ABSTRACT

Beef, pork and lamb loins were vacuum-packaged as subprimal cuts (controls), reformed subprimal cuts and as retail cuts (steaks or chops). Subprimal cuts, reformed subprimal cuts and one group of retail cuts remained vacuum-packaged. Other groups of retail cuts were injected with atmospheres of either 20% CO$_2$ + 80% N$_2$ or 40% CO$_2$ + 60% N$_2$. Cuts were randomly assigned to storage periods of 0-21 days at 2 ± 1 C. At weekly intervals, steaks or chops were removed from each treatment and examined after storage for 5 days under retail display conditions. Psychrotrophic bacterial counts and lactobacilli counts of steaks and chops stored in CO$_2$-N$_2$ atmospheres usually were lower, though not often statistically significant, than those of comparable vacuum-packaged steaks, chops or loins. Psychrotrophic counts of steaks and pork chops, initially held in CO$_2$-N$_2$ atmospheres and then subjected to retail display, usually were lower than those of comparable steaks and chops that had been vacuum-packaged (without added CO$_2$-N$_2$) or prepared from vacuum-packaged loins.

Our current meat packaging research (3,4,17,18) is focused on reducing quality loss of product and extending shelf life by (a) capitalizing on the economic advantages of centralized breaking and prefabrication, (b) further characterizing the advantages of vacuum packaging and (c) exploring the potential use of new gas atmospheres in meat packaging. The effect of air on microbiological and chemical changes in meat has been investigated extensively. Under normal refrigerated storage, exposure of meat surfaces to air enables aerobic spoilage bacteria to increase and affect color and shelf life. Common aerobic spoilage bacteria such as Pseudomonas spp. frequently are responsible for quality losses because of their active proteolytic and lipolytic enzyme systems. Reducing the amount of O$_2$ inside a package can be accomplished by (a) vacuum packaging or (b) replacing the atmosphere with one that does not contain oxygen (i.e., use of a modified gas atmosphere). The effectiveness of both methods in controlling growth of common aerobic bacteria, and thereby extending shelf life of the product has been demonstrated (2,7,10,15,20). In recent studies (3,4,17,18), a comparison was made of the retail quality of vacuum-packaged meat and of meat packaged in modified gas atmospheres. One of the most effective gas atmospheres for maintaining meat quality in those studies was a mixture of 20% CO$_2$ and 80% N$_2$. Included in current research is an examination of packaging systems for protecting reformed subprimal cuts prepared at a centralized location for distribution to retail outlets. This paper compares (a) the microbial conditions of vacuum-packaged reformed subprimal cuts, vacuum-packaged retail cuts and modified atmosphere-packaged retail cuts of beef, pork and lamb with that of vacuum-packaged subprimal cuts and (b) the effect of these different packaging techniques on the microbial quality of retail steaks and chops during subsequent retail storage.

MATERIALS AND METHODS

The sources of the beef, pork and lamb loins and preparation of these meats as subprimal cuts, reformed subprimal cuts or as steaks or chops are described by Seideman et al. (19) in a companion paper. Sub primal cuts were packaged at the maximum capacity of the machine (747 mm Hg). Reformed subprimal cuts were prepared by cutting loins into retail cuts (2.5-cm thick), reforming them, followed by vacuum packaging. Retail steaks and chops (2.5-cm thick) were randomly assigned storage treatments for periods of 0, 7, 14 or 21 days at 2 ± 1 C. These cuts were placed on styrofoam trays and overwrapped with oxygen-permeable polyvinyl chloride film (19). Groups of 3 retail steaks or chops were packaged for retail display and placed in 3-shelf cardboard containers which were then vacuum-packaged. Retail cuts in cardboard containers were assigned, at random, to each of three treatments: (a) one group remained under vacuum, (b) one group was injected with 1,700 cm$^3$ of a 20% CO$_2$ + 80% N$_2$ gas mixture, and (c) one group was injected with 1,700 cm$^3$ of a 40% CO$_2$ + 60% N$_2$ gas mixture. In each of the storage periods, there were 3 steaks or chops per treatment for a total of 12 per atmospheric treatment. All subprimal, reformed subprimal and retail cuts were packaged in polyethylene nylon-surfyn film with the following characteristics: Oxygen Transmission Rate = 69 cc/m$^2$/24 h; Carbon Dioxide Transmission Rate = 206 cc/m$^2$/24 h. Initially and at the end of each storage interval, comparable packages from each treatment were opened and subjected to microbiological examination. Three steaks or chops from each treatment (Table 1) were examined by swabbing at 12.9 cm$^2$ (2 in.$^2$) area of muscle surface with a dacron swab moistened in 0.1% sterile peptone broth. Psychrotrophic plate counts were made by both the pour- and spread-plate techniques on Plate Count Agar (Difco). Plates were incubated for 10 days at 7 C. A lactobacillus count was made by the pour-plate technique with Lactobacillus MRS broth (Difco) with 1.5% agar added. Plate incubation was at 25 C for 4 days.

