Growth Depth Effects of Bacteria in Ground Turkey Meat Patties Subjected to High Carbon Dioxide or High Oxygen Atmospheres

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ABSTRACT

Modified atmosphere packaging (MAP) is used to extend the shelf life of ground meats by altering the gas atmosphere surrounding the meat. This study evaluated how deep MAP bactericidal effects penetrate into a ground meat patty. Patties made from freshly ground turkey breasts were subjected to 2 MAP treatments of high CO2 (97%) or high O2 (80% O2, 20% CO2). Total plate and lactic acid bacterial counts were determined for 3 patty depths (top, middle, bottom). Meat surface color and the package gas headspace composition were also measured. All analyses were performed on 0, 3, 6, 9, and 12 d. Changes in gas headspace and meat surface color were also measured at 0, 3, 6, 9, and 12 d. High CO2 atmosphere maintained a better meat surface color than high O2 atmosphere over the whole storage period. Overall counts were lower ($P \leq 0.05$) in a high-CO2 atmosphere compared with a high-O2 modified atmosphere. Patties stored under a high-CO2 atmosphere displayed slower bacterial growth in the top layer compared with the middle and bottom layers. Total plate count did not differ ($P > 0.05$) in layers for patties packaged in a high-O2 atmosphere. Lactic acid bacterial counts increased in the high-O2 modified atmosphere by d 9 and 12 of storage; no increase was observed in CO2-packaged patties. Thus, high-CO2 MAP slowed the growth of total bacteria as well as lactic acid bacteria. Also, there was slower growth in the top meat layer exposed to CO2 compared with interior layers.

Key words: modified atmosphere packaging, ground turkey meat, bacterial growth depth meat color

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INTRODUCTION

Three sensory properties by which consumers judge meat quality are appearance, texture, and flavor. The most important property at the time of purchase is appearance, because texture and flavor cannot be evaluated when the product is packaged. Surface discoloration is inevitable and is used as an indicator of freshness. Both deoxymyoglobin and oxymyoglobin are oxidized to form metmyoglobin, which has a dull, brown color associated with deterioration of quality (Hood and Riordan, 1973). The oxidation of deoxymyoglobin is more rapid than the oxidation of oxymyoglobin (Gill, 1996), and oxidation of myoglobin at low O2 (~5 to 7%) is more rapid than at high concentrations of O (O’Keefe and Hood, 1982; Gill, 1996). The oxygenation of myoglobin is rapid and reversible, and the fraction of the pigment in the oxygenated form increases with increasing concentrations of O (Forrest et al., 1975). Ground meat color stability is achieved by slowing the reactions associated with pigment oxidation and by increasing the depth of the oxygenated surface layer. Apart from maintaining meat at low temperatures without freezing, there are 2 obvious means of preserving muscle tissue color. The atmosphere surrounding the meat can be modified (Rousset and Renerre, 1990) by exposing the meat to high concentrations of O to increase the fraction of oxidation resistant oxymyoglobin or O can be completely excluded to increase deoxymyoglobin levels.

Ledward (1992) stated that a typical modified atmosphere for storing ground red meat was 80% O2 and 20% CO2, in which the high O level serves to increase the depth of the oxymyoglobin layer at the meat surface, and the CO2 level slows microbial growth. Skandamis et al. (2002) reported that 100% CO2 extended fresh meat shelf life compared with air, vacuum, 40% CO2, and 80% CO2 mixtures of modified atmospheres. Similar high-O2 gas compositions have been utilized for ground turkey; however, Baker et al. (1985) reported that high-CO2 modified atmosphere packaging (MAP) improved ground chicken shelf life. Furthermore, Saucier et al. (2000) found that the hue of ground chicken and turkey remained more stable in gas atmospheres devoid of O2. Modification of the atmosphere within the package by reducing the O content and increasing the levels CO2, N2, or both has been shown to significantly extend the shelf life of perishable foods at chill temperatures by suppressing spoilage bacterial growth (Parry, 1993). Carbon dioxide atmospheres have been found to suppress the growth of Pseu-
Pseudomonas spp. has been detected in meat stored in a low-
O2 atmosphere containing CO2 but not in an O2-free atmos-
phere with or without CO2 (Molin, 1985b). This indicated
that although CO2 reduced the growth rate of P. spp, the
complete inhibition of these organisms can only be
achieved by a nearly complete removal of O (Newton
and Gill, 1978). Packaging chicken under CO2 reduced
growth of total aerobes, psychrotrophs, Enterobacteriaceae,
and P. spp (Sawaya et al., 1995).

