Retail Shelf-Life of Pork Dipped in Organic Acid before Modified Atmosphere or Vacuum Packaging

NAI-YUN HUANG, CHUNG-PING HO, AND KENNETH W. MCMILLIN

ABSTRACT: Modified atmosphere packaging (MAP) is increasingly popular for meat, but raw, chilled pork in vacuum or anoxic environments has a purple color. The retail shelf-life of pork chops dipped in 500 ppm ascorbic acid, 250 ppm citric acid, or no acid dip and stored at 1 °C before simulated retail display in MAP with gas exchange or air-permeable packaging after vacuum pouch storage was determined. The 80% N_2:20% CO_2 in MAP was exchanged with 80% O_2:20% CO_2, and chops were removed from vacuum packages and overwrapped with permeable film (VP-PVC) on the 7th day before simulated retail display at 4 °C. Shelf-life traits were determined at 1, 7, 8, 10, 12, and 14 d postpackaging. The pH values changed with time, but returned to post-dipped, prepackaged levels at the end of simulated retail storage. Weight loss of chops increased ($P < 0.05$) in VP-PVC compared with MAP. The a^* values increased ($P < 0.05$) and L^* and b^* values decreased during simulated retail display, with higher L^*, a^*, and b^* color values for chops in MAP than VP-PVC. Log numbers of psychrotrophic microorganisms were higher ($P < 0.05$) on VP-PVC samples than for chops in MAP on days 12 and 14. Psychrotrophic counts on ascorbic acid–treated samples were decreased compared with citric acid or no dipping on pork during simulated retail display. Pork chops in MAP with gas exchange had lighter and redder color, increased weight retention, decreased psychrotrophic counts, and increased lipid oxidation compared with conventional vacuum and overwrap packaging systems.

Keywords: pork, modified atmosphere packaging, shelf-life, psychrotrophs, organic acids

Introduction

Consumer retail purchases of raw chilled meat are critically influenced by color because appearance is the first impression of meat at retail (Cassens and others 1995). Other important aspects of meat quality are composition, palatability, and safety (Warriss 2000). Raw, chilled meat may be displayed at retail in 1 of 3 packaging systems (Cole 1986). Traditional meat packaging uses atmospheric oxygen and permeable film materials to cause bloomed meat color with oxymyoglobin pigment forms. Oxygen concentrations higher than 21% in modified atmosphere packaging (MAP) using combinations of O_2, CO_2, and/or N_2 will increase the proportions of oxymyoglobin pigments. Low oxygen packaging may be vacuum (VP) or MAP without O_2 (McMillin and others 1999). VP extends shelf-life, but meat has a purple color that is unfamiliar to customers (Lynch and others 1986). Meat packaged with O_2 has limited distribution and display life because color and/or lipid oxidation occurs within a relatively short time (Cole 1986). Extension of distribution time and display of fresh meat with a bloomed color can be obtained in MAP using CO_2 and N_2 for distribution storage and using active gas exchange of the gaseous environment in the MAP package for O_2 and CO_2 before retail case display (McMillin and others 1999).

Treating meat with organic acids provides another means of extending distribution and display life in fresh meat (Bauernfeind and Pinkert 1970). Ascorbic acid and citric acid are approved additives to improve color stability of fresh pork (CFR 2005). Citric acid inhibited rate of lipid oxidation on pork cuts (Cannon and others 1993), pork sausage (Ho and others 1995a), and minced pork (Cheah and Ledward 1997), while a citric acid, sodium erythorbate, and tetrasodium pyrophosphate solution did not increase lipid stability or alter color in pork loin chops (Manu-Tawiah and others 1991). A dip of sodium ascorbate (550 ppm) decreased lipid oxidation in irradiated pork chops (Zhao and Sebranek 1996). Ascorbic and citric acid or their salt derivatives have been patented for use in fresh meat in case-ready and modified atmosphere packaging of pork (Cheng 1987 1989). The objectives of this study were to determine the shelf-life attributes of case-ready boneless pork chops without dipping (control) or after dipping in ascorbic acid (500 ppm) or citric acid (250 ppm) with VP and air-permeable packaging or MAP (20% CO_2:80% N_2) after dynamic gas exchange for high O_2 atmosphere (20% CO_2:80% O_2).

Material and Methods

Case-ready boneless pork chops from pigs sacrificed in the Louisiana State Univ. Agricultural Center Meat Lab (Baton Rouge, La., U.S.A.) were obtained at 72 h postmortem after chilling of carcasses to 1 °C. Pork chops were prepared from *M. longissimus dorsi* (1.27-cm thick) with an average weight of 100 g. Pork chops were randomly assigned to acid dipping and packaging treatments. Chops were dipped in the 250 ppm citric acid or 500 ppm ascorbic acid solutions at 4 °C for approximately 15 s and allowed to drain for 5 min before packaging. Pork chops for MAP were packed on an absorbent pad (Dri-L® 50 pad, Sealed Air Co., Food Packaging Div., Patterson, N.C., U.S.A.) in barrier laminated foam trays (3P White,

