Effects of Organic Acids Mix and Modified Atmosphere Packaging on the Storage Quality of Sliced Bacon

Muhlisin, Sun Moon Kang¹, Won Hee Choi, Keun Taik Lee², Sung Hee Cheong³, and Sung Ki Lee*

Department of Animal Products and Food Science, Kangwon National University, Chuncheon 200-701, Korea

¹National Institute of Animal Science, Rural Development Administration, Suwon 441-706, Korea

²Department of Food Processing and Distribution, Gangneung-Wonju National University, Gangneung 210-702, Korea

³Geo Food Tech Institute, Seongnam 463-741, Korea

Abstract

The effects of organic acids mix (0.4%) and modified atmosphere packaging (MAP) on the storage quality of sliced bacon were investigated. Pork bellies were treated with or without organic acids at the curing stage. The organic acids mix comprised 35% sodium acetate, 25% salt, 15% calcium lactate, 11% trisodium citrate, 7% ascorbate, and 7% citric acid. The cured pork bellies were smoked and packaged with 50% CO₂ + 50% N₂ (50% CO₂-MAP) and 100% N₂ (100% N₂-MAP), and stored at 5°C for 14 d. The 50% CO₂-MAP showed a higher pH value ($p < 0.05$) up to 10 d, a lower protein deterioration ($p < 0.05$) as measured by volatile basic nitrogen (VBN) from 6 to 14 d, and a higher color value of lightness (CIE L*) compared to 100% N₂-MAP. The development of lipid oxidation measured by thiobarbituric acid reactive substance (TBARS) values seemed to be effectively controlled throughout the storage period in both 50% CO₂-MAP and 100% N₂-MAP regardless of the application of organic acids. The 50% CO₂-MAP inhibited the growth of aerobic and anaerobic bacteria ($p < 0.05$) both in non-added and bacon added with organic acids mix. The 50% CO₂-MAP alone seemed to be effective in delaying the growth of bacteria since the use of organic acids mix gave no additional effects. The addition of organic acids mix lowered the pH value ($p < 0.05$), effectively retarded the protein deterioration ($p < 0.05$), and showed a higher color value of lightness (CIE L*) value ($p < 0.05$) and lower color value of redness (CIE a*) value ($p < 0.05$). In conclusion, 50% CO₂-MAP showed better quality and self-life of sliced bacon during storage. However, the beneficial effect of organic acids mix was not noticed in the concentration used in this experiment.

Key words: modified atmosphere packaging, organic acids mix, sliced bacon, storage quality

Introduction

Fresh pork belly (*Samgyeopsal*) is popular meat-based cuisine in Korea (Nam *et al.*, 2010). Bacon is the cured meat product prepared from pork belly (Yi and Chen, 2003). Recently, the meat industries in Korea have been trying to develop a new type of the pork belly-based products which is manufactured as a ready-to-cook product. Since this kind of products is not cooked, it can possess different quality and storage characteristics. Therefore, it is necessary to develop the packaging methods and the suitable preservatives in order to keep the quality of smoked pork belly (bacon) during storage and marketing.

Modified atmosphere packaging (MAP) has been used by meat industry to extend the shelf-life as well as to keep the quality characteristics of meat products. Usually, gases used in MAP are oxygen (O₂), carbon dioxide (CO₂), nitrogen (N₂), and other gases in small percentage such as, carbon monoxide (CO), etc. MAP is commonly divided into low oxygen and high oxygen MAP based on the oxygen contents. High O₂ MAP may contain 25-90% O₂ and 15-80% CO₂ (Blakistone, 1999), and the common composition of high O₂ MAP is 80% O₂: 20% CO₂ (Kim *et al.*, 2010; McMillin, 2008). High O₂ MAP preserves the bright red color of meat (Jayasingh *et al.*, 2002; Okayama *et al.*, 1995), but due to the elevated oxidative conditions, this MAP promotes the lipid oxidation (Cayuela *et al.*, 2004), and has negative effects on color and flavor stability (Grobbel *et al.*, 2008; Kim *et al.*, 2010; Zakrys *et al.*, 2008). Premature browning during the cooking is another negative effect of high O₂ MAP