The antimicrobial effect of a CO2-enriched atmosphere
requires continuous contact of CO2 with meat, as short
exposure to even high levels of CO2 is ineffective in pro-
viding a residual effect (Narasimha and Sachindra, 2002).
In one study, residual effect of CO2 on microbial growth
observed when chicken meat was stored in 80% CO2
whereas a CO2 concentration of 60% was not sufficient
to slow microbial growth compared with chicken stored
in ambient air (Baker et al., 1985). Bacteria grow faster in
minced meat compared with intact muscle due to the
enhanced substrate availability in minced meat (Blonsack
and Hope, 1990). Dissolution of CO2 into the aqueous
phase of the meat will likely enhance the inhibition of
bacterial growth in meat. Because meat is ground in air
and then packaged in a modified atmosphere, the depth
of the antimicrobial effect into the meat may be limited
by how far the gas penetrates into the meat. The objective
of this study was to determine how MAP of ground tur-
key affected the growth of bacteria at different depths
from the meat surface into the ground meat.

**MATERIALS AND METHODS**

**Meat and Packaging**

Whole fresh turkey breast meat was purchased from a
local retail market. Skin was removed, and meat was cut
into small pieces using a sterile knife. Cut meat pieces
were thoroughly mixed before grinding. The meat was
then ground (American Eagle Food Machinery Inc., Chi-
cago, IL) twice using 2 sieves, 1 with a 1.2-mm diameter,
followed by 1 with a 0.4-mm diameter. Patties were
prepared from 220 g of ground meat, packaged in expanded
polystyrene barrier trays, and sealed with barrier lid stock
(Sealed Air Corp., Duncan, SC). Container volume was
approximately 880 mL, and 220 g of meat was selected
to give approximately a 3:1, package headspace:meat vol-
ume ratio. Trays containing patties were packaged in high
CO2 (97%) or high O2 (80%) using a preformed tray pack-
aging machine (Robert Reiser & Co Inc., Canton, MA).
Gas tanks were premixed (National Welders Supply Co.
Inc., Greenville, SC) to target high CO2 (100% CO2) or high
O2 (80% O2, 20% CO2). Packaged meat was refrigerated at
4°C ± 1°C in a lighted refrigerator. Package gas headspace,
meat color, and total plate and lactic acid bacterial (LAB)
counts were determined 0, 3, 6, 9, and 12 d after
packaging.

**Package Headspace Gas Analysis**

A 500-µL sample of package gas headspace was drawn
by syringe through a silicone septum on the package
surface. Gas samples were analyzed by gas chromatogra-
phy using a thermal conductivity detector (series 580,
Gow-Mac Instrument Co., Bethlehem, PA) with a column
catalog number 8700, Alltech Associates Inc., Deerfield,
IL) at 30°C. The injector and conductivity detector were
100°C, and He was the carrier gas, with a flow rate of 60
mL/min. Percentage of CO2, O2, and N2 was calculated
from the response recorded on a strip recorder.

**Color Analysis**

Ground turkey patty surface color was measured using a
colorimeter (Minolta Chroma Meter Model CR-300, Mi-
olta Corp., Ramsey, NJ) having an 8-mm measuring orifice. The colorimeter was calibrated using a calibration
plate (Y = 92.80; x = 0.3134, y = 0.3197). Sample lightness
(L*), redness (a*), and yellowness (b*) values were deter-
mined using an International Commission on Illumination
illuminant incandescent light source. Lightness, a*,
and b* are color measurement units quantitating the meat
surface lightness-darkness, redness-greenness, and blue-
ness-yellowness, respectively. One patty was taken from
each modified atmosphere on d 0, 3, 6, 9, and 12 for color
analysis. All 4 sides of the packaging film were cut so
that the colorimeter orifice could be pressed smoothly
against the package film meat surface. Color measure-
ments were taken through the film, and film color properti-
ties were subtracted from the color readings. Three mea-
surements at different locations were taken from each
sample. Three measurements were averaged as the sam-
ples’ color coordinate value. Hue was calculated using
tan⁻¹ (b*/a*; Francis and Clydesdale, 1975) and chroma
value was calculated using a² + b² (Acton and Dawson,
1994).

