METHOD FOR EXTENDING SHELF-LIFE AND PREVENTION OF DISCOLORATION OF MEAT

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ABSTRACT

The current invention covers an improved meat-packaging procedure and machine for packaging meat cuts for long-term storage at temperatures of between 28° and 32° F. The process includes sealing meat cuts within a master bag containing oxygen scavenger materials capable of reducing the residual oxygen content of the atmosphere within the bag to 0 ppm within 24 hours of sealing. Gas is injected into the master bag to form a nitrogen-rich storage environment of at least 50% nitrogen. A small amount of carbon monoxide gas (0.1% to 5%) is preferred for the storage environment, as this helps to preserve the red coloration of meat under long-term storage conditions. The over-wrap of the meat trays can be perforated so that gas exchange occurs within the master bag between the interior and exterior of the meat tray to absorb the residual oxygen inside the meat trays. For meat trays containing meat with poor color stability, oxygen scavengers are preferably placed within the meat trays. For cuts with good color stability, the oxygen scavengers may be placed outside the meat trays. Meat can be stored by this system for up to 15 weeks and up to nine days of retail display life.
TABLE 1A

Half-life of O₂ in bags containing scavengers based upon enzymes and iron chemical systems, and air or N₂ atmosphere.

<table>
<thead>
<tr>
<th>Scavenger-type</th>
<th>Atmosphere</th>
<th>25°C</th>
<th>12°C</th>
<th>2°C</th>
<th>-1.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron chemical system</td>
<td>Air</td>
<td>0.6 (0.06)</td>
<td>0.7 (0.07)</td>
<td>1.0 (0.03)</td>
<td>2.5 (0.04)</td>
</tr>
<tr>
<td>(type 1) N₂ + air</td>
<td>1.3 (0.03)</td>
<td>1.5 (0.04)</td>
<td>2.2 (0.05)</td>
<td>2.3 (0.05)</td>
<td></td>
</tr>
<tr>
<td>Enzyme system (type 1)</td>
<td>Air</td>
<td>1.0 (0.03)</td>
<td>1.6 (0.02)</td>
<td>4.0 (0.02)</td>
<td>7.1 (0.04)</td>
</tr>
<tr>
<td>N₂ + air</td>
<td>3.3 (0.02)</td>
<td>7.0 (0.03)</td>
<td>12.0 (0.03)</td>
<td>8.0 (0.03)</td>
<td></td>
</tr>
<tr>
<td>Iron chemical system</td>
<td>Air</td>
<td>0.6 (0.04)</td>
<td></td>
<td>0.8 (0.05)</td>
<td>0.8 (0.04)</td>
</tr>
<tr>
<td>(type 2) N₂ + air</td>
<td>0.9 (0.02)</td>
<td></td>
<td></td>
<td>0.9 (0.04)</td>
<td>1.3 (0.04)</td>
</tr>
<tr>
<td>Enzyme system (type 2)</td>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂ + air</td>
<td>1.6 (0.02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron chemical system</td>
<td>Air</td>
<td>4.5 (0.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(type 1 in over-wrapped N₂ + air tray)</td>
<td>5.0 (0.08)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Standard deviation.
—An experiment was not performed under this condition.

TABLE 1B

Constants of first order kinetics equation for different scavengers.

<table>
<thead>
<tr>
<th>Scavenger-type</th>
<th>Temp. (°C)</th>
<th>Atmosphere</th>
<th>Initial O₂ concentration (ppm)</th>
<th>k (h⁻¹)</th>
<th>A₀</th>
<th>Calculated O₂ half-life (h)</th>
<th>Correlation coefficient (r²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron chemical system</td>
<td>25</td>
<td>Air</td>
<td>200,000</td>
<td>2.46</td>
<td>3.04</td>
<td>0.3</td>
<td>0.98</td>
</tr>
<tr>
<td>(type 1) N₂ + air</td>
<td>25</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.35</td>
<td>0.51</td>
<td>1.8</td>
<td>0.92</td>
</tr>
<tr>
<td>12</td>
<td>Air</td>
<td>200,000</td>
<td>1.82</td>
<td>3.96</td>
<td>0.4</td>
<td>1.9</td>
<td>0.96</td>
</tr>
<tr>
<td>12</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.56</td>
<td>0.61</td>
<td>1.0</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Air</td>
<td>200,000</td>
<td>0.69</td>
<td>3.61</td>
<td>1.0</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.25</td>
<td>0.79</td>
<td>2.7</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>-1.5</td>
<td>Air</td>
<td>200,000</td>
<td>0.31</td>
<td>3.54</td>
<td>2.3</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>-1.5</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.26</td>
<td>0.76</td>
<td>2.7</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Enzyme (type 1)</td>
<td>25</td>
<td>Air</td>
<td>200,000</td>
<td>0.54</td>
<td>3.34</td>
<td>1.2</td>
<td>0.99</td>
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<tr>
<td>25</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.20</td>
<td>0.88</td>
<td>3.5</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Air</td>
<td>200,000</td>
<td>0.40</td>
<td>3.62</td>
<td>1.7</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.09</td>
<td>0.84</td>
<td>7.7</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Air</td>
<td>200,000</td>
<td>0.20</td>
<td>3.45</td>
<td>3.5</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.06</td>
<td>0.80</td>
<td>11.5</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>-1.5</td>
<td>Air</td>
<td>200,000</td>
<td>0.08</td>
<td>3.72</td>
<td>8.7</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>-1.5</td>
<td>N₂ + air</td>
<td>500</td>
<td>0.08</td>
<td>0.84</td>
<td>8.7</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