*Corresponding author: Sung Ki Lee, Department of Animal Products and Food Science, Kangwon National University, Chuncheon 200-701, Korea. Tel: 82-33-250-8646, Fax: 82-33-251-7719, E-mail: skilee@kangwon.ac.kr

(John *et al.*, 2005; Seyfert *et al.*, 2004). Low oxygen MAP may contain less than 20% of O₂ and the rest composition is composed of CO₂ and N₂. CO₂ is utilized in MAP gas composition because of its antibacterial effects, which are well documented by Jakobsen and Bertelsen (2000), McMillin (2008), and Renner and Labadie (1993). In addition, Smith *et al.* (1990) suggested that 20–60% of CO₂ in MAP is required to detain the growth of bacteria. Due to the absence of oxygen in low O₂ MAP, the metmyoglobin (brown pigment) will be formed instead of oxymyoglobin (bright-red pigment) (Mancini and Hunt, 2005), and the meat color will appear darker and not attractive as like fresh meat. Sebranek and Houser (2006) noted that for cured meats, low oxygen MAP either with 100% nitrogen or carbon dioxide/nitrogen blends can be used for MAP applications.

Besides the packaging aspect using MAP, prolonging the shelf-life can be achieved by the addition of diverse preservatives to the meat and meat products. Cured meat products are characterized by the addition of nitrite and nitrate to the meat products, while other preservatives such as salts, like sodium chloride (NaCl), ascorbic acid, and other organic acids were added (Sebranek and Bacus, 2007). Nitrite reactions are responsible on the characteristics of meat color, microbial inhibition, antioxidants effects and flavor of cured meat (Sebranek and Bacus, 2007). Salt has been used since ancient times as ingredient of processed meat products, because of its preservative properties by reducing the bacterial growth and improvement in flavor and texture (Desmond, 2006). Ascorbic acid is known as an effective antioxidant to inhibit color changes in meat (Lee *et al.*, 1999; Sanchez-Escalante *et al.*, 2001). Sodium salt, the salt form of the low molecular weight organic acids such as acetic acid, lactic acid and citric acid has been used to control the microbial growth and to improve the color stability, and shelf-life in meat (Maca *et al.*, 1997; Sallam and Samejima, 2004; Shelef *et al.*, 1997). Sallam (2007) studied that sodium acetate and sodium lactate delayed the lipid oxidation and microbial growth in sliced salmon. It was also reported that sodium acetate improved the color stability in pork (Livingston *et al.*, 2004), and the combined use of sodium acetate with potassium lactate resulted in a synergistic effect on improving color stability in pork (Jensen *et al.*, 2003). Calcium lactate is generally recognized as safe food ingredient, and is commonly used in meat industry (Daengprok *et al.*, 2002), as an antibacterial agent (Shelef and Potluri, 1995). Preservatives combined with MAP may improve the antibacterial activity. Schirmer and Langsrud (2010)

reported that citric acid and acetic acid in combinations with CO₂ packaging inhibited bacterial growth in marinated pork meat. In addition, Schirmer *et al.* (2009) showed that the combination of preservatives and CO₂-MAP prolonged the shelf-life of salmon without negative effects on sensory characteristics.

Previous studies have evaluated the effects of preservatives and CO₂ in fresh pork (Schirmer and Langsrud, 2010), Hanwoo ground beef (Muhlisin *et al.*, 2010), and salmon (Schirmer *et al.*, 2009), but there is a dearth information on the effects of organic acids mix and CO₂ on the bacon quality. Therefore, this study was conducted to investigate the effects of organic acids mix and organic acids salt on the storage quality of sliced bacon.

