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Spoilage characteristics of traditionally packaged ground beef with added lactic acid bacteria displayed at abusive temperatures

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ABSTRACT: Growth of pathogenic organisms such as *Escherichia coli* O157:H7 and *Salmonella* spp. can be inhibited in ground beef through the addition of certain lactic acid-producing bacteria (LAB; *Lactobacillus acidophilus* NP51, *Lactobacillus crispatus* NP35, *Pediococcus acidilactici*, and *Lactococcus lactis* ssp. *lactis*). This study evaluated the effects of LAB inclusion on the organoleptic and biochemical properties typically associated with spoilage in traditionally packaged ground beef displayed at abusive (10°C) temperatures for 36 h. Trained and untrained panelist evaluations of lean color and off-odor, as well as instrumental color analyses, did not indicate an effect on spoilage traits due to LAB utilization ($P > 0.05$). However, display length affected each variable independently and was indicative of decreased stability and acceptability as display time (h) increased ($P < 0.05$). Thiobarbituric acid values were decreased for ground beef with added LAB ($P < 0.05$), but likely can be related to bacterial degradation of lipid oxidation by-products because no reduction in organoleptic traits due to oxidation was noted between treatments. Overall, LAB did not adversely influence the spoilage characteristics of traditionally packaged ground beef displayed at abusive temperatures for up to 36 h. Furthermore, biochemical and sensory indicators of spoilage were present for all treatments at the conclusion of display. Therefore, LAB can be added to ground beef in traditional packaging as a processing intervention without masking or delaying the expected spoilage characteristics.

Key words: ground beef, lactic acid bacteria, overwrap packaging, spoilage, temperature abuse

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INTRODUCTION

Few interventions exist for pathogen reduction in retail ground beef. Prior research shows lactic acid bacteria (**LAB**) reduce pathogens (Smith et al., 2005). The use of LAB is generally recognized as safe in fresh ground beef and is approved by the USDA Food Safety and Inspection Service and the US Food and Drug Administration (USDA, 2003). Brashears et al. (2005) determined 4 LAB strains establish a competitive environment through various mechanisms that ultimately result in an environment not conducive to the growth of other bacteria (Aguirre and Collins, 1993).

Though LAB are effective in pathogen reduction, interest also lies in the effects of LAB on spoilage characteristics of ground beef. Hoyle et al. (2009) determined that added LAB did not alter growth of spoilage microflora, whereas Smith et al. (2005) found no change in acceptability of cooked ground beef with added LAB. Little investigation of the sensory properties of ground beef with added LAB at retail exists.

Beef appearance (a primary factor of acceptability) is affected by various mechanisms, including temperature. James and Bailey (1990) and Greer et al. (1994) concluded retail display is the weakest point in the commercial cold chain. The deleterious effect of temperature abuse on shelf life has been documented (Andersen and Skibsted, 1991). Additionally, Greer et al. (1994) correlated *Escherichia coli* growth to display temperatures between 4 and 8°C.

Though Ronnow (2006) found optimal stability is obtained at 0 to 4°C, abusive temperatures [defined by Limbo et al. (2010) as temperatures from 7 to 10°C] can be observed at retail (Luiten et al., 1982; Grau, 1987). However, few data exist regarding efficacy of antimicrobials at abusive temperatures or their effects on ground beef characteristics at abusive temperatures. Therefore, the objective was to examine effects of LAB on the sensory characteristics of ground beef displayed at abusive temperatures.

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MATERIALS AND METHODS

Live animals were not used in this study; therefore, no approval from the Institutional Animal Care and Use Committee was obtained. Meat was obtained from a federally inspected meat processing facility.