MS 20050082 Submitted 2/8/05, Revised 3/16/05, Accepted 6/2/05. *Author Huang is with Food Science And Nutrition Dept., Shih-Thien Univ., Taipei, Taiwan. Author Ho is with Food Safety Inst. Intl., Taipei, Taiwan. Author McMillin is with Dept. of Animal Sciences, Louisiana State Univ. Agricultural Center, Baton Rouge, LA 70803-4201. Direct inquiries to author McMillin (E-mail: kmcmillin@agcenter.lsu.edu)*

Table 1—pH values of pork after acid dipping and storage in gas exchange modified atmosphere packaging or vacuum and air-permeable packaging

Package type[a]	Acid dipping[b]	0 d[c]	7 d[c]	8 d[c]	10 d[c]	12 d[c]	14 d[c]
MAP	None	5.68^{d}	5.45^{c}	5.45^{c}	5.61^{cdyz}	5.61^{cd}	5.51^{cd}
MAP	Ascorbic	5.74^{d}	5.57^{cd}	5.59^{cd}	5.50^{cy}	5.58^{cd}	5.60^{cd}
MAP	Citric	5.62^{de}	5.52^{cd}	5.43^{c}	5.55^{cdy}	5.76^{e}	5.47^{cd}
VP-PVC	None	5.79^{e}	5.47^{c}	5.60^{cd}	5.77^{dez}	5.68^{de}	5.53^{cd}
VP-PVC	Ascorbic	5.67^{c}	5.52^{c}	5.54^{c}	5.49^{a}y	5.49^{c}	5.54^{c}
VP-PVC	Citric	5.64^{cd}	5.48^{cd}	5.46^{c}	5.66^{dyz}	5.53^{cd}	5.53^{cd}
	SEM	0.06	0.07	0.07	0.07	0.07	0.07

[a]MAP had 20% CO_2:80% N_2 initially before exchange for 80% O_2:20% CO_2 7 d after packaging, and VP was vacuum packaging before removal of chops 7 d after packaging and then repackaging in air-permeable polyvinylidene chloride film.
[b]Treatments were 550 ppm ascorbic acid, 250 ppm citric acid, or no dipping.
[c]Least square means in the same row with same letters (c,d,e,) are not different ($P < 0.05$). Least square means in the same column with same letters (y,z) are not different ($P < 0.05$).

Amoco Foam, Atlanta, Ga., U.S.A.; oxygen permeability of 1.55 cc/m^2/24 h at 23 °C, 0% RH; moisture vapor transmission rate of 3.10 g/m^2/24 h at 38 °C, 90% RH) using lidding film (Type Curlam, Curwood, New London, Wis., U.S.A.; oxygen permeability of 0.1 cc/m^2/24 h at 23 °C, 0% RH; moisture vapor transmission rate of 1.5 cc/m^2/24 h at 22.8 °C, 0% RH) to seal packages (InPack tray sealer, Model 580, Ross Industries, Midland, Va., U.S.A.) with a distribution gas mixture of 80% N_2:20% CO_2. Samples for VP-PVC were placed on absorbent pads and packaged in vacuum pouches (SealFresh™, 3 mil nylon/polyethylene, 20.32 cm × 25.4 cm, Koch Supplies Inc., Kansas City, Mo., U.S.A.; oxygen permeability of 9.3 cc/m^2/24 h at 23 °C, 0% RH; moisture vapor transmission rate of 9.3 cc/m^2/24 h at 23 °C, 90% RH) using a vacuum machine (Model VM200H, Westglen Co., Los Angeles, Calif., U.S.A.). All packages contained 1 pork chop and were stored in cardboard boxes during distribution storage at 1 °C.

At 7 d post-packaging storage, the gaseous contents of MAP were exchanged using a commercial gas exchange machine (Windjammer, Pakor, Inc., Livingston, Tex., U.S.A.) for 80% O_2:20% CO_2 before display under simulated retail conditions of 4 °C and 1345 lux cool white fluorescent light. The pork chops in vacuum pouches were removed from the pouches, transferred to foam trays, and overwrapped with polyvinyl chloride film (PVC, Borden Resinite, 62 gauge, O_2 transmission rate 325 cc/cm^2/24 h at 23 °C, 0% RH; CO_2 transmission rate 2,500 cc/cm^2/24 h at 23°C, 90% RH) before display under the same conditions as the pork chops in MAP. Duplicate packages of each treatment combination were randomly sampled on days 0, 7, 8, 10, 12, and 14 after packaging to measure gas content; pH; weight loss; HunterLab L^*, a^*, and b^* values; psychrotrophic plate counts; and lipid stability as thiobarbituric acid reactive substances (TBARS).

Headspace O_2 and CO_2 were measured in each sampled package (Food Package Analyzer Series 1400, Servomex, Sussex, England), allowing 20 s for equilibration of readings per sample. The pH values were measured using a probe surface electrode (Extech Instruments Corp., Waltham, Mass., U.S.A.). Three readings were taken for each sample. Pork chops and absorbent pads in each tray were weighed separately at the time of initial packaging and at the time of sampling. Weight loss percentage was calculated as the difference in final sample weight and initial sample weight divided by the initial sample weight.

Objective color was analyzed with a reflectance spectrophotometer, (Model LABSCAN-2 0/45, Hunter Associates Laboratory, Inc., Reston, Va., U.S.A.) using cool white fluorescent (F2) illuminant, 10° observer angle, and specular component excluded. Samples were removed from packages and analyzed within 30 s. The L^* (lightness), a^* (degree of red/green), and b^* (degree of yellow/blue) values were averaged on each sample after rotating the sample 90° between each of 3 sample readings. A white plate ($L^* = 92.4$, $a^* = -0.7$, and $b^* = -0.9$) and a black plate were used for instrument standardization.