Materials and Methods

Sample preparation

The samples were prepared from pork belly (with thickness 5±1 cm) by injecting the curing solution with formulation as described in Table 1. Frozen pork bellies were thawed at 2°C for 12 h. The bellies were divided into two groups, one group was treated with 0.4% organic acids mix added in the curing solution, and the other was without addition of organic acid mix (non-added). After the injection of curing solution, the bacon was tumbled for 90 min at 10°C, followed by curing for 24 h at 0°C. The cured bellies (bacon) were smoked at 60°C for 15 min and cooled at 2°C for 12 h. The bacon was then sliced

Table 1. Formulas of experimental sliced bacon

Ingredients	Concentration	
	Non-added	Added with organic acids mix
Pork belly	84.95	84.55
Curing solution		
Water	12.74	12.74
Salt	0.85	0.85
Sodium nitrite	0.01	0.01
Phosphates	0.21	0.21
Potassium erythorbate	0.04	0.04
L-glutamate	0.17	0.17
Sugar	0.85	0.85
White pepper	0.17	0.17
Allspice	0.01	0.01
Organic acids mix ¹⁾	0.00	0.40
Total	100.00	100.00

¹⁾This product is GF Bactostop (Product number: 1379) made by Pacovis Co. (Switzerland). It contains 25% salt, 7% ascorbic acid, 35% sodium acetate, 15% calcium lactate, 11% tri-sodium citrate, and 7% citric acid, and its pH value is 5.5±0.5.

into 3 ± 0.5 mm of thickness. Three slices of bacon were placed on the tray (max. O_2 transmission rate= 0.1 cc/24 h/cm² at 23°C, 0% RH; water vapor transmission rate= 7.87 mg/24 h/cm² at 38°C, 100% RH, Cryovac Sealed Air Corp., USA) for the following packaging methods. The trays were sealed with O_2 barrier film (max. O_2 transmission rate= 0.39 cc/24 h/cm² at 4.4°C, 100% RH; Cryovac Sealed Air Corp., USA). The trays were filled with either 50% CO_2 +50% N_2 (50% CO_2 -MAP) or 100% N_2 (100% N_2 -MAP) using a modified atmosphere packaging machine (Hypervac, Korea) equipped with the gas mixture (MAP Mix 9001 ME, PBI Dansensor, Denmark). Carbon dioxide and nitrogen were obtained from a local gas supplier (Baeklyung Specialty Gas Co., Korea). Four treatments used in this research are 1) non-treated sliced bacon+50% CO_2 -MAP, 2) non-treated sliced bacon+100% N_2 -MAP, 3) sliced bacon added with organic acids mix+50% CO_2 -MAP, and 4) sliced bacon added with organic acids mix+100% N_2 -MAP. All samples were stored at 5°C for 14 d.

The pH determination

Ten grams of lean meat part of sliced bacon were added with 100 mL of distilled water and then homogenized at 10,000 rpm for 60 sec 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 in every sample in triplicates.

Thiobarbituric acid reactive substance (TBARS) value analysis

The TBARS value was measured according to Sinhuber and Yu (1977). Briefly, 0.5 g of lean meat part of sliced bacon was mixed with 3 drops of antioxidants solution, 3 mL of thiobarbituric acid (TBA) solution, and 17 mL of 25% (w/v) TCA. The mixture was heated at 100°C for 30 min and then 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 result was calculated as mg malonaldehyde (MA) per kg of sample.

Volatile basic nitrogen (VBN) value analysis

The analysis of VBN value was performed according to Kohsaka (1975) method. Five grams of lean meat part of sliced bacon were homogenized with 30 mL of 5% (w/v) TCA using a homogenizer (Ultra-Turrax T25 basic, Ika Werke GmbH & Co., Germany) at 13,500 rpm for 2 min. The homogenate was made up to 50 mL of final volume

with 5% (w/v) TCA and filtered using the Whatman filter paper No. 1. One mL of filtrate and 1 mL of borate buffer were placed in outer and inner of Conway dish, respectively, and then incubated at 37°C for 100 min. Finally, the inner solution was titrated with 0.01N HCl.

Instrumental color measurement

The surface color of the lean meat part of sliced bacon was monitored by measuring the CIE L^* (lightness), CIE a^* (redness), and CIE b^* (yellowness) using a color difference meter (CR-400, Konica Minolta Sensing Inc., Japan) and an illuminant C. The lean part of sliced bacon for instrumental color measurement was obtained by separation of lean layer and fat layer of bacon. All lean layers obtained from one pack were arranged so that wide surface was formed. The color instrument was calibrated using a white plate (2° observer, CIE $L^*=97.46$, CIE $a^*=0.08$, CIE $b^*=1.81$). The color measurements were performed 10-15 times on each pack.