Patty Preparation

A total of 104.5 kg of coarsely ground beef (80% lean, 20% fat) was obtained from a commercial beef-packing facility over a 3-wk period. A 4-strain LAB cocktail, consisting of *Lactobacillus acidophilus* NP51, *Lactobacillus crispatus* NP35, *Pediococcus acidilactici*, and *Lactococcus lactis* spp. *lactis*, was provided by Culture Systems Inc. (Mishawaka, IN) for use at a targeted inoculation level of 10^9 cfu/g of ground beef. Inoculation levels were verified using procedures outlined previously by Hoyle et al. (2009). The ground beef was divided into 2 treatments, control (**CON**) and LAB, and each treatment was replicated 3 times. For the CON patties, ground beef was mixed thoroughly for 1 min using a commercial blender (model A-80, Koch Supplies Inc., Kansas City, MO), then 500 mL of sterile distilled water was added, the mixer direction was reversed, and the ground beef was mixed for an additional 1 min. Ground beef treated with LAB was prepared in the same manner as CON, but with 500 mL of the LAB solution suspended in sterile distilled water added to the ground beef. Using a 0.32-cm fine-grind plate, the coarse ground beef was passed through a 3-phase meat grinder (model 346, Biro, Ft. Smith, AR). Patties weighing 145 g were formed using a patty-forming machine (model 54, Hollymatic Corp., LaGrange, IL), and 2 patties were placed on expanded polystyrene trays (Pactiv Corporation, Lake Forest, IL). Trays were overwrapped with a polyvinylchloride film (MAPAC L, oxygen transmission rate = 21,700 mL of O_2 per m^2 per 24 h; Borden Packaging and Industrial Products, North Andover, MA) in an overwrap machine (Heat Sealing Equipment Co., Cleveland, OH). Packages in each treatment group were individually identified before random placement in the retail case.

Simulated Retail Display and Temperature Abuse

Overwrapped packages were displayed in a coffin-style retail display case (model M1, Hussman, Bridgeton, MO) maintained at 10°C. Temperature was monitored continuously using remote temperature recorders (Multi-Trip, Temprecord Monitor Company, Modesto, CA). Packages were subjected to an average of 1,900 lx of continuous fluorescent lighting using high-output bulbs with a color temperature rating of 3,500 K and a color rendering index of 70. Packages were displayed in the retail cases for up to 36 h, with sensory and biochemical analyses occurring every 12 h.

Trained Sensory Analysis and Untrained Panelist Evaluation

Both trained and untrained panelists were used to evaluate the color and odor of traditionally packaged ground beef patties at 0-, 12-, 24-, and 36-h sampling intervals. At each sampling interval, trained (n = 6 to 8) and untrained preference panelists (n = 4 to 13) evaluated 6 packages (n = 3 per treatment). A total of 9 packages per treatment were evaluated (n = 3 packages per treatment × 3 replications). Members of the faculty and graduate student populations were recruited to serve as trained panelists. The trained panelists were trained by experienced meat science faculty in multiple sessions using representative samples of overwrapped ground beef before the start of the project. Trained sensory panelists were asked to score the lean color of ground beef patties using a 5-point verbally anchored scale (1 = very bright red; 2 = bright red; 3 = slight dark red or brown; 4 = moderately dark red or brown; 5 = very dark red or brown) as well as surface discoloration (1 = no discoloration; 2 = slight, 1 to 10%; 3 = small, 11 to 20%; 4 = moderate, 21 to 60%; 5 = severe discoloration, 61 to 100%) as outlined by American Meat Science Association color guidelines (AMSA, 1991). Untrained graduate students were used as untrained (preference) panelists and were asked to determine if the ground beef patties had good color (1 = very strongly agree; 7 = very strongly disagree) and how likely they were to purchase the package based on patty color (1 = definitely would purchase; 5 = definitely would not purchase; AMSA, 1991).

Odor panels were conducted on packages removed from the case at each sampling interval (12 h). The packages were opened in a random order, and panelists were allowed to smell the patties without touching them using a verbally anchored numerical scale from Payne et al. (2002). Trained panelists were asked to determine the presence of an off-odor (1 = no off-odor; 5 = extreme off-odor) and to characterize the off-odor if present (1 = rancid; 2 = arid; 3 = sweet; 4 = sour; 5 = acid; and 6 = putrid). Untrained panelists were asked if meat in the packaged smelled fresh (1 = very strongly agree; 7 = very strongly disagree) and how likely they were to consume the meat (1 = definitely would consume; 5 = definitely would not consume) based on the odor.