**Microbiological Analysis**

Ground turkey breast meat patties were prepared to a
height of 3 cm using a petri dish having a depth of 5 cm
(dimensions of 50 × 100 mm). These patties were placed
in expanded polystyrene trays and subjected to MAP. For
patty depth analysis, each patty was divided into 3 layers:
top, middle, and bottom. The initial depth of 1 cm starting
from the surface of the patty in contact with the modified
atmosphere was designated the top layer, followed by
the next 1-cm depth as the middle layer, and the last 1-
cm depth of the patty, which was in contact with tray,
the bottom layer of the patty. For the top layer, 11 g of
meat taken from the surface of the patty was used for
analysis. For the middle layer, 11 g of meat was taken at
a depth of 1 cm from the surface of the patty using a
sterile spatula. For this layer, 1 cm was left from the outer
rim of the patty in a circumference to avoid any effect of
the modified atmosphere from the patty sides when tak-
ing the middle layer. For the bottom layer, meat was
flipped over a sterile Al foil sheet, and 11 g of sample was taken using a sterile spatula. These depths were chosen after preliminary studies to account for the entire meat patty. The middle and bottom layers did not include the outer 1-cm edge of the patty, so none of these layers were directly exposed to the gas during storage. Meat layers were measured and removed using a sterile stainless steel ruler and spatula, respectively. On 3, 6, 9, and 12 d, 3 layers from 1 patty from each atmosphere were taken for microbiological analysis.

Eleven grams obtained from the different layers were each diluted with 99 mL of 0.1% wt/vol sterile peptone solution (Bacto peptone, Difco Laboratories, Detroit, MI) for a 1:10 dilution. Contents were then homogenized in a stomacher (Seward Ltd., London, UK) for 2 min at 230 rpm. Cell numbers were determined using the pour plate method (Speck, 1984). Total aerobic plate count was determined using plate count agar (Difco Laboratories), and lactobacilli counts were determined using de Man, Rogosa, and Sharpe medium (Difco Laboratories). Total aerobic plates were incubated at 37°C for 48 h before counting. Lactobacilli plates were placed in a CO2 incubator (model 2300, VWR Scientific Products, West Chester, PA) with 5% CO2 injected (35 psi) at 37°C for 48 h. All platings were performed in duplicate. Plated dilutions with 25 to 250 colonies were counted, and then numbers were converted to log10 cfu/g of meat.

### Statistical Analysis

The experimental design was a $3 \times 2 \times 5$ randomized complete block design (3 levels of depth, 2 levels of modified atmosphere, and 5 levels of storage time). A GLM was used to determine the ANOVA. When the treatment effect was significant ($P \leq 0.05$), the means were separated using the LSMEANS, PDFF, and STDERR statement using SAS Release 8.0 (SAS Institute, 1999). The experiment was replicated using 3 separate batches of meat. The replications were used as the blocking factor.

### RESULTS AND DISCUSSION

#### Package Headspace Gas

For the high-O2 treatment (Table 1), headspace O concentration was relatively high from d 0 to 6, with a decrease by d 12. The decrease in headspace O for the high-O treatment may be due to growth of microorganisms that consumed O2 and produced CO2 (Butler et al., 1953). The decrease in O concentration was accompanied by an increase in total aerobic bacterial count that may have included pseudomonads. Nychas and Arkoudelos (1990) also reported that the composition of the gas phase changed during storage, with a decrease in O concentration and a subsequent increase in the number of pseudomonads and the concentration of gluconate (a product of aerobic metabolism). Some of the reduction in O concentration may be attributed to meat tissue respiration (Lawrie, 1998).

In the high-CO2 treatment, CO2 decreased by the d 6 from initial levels. Decrease in headspace CO2 can be attributed to CO2 solubilization in meat and gas production by bacteria. Decrease in headspace CO2 during the storage of MAP meat [d 0 (96%) to d 12 (90%)] was previously attributed to CO2 dissolving in the meat tissue (Baker et al., 1985; McMullen and Stiles, 1991; Gill, 1996). Gill (1988) stated that CO2 is highly soluble in both water and oil, thus it can readily absorb into muscle and fat tissue during storage. Because N2 is an inert gas, the change in N2 in the high-CO2 treatment was likely only a reflection of the changes in CO2 concentration.