Microbial analysis

Ten grams of lean meat part of sliced bacon were 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) at medium speed for 2 min. Serial 10-fold dilution was performed by mixing 1 mL of solution with 9 mL of 0.1% (w/v) peptone solution. The plate count agars (Difco, USA) were used for aerobic and anaerobic bacterial counts. Agar plates were prepared according to the manufacturer's instruction. Samples were incubated for 48 h at 35°C. Microbial populations were counted in 30-300 colonies and expressed as Log CFU per gram of 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

The pH value

The pH value of non-added sliced bacon packed with 50% CO_2 -MAP was higher ($p<0.05$) than pH value of

Table 2. Effects of organic acids mix and modified atmosphere packaging on the pH value, TBARS, and VBN of sliced bacon during storage at 5°C

Parameters	Storage time (d)	Treatments			
		50% CO ₂ -MAP		100% N ₂ -MAP	
		Non-added ¹⁾	Org. acids mix ²⁾	Non-added	Org. acids mix
pH	0	6.23±0.03 ^{aC}	6.22±0.01 ^{aB}	6.23±0.03 ^{aB}	6.22±0.01 ^{aA}
	2	6.45±0.10 ^{aB}	6.34±0.02 ^{abA}	6.30±0.06 ^{bB}	5.96±0.04 ^{cB}
	4	6.65±0.03 ^{aA}	6.33±0.10 ^{bA}	6.40±0.10 ^{bAB}	6.12±0.03 ^{cA}
	6	6.51±0.06 ^{aA}	6.38±0.08 ^{bA}	6.53±0.06 ^{aA}	6.24±0.18 ^{bA}
	8	6.62±0.04 ^{aA}	6.12±0.04 ^{cC}	6.36±0.08 ^{bAB}	6.03±0.02 ^{cB}
	10	6.65±0.09 ^{aA}	6.18±0.09 ^{bBC}	6.55±0.13 ^{aA}	6.15±0.01 ^{bAB}
	14	6.28±0.06 ^{bC}	6.12±0.03 ^{bC}	6.60±0.09 ^{aA}	6.19±0.11 ^{bA}
TBARS ³⁾ (mg MA/kg sample)	0	0.18±0.05 ^{aA}	0.18±0.02 ^{aA}	0.18±0.05 ^{aA}	0.18±0.02 ^{aA}
	2	0.21±0.05 ^{aA}	0.19±0.01 ^{aA}	0.19±0.03 ^{aA}	0.19±0.05 ^{aA}
	4	0.15±0.03 ^{aA}	0.18±0.04 ^{aA}	0.17±0.02 ^{aA}	0.19±0.05 ^{aA}
	6	0.12±0.03 ^{aA}	0.17±0.03 ^{aA}	0.16±0.04 ^{aA}	0.15±0.06 ^{aA}
	8	0.18±0.03 ^{aA}	0.19±0.05 ^{aA}	0.17±0.04 ^{aA}	0.20±0.04 ^{aA}
	10	0.17±0.03 ^{aA}	0.16±0.06 ^{aA}	0.16±0.02 ^{aA}	0.18±0.04 ^{aA}
	14	0.18±0.05 ^{aA}	0.15±0.03 ^{aA}	0.24±0.03 ^{aA}	0.17±0.03 ^{aA}
VBN ⁴⁾ (mg%)	0	12.77±0.71 ^{aD}	11.41±0.27 ^{bC}	12.77±0.71 ^{aD}	11.41±0.27 ^{bE}
	2	13.54±0.49 ^{aCD}	11.60±0.47 ^{bC}	13.31±0.55 ^{aCD}	11.41±0.50 ^{bE}
	4	13.77±0.40 ^{aC}	12.19±1.07 ^{bC}	13.91±0.33 ^{aC}	12.95±0.54 ^{bD}
	6	13.22±0.23 ^{bCD}	11.59±0.60 ^{cC}	13.70±0.87 ^{abC}	14.32±0.56 ^{cC}
	8	15.23±0.54 ^{bB}	13.46±0.45 ^{dB}	17.11±0.33 ^{aB}	14.19±0.29 ^{cC}
	10	14.92±1.00 ^{bB}	13.79±0.42 ^{cB}	17.10±0.56 ^{aB}	16.92±0.52 ^{aB}
	14	17.24±0.96 ^{bcA}	16.52±0.50 ^{cA}	18.33±0.34 ^{aA}	17.97±0.67 ^{abA}