Instrumental Color Analysis

Instrumental color values were measured at 0, 12, 24, and 36 h during the display period. Color values were obtained for each patty using a portable colorimeter (Hunter MiniScan XE Plus, model MSXP-4500C, Hunter Association Laboratory Inc., Reston, VA) with illuminant A for CIE L*, a*, and b* and a standard observer angle of 10° and 2.54-cm aperture (CIE, 1978). The instrument was standardized before sampling using a white and black tile. Two color evaluations from

randomly selected locations were taken from each patty and averaged to determine the L*, a*, and b* values. Additionally, Hunter a* and b* values were converted to hue angle ($\tan^{-1}$ b*/a*) and saturation $(a^{*2} + b^{*2})^{1/2}$ values.

Thiobarbituric Acid Assays

Thiobarbituric acid reactive substances (**TBARS**) were analyzed as a measure of lipid oxidation using the wet method procedures described by Luqué et al. (2011). Sample analyses were performed in duplicate for each patty after 0, 12, 24, and 36 h of display.

Statistical Analysis

The experimental design was a completely randomized split-plot design. Ground beef served as blocks to which treatment was assigned. Each treatment was replicated 3 times. Statistical analyses were performed using the MIXED procedure (SAS Inst. Inc., Cary, NC) to evaluate the effect of LAB, display (h) length, and any potential interaction, on the trained and untrained panelist evaluations, instrumental color values, and lipid oxidation values of traditionally packaged ground beef patties. Random variables included packaged identification, replication, and package identification by replication. Significant main effects and interactions were analyzed using the least squares means method and separated using the PDIFF statement. Differences were considered significant at $P < 0.05$, unless otherwise noted.

RESULTS AND DISCUSSION

Trained Sensory Analysis

Trained panelist responses for lean beef color, percent surface discoloration, and immediate off-odor did not differ between treatments (Table 1; $P = 0.8208$, $P = 0.8076$, and $P = 0.9762$, respectively). These results concur with previous literature suggesting a lack of noticeable effect of LAB inclusion on the shelf-life attributes of beef steaks (Djenane et al., 2005); however, different strains of LAB were used by Djenane et al. (2005; *Lactobacillus sakei* CTC 372 and *Lactobacillus* CTC 711). Although the strains of LAB used in the either study differ, all strains used have been associated with creation of environments antagonizing the growth of spoilage and pathogenic microorganisms (Bredholt et al., 2001; Hoyle et al., 2009). Additionally, previous studies have shown increased numbers of total aerobic bacteria due to the addition of LAB; however, the LAB numbers did not change over 36 h of retail display (Hoyle et al., 2009). The absence of distinguishable differences between treatments suggests LAB can be added to ground beef to control the growth of pathogenic microorganisms without alteration of spoilage characteristics under abusive conditions.

Table 1. Effect of treatment (control or lactic acid bacteria, LAB) on trained panel scores for lean color, percentage patty discoloration, and detection of off-odor of traditionally packaged ground beef patties displayed at 10°C for up to 36 h[1,2]

	Trained sensory evaluation		
Treatment	Lean color[3]	Percent discoloration[4]	Immediate off-odor[5]
Control	3.3	2.5	1.7
LAB	3.3	2.5	1.7
P-value	0.8208	0.8076	0.9762
SEM	0.10	0.16	0.12

[1]LAB: 250 mL of solution added to ground beef to achieve 10^9 cfu of LAB/g of ground beef.

[2]Scores represent main effect least squares means of treatment, pooled across display time (h).

[3]Lean color: 3 = slightly dark red or brown; 4 = moderately dark red or brown.

[4]Percent discoloration: 2 = slight, 1 to 10%; 3 = small, 11 to 20%.

[5]Immediate off-odor: 1 = no off-odor; 2 = slight off-odor.