Psychrotrophic plate counts (PPC) were determined by plate count procedures. Each sample (20 g) was placed aseptically in a stomacher bag with sterile 0.1% peptone solution (180 g) for homogenization (Stomacher 400 lab blender) for 2 min. Using "pour-plate" methods (APHA 1976), suitable serial dilutions of the samples were plated with Standard Plate Count Agar (Difco) and incubated at 6 °C for 8 to 10 d before counting. The average numbers of colonies from the duplicate plates were reported as log colony-forming units (CFU) per gram. Oxidative stability was determined by TBARS values using a distillation method as outlined by Tarladgis and others (1960). The distillate optical absorbance was ascertained with a spectrophotometer (U-2000, Hitachi, Conroy, Tex., U.S.A.) at 535 nm. Lipid stability as TBARS was expressed in mg malondialdehyde/kg sample.

The statistical model of the present study was a split-plot design with main plot effects of acid dipping and packaging methods (MAP and VP-PVC) and the sub-plot as storage time. Data were analyzed by analysis of variance (ANOVA) using the general linear model (GLM) procedure of Statistical Analysis System (SAS 1985). Treatment means were separated by least square means procedures if a difference was detected at $P < 0.05$.

Results and Discussion

The headspace O_2 and CO_2 concentrations in MAP were affected ($P < 0.05$) by storage time and packaging type, but not by acid-dipping treatments (Figure 1). Exchange of the gas from 80 %N_2:20% CO_2 to 80 %O_2:20% CO_2 after 7 d post-packaging caused O_2 to increase from less than 1% to greater than 30%. The efficiency of MAP gas exchange was approximately 35% as determined by increased ratio of O_2. The variation in machine operation and headspace volumes contributed to the different O_2 after gas exchange, but O_2 in packages of pork dipped in ascorbic acid was decreased ($P < 0.05$) after 7 d of display compared with pork dipped in citric acid or not dipped. The initial 20% CO_2 concentration was not altered greatly after gas exchange because the 2nd gas also contained 20% CO_2. CO_2 would be expected to change if absorbed by the meat or evolved due to respiration (Jakobsen and Bertelsen 2002).

The pH decreased immediately after gas exchange or repackaging, but returned to the initial levels after dipping after 7 d of simulated retail display—except for chops in VP-PVC that were not dipped (Table 1). The pH of chops dipped in ascorbic acid was slightly lower after 3 d of simulated retail display than for other dipping treatments, but generally the pH of acid-dipped chops was not different than for non-dipped chops. The initial pH value of the pork ranged from 5.62 to 5.79 while final pH values were slightly lower, ranging from 5.47 to 5.60. Bendall (1972) indicated that dis-

solution of CO_2 in muscle tissue produced a fall in pH regardless of the buffering capacity of the tissue and also that decline in pH values during storage might be due to the accumulation of lactic acid because of anaerobic respiration in muscles and/or the degradation products of carbohydrates caused by microorganism growth. However, the decline in pH during the storage period in this study was not large. Zhao and Sebranek (1996) reported no change in pH between chops dipped in sodium ascorbate before irradiation and control chops after 2 wk of storage, while addition of 0.02% citric acid to minced pork decreased pH by 0.4 units (Cheah and Ledward 1997).

The weight losses of pork chops were affected ($P < 0.05$) by packaging type and storage time. The weight loss of pork chop packaged in MAP remained fairly stable, between 3% and 5% during the packaging period, whereas weight loss during storage in VP was 8% or higher and increased during display in air-permeable packaging (Figure 2). This weight loss during VP was attributed to higher purge while the increased weight loss during display was probably due to some surface drying of the pork during over-wrapping and vapor transmission loss during simulated retail display. McMillin and others (1994) reported less weight retention of *M. longissimus lumborum* beef steaks in VP-PVC systems compared with gas exchange MAP. Drip loss was higher in pork dipped in 550 ppm sodium ascorbate before irradiation compared with control chops (Zhao and Sebranek 1996).

Objective color was affected ($P < 0.05$) by packaging, acid dipping, and the interactions of packaging and acid dipping. The L^* values were similar with anoxic distribution storage in both packaging types (Figure 3). After gas exchange of MAP or repackaging of chops in PVC, L^* values decreased ($P < 0.05$) due to changes in the pigment state. During simulated display, pork in high oxygen MAP had lighter color (higher L^*) than pork in air-permeable packaging. Brewer and others (2001) indicated that L^* values in pork are unrelated to oxymyoglobin pigment concentrations, so the reason for