^{a-d}Values (Means±SD) with different superscripts in the same row differ significantly ($p<0.05$).

^{A-E}Values (Means±SD) with different superscripts in the same column differ significantly ($p<0.05$).

¹⁾Non-added : The bacons were treated with curing solution without addition of organic acids mix.

²⁾Organic acids mix : The bacons were treated with curing solution with organic acids mix (contained 25% salt, 7% ascorbic acid, 35% sodium acetate, 15% calcium lactate, 11% tri-sodium citrate, and 7% citric acid), respectively.

³⁾Thiobarbituric acid reactive substances

⁴⁾Volatile basic nitrogen

non-added group with 100% N₂-MAP at 2, 4 and 8 d of storage (Table 2). The pH value of sliced bacon treated with organic acids mix and packed with 100% N₂-MAP was the lowest at 2, 4 and 8 d of storage. Different results have been reported by Rubio *et al.* (2007) in which there were no effect of different composition of CO₂ on pH value of dry cured beef. In addition, Viana *et al.* (2005) also reported that MAP did not show strong variation in pH of fresh pork loin. However, the addition of organic acids significantly lowered ($p<0.05$) the pH value of sliced bacon compared to the non-added groups both in 50% CO₂-MAP and 100% N₂-MAP. The lower pH value in sliced bacon treated with organic acid might be due to the acid form of organic acids mix. According to the product information, the pH value of organic acids mix is 5.5±0.5. The lowering effect of pH by the addition of organic acids mix was also reported by previous studies. For instance, Aran (2001) showed the decreasing pH

value of beef from 6.0 to 5.5 due to the addition of 3% calcium lactate; Kim *et al.* (2009) reported the lower pH due to calcium lactate enhancement in beef steaks and Velugoti *et al.* (2007) reported the decreased pH level in pork by increasing the concentration of calcium lactate.

TBARS value

Lipid oxidation causes rancidity (off-flavor and off-odor) in meat (Jakobsen and Bertelsen, 2000), and TBARS is a strong objective predictor of the rancidity perception of meat and meat products (McMillin, 2008). Skibsted *et al.* (1998) mentioned the factors affecting the lipid oxidation, like oxygen concentration, lighting, temperature, the presence of pro- and antioxidant, the saturation degree of fatty acids, and the presence of enzymes. The TBARS levels were around 0.15 to 0.24 mg MA/kg sample (Table 2). For comparison, Lin and Lin (2002) reported the TBARS value of Chinese-style sausage added with sodium lactate

and trisodium phosphate were less than 0.5 mg MA/kg sample. No differences were found in TBARS value ($p > 0.05$) due to the effects of gas composition of MAP. The addition of organic acids mix also gave no effects on TBARS value during the storage. Lin and Chuang (1999) reported no differences in TBARS value because of organic acids addition in low-fat Chinese sausage. In addition Brewer *et al.* (1991) also found no effect of different level of organic acids on TBARS value of fresh pork sausage.