#### Color

The gas MAP treatment by storage time interaction for L* value was significant ($P \leq 0.05$). A lower L* value and a higher a* value reflected a good meat color stability in

### Table 2. CIE lightness (L*) and redness (a*) values for ground turkey meat packaged in high CO2 or high O2 under refrigeration (4°C ± 1°C) for 12 d

<table>
<thead>
<tr>
<th>Days</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIE color value</td>
<td>L*</td>
<td>a*</td>
<td>L*</td>
<td>a*</td>
<td>L*</td>
</tr>
<tr>
<td>Gas treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High CO2</td>
<td>56.80a</td>
<td>6.15a</td>
<td>55.64a</td>
<td>4.94c</td>
<td>55.59c</td>
</tr>
<tr>
<td>High O2</td>
<td>56.80b</td>
<td>6.15c</td>
<td>53.42b</td>
<td>4.62c</td>
<td>54.29b</td>
</tr>
</tbody>
</table>

*Means for all a* values with different superscripts significantly differ ($P \leq 0.05$).

**Means for all L* values with different superscripts significantly differ ($P \leq 0.05$).

1Number of observations = 45.
Boulianne and King (1995) suggested that $L^*$ value could be used with high sensitivity and high specificity to distinguish pale, soft, exudative meat from normal meat. Thus, $L^*$ value can distinguish differences in $L^*$ for intact meat pieces. Ground turkey meat is lighter and, therefore, may show higher $L^*$ as compared with ground beef due to lower pigment concentration (Saucier et al., 2000).

The meat packaged in high CO$_2$ maintained higher $a^*$ values (Table 1) and redder color (Figure 1) from 6 to 12 d compared with meat packaged in high O$_2$. There was no difference ($P > 0.05$) between $a^*$ values of the patties packaged under a high-CO$_2$ atmosphere and patties packaged under a high-O$_2$ atmosphere until d 6 of storage.

This could be due to the limited ability of the poultry meat to bloom (form oxymyoglobin) as compared with beef and pork. Millar et al. (1994) observed little evidence of oxymyoglobin formation when chicken meat was kept at 5°C for 48 h, and no oxymyoglobin was found in chicken meat stored at 23°C. The lack of oxymyoglobin formation in poultry is supported by Millar et al. (1994), who observed that chicken and turkey retail samples appeared to be either purple or purple-brown in color. This is attributed to high metmyoglobin-reducing activity and the high O consumption rate of poultry meat. Mercier et al. (1998) reported that ground poultry meat stored in a gas mixture without O (20% CO$_2$, 80% N$_2$) increased in $a^*$ value, indicating the gas mixture maintained myoglobin.
Millar et al. (1994) also demonstrated that, after 24 h of storage, high CO2 or high O2 under refrigeration (4°C) for 12 d encouraged the formation of metmyoglobin at the surface. The O consumption rate associated with these muscles dropped to 62% CO2, 8% O2, 30% N2 as compared with packaging in air. Millar et al. (1994) reported that chicken breast muscles had little capacity to retain O (20% CO2, 80% N2) whereas only slightly increase the microbiological shelf life compared with packaging in air. High concentrations of O2 and 20% CO2 will slow color deterioration but will probably through metmyoglobin-reducing activity. The decrease in a* value of meat packaged in the high-O2 atmosphere in this study reflects myoglobin oxidation.

**Hue Angle**

Hue angles of patties kept under a high-O2 atmosphere increased by d 6 of storage. Increase in hue angle (Figure 2) indicates a shift in color from red to yellow, which may indicate increased pigment oxidation and the formation of metmyoglobin. Discoloration of meat stored in high O2 by d 6 of storage may be attributed to the high O consumption rate of the meat. Millar et al. (1994) reported that chicken breast muscles had little capacity to form oxymyoglobin when exposed to air, and the high O consumption rate associated with these muscles encouraged the formation of metmyoglobin at the surface. Millar et al. (1994) also demonstrated that, after 24 h at 5°C, chicken muscle tissue oxidized to produce some metmyoglobin at the surface. The relative differences in total myoglobin content between meat from different species and muscle will affect the appearance and intensity of color due to changes in myoglobin state. Sauzier et al. (2000) found an increase in hue angle for ground chicken and turkey meat during storage in an atmosphere containing O (62% CO2, 8% O2, 30% N2) as compared with an atmosphere without O2 (20% CO2, 80% N2), whereas hue values for ground chicken and turkey meat remained relatively stable in an atmosphere devoid of O. Gill (1996) stated that retail cuts of pork and beef containing 80% O2 and 20% CO2 will slow color deterioration but will only slightly increase the microbiological shelf life compared with packaging in air.