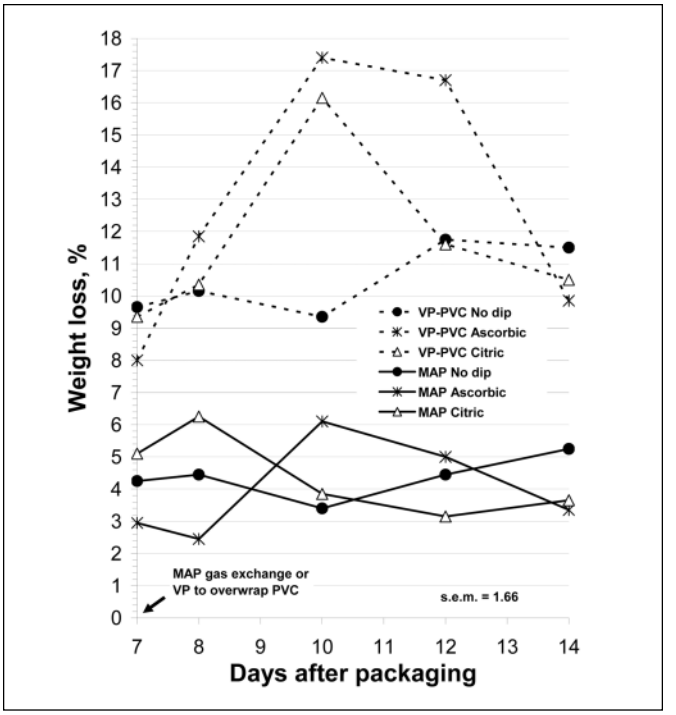

Figure 2—Weight loss of control, citric acid–, or ascorbic acid–dipped pork chops during retail storage in modified atmosphere packaging after gas exchange or overwrap packaging after vacuum packaging.

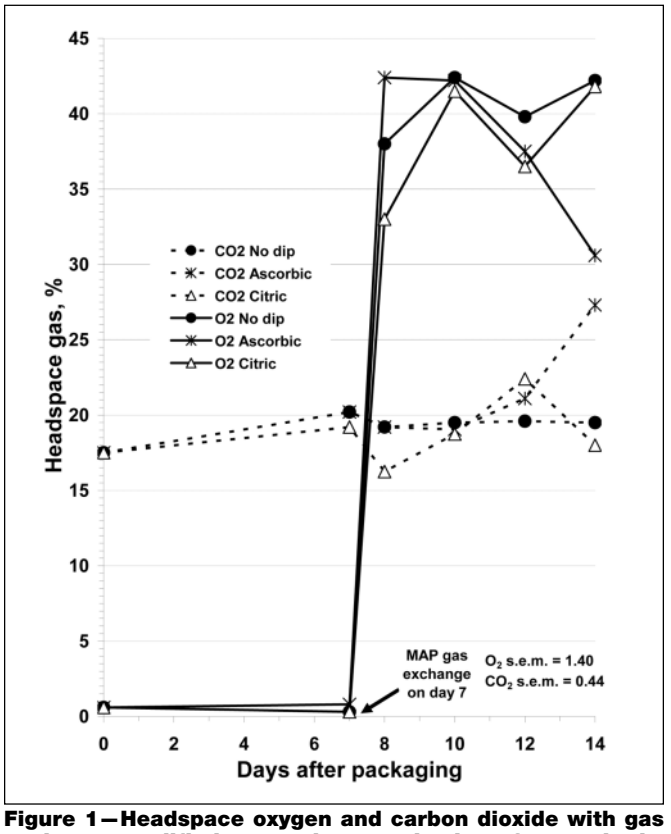

Figure 1—Headspace oxygen and carbon dioxide with gas exchange modified atmosphere packaging of control, citric acid–, or ascorbic acid–dipped pork chops.

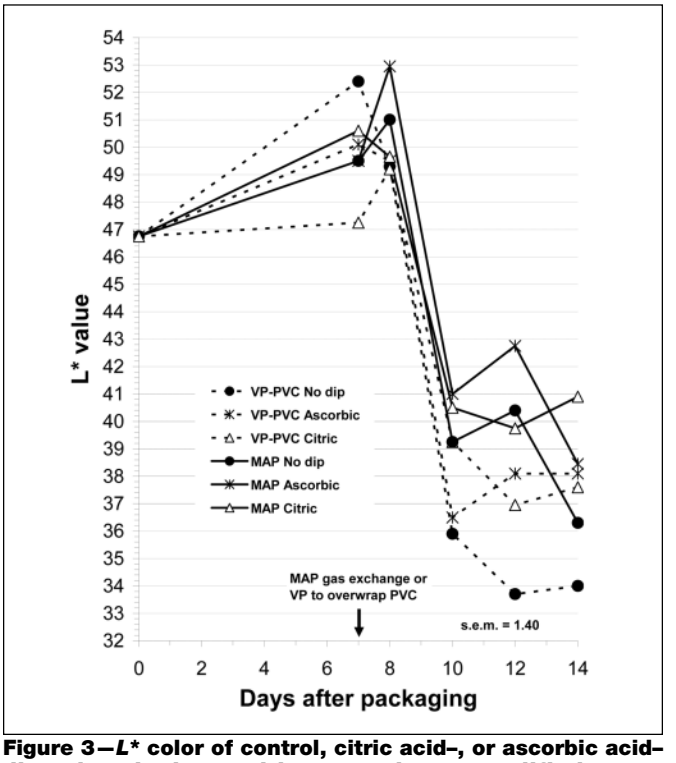

Figure 3—L^* color of control, citric acid–, or ascorbic acid–dipped pork chops with gas exchange modified atmosphere packaging or vacuum and overwrap packaging.