Volatile basic nitrogen (VBN)

The protein deterioration, represented as VBN of sliced bacon during storage is showed in Table 2. VBN value increased with the increase of storage days. Arashihar *et al.* (2004) reported that VBN increased with the increasing of storage time in Air-P, vacuum and MAP of rainbow trout (*Oncorhynchus mykiss*) filets. The using of 50% CO₂-MAP significantly detained the protein deterioration ($p < 0.05$) both in the non-added and group added with organic acids mix, from 6 d to 14 d of storage. The lower VBN formation may be related with the lower bacterial counts of sliced bacon under 50% CO₂-MAP compared

to 100% N₂-MAP (Table 5). Protein deterioration (represented by VBN value) is associated with the activity of amino acid decarboxylase of microorganisms (Lin and Lin, 2002). The addition of organic acids mix detained the protein deterioration in 50% CO₂-MAP during the storage, while in 100% N₂-MAP the detaining effect of organic acids on the protein deterioration only can be shown at 0, 2, 4 and 8 d of storage. The combination of organic acids mix and 50% CO₂-MAP showed the lowest VBN value compared to other treatments. Similar results were also reported by Lin and Lin (2002) that the addition of organic acids mix lowered the VBN value of low-fat Chinese style sausage. Little information about the protein deterioration (VBN) of bacon is available. Therefore, the detaining effects of organic acids mix on protein deterioration must be useful for further studies.

Instrumental color

The CIE L* value (lightness) is presented in Table 3. The CIE L* value of lean meat of sliced bacon under 50% CO₂-MAP fluctuated during storage. The CIE L* value of lean meat of non-added sliced bacon under 50%

Table 3. Effects of organic acids mix and modified atmosphere packaging on the instrumental color of sliced bacon during storage at 5°C

Color Parameters	Storage time (d)	Treatments			
		50% CO ₂ -MAP		100% N ₂ -MAP	
		Non-added	Org. acid mix	Non-added	Org. acid mix
CIE L* (Lightness)	0	49.80±2.47 ^{ab}	48.87±4.03 ^{ad}	49.81±2.47 ^{ab}	48.87±4.03 ^{ad}
	2	51.16±3.94 ^{ba}	52.52±4.74 ^{aA}	52.03±3.21 ^{abA}	52.05±2.90 ^{abA}
	4	50.79±3.17 ^{baB}	52.46±3.05 ^{aA}	49.23±3.39 ^{cB}	50.18±3.64 ^{bcBC}
	6	51.62±3.56 ^{aA}	48.83±3.22 ^{bcD}	48.15±4.04 ^{cC}	49.49±3.94 ^{bCD}
	8	49.49±2.44 ^{baB}	50.73±3.48 ^{abC}	49.08±3.33 ^{bBC}	50.54±3.46 ^{abC}
	10	50.84±3.44 ^{aAB}	51.38±3.28 ^{aAB}	49.26±3.57 ^{bB}	50.72±2.77 ^{ab}
	14	48.66±3.12 ^{bc}	49.96±3.42 ^{cd}	48.12±2.99 ^{bc}	49.59±2.88 ^{cd}
CIE a* (Redness)	0	9.58±1.50 ^{bE}	11.74±1.87 ^{aE}	9.58±1.50 ^{bD}	11.74±1.87 ^{aC}
	2	15.35±2.41 ^{bD}	16.42±2.72 ^{aAB}	15.24±2.52 ^{bC}	16.61±1.98 ^{aA}
	4	16.64±2.20 ^{aB}	16.67±2.02 ^{aA}	15.92±2.28 ^{bC}	16.71±2.34 ^{aA}
	6	16.77±2.52 ^{aB}	15.94±2.00 ^{bBC}	16.71±2.62 ^{aB}	15.32±2.83 ^{bb}
	8	17.74±1.85 ^{aA}	14.85±2.21 ^{cD}	17.68±2.55 ^{aA}	16.82±2.34 ^{ba}
	10	17.69±2.48 ^{aA}	14.60±1.97 ^{cD}	17.27±2.19 ^{abAB}	16.82±2.31 ^{ba}
	14	17.39±2.14 ^{aA}	15.62±2.01 ^{cC}	17.62±2.28 ^{aA}	16.41±1.87 ^{ba}
CIE b* (Yellowness)	0	6.39±1.09 ^{bE}	6.94±1.24 ^{ab}	6.39±1.09 ^{bD}	6.94±1.24 ^{ad}
	2	9.47±1.28 ^{ad}	9.57±1.38 ^{aA}	9.91±1.47 ^{ab}	8.91±1.61 ^{bc}
	4	9.98±1.58 ^{abC}	9.57±1.47 ^{ba}	9.27±1.34 ^{bc}	9.30±1.42 ^{bcC}
	6	9.63±1.64 ^{cd}	9.69±1.31 ^{aA}	9.94±1.31 ^{ab}	8.99±1.77 ^{bc}
	8	10.38±1.59 ^{aB}	9.44±1.47 ^{aA}	10.07±1.29 ^{abAB}	9.88±1.19 ^{ba}
	10	11.17±1.65 ^{aA}	9.07±1.55 ^{dA}	10.25±1.10 ^{baB}	9.60±1.50 ^{ab}
	14	9.17±1.22 ^{cd}	9.15±1.42 ^{ca}	10.37±1.14 ^{aA}	9.65±1.37 ^{baB}

