calcium lactate resulted in higher population of coliform in OxyMAP from 5 to 9 d, while in NitroMAP organic acid salts gave no effect. Coliform was not detected in Air-P from 7 d. In OxyMAP, no coliform bacteria were found in the control ground beef from 9 d, and in organic acids treatment ground beef on 11 d. In NitroMAP, no coliform bacteria were found on 11 d both in the control and organic acids treatment ground beef. During the storage, aerobic, anaerobic, and lactic acid bacterial counts in all the treatments increased until 5 d and decreased thereafter. The counts of bacteria were lower than 7 log CFU in the control among all the treatments during the storage. This effect might be attributed to the addition of ascorbic acid. Although ascorbic acid is known as antioxidant additives in meat, Giroux *et al.* (2001) showed the antimicrobial properties of ascorbic acid in beef patties in terms of aerobic plate and total coliform counts. Antibacterial properties of ascorbic acid in combination with other organic acids might have additive effect. In addition, some researches reported the antimicrobial effect of organic acid salts on the microbial growth. Papadopoulas *et al.* (1991) reported that 3% or 4% sodium lactate had 2 log units reduction in microbial population of cooked beef. Stillmunkes *et al.* (1993) found an inhibitory effect against pathogens with a concentration up to 3.5% of sodium lactate in cooked beef roast.

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