In addition, steaks or chops from each of the five treatments were stored for 5 days under simulated retail display conditions (0-3 C, 970 lux of incandescent light). Vacuum-packaged steaks and chops were removed from storage containers and displayed without rewarming. Steaks or chops from vacuum-packaged subprimal cuts were cut and reformed subprimal cuts were removed from the original package and wrapped with polyvinyl chloride film before retail display. Microbiological analysis of these steaks and chops was as described above.

Analysis of variance comparing data for vacuum-packaged subprimal cuts or data for retail cuts from subprimal cuts stored in...

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Table 1: Number of samples examined bacteriologically arranged according to packaging treatment and length of storage.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Packaging treatment</th>
<th>Vacuum packaged</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Retail cuts</th>
<th>20% CO₂</th>
<th>80% N₂</th>
<th>40% CO₂</th>
<th>60% N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)Initial counts were obtained on three subprimal cuts and were common to all treatments.

Table 2: Mean values for psychrotrophic bacterial counts\(^{a}\) of beef after storage stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Packaging treatment</th>
<th>Vacuum packaged</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Retail cuts</th>
<th>20% CO₂</th>
<th>80% N₂</th>
<th>40% CO₂</th>
<th>60% N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>2.79d</td>
<td>2.79g</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>2.98d</td>
<td>3.37e</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>3.96d</td>
<td>3.92d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.02e</td>
<td>4.69c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)Counts (\(\log_{10}\)) per 6.45 cm\(^2\) (1 in.\(^2\)) (spread-plate method).

\(^{b}\)Counts within a common storage interval that are underlined are significantly different \((P < .05)\) from counts obtained from vacuum packaged subprimal cuts.

\(^{c}\)Counts in the same column bearing a common superscript letter do not differ \((P > .05)\).

Table 3: Mean values for lactobacilli counts\(^{a}\) of beef after storage stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Packaging treatment</th>
<th>Vacuum packaged</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Retail cuts</th>
<th>20% CO₂</th>
<th>80% N₂</th>
<th>40% CO₂</th>
<th>60% N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1.70d</td>
<td>1.70e</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>1.54d</td>
<td>1.45c</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>3.76e</td>
<td>2.50e</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.11b</td>
<td>4.72b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)Counts (\(\log_{10}\)) per 6.45 cm\(^2\) (1 in.\(^2\)).

\(^{b}\)Counts in the same column bearing a common superscript letter do not differ \((P > .05)\).
vacuum-packaged subprimal cuts. In three of five instances where counts were lower, the differences in count were statistically significant. Counts of steaks derived from retail cuts initially stored for 21 days (with or without CO$_2$-N$_2$) were significantly lower than those of steaks derived from vacuum-packaged subprimal cuts. After retail display, counts of steaks derived from reformed subprimal cuts were significantly lower than those from vacuum-packaged subprimal cuts in two of three comparisons. Increases in count during retail display of steaks initially stored in CO$_2$-N$_2$ for 7 or 14 days were smaller than those for cuts initially stored in vacuum packages (Tables 2 and 4). However, increases in count during retail display of steaks initially stored for 21 days in vacuum packages were somewhat lower than those of steaks derived from comparable packages with CO$_2$-N$_2$.

Psychrotrophic counts of various pork cuts after storage for 0 to 21 days are presented in Table 5. Storage of chops for 7 days in CO$_2$-N$_2$ caused slight numerical decreases in count. Counts of chops stored for 7, 14 and 21 days in CO$_2$-N$_2$ atmospheres were consistently numerically lower than those of comparable vacuum-packaged chops and usually significantly lower than those of comparable vacuum-packaged subprimal cuts. After storage for 7 or 14 days, counts of reformed subprimal cuts were lower than those of corresponding pork loins; these differences were statistically significant at 14 days. Largest increases in count occurred either between 7 to 14 days of storage (vacuum-packaged loins, vacuum-packaged chops) or between 14 to 21 days (reformed pork loins, chops packaged in CO$_2$-N$_2$). Data obtained with pour plate counts gave essentially the same information.