^{a-c} Values (Means±SD) with different superscripts in the same row differ significantly ($p < 0.05$).

^{A-E} Values (Means±SD) with different superscripts in the same column differ significantly ($p < 0.05$).

CO₂-MAP was higher ($p<0.05$) than control group under 100% N₂-MAP at 4, 6, and 10 d of storage. The addition of organic acids increased ($p<0.05$) the CIE L* value of lean meat of sliced bacon packaged with 50% CO₂-MAP at 2, 4, 8, and 14 d, while in 100% N₂-MAP the addition of organic acids mix increased the CIE L* value from 6 to 14 d. Arganosa and Marriot (1989) reported similar results, that CIE L* value of beef with organic acids mix addition was higher compared to the non-treated beef. Other previous studies also showed the lightening ability of organic acids (Knock *et al.*, 2006; Lawrence *et al.*, 2003), but different with Maca *et al.* (1999), and Mancini *et al.* (2005) who found darkening effect of organic acids in various meat commodities. The combination of 50% CO₂-MAP and organic acids showed the highest ($p<0.05$) CIE L* value on 4 d.

The CIE a* value (redness) of lean meat of non-added sliced bacon under 50% CO₂-MAP and 100% N₂-MAP increased until 6 d of storage and slightly decreased from 8 to 4 d (Table 3). Generally, no difference was found in the CIE a* value of lean meat color of control sliced bacon packaged with 50% CO₂-MAP and 100% N₂-MAP. The addition of organic acids resulted in more red ($p<0.05$) color of lean meat of sliced bacon (higher CIE a* value) only at the beginning of storage (0 and 2 d in 50% CO₂-MAP and 0 to 4 d in 100% N₂-MAP). The CIE a* value of lean meat of sliced bacon treated with organic acids mix was lower ($p<0.05$) than the control from 6 d until

the end of storage time both in 50% CO₂-MAP and 100% N₂-MAP. Significant loss of redness was reported by Shrestha and Ming (2006) on fresh pork due to the effects of lactic acids. Similar results were reported by Arganosa and Marriott (1989) on beef treated with organic acids mix; in pork loin by Hayes *et al.* (2005), and Jensen *et al.* (2003) on enhanced pork chops treated with phosphate. Arganosa and Marriott (1989) noted lower CIE a* values on the meat with lower pH values. This statement is in accordance with our pH data in which pH value of bacon treated with organic acids mix also was lower. The combination of 50% CO₂-MAP and organic acids showed the lowest CIE a* value from 8 d to the end of storage time ($p<0.05$). The addition of organic acids mix resulted in lower CIE b* value of lean meat of sliced bacon in 50% CO₂-MAP at 4, 8, and 10 d of storage, and at 2, 6, 10, and 14 d of storage in 100% N₂-MAP.