Although no interaction existed between LAB treatment and display length for either lean color ($P = 0.3009$) or discoloration ($P = 0.9847$), display time affected each variable independently. As display time (h) increased, lean beef color migrated from bright cherry red to brown, as indicated by lean color ($P < 0.0001$) and percent discoloration ($P < 0.0001$) scores at each display interval (Table 2) of trained panelists. The increase in metmyoglobin accumulation as display time progressed is supported by numerous other researchers (Kropf, 1980; Djenane et al., 2001; Jeremiah and Gibson, 2001; Brooks et al., 2008).

The rapid change in lean color discernible to trained panelists is likely attributed to the abusive display temperature used in the current study. Previous researchers have illustrated negative effects of increased temperature on beef quality attributes associated with increased rates of enzymatic spoilage and bacterial growth (Giannuzzi et al., 1998; Bhattacharya et al., 2006). Solberg (1968) reported reduced oxygen solubility and diffusion potential at higher temperatures, citing one-half as much oxygen diffusion at 15°C compared with 5°C. Furthermore, Solberg (1968) hypothesized higher temperatures reduced the rate of reduction to deoxymyoglobin while increasing rate of oxidation to metmyoglobin.

The detection of off-odor by trained panelists increased as display time increased (Table 2; $P < 0.0001$). Brooks et al. (2008) also noted increased off-odor production as display progressed. Furthermore, Jeremiah and Gibson (2001) noted increased off-odor production in beef steaks subjected to higher temperature storage (5°C).

Analysis of characterization of off-odors from CON and LAB treated ground beef by trained panelists is presented in Table 3. Neither a treatment × display time (h) interaction ($P = 0.9825$) nor a treatment effect ($P = 0.8999$) was noted for the percentage of packages

Table 2. Effect of retail display time (0, 12, 24, 36 h) on trained panel sensory scores for traditionally packaged ground beef patties held at abusive temperatures (10°C)[1]

	Display, h					
Characteristic	0	12	24	36	*P*-value	SEM
Lean color[2]	2.0[a]	3.1[b]	3.7[c]	4.3[d]	<0.0001	0.08
Percent discoloration[3]	1.0[a]	1.6[b]	2.7[c]	4.6[d]	<0.0001	0.24
Immediate off-odor[4]	1.0[a]	1.2[b]	1.9[b]	2.9[c]	<0.0001	0.20

[a–d]Least squares means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Scores represent least squares main effect means for display time (h), pooled among treatments.

[2]Lean color: 1 = very bright red; 2 = bright red; 3 = slightly dark red or brown; 4 = moderately dark red or brown; 5 = very dark red or brown.

[3]Percent discoloration: 1 = no discoloration; 2 = slight, 1 to 10%; 3 = small, 11 to 20%; 4 = moderate, 21 to 60%; 5 = severe discoloration, 61 to 100%.

[4]Immediate off-odor: 1 = no off-odor; 2 = slight off-odor; 3 = small off-odor.

with no off-odor after display for 36 h at 10°C. However, a decrease in the percentage of packages without off-odor was noted as display time increased ($P < 0.0001$). Frequency analysis of characterization data (not presented in tabular format) indicated increased prevalence of sour and rancid odors as display time increased. Previous research has reported increased off-odor production as display increases (Djenane et al., 2001; Brooks et al., 2008).

Untrained Panelist Evaluations

Analysis of untrained panel responses showed no differences between treatments for freshness of lean color ($P = 0.6353$), purchase intent ($P = 0.4942$), freshness of odor ($P = 0.8763$), and likelihood for consumption ($P = 0.7246$; Table 4). Whereas these data are limited by the number of untrained panelists who participated in the study, these results coincide with responses by trained panelists and instrument color values for each treatment. Thus, the untrained panel data provide additional documentation to support the conclusion that LAB inclusion does not alter spoilage processes of ground beef displayed at abusive temperatures.

As with evaluations by trained panelists, retail display length (h) affected evaluations of untrained panelists of lean color and odor (Table 5). Untrained preference panelists noted a decline in desirable lean color after 12 h of display ($P < 0.05$). By the conclusion of the display period (36 h), panelist scores indicated slight disagreement with the statement "this package of beef had good color" (5.8; 5 = slightly disagree, 6 = strongly disagree). A lack of desirable lean color as time increased was manifested in the likelihood of the panelists not to purchase retail packages after 36 h (4.4; 4 = probably would not purchase, 5 = definitely would not purchase).