After 7, 14 and 21 days of storage, lactobacillus counts of reformed pork loins and those of chops (vacuum-packaged or in CO$_2$-N$_2$) usually were lower than those of corresponding vacuum-packaged pork loins (Table 6). At 14 days of storage, these differences in count were statistically significant. At 21 days, the differences in lactobacillus count of vacuum-packaged subprimal cuts and retail cuts held in 40% CO$_2$ + 60% N$_2$ were statistically significant. Largest increases in lactobacillus counts for the pork loins and reformed pork loins

### TABLE 4. Mean values for psychrotrophic bacterial counts$^a$ of beef steaks after 5 days of retail display.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Vacuum packaged</th>
<th>20% CO$_2$</th>
<th>80% N$_2$</th>
<th>40% CO$_2$</th>
<th>60% N$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>4.63$^d$</td>
<td>4.18$^e$</td>
<td>5.20$^d$</td>
<td>3.19$^d$</td>
<td>2.23$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>5.92$^d$</td>
<td>5.50$^d$</td>
<td>8.49$^c$</td>
<td>6.77$^e$</td>
<td>5.50$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>8.14$^e$</td>
<td>7.23$^c$</td>
<td>7.45$^e$</td>
<td>7.91$^c$</td>
<td></td>
<td></td>
<td>6.35$^e$</td>
</tr>
</tbody>
</table>

$^a$Counts (log$_{10}$) per 6.45 cm$^2$ (1 in.$^2$) (spread-plate method).
$^b$Counts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from steaks from vacuum packaged subprimal cuts.
$^c$Counts in the same column bearing a common superscript letter do not differ (P > .05).

### TABLE 5. Mean values for psychrotrophic bacterial counts$^a$ of pork stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Vacuum packaged</th>
<th>20% CO$_2$</th>
<th>80% N$_2$</th>
<th>40% CO$_2$</th>
<th>60% N$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>2.64$^e$</td>
<td>2.64$^e$</td>
<td>2.64$^e$</td>
<td>2.64$^e$</td>
<td>2.64$^e$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3.65$^e$</td>
<td>2.84$^e$</td>
<td>2.93$^e$</td>
<td>2.43$^e$</td>
<td>2.30$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>5.66$^d$</td>
<td>5.15$^d$</td>
<td>6.09$^d$</td>
<td>3.48$^d$</td>
<td>3.39$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>7.01$^c$</td>
<td>7.88$^c$</td>
<td>7.33$^e$</td>
<td>5.72$^c$</td>
<td>5.06$^c$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Counts (log$_{10}$) per 6.45 cm$^2$ (1 in.$^2$) (spread-plate method).
$^b$Counts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from vacuum packaged subprimal cuts.
$^c$Counts in the same column bearing a common superscript letter do not differ (P > .05).

### TABLE 6. Mean values for lactobacilli counts$^a$ of pork stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Subprimal cuts</th>
<th>Reformed subprimal cuts</th>
<th>Vacuum packaged</th>
<th>20% CO$_2$</th>
<th>80% N$_2$</th>
<th>40% CO$_2$</th>
<th>60% N$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>2.49$^d$</td>
<td>2.49$^d$</td>
<td>2.49$^d$</td>
<td>2.49$^d$</td>
<td>2.49$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.53$^d$</td>
<td>2.33$^d$</td>
<td>2.96$^d$</td>
<td>2.43$^d$</td>
<td>2.50$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>5.13$^c$</td>
<td>4.14$^c$</td>
<td>3.98$^c$</td>
<td>1.69$^e$</td>
<td>3.03$^d$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>5.79$^c$</td>
<td>5.61$^c$</td>
<td>5.32$^c$</td>
<td>5.31$^c$</td>
<td>4.58$^c$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Counts (log$_{10}$) per 6.45 cm$^2$ (1 in.$^2$).
$^b$Counts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from vacuum packaged subprimal cuts.
$^c$Counts in the same column bearing a common superscript letter do not differ (P > .05).

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occurred between 7 and 14 days, for the retail chops between 14 and 21 days of storage.

Psychrotrophic counts of pork chops after retail display are presented in Table 7. Pork chops originally stored for 7 days in 20% CO₂ + 80% N₂ and for 7 to 21 days in 40% CO₂ + 60% N₂ had significantly lower counts than did chops prepared from vacuum-packaged pork loins. Counts of chops initially stored in CO₂-N₂ were, after display, numerically lower than those of chops which had been stored in vacuum packages.