higher L^* values in the present study with higher O_2 was not readily apparent. Dipping in ascorbic acid or citric acid maintained lightness more than not dipping, particularly after an additional 7 d of simulated retail display. The a^* values during the 7 d of anoxic distribution storage were also not different ($P > 0.05$) with packaging type. Increased HunterLab a^* values indicated more red and less green in the surface color. After initial packaging, both VP and MAP samples decreased ($P < 0.05$) slightly in HunterLab a^* values because of the formation of metmyoglobin on the sample surface in the anaerobic environment. Samples increased ($P < 0.05$) in HunterLab a^* values after exchange of the initial gas for 80% O_2:20% CO_2 display gas or repackaging in air-permeable packaging, which oxygenated myoglobin in the samples. HunterLab a^* values of pork in MAP were generally redder ($P < 0.05$) than the pork chops in VP. Metmyoglobin formation in pork was less through 20 d of storage in 80% or 90% O_2 (balance CO_2) than in air (Ordoñez and Ledward 1977). Pork required blooming for 10 min to increase a^* value to a stable level (Brewer and others 2001). Zhu and others (2001) reported that storage time in vacuum influenced a^* values during a 30-min blooming period. Pork in 80% O_2:20% CO_2 with higher pH had lower discoloration scores than pork with lower pH (Livingston and others 2004).

In our study, chops dipped in citric acid had lower a^* values during simulated retail display than chops not dipped or dipped in ascorbic acid. Pork chops in MAP had higher ($P < 0.05$) b^* values than those in PVC during simulated retail display (Figure 5). Chops dipped in citric or ascorbic acid had higher ($P < 0.05$) b^* values compared with pork that was not dipped before packaging. Bentley and others (1989) reported that ground beef patties stored at 0, 4, and 8 °C in N_2 had the highest browning discoloration scores, followed by CO_2 and VP. Lopez-Lorenzo and others (1980) packaged ground pork in 100% O_2, 20% O_2:80% O_2, 20% CO_2:80% air, and air. They reported that elevated O_2 (80% to 100%) depressed the percentage of metmyoglobin formation, which increased the time necessary to reach 50% metmyoglobin formation from 4 to 13 d. Steaks stored at 0 °C during distribution had higher HunterLab L^*, a^*, and b^* values than samples stored at –4.4 and 4.4 °C, with samples in MAP brighter and redder than samples in VP-PVC (Ho and others 1995b). Huang and others (1993) reported that HunterLab L^* and b^* values of beef patties and steaks were higher ($P < 0.10$) with initial packaging in 80% O_2:20% CO_2 compared with other treatments where 80% N_2:20% CO_2 was followed by gas exchange at 14 d with 80% O_2:20% CO_2. Dipping of pork chops in ascorbic acid prior to irradiation maintained color equal to non-irradiated control pork after 2 wk of dark storage at 2°C (Zhao and Sebranek 1996). Lightness of catfish fillets was increased by treatment with 0.5 or 2% citric acid (Forrester and others 2002).

TBARS were affected by packaging type, acid dip, interactions between packaging type and acid dipping, and storage time. Lipid instability increased ($P < 0.05$) with increased time after packaging (Figure 6). Pork in MAP had increased ($P < 0.05$) lipid oxidation measured by TBARS than samples in vacuum or air-permeable packaging. This contradicted findings of Ordoñez and Ledward (1977) who reported that TBARS numbers in pork increased with time in 1 °C, but were not different between air, 80% O_2, and 90% O_2. However, Lopez-Lorenzo and others (1980) reported that 20% CO_2 greatly reduced the rate of lipid oxidation in ground pork. Dipping of chops in ascorbic or citric acid increased ($P < 0.05$) the lipid stability of pork chops compared with control samples when packaged in MAP. The antioxidant capability was evidently not sufficient to overcome the oxidation of lipids caused by the increased amount of O_2 in MAP compared with the lower O_2 in air. The influence of ascorbic acid on lipid oxidation in a foodstuff is dependent upon the oxidation-reduction potential of the system; pH; aerobic or anaerobic environment; presence or absence of other reductants, oxidants, or trace metals; enzymes; and time (Bauernfeind

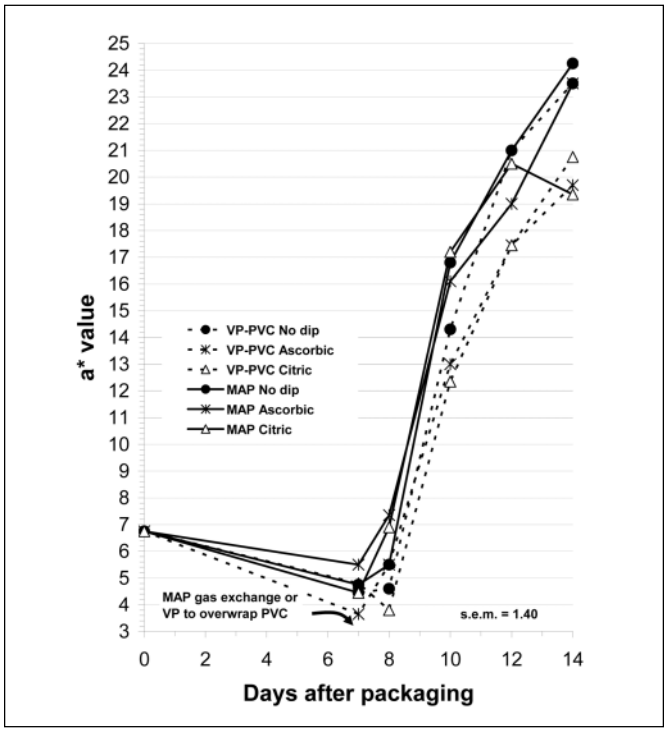

Figure 4—*a color of control, ascorbic acid–, or citric acid–dipped pork chops with gas exchange modified atmosphere packaging or vacuum and overwrap packaging.**