A similar decline in untrained panel acceptability as display time increased was noted by Brooks et al. (2008), although products were displayed at traditional refrigeration temperatures (0 to 2°C). Of interest is the period of time required to attain unacceptability in the current study when compared with previously published work in our laboratory (Brooks et al., 2008). The investigation performed by Brooks et al. (2008) illustrated a display period of 3 d for the attainment of congruent untrained panel lean color scores observed after only 36 h in the current study. The accelerated discoloration can be attributed to higher display temperatures used in the current trial. Jeremiah and Gibson (2001) found metmyoglobin accumulated during both storage and display; however, the accumulation was temperature dependent and occurred most rapidly at increased temperatures.

Table 3. Percentage of trained panelists detecting no off-odor in traditionally packaged control and lactic acid bacteria (LAB) treated ground beef patties displayed at 10°C for 36 h[1]

	Display, h						
Treatment	0	12	24	36	Treatment main effect[2]	Main effect *P*-value	Main effect SEM
Treatment[3]						0.8999	8.78
Control	100.0	81.4	39.6	3.3	56.07	—	—
Lactic acid bacteria	100.0	88.2	40.3	0.3	57.20	—	—
Main effect[2]							
Display time, h	100.0[c]	84.8[c]	39.9[b]	1.8[a]	—	<0.0001	12.42

[a–c]Least squares means within a row and variable lacking a common superscript letter differ ($P < 0.05$).

[1]Lactic acid bacteria (LAB): 250 mL of solution added to ground beef to achieve 10^9 cfu of LAB/g of ground beef.

[2]Main effect least squares means (treatment and display time, h) were pooled among display time (h) or treatment, respectively.

[3]Treatment × display time (h) interaction: $P = 0.9825$, SEM = 17.57.

Table 4. Untrained panelist preference scores for traditionally packaged control and lactic acid bacteria (LAB) treated ground beef patties displayed at 10°C[1]

	Untrained panelist evaluation			
Treatment	Lean color[2]	Purchase intent[3]	Freshness of odor[4]	Likelihood of consumption[5]
Control	3.8	2.9	3.5	2.6
LAB[6]	3.8	2.9	3.5	2.6
P-value	0.6353	0.4942	0.8763	0.7246
SEM	0.17	0.10	0.16	0.14

[1]Scores represent main effect least squares means of treatment, pooled across display time (h). A total of 9 samples per treatment were evaluated in 3 sessions, with 4 to 13 untrained panelists per session.

[2]Lean color: "Do the patties have good color?" 3 = slightly agree; 4 = no opinion.

[3]Purchase intent: 2 = probably would purchase; 3 = may or may not purchase.

[4]Freshness of odor: "Does meat in the package smell fresh?" 3 = slightly agree; 4 = no opinion.

[5]Likelihood of consumption: 2 = probably would consume; 3 = may or may not consume.

[6]LAB: 250 mL of solution added to ground beef to achieve 10^9 cfu of LAB/g of ground beef.

Similar to trained panelists, untrained panelist evaluations were indicative of increased off-odor as display increased ($P < 0.0001$; Table 5). The likelihood of untrained panelists to consume ground beef patties declined as display time increased ($P < 0.0001$), although panelists indicated their probable consumption of the ground beef through 24 h of display. Regardless, after 36 h of display at 10°C, untrained panelists indicated probable rejection to consume traditionally packaged ground beef patties based on odor (4.14; 4 = probably would not consume).

Instrumental Color Evaluation

In agreement with evaluations of trained and untrained panelists, no differences between treatments were noted for Hunter L* ($P = 0.9479$), hue angle ($P = 0.5755$), and saturation values ($P = 0.2622$; Table 6) of traditionally packaged ground beef patties displayed for 36 h at 10°C. However, display time did affect instrumental color values, resulting in decreased L* ($P = 0.0013$), increased hue angle ($P < 0.0001$), and decreased saturation values ($P < 0.0001$) as display time increased. Decreased L* values, indicative of darkening or increased dullness, are correlated with increased discoloration (Kropf, 1980; Mancini and Hunt, 2005). These results correspond with trained panelists who noted increased discoloration as display progressed. Interestingly, after 36 h of display, an increase in L* values was observed ($P < 0.05$). The increased lightness could be associated with a bleached red or gray lean color. Bertelsen and Skibsted (1987) associated a faded red appearance in displayed beef steak lean color with photo-oxidation of the myoglobin pigment, resulting in the formation of metmyoglobin.