After 7 days of storage, psychrotrophic counts of retail lamb chops stored in CO₂-N₂ had decreased slightly, although the differences in count were not statistically significant (Table 8). Psychrotrophic counts of lamb chops stored for 7, 14 or 21 days either vacuum-packaged or in CO₂-N₂ atmospheres frequently were significantly lower than those of corresponding vacuum-packaged lamb loins. Counts of lamb chops stored in CO₂-N₂ were consistently numerically lower than those of chops that were vacuum-packaged only. Largest increases in count occurred either between 14 and 21 days (vacuum-packaged lamb loins, chops packaged in 40% CO₂ plus 60% N₂) or between 7 and 14 days (reformed lamb loins, vacuum-packaged chops and chops stored in 20% CO₂ plus 80% N₂).

Large increases in lactobacillus counts occurred only between 14 and 21 days of storage (Table 9). In most instances, differences in lactobacillus counts of vacuum-packaged subprimal cuts and reformed subprimal and retail cuts were not statistically significant, except that at 14 days counts of retail chops were significantly higher than those of comparable vacuum-packaged loins. Counts of chops stored in CO₂-N₂ for 7 and 14 days were numerically slightly lower than those of corresponding vacuum-packaged chops.

Psychrotrophic counts of lamb chops initially stored for 21 days in CO₂-N₂ were, after retail display, numerically lower than those of chops prepared from corresponding vacuum-packaged loins, reformed loins, or from vacuum packaged chops (Table 10). After 7 days counts of chops derived from the five packaging treatments were very similar.

**DISCUSSION**

Although differences in counts reported here often were not statistically significant and some exceptions are

### TABLE 7. Mean values for psychrotrophic bacterial counts of pork chops after 5 days of retail display.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Vacuum packaged</th>
<th>Reformed subprimal cuts</th>
<th>Packaging treatment</th>
<th>Retail cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vacuum</td>
<td>Retail cuts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>packaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20% CO₂, 80% N₂</td>
<td>40% CO₂, 80% N₂</td>
</tr>
<tr>
<td>7</td>
<td>4.55e</td>
<td>4.73e</td>
<td>6.03e</td>
<td>4.75e</td>
</tr>
<tr>
<td>14</td>
<td>7.25d</td>
<td>7.27d</td>
<td>7.53d</td>
<td>7.29d</td>
</tr>
<tr>
<td>21</td>
<td>8.15e</td>
<td>8.82e</td>
<td>9.12e</td>
<td>8.56e</td>
</tr>
</tbody>
</table>

aCounts (log₁₀) per 6.45 cm² (1 in.²) (spread-plate method).
bCounts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from chops from vacuum packaged subprimal cuts.
cCounts in the same column bearing a common superscript letter do not differ (P > .05).

### TABLE 8. Mean values for psychrotrophic bacterial counts of lamb after storage stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Vacuum packaged</th>
<th>Reformed subprimal cuts</th>
<th>Packaging treatment</th>
<th>Retail cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vacuum</td>
<td>Retail cuts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>packaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20% CO₂, 80% N₂</td>
<td>40% CO₂, 80% N₂</td>
</tr>
<tr>
<td>Initial</td>
<td>2.97e</td>
<td>2.97e</td>
<td>2.97e</td>
<td>2.97d</td>
</tr>
<tr>
<td>7</td>
<td>3.51e</td>
<td>3.55d</td>
<td>2.96e</td>
<td>2.54e</td>
</tr>
<tr>
<td>14</td>
<td>5.38d</td>
<td>5.91d</td>
<td>6.11d</td>
<td>4.86d</td>
</tr>
<tr>
<td>21</td>
<td>7.75e</td>
<td>7.75e</td>
<td>7.28e</td>
<td>6.65e</td>
</tr>
</tbody>
</table>

aCounts (log₁₀) per 6.45 cm² (1 in.²) (spread-plate method).
bCounts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from vacuum packaged subprimal cuts.
cCounts in the same column bearing a common superscript letter do not differ (P > .05).