*1/2[O₂] = -kt + A₀ = -kt + 3k[O₂]₀ [O₂]₀ is volume (cm³) of O₂ in the pack atmosphere at time t (hour) and [O₂]₀ is volume (mL) of O₂ in the pack atmosphere at t = 0 h.

⁹Calculated half-life (h) = 0.693/k; observed half-life in Table 1.
### TABLE 2b

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>Lidded control tray with meat</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>Lidded tray containing meat and grid</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>Lidded tray with meat and absorbent pad</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>Lidded tray containing meat and ( O_2 ) scavengers inside the retail tray</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>Lidded tray containing meat, grid, and absorbent pad</td>
</tr>
<tr>
<td>F</td>
<td>3</td>
<td>Lidded tray containing meat, grid, and ( O_2 ) scavengers inside the retail tray</td>
</tr>
<tr>
<td>G</td>
<td>3</td>
<td>Lidded tray containing meat, absorbent pad, and ( O_2 ) scavengers inside the retail tray</td>
</tr>
<tr>
<td>H</td>
<td>3</td>
<td>Lidded tray with meat, grid, absorbent pad, and ( O_2 ) scavengers inside the retail tray</td>
</tr>
<tr>
<td>D1</td>
<td>3</td>
<td>Treatment D with ( O_2 ) scavengers outside the retail tray</td>
</tr>
<tr>
<td>F1</td>
<td>3</td>
<td>Treatment F with ( O_2 ) scavengers outside the retail tray</td>
</tr>
<tr>
<td>G1</td>
<td>3</td>
<td>Treatment G with ( O_2 ) scavengers outside the retail tray</td>
</tr>
<tr>
<td>H1</td>
<td>3</td>
<td>Treatment H with ( O_2 ) scavengers outside the retail tray</td>
</tr>
</tbody>
</table>

*Number of retail trays in a master pack.