The accumulation of undesirable pigmentation as display time increased is supported by decreased saturation values over the display period ($P < 0.05$), indicating a loss of red saturation. Furthermore, evaluations of trained panelists of lean color signified loss of red pigmentation during display. Loss of red saturation and accumulation of discoloration have been widely re-

Table 5. Untrained panelist preference scores for traditionally packaged ground beef patties displayed at 10°C for 36 h[1]

	Display, h					
Characteristic	0	12	24	36	*P*-value	SEM
Lean color[2]	2.0[a]	3.3[b]	4.2[c]	5.8[d]	<0.0001	0.22
Purchase intent[3]	1.6[a]	2.5[b]	3.1[c]	4.4[d]	<0.0001	0.14
Freshness of odor[4]	1.7[a]	2.8[b]	3.9[c]	5.4[d]	<0.0001	0.25
Likelihood of consumption[5]	1.3[a]	2.1[b]	2.8[c]	4.1[d]	<0.0001	0.20

[a–d]Least squares means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Scores represent main effect least squares means of display time (h), pooled among treatments. A total of 18 samples per display time were evaluated in 3 sessions by 4 to 13 untrained panelists per display time.

[2]Lean color: "Do the patties have good color?" 1 = very strongly agree; 2 = strongly agree; 3 = slightly agree; 4 = no opinion; 5 = slightly disagree; 6 = strongly disagree.

[3]Purchase intent: 1 = definitely would purchase; 2 = probably would purchase; 3 = may or may not purchase; 4 = probably would not purchase; 5 = definitely would not purchase.

[4]Freshness of odor: "Does meat in the package smell fresh?" 1 = very strongly agree; 2 = strongly agree; 3 = slightly agree; 4 = no opinion; 5 = slightly disagree; 6 = strongly disagree.

[5]Likelihood of consumption: 1 = definitely would consume; 2 = probably would consume; 3 = may or may not consume; 4 = probably would not consume; 5 = definitely would not consume.

Table 6. Instrumental L*, hue angle, and saturation values for traditionally packaged ground beef patties displayed at 10°C for 36 h[1]

Treatment and display	L*[2]	Hue angle[3]	Saturation[4]
Treatment			
Control	46.5	0.9	24.4
LAB[5]	46.5	0.9	25.1
P-value	0.9479	0.5755	0.2622
SEM	0.40	0.02	0.58
Display, h			
0	48.1[c]	0.8[a]	33.0[d]
12	45.2[a]	0.9[b]	24.9[c]
24	45.9[a]	1.0[c]	21.6[b]
36	46.8[b]	1.1[d]	19.3[a]
P-value	0.0013	<0.0001	<0.0001
SEM	0.43	0.01	0.50

[a–d]Least squares means within a column and variable lacking a common superscript differ ($P < 0.05$).

[1]Main effect least squares means (treatment and display time; h) were pooled among display time (h) or treatment, respectively. A total of 9 samples per treatment were evaluated.

[2]L* as defined by CIE (1978) and AMSA (1991).

[3]Hue angle = $\tan^{-1}$ b*/a*.

[4]Saturation = $(a^{*2} + b^{*2})^{1/2}$.

[5]Lactic acid bacteria (LAB): 250 mL of solution added to ground beef to achieve 10^9 cfu of LAB/g of ground beef.

corded in shelf-life research (Kropf, 1980; Bertelsen and Skibsted, 1987; Mancini and Hunt, 2005). The manifestation of such a phenomenon after only 36 h of display could be attributed to increased display temperatures, which are implicated in accelerated rates of oxidation.