### TABLE 9. Mean values for lactobacilli counts of lamb stratified according to packaging treatment and storage interval.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Vacuum packaged</th>
<th>Reformed subprimal cuts</th>
<th>Packaging treatment</th>
<th>Retail cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vacuum</td>
<td>Retail cuts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>packaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20% CO₂, 80% N₂</td>
<td>40% CO₂, 80% N₂</td>
</tr>
<tr>
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<td>2.05d</td>
<td>2.05f</td>
<td>2.05e</td>
</tr>
<tr>
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<td>2.64d</td>
<td>2.03d</td>
<td>2.71e</td>
<td>2.48e</td>
</tr>
<tr>
<td>14</td>
<td>2.54de</td>
<td>2.58d</td>
<td>3.58d</td>
<td>3.12d</td>
</tr>
<tr>
<td>21</td>
<td>5.86e</td>
<td>6.03e</td>
<td>5.75e</td>
<td>5.96e</td>
</tr>
</tbody>
</table>

aCounts (log₁₀) per 6.45 cm² (1 in.²).
bCounts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from vacuum packaged subprimal cuts.
cCounts in the same column bearing a common superscript letter do not differ (P > .05).
noted, some general observations can be made regarding
the psychrotrophic bacterial counts of the various beef,
pork and lamb cuts: (a) counts of steaks and chops stored
in CO₂-N₂ decreased slightly during the first week of
storage, this was also true for vacuum-packaged steaks,
(b) counts of steaks and chops stored in CO₂-N₂ were
consistently lower than those of comparable vacuum
packaged steaks and chops, (c) compared with the counts
of vacuum-packaged loins, counts of steaks and chops
stored in CO₂-N₂ were nearly always lower; in 13 of 18
comparisons the differences were statistically significant
and (d) counts of vacuum-packaged reformed loins often
were numerically lower than those of comparable
vacuum-packaged loins.

With respect to lactobacillus counts of the various
cuts: (a) counts of vacuum-packaged steaks decreased
slightly during the first week of storage, those of pork
and lamb increased slightly, (b) counts of steaks and
chops stored in CO₂-N₂ were in most instances lower than
those of comparable vacuum-packaged steaks or chops,
(c) compared with the counts of vacuum-packaged loins,
counts of steaks or chops stored in CO₂-N₂ were usually
lower, the same was true for vacuum-packaged steaks
and pork chops but not for lamb chops and (d) counts of
vacuum-packaged reformed loins were usually lower than
those of comparable vacuum-packaged loins.

With respect to the psychrotrophic bacterial counts of
steaks and chops held under simulated caselife
conditions: (a) counts of vacuum-packaged steaks stored
initially in CO₂-N₂ usually were lower than those of
vacuum-packaged steaks or chops or those prepared
from vacuum-packaged loins, for lamb chops this was
true only for chops which initially had been held for 21
days in CO₂-N₂, and (b) increases in count of steaks
during display were smaller for steaks initially stored in
CO₂-N₂ for 7 or 14 days than for those which were
vacuum-packaged; for those initially stored for 21 days
in CO₂-N₂, increases in count during display were
somewhat greater than for those which were vacuum
packaged.

Differences in psychrotrophic bacterial counts be-
 tween steaks and chops stored in CO₂-N₂ and those of
vacuum-packaged steaks, chops and loins are most likely
cased by the immediate effect of CO₂ on growth of
common gram-negative aerobic bacteria. The inhibitory
effect of CO₂ on the aerobic microflora of beef, pork
and lamb is clearly demonstrated in reports by Huffman et
al. (8), Bala et al. (1), Newton et al. (14) and Silliker et
al. (22). This effect is probably the result of action on
decarboxylating enzymes, especially isocitric and malate
dehydrogenases (11, 12). Although somewhat speculative
at the present time, the effect of CO₂ on cell membrane
fluidity and hence on its functional properties such as
permeability and transport should be considered (5, 6).

The role of N₂ in the effect of CO₂-N₂ mixtures on
psychrotrophic counts of meat is less clear. Huffman et
al. (8) reported that microbial counts of steaks held in N₂
were similar to those of cuts held in air. However,
according to Newton et al. (14), counts of lamb chops
stored in oxygen-free N₂ were much lower than those of
chops stored in air, O₂ + N₂ (80:20) or in air + CO₂
(80:20). Differences in experimental procedures between
these studies related to animal species, method of
sampling, agar media, plate incubation conditions,
purity of gases) made comparison of data difficult.