**Microbiology**

Because of the homogenous nature of the sample, all samples initially started with the same microbial load on d 0 of storage. High concentrations of O are lethal to living cells, causing inactivation of certain enzymes, an increase in intracellular concentration of H2O2, oxidation of membrane lipids, and production of superoxide in the cell (Zeitoun and Debevere, 1993). High concentrations of CO2 are bacteriocidal, decreasing intracellular pH, inhibiting enzymatically catalyzed reactions and enzyme synthesis, and interacting with the cell membrane. High CO2 MAP has previously been shown to improve the shelf life of chicken carcasses (Sawaya et al., 1995) and ground chicken (Baker et al., 1985). Patties packaged in a high-O2 atmosphere showed higher total aerobic bacterial counts (5.6 log10 cfu/g) compared with patties packaged in high CO2 (4.3 log10 cfu/g).

**Total Aerobic Plate Count.** There was a slower bacterial growth rate in patties packaged under a high-CO2 atmosphere compared with a high-O2 atmosphere throughout storage (P < 0.05). The average total aerobic plate count throughout storage for the high-O2 and high-CO2 packaged meat was 5.69 and 4.37 cfu/g, respectively. Furthermore, the bacterial population of CO2-packaged meat in the top layer (3.93 cfu/g) was lower than the middle (4.61 cfu/g) and bottom (4.56 cfu/g) layers. The top layer of meat packaged in high O2 had a higher (P < 0.05) bacterial population (5.58 cfu/g) than the top layer of meat packaged in high CO2 (3.93 cfu/g). This has been attributed to the effect of CO2 in the package headspace, creating anaerobic conditions and reducing meat pH. Carbon dioxide retards the growth of the fast-growing pseudomonads that usually cause the spoilage of meat under aerobic conditions (Wolfe, 1980; Zeitoun and Debevere, 1993; Devlieghere and Debevere, 2000; Luno et al., 2000; Narasimha and Sachindra, 2002). Gram-negative bacteria would also be more susceptible to inhibition by CO2 than the gram-positive bacteria (Sutherland et al., 1997). These results are supported by Eriksen and Molin (1981), who found lower total aerobic bacterial counts for beef in 100% CO2 compared with beef stored in air, a vacuum, or a gas mixture of 78% N2, 20% CO2, and 2% O2 when held at 4°C. Packaging chicken under CO2 compared with air slowed growth of total aerobes, psychrotrophs, and Enterobacteriaceae (Gill, 1996). Carbon dioxide is believed to inhibit the metabolism of Pseudomonas aeruginosa by decreasing isocitrate dehydrogenase and malate dehydrogenase activity (Hammes et al., 1983).

Patties packaged in a high-CO2 atmosphere had lower (P ≤ 0.05) total aerobic bacterial counts in the top layer compared with the middle and bottom layers (Figure 3). There was no difference (P > 0.05) in total aerobic bacterial counts between the middle and bottom layers of patties. The reduced bacterial growth in the top layer was probably due to dissolving of CO2 into part of the first 1-cm depth of the patty, which was in constant contact with high-CO2 gas in the package headspace. There was a noticeable collapse of the package observed by d 3 of storage, which may be due to CO2 dissolving in the water and fat phases of the meat (Devlieghere et al., 1998). Devlieghere et al. (1998) demonstrated that concentration of dissolved CO2 determines the growth inhibition of microorganisms in a modified atmosphere. There was no difference in total aerobic bacterial counts among the 3 layers for patties packaged in a high-O2 atmosphere.
Figure 3. Total plate count for 1-cm meat layers [top (t), middle (m), bottom (b)] for ground turkey meat patties packaged in high CO2 or high O2 under refrigeration (4°C) for 12 d. Slopes for the linear regression over 12 d of aerobic bacteria populations with different superscripts are significantly different (P ≤ 0.05); number of observations = 6.

atmosphere after 12 d of storage (Figure 3). This result is supported by Borch et al. (1996), who stated that packages containing up to 80% O2 and 20% CO2 will reduce the color deterioration of retail cuts of meat but will only slightly increase the shelf life compared with aerobic storage. Ordonez et al. (1991) and Jackson et al. (1992) showed that Brochothrix thermosphacta, P. spp., Leuconostoc spp., and Lactobacillus spp. are able to grow to high numbers in a high-O2 modified atmosphere.