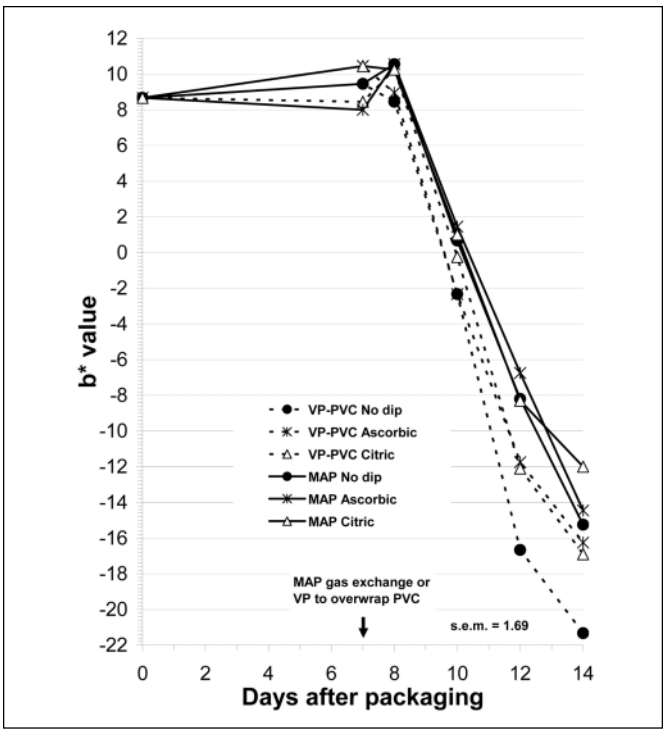

Figure 5—*b color of control, ascorbic acid–, or citric acid–dipped pork chops with gas exchange modified atmosphere packaging or vacuum and overwrap packaging.**

and Pinkert 1970). Citric acid at 0.02% inhibited lipid oxidation in washed pork fibers but did not affect TBARS in minced pork compared with control samples following high pressure treatment (Cheah and Ledward 1997). Lopez-Lorenzo and others (1980) reported that 0.3% ascorbic acid was effective in inhibiting lipid oxidation, but 0.3% citric acid was not effective.

Cousin and others (1992) defined the psychrotrophs as the microorganisms that could have a visible growth at 7 ± 1 °C within 7 to 10 d, regardless of their optimum growth temperatures. The growth of psychrotrophs during storage was influenced ($P < 0.05$) by packaging, storage time, and acid dipping in the present study (Figure 7). Samples in VP had higher ($P < 0.05$) counts of psychrotrophic microorganisms than pork in MAP. This was indicative of the inhibitory effect of CO_2 on microbial growth (Hintlian and Hotchkiss 1987). The rate of growth during simulated retail display was similar on pork in PVC with the different acid treatments, but was more variable in MAP with higher O_2. Psychrotrophic microorganism growth was less ($P < 0.05$) on samples dipped in ascorbic acid than with citric acid or no dipping before packaging. Psychrotrophic plate counts were log 6 CFU/g or higher in all samples by the end of 7 d of display, indicating an effective end of shelf-life. A 2% organic acid immersion and water spraying reduced coliforms by log 1.4 and 1.5 and *E. coli* by log 1.3 and 1.6 CFU per gram (Delmore and others 2000). Lactic acid was more effective than citric acid and 9% concentrations were more effective than 1% concentrations in decontamination of chicken skin by immersion in acid (Deumier 2004).

Huang and others (1993) reported that PPC of beef patties and steaks stored at 4.4 °C in 80% O_2:20% CO_2 on day 0 were higher ($P < 0.05$) than in samples packaged in 80% N_2:20% CO_2 with gas exchange for 80% O_2:20% CO_2 after 14 d distribution storage at 4 °C or –12.2 °C. Ho and others (1995b) also reported that PPC in beef was higher in VP-PVC than in MAP with gas exchange.

Conclusions

The technologies of organic acid treatment combined with dynamic gas exchange modified atmosphere packaging improved some shelf-life properties of retail pork chops. Packaging in MAP influenced objective color of pork compared VP-PVC. Ascorbic acid dipping reduced psychrotrophic microbial counts, while ascorbic and citric acid improved lipid stability. MAP with dynamic gas exchange would be expected to extend retail shelf-life of case-ready pork chops compared with more conventional VP-PVC systems, but the increased lipid oxidation with higher O_2 levels must be addressed.

Acknowledgments

Approved for publication by the director of the Louisiana Agric Exp Sta as manuscript no. 05-18-0267.

References

[APHA] American Public Health Assoc. 1976. Compendium of methods for the microbiological examination of foods. Washington, D.C.: American Public Health Assoc. 701 p.