The decreases in psychrotrophic counts during the
first week of storage of steaks and chops stored in
CO₂-N₂ reflect the effect of CO₂ on the aerobic
microflora. When CO₂ is introduced into the package,
inhibition can be expected sooner and probably to a
greater extent than in comparable vacuum-packaged
cuts. Some residual oxygen is still present in the
vacuum-packaged steaks, chops and loins and CO₂ will
develop gradually because of microbial and muscle tissue
enzyme activities. This agrees with the finding that the
counts of steaks and chops in CO₂-N₂ were lower than
those of comparable vacuum-packaged steaks, chops
and loins.

Previous reports from our laboratory as well as by
others (3, 4, 9, 16) have shown that lactic acid bacteria
became a significant and often dominant part of the
microflora of vacuum-packaged meats and meats stored
in gaseous environments which suppress gram-negative
aerobic psychrotrophic bacteria. It is difficult to explain
why lactobacillus counts of steaks and chops held in
CO₂-N₂ usually were lower than those of comparable
vacuum-packaged steaks, chops or loins. In a previous
report (3), lactobacillus counts of conventional vacuum
packaged beef roasts also were often somewhat higher
than those of roasts stored for 21-35 days in any of six
different gas atmospheres. Perhaps this gaseous environ-
mant in the vacuum-packaged products was more
conducive to development of lactobacilli. Data in the
companion paper (19) show that the weight percentages
of CO₂ of the vacuum-packaged steaks and chops were
lower than those of the steaks and chops stored in

### TABLE 10. Mean values for psychrotrophic bacterial counts of lamb chops after 5 days of retail display.

<table>
<thead>
<tr>
<th>Storage interval (days)</th>
<th>Vacuum packaged</th>
<th>Reformed subprimal cuts</th>
<th>Vacuum packaged</th>
<th>20% CO₂</th>
<th>50% N₂</th>
<th>80% CO₂</th>
<th>80% N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subprimal cuts</td>
<td>Reformed subprimal cuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.18&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.17&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.02&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.05&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>8.72&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.62&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.79&lt;sup&gt;c&lt;/sup&gt;</td>
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<td></td>
</tr>
</tbody>
</table>

*Counts (log<sub>10</sub>) per 6.45 cm<sup>2</sup> (1 in.²) (spread-plate method).

*Counts within a common storage interval that are underlined are significantly different (P < .05) from counts obtained from chops from vacuum packaged subprimal cuts.

*Counts in the same column bearing a common superscript letter do not differ (P > .05).
CO₂-N₂ atmospheres. On the other hand, Shaw and Nicol (21) reported that neither CO₂ nor O₂ affected lactobacilli.

The effect of CO₂-N₂ on the psychrotrophic counts of steaks and pork chops, and to a lesser extent on those of lamb chops was still noticeable after simulated retail display for 5 days. Counts of steaks and pork chops initially stored in CO₂-N₂ were, after display, usually numerically lower than those of comparable vacuum-packaged steaks, pork chops or loins. Also, increases in psychrotrophic counts of steaks during display were smaller for those held in CO₂-N₂ than for those initially stored in vacuum-packages. These differences may reflect differences in the number and types of microorganisms on the samples stored in CO₂-N₂ versus those held in vacuum packages at the time they were exposed to retail display. No data were collected relative to microbial types. In addition, there may have been, at least for beef steaks (7-14 days in CO₂-N₂) and for pork chops (7 days in CO₂-N₂), a residual effect of the CO₂-N₂ mixture on the microbial flora that developed during retail display. At least for CO₂ this effect can take place because of reactivity of this gas with free amino groups of amino acids, peptides, amines and proteins (13). This effect may be different with meats from different species because of differences in physical or chemical characteristics of muscle.

Data presented by Seideman et al. in a companion paper (19) describe surface discoloration and overall appearance of retail beef, pork and lamb samples examined in this study. They reported that prepackaged retail cuts (vacuum-packaged or packaged in CO₂-N₂) usually had significantly more surface discoloration and lower overall appearance ratings than retail cuts derived from vacuum-packaged subprimal cuts. Microbiological analyses show that psychrotrophic bacterial counts of steaks and chops prepackaged in CO₂-N₂ usually were somewhat lower than those of comparable prepackaged vacuum-packaged steaks or chops or vacuum-packaged subprimal cuts. Also, counts of prepackaged vacuum packaged steaks or chops often were higher than those of comparable vacuum-packed subprimal cuts. Hence, under the present experimental conditions, changes in surface discoloration or overall appearance do not seem to be related to changes in psychrotrophic bacterial counts. It is more likely that the gases, CO₂ and N₂, had detrimental effects on muscle pigments and thus on color and appearance.

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REFERENCES