Microbial changes

The aerobic bacterial counts of sliced bacon were increase in all the treatments after 2 d of storage (Table 4). In the non-added group, 50% CO₂-MAP delayed the growth of aerobic bacteria from 2 to 10 d of storage ($p<0.05$) compared to 100% N₂-MAP. The survival and the growth of pathogenic microorganism are affected by MAP (Blakistone, 1999). Carbon dioxide is well known as the antimicrobial gas used in MAP. The antimicrobial activity of CO₂ was reported by Jacobsen and Bertelsen

Table 4. Effects of organic acids mix and modified atmosphere packaging on the aerobic and anaerobic bacterial population of sliced bacon during storage at 5°C (Unit: Log CFU/g sample)

Microorganism	Storage time (d)	Treatments			
		50% CO ₂ -MAP		100% N ₂ -MAP	
		Non-added	Org. acids mix	Non-added	Org. acids mix
Aerobic bacteria	0	4.52±0.28 ^{aD}	3.70±0.06 ^{bD}	4.59±0.22 ^{aE}	3.48±0.20 ^{bD}
	2	3.80±0.48 ^{bE}	4.23±0.51 ^{abCD}	4.27±0.43 ^{aE}	4.12±0.18 ^{abC}
	4	4.99±0.30 ^{cD}	5.33±0.59 ^{bcB}	6.35±0.35 ^{aD}	5.74±0.65 ^{abB}
	6	4.68±0.26 ^{bD}	4.67±0.19 ^{bc}	5.86±0.27 ^{aE}	5.61±0.40 ^{aB}
	8	5.90±0.34 ^{bc}	5.46±0.20 ^{bb}	6.90±0.28 ^{aC}	5.89±0.76 ^{bb}
	10	6.80±0.71 ^{cB}	7.69±0.21 ^{bA}	8.11±0.30 ^{aA}	7.91±0.28 ^{bA}
	14	7.44±0.13 ^{aA}	7.21±0.39 ^{aA}	7.57±0.28 ^{aB}	7.33±0.21 ^{aA}
Anaerobic bacteria	0	5.02±0.61 ^{aD}	4.28±0.64 ^{aE}	5.02±0.61 ^{aC}	4.28±0.64 ^{aD}
	2	4.04±0.56 ^{aE}	4.41±0.76 ^{aDE}	4.56±0.65 ^{aC}	4.40±0.58 ^{aD}
	4	5.68±0.53 ^{bc}	5.57±0.75 ^{bc}	6.54±0.30 ^{aB}	6.18±0.51 ^{abC}
	6	4.90±0.63 ^{bD}	5.10±0.51 ^{bCD}	6.20±0.49 ^{aB}	6.02±0.47 ^{aC}
	8	5.77±0.23 ^{bcC}	5.51±0.20 ^{cC}	6.84±0.27 ^{aB}	5.97±0.51 ^{bc}
	10	6.78±0.75 ^{bb}	7.65±0.02 ^{abB}	8.56±0.49 ^{aA}	7.78±0.28 ^{aB}
	14	8.13±0.26 ^{bA}	8.46±0.46 ^{abA}	8.92±0.26 ^{aA}	9.01±0.44 ^{aA}

^{a-c} Values (Means±SD) with different superscripts in the same row differ significantly ($p<0.05$).

^{A-E} Values (Means±SD) with different superscripts in the same column differ significantly ($p<0.05$).

(2000) in fresh beef; and McMillin (2008) in several meat products. Moreover, Schirmer and Langsrud (2010) found that 50% CO₂-MAP resulted in greater antimicrobial activity when it was combined with organic acids mix during the storage. These results are slightly different with ours, in which the antibacterial effects of organic acids mix were found at 0 d and 10 d in 50% CO₂-MAP and at 0, 6 and 10 d of storage in 100% N₂-MAP. At the end of storage, no differences were found in aerobic bacterial counts among the treatments. The anaerobic bacterial count showed similar trends with aerobic bacteria. In the non-added group, the 50% CO₂-MAP showed lower anaerobic bacterial counts compared to 100% N₂-MAP from 4 to 14 d ($p < 0.05$). The addition of organic acids showed no effects on anaerobic bacterial counts both in 50% CO₂-MAP and 100% N₂-MAP. In other words, 50% CO₂-MAP alone is enough to detain the anaerobic bacterial growth. It is well known that CO₂ prolonged the shelf-life by inhibiting microbial growth (Gill and Tan, 1980; Wimpfheimer *et al.*, 1990). In addition, Schirmer *et al.* (2009) showed that the combination of organic acid and CO₂ packaging prolonged the shelf-life.

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