Bauernfeind JC, Pinkert DM. 1970. Food processing with added ascorbic acid. Adv Food Res 18:219–315.

Bendall JR. 1972. Consumption of oxygen by the muscles of beef animals and related species, and its effect on the color of meat. I. Oxygen consumption in pre-rigor muscle. J Sci Food Agric 23:61-72.

Bentley DS, Reagan JO, Miller MF. 1989. Effects of gas atmosphere, storage temperature and storage time on the shelf-life and sensory attributes of vacuum-packaged ground beef patties. J Food Sci 54:284–6.

Brewer MS, Zhu LB, Bidner B, Meisinger DJ, McKeith FK. 2001. Measuring meat color: effects of bloom time, muscle, pH and relationship to instrumental parameters. Meat Sci 57:169–76.

Cannon JE, McKeith FK, Martin SE, Novakofski J, Carr TR. 1993. Acceptability and shelf-life of marinated fresh and precooked pork. J Food Sci 58:1249–53.

Cassens RG, Demeyer D, Eikelenboom G, Honikel KO, Johansson G, Nielsen T, Renerre M, Richardson I, Sakata R. 1995. Recommendation of reference method for assessment of meat color. Int Cong Meat Sci Technol Proc 41:410–1.

[CFR] Code of Federal Regulations. 2005. Use of food ingredients and sources of radiation. Washington, D.C.: Code of Federal Regulations Title 9 Food Safety

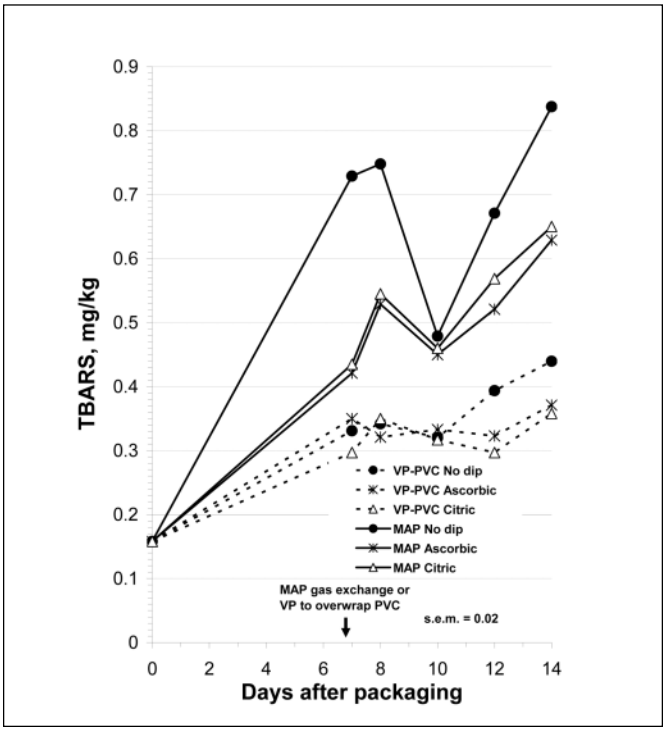

Figure 6—Lipid stability as TBARS control, ascorbic acid–, or citric acid–dipped pork chops with gas exchange modified atmosphere packaging or vacuum and overwrap packaging.

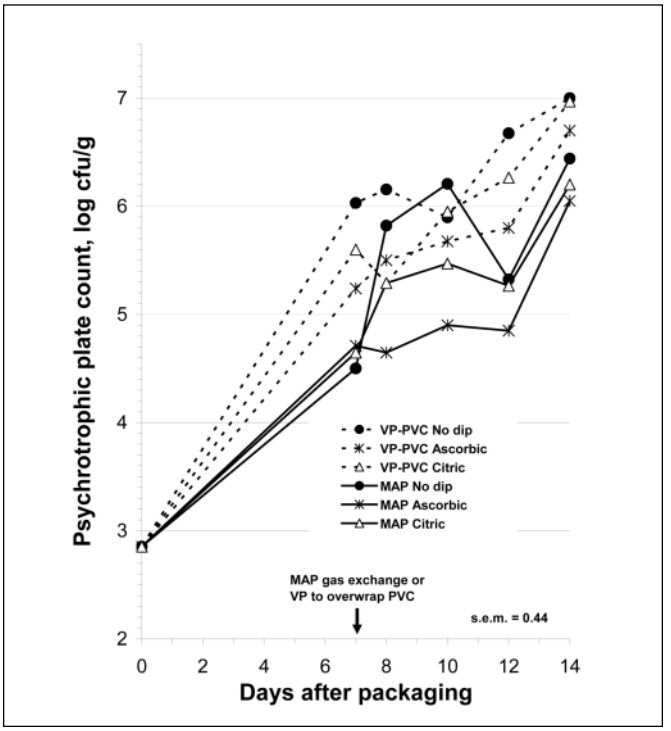

Figure 7—Psychrotrophic microorganism plate counts of control, ascorbic acid–, or citric acid–dipped pork chops with gas exchange modified atmosphere packaging or vacuum and overwrap packaging.