It has been proposed that CO2 penetrates the bacterial cell membrane, causing intracellular pH changes of a greater magnitude than that would be found in similar external acidification, which can be effectively buffered by the organism (Aickin and Thomas, 1975). Zeitoun and Debevere (1993) stated that CO2 could cause inhibition of cytoplasmic enzymes by affecting the rate at which particular reactions proceeded. Although the mechanisms of inhibition by CO2 are sometimes debated, Young et al. (1998) demonstrated that the result is an increase in the lag phase and generation time, which slows the increase in bacterial populations.

**Lactic Acid Bacteria**

Lactic acid bacterial counts in ground turkey meat were lower (P ≤ 0.05) in a high-CO2 atmosphere (2.06 log10 cfu/g) compared with a high-O2 atmosphere (2.77 log10 cfu/g) after 12 d of storage (Figure 4). For the meat stored in high CO2, LAB populations did not increase during the 12-d storage period. Samelis and Georgiadou (2000) found that 100% CO2 slightly retarded LAB growth at 4 and 10°C, and this may explain the lower LAB counts compared with total aerobic bacterial counts observed at high CO2 concentrations. The lack of increase in LAB populations during storage in high CO2 may also be partially because LAB form a diverse group of organisms (homofermentative and heterofermentative) and are difficult to enumerate with 1 growth medium. Pseudomonads may have outgrown the LAB due to their ability to grow in a wide range of CO2 levels. Baker et al. (1985) found that, after 7 d of storage, P. spp. was the predominant bacteria detected in ground chicken, regardless of the concentration of CO2 in the atmosphere. After 14 d of storage, P. spp. represented 50% of the genera in all CO2-treated samples. Pseudomonas spp. are able to grow under near-anaerobic conditions, as shown by Saucier et al. (2000). Furthermore, Saucier et al. (2000) found that the bacterial populations obtained on all-purpose tween agar were significantly higher than those obtained on de Man, Rogosa, and Sharpe medium (standard medium used for LAB) in or from samples stored in an atmosphere containing 62% CO2, 8% O2, and balanced with N2. For meat packaged in a high-O2 gas environment, the LAB growth was biphasic in that from d 0 to 6 there was no increase in their populations; from d 6 through 12, there was a significant increase in the slope of the growth curves.

There was no difference (P ≥ 0.05) in LAB populations from the 3 layers for the patties subjected to a high-O2 or a high-CO2 atmosphere until d 6 of storage, after which an increase in counts was observed for patties stored in a high-CO2 atmosphere (Figure 4). Ordonez et al. (1991), Jackson et al. (1992), and Pin et al. (2002) showed that B. thermosphacta, P. spp., Leuconostoc spp., and L. spp. are able to grow to high numbers in a high-O2 modified atmosphere. Blickstad et al. (1981) and Greer et al. (1993) stated that the shelf life is extended by using a high-CO2 atmosphere, because some LAB grow more slowly under these conditions. Depending upon the pH and storage temperature, other bacteria, such as Aeromonas spp., B. thermosphacta, and Enterobacteriaceae, may grow (Blickstad and Molin, 1983; McMullen and Stiles, 1993).

A high-CO2 atmosphere helped maintain the color of ground turkey meat, as indicated by higher a* values, constant hue angles, and lower L* values throughout refrigerated storage compared with meat packaged in high

Figure 4. Lactic acid bacterial (LAB) plate count for 1-cm meat layers [top (t), middle (m), bottom (b)] for ground turkey meat patties packaged in high CO2 or high O2 under refrigeration (4°C) for 12 d. Slopes for the linear regression from d 6 through 12 of LAB populations with different superscripts are significantly different (P ≤ 0.05); number of observations = 6.
CO₂ dissolution occurred. Lower total aerobic bacterial and LAB counts in ground and inhibited the growth of microorganisms, resulting in compared with a high-O₂ atmosphere. A layer effect was observed in patties packaged under high CO₂ atmosphere, both maintaining meat color and the bottom layers. There was no layer effect observed in the patty packaged under a high-O₂ atmosphere. Thus, the high CO₂ atmosphere both maintained meat color and inhibited the growth of microorganisms, resulting in lower total aerobic bacterial and LAB counts in ground turkey. The suppression of bacterial growth was greatest in the top surface layer of the patty, where maximum CO₂ dissolution occurred.

**REFERENCES**