Lipid Oxidation

Treatment and display time independently affected TBA values of traditionally packaged ground beef (Table 7). Ground beef patties containing LAB had decreased TBA values (2.24 mg of malonaldehyde/kg of meat) compared with CON ground beef (2.54 mg of malonaldehyde/kg of meat; $P = 0.017$), indicative of decreased lipid oxidation. Previous researchers have proposed deterred accumulation of lipid oxidation by-products via microbial utilization of TBARS (Moerck and Ball, 1974; McMillin et al., 1991; Rhee et al., 1997). Furthermore, Smith and Alford (1968) and Brown et al. (1979) have identified numerous species of yeasts, molds, and bacteria capable of destroying lipid oxidation products. Although microbial utilization of lipid oxidation by-products provides potential explanation for reduced TBA values in ground beef with added LAB, further investigation is needed into the relationship of TBARS and the LAB strains used in the current study.

In a review of the effects of LAB inclusion on spoilage and pathogenic microflora, Hoyle et al. (2009) noted increased total aerobic bacteria in traditionally packaged LAB treated ground beef stored at 10°C. These results were expected due to addition of LAB and were not indicative of increased spoilage. Additionally, no differences were noted in the growth of other spoilage microflora (i.e., *Bronchothrix thermosphacta*, coliforms, and pseudomonads). Furthermore, no increase in LAB proliferation was observed over the display period. Regardless, the increased aerobic microflora in ground beef with added LAB does support the microbial destruction of lipid oxidation by-products. Although this does convey the deterring of by-product accumulation, it does not imply reduced oxidation or alteration of spoilage characteristics, as supported by previously discussed evaluations of trained and untrained panelists.

Accumulation of lipid oxidation by-products increased as display progressed ($P < 0.0001$; Table 7). These results are supported by previous investigations noting increased oxidation due to the oxidizing effect of lighted retail display (Andersen and Skibsted, 1991; Brooks et al., 2008).

The sensory and biochemical analyses indicate the addition of LAB does not affect the spoilage characteristics of traditionally packaged ground beef displayed at abusive temperatures for up to 36 h. Furthermore, no interactions were noted between LAB treatment and display length on spoilage and stability characteristics, although display did result in the expected production of off-odor and declining lean color scores.

When compared with previous results obtained in our laboratory (Brooks et al., 2008), the onset of spoilage traits is accelerated in the current study. Likely, the expedited loss of stability and more rapid onset of spoilage traits is due to increased display temperature. Previous research suggests that exposure to higher temperatures results in altered and accelerated rates of microbial growth and lipid and pigment oxidation. These accelerated enzymatic and microbial reproduction rates have been associated with proportional decreases in shelf-life and stability of ground beef products (Jer-

Table 7. Thiobarbituric acid (TBA; mg of malonaldehyde/kg of meat) values for traditionally packaged ground beef patties displayed at 10°C for 36 h[1]

Item	TBA value
Treatment	
Control	2.5[b]
LAB[2]	2.2[a]
P-value	0.0173
SEM	0.11
Display, h	
0	1.4[a]
12	2.1[b]
24	2.8[b]
36	3.3[c]
P-value	<0.0001
SEM	0.31

[a–c]Least squares means within a column and variable lacking a common superscript differ ($P < 0.05$).

[1]Main effect least squares means (treatment and display time, h) were pooled among display time (h) or treatment, respectively. A total of 9 samples per treatment were evaluated.

[2]Lactic acid bacteria (LAB): 250 mL of solution added to ground beef to achieve 10^9 cfu of LAB/g of ground beef.

emiah and Gibson, 2001). Additionally, increased temperatures can result in the proliferation of undesirable or pathogenic bacteria, thus compromising the quality and safety of beef products (Seideman and Durland, 1983).

Previous research has shown that the LAB used in this study can control the proliferation of pathogenic bacteria such as *E. coli* O157:H7 and *Salmonella* spp. (Smith et al., 2005; Hoyle et al., 2009). These existing data and the current research illustrate that these LAB strains can be added to prevent pathogen growth in traditionally packaged ground beef without altering the spoilage characteristics associated with display at abusive temperatures.

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