Inspection Service Dept. of Agriculture Subpart C 424.21.
Cheah PB, Ledward DA. 1997. Catalytic mechanism of lipid oxidation following high pressure treatment in pork fat and meat. J Food Sci 62:1135–8, 1141.
Cheng CS, inventor; Wilson Foods Corp., assignee. 1987 Jul. 28. Process for prepacking fresh meat. U.S. patent 4,683,139.
Cheng CS, inventor; Wilson Foods Corp., assignee. 1989 Apr. 4. Method of treating fresh meat cuts. U.S. patent 4,818,548.
Cole AB Jr. 1986. Retail packaging systems for fresh red meat cuts. Recip Meat Conf Proc 39:106–10.
Cousin MA, Jay JM, Vasavada PC. 1992. Psychrotrophic microorganisms, Ch. 9. In: Vanderzant C, Splittstoesser DF, editors. Compendium of methods for the microbiological examination of foods. 3rd ed. Washington, D.C.: Am Public Health Assoc. p 88
Delmore RJ, Sofos JN, Schmidt GR, Belk KE, Lloyd WR, Smith GC. 2000. Interventions to reduce microbiological contamination of beef variety meats. J Food Prot 63:44–50.
Deumier F. 2004. Pulsed-vacuum immersion of chicken meat and skin in acid solutions. Effects on mass transfers, color and microbial quality. Int J Food Sci Technol 39(3):277–86.
Forrester PN, Prinyawiwatkul W, Godber JS, Plhak. 2002. Treatment of catfish fillets with citric acid causes reduction of 2-methylisoborneol, but not musty flavor. J Food Sci 67:2615–8.
Hintlian CB, Hotchkiss JH. 1987. Comparative growth of spoilage and pathogenic organisms on modified atmosphere-packaged cooked beef. J Food Protect 50:208–23.
Ho CP, Huffman DL, Bradford DD, Egbert WR, Mikel WB, Jones WR. 1995a. Storage stability of vacuum packaged frozen pork sausage containing soy protein concentrate, carrageenan or antioxidants. J Food Sci 60:257–61.
Ho CP, McMillin KW, Huang NY, Smith BS. 1995b. Shelf-life of steaks and ground beef at different distribution storage temperatures. New Orleans, La.: 1995 Jan 28- Feb 1. Chicago, Ill.: Southern Regional Section of Inst Food Tech. 92nd Annual Meeting Southern Assoc Agric Scientists. p 14 (Abstr.)
Huang NY, McMillin KW, Ho CP, Smith BS. 1993. Retail beef in dynamic gas exchange modified atmosphere packaging with different distribution storage temperatures. Calgary, Alberta, canada, 1993 Aug 1-6. Ottawa, Canada: Clearbrook Communications. 39th Int Congress of Meat Sci and Technol Proc. Session 8, p 395. (Abstr.).
Jakobsen M, Bertelsen G. 2002. The use of CO_2 in packaging of fresh red meats and its effect on chemical quality changes in the meat: a review. J Muscle Foods 13:143–68.
Livingston M, Brewer MS, Killifer J, Bidner B, McKeith F. 2004. Shelf life characteristics of enhanced modified atmosphere packaged pork. Meat Sci 68:115–22.
Lopez-Lorenzo P, Hernandez P, Sanz-Perez B, Ordoñez JA. 1980. Effect of oxygen- and carbon dioxide-enriched atmospheres on shelf-life extension of refrigerated ground pork. Meat Sci 4:89–94.
Lynch NM, Kastner CL, Kropf DH. 1986. Consumer acceptance of vacuum packaged ground beef as influenced by product color and educational materials. J Food Sci 51:253–5, 272.
Manu-Tawiah W, Ammann LL, Sebranek JG, Molins RA. 1991. Extending the color stability and shelf life of fresh meat. Food Technol 45(3):94, 96–8, 100–2.
McMillin KW, Huang NY, Ho CP, Smith BS. 1994. Beef traits with differing fabrication times and gases in modified atmosphere packaging. The Hague, Netherlands, Aug 28-Sep 2. Zeist, Netherlands: Nutrition and Food Research. 40th Int Congress of Meat Sci and Technol Proc. Session S-IIA.10, p. 9. (Abstr.)
McMillin KW, Huang NY, Ho CP, Smith, BS. 1999. Quality and shelf-life of meat in case-ready modified atmosphere packaging. In: Xiong YL, Ho CT, Shahidi F, editors. Quality attributes of muscle foods. New York: Kluwer Academic. p 73–93.
Ordoñez JA, Ledward DA. 1977. Lipid and myoglobin oxidation in pork stored in oxygen- and carbon dioxide-enriched atmospheres. Meat Sci 1:41–8.
SAS. 1985. SAS user's guide: Statistic. 5th ed. Cary, N.C.: SAS Inst., Inc.
Tarladgis BG, Watts BG, Watts BM, Younathan MT. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. J Amer Oil Chem Soc 37:44–8.
Warriss PD. 2000. Meat science an introductory text. Oxon, U.K.: CABI. 310 p.
Zhao Y, Sebranek, JG. 1996. Physicochemical and sensory qualities of fresh pork chops as affected by phosphate, ascorbate or sorbate dipping prior to irradiation. J Food Sci 61:1281–4.
Zhu LG, Bidner B, Brewer MS. 2001. Postmortem pH, muscle, and refrigerated storage effects on ability of vacuum-packaged pork to bloom. J Food Sci 66:1230–5.