### TABLE 2c

Mean colour, surface discoloration, and retail appearance scores and standard errors for pork chops and beef steaks after various treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Color$^{a,b}$</th>
<th>SE$^{c}$</th>
<th>Discoloration$^{a,b}$</th>
<th>SE$^{c}$</th>
<th>Retail Appearance$^{a,b}$</th>
<th>SE$^{c}$</th>
<th>Color$^{a,b}$</th>
<th>SE$^{c}$</th>
<th>Discoloration$^{a,b}$</th>
<th>SE$^{c}$</th>
<th>Retail Appearance$^{a,b}$</th>
<th>SE$^{c}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.75$^{a}$</td>
<td>0.22</td>
<td>5.58$^{a}$</td>
<td>0.69</td>
<td>2.09$^{a}$</td>
<td>0.42</td>
<td>2.75$^{a}$</td>
<td>0.22</td>
<td>3.83$^{a}$</td>
<td>0.74</td>
<td>3.67$^{a}$</td>
<td>0.75</td>
</tr>
<tr>
<td>B</td>
<td>5.90$^{a,c}$</td>
<td>0.26</td>
<td>5.50$^{a,b}$</td>
<td>0.40</td>
<td>1.92$^{a}$</td>
<td>0.45</td>
<td>2.75$^{a}$</td>
<td>0.22</td>
<td>3.33$^{a,b}$</td>
<td>0.68</td>
<td>4.58$^{a}$</td>
<td>0.72</td>
</tr>
<tr>
<td>C</td>
<td>3.00$^{a,b}$</td>
<td>0.00</td>
<td>1.77$^{a}$</td>
<td>0.20</td>
<td>2.25$^{a}$</td>
<td>0.44</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.25$^{a}$</td>
<td>0.22</td>
<td>6.75$^{a,b}$</td>
<td>0.22</td>
</tr>
<tr>
<td>D$^{**}$</td>
<td>5.00$^{a,c}$</td>
<td>0.20</td>
<td>1.92$^{a}$</td>
<td>0.03</td>
<td>6.25$^{a}$</td>
<td>0.22</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.00$^{a}$</td>
<td>0.00</td>
<td>6.75$^{a,b}$</td>
<td>0.22</td>
</tr>
<tr>
<td>E</td>
<td>5.75$^{a}$</td>
<td>0.25</td>
<td>4.67$^{a}$</td>
<td>0.39</td>
<td>1.92$^{a}$</td>
<td>0.34</td>
<td>3.25$^{a}$</td>
<td>0.22</td>
<td>1.00$^{a}$</td>
<td>0.00</td>
<td>6.50$^{a,b}$</td>
<td>0.26</td>
</tr>
<tr>
<td>F$^{***}$</td>
<td>5.00$^{a,c}$</td>
<td>0.09</td>
<td>1.67$^{a,b}$</td>
<td>0.39</td>
<td>6.25$^{a}$</td>
<td>0.44</td>
<td>3.00$^{a,b}$</td>
<td>0.15</td>
<td>1.17$^{a,c}$</td>
<td>0.20</td>
<td>6.60$^{a,b}$</td>
<td>0.26</td>
</tr>
<tr>
<td>G$^{***}$</td>
<td>5.00$^{a,c}$</td>
<td>0.30</td>
<td>1.83$^{a,b}$</td>
<td>0.56</td>
<td>4.75$^{a}$</td>
<td>0.57</td>
<td>2.83$^{a,c}$</td>
<td>0.20</td>
<td>1.42$^{a,c}$</td>
<td>0.25</td>
<td>6.38$^{a,c}$</td>
<td>0.25</td>
</tr>
<tr>
<td>H$^{***}$</td>
<td>6.00$^{a,b}$</td>
<td>0.06</td>
<td>3.00$^{a,b}$</td>
<td>0.45</td>
<td>3.25$^{a}$</td>
<td>0.36</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.17$^{a,c}$</td>
<td>0.20</td>
<td>6.85$^{a,b}$</td>
<td>0.20</td>
</tr>
<tr>
<td>D$^{+}$</td>
<td>5.50$^{a,c}$</td>
<td>0.30</td>
<td>2.83$^{a,c}$</td>
<td>0.62</td>
<td>5.00$^{a,b,c}$</td>
<td>0.62</td>
<td>2.36$^{a,c}$</td>
<td>0.26</td>
<td>2.43$^{a,b}$</td>
<td>0.94</td>
<td>5.35$^{a}$</td>
<td>0.24</td>
</tr>
<tr>
<td>F$^{+}$</td>
<td>5.67$^{a,c}$</td>
<td>0.32</td>
<td>1.92$^{a}$</td>
<td>0.86</td>
<td>5.00$^{a,c}$</td>
<td>0.58</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.00$^{a}$</td>
<td>0.00</td>
<td>7.00$^{a}$</td>
<td>0.00</td>
</tr>
<tr>
<td>G$^{+}$</td>
<td>5.50$^{a,b}$</td>
<td>0.29</td>
<td>5.83$^{a}$</td>
<td>0.67</td>
<td>1.63$^{a}$</td>
<td>0.36</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.08$^{a}$</td>
<td>0.15</td>
<td>6.92$^{a}$</td>
<td>0.15</td>
</tr>
<tr>
<td>H$^{+}$</td>
<td>5.67$^{a,c}$</td>
<td>0.25</td>
<td>3.18$^{a}$</td>
<td>0.34</td>
<td>5.75$^{a}$</td>
<td>0.38</td>
<td>3.00$^{a,c}$</td>
<td>0.00</td>
<td>1.08$^{a}$</td>
<td>0.15</td>
<td>6.92$^{a}$</td>
<td>0.15</td>
</tr>
</tbody>
</table>

$^a$Color scale (pork chop): 0 = Completely discolored, 1 = Extremely pale, 2 = Pale, 3 = Normal, 4 = Dark, 5 = Extremely dark; Color scale (beef steak): 0 = Completely discolored, 1 = White, 2 = Pale pink, 3 = Pink, 4 = Pale red, 5 = Bright cherry red, 6 = Slightly dark red, 7 = Moderately dark red, 8 = Extremely dark red.

$^b$Discoloration scale (pork chop or beef steak): 1 = 0-5%, 2 = 5-10%, 3 = 11-25%, 4 = 26-50%, 5 = 51-75%, 6 = 76-99%, 7 = 100% (complete).

$^c$Retail appearance scale (pork chop or beef steak): 1 = Extremely undesirable, 2 = Undesirable, 3 = Slightly undesirable, 4 = Neither desirable nor undesirable, 5 = Slightly desirable, 6 = Desirable, 7 = Extremely desirable.

*Means in the same column bearing a common letter do not differ significantly (p > 0.05).

**Standard errors of difference.

$^{+}$O$_2$ scavengers inside the retail tray.

$^{***}$O$_2$ scavengers outside the retail tray.
Table 2d: Mean values of the chemical states of myoglobin (% met, % deoxy, and % oxy-myoglobin) and standard errors of difference for pork chops and beef steaks after various treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pork % met</th>
<th>Pork SE</th>
<th>Pork % deoxy</th>
<th>Pork SE</th>
<th>Pork % oxy</th>
<th>Pork SE</th>
<th>Beef % met</th>
<th>Beef SE</th>
<th>Beef % deoxy</th>
<th>Beef SE</th>
<th>Beef % oxy</th>
<th>Beef SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>26.35</td>
<td>1.50</td>
<td>24.10</td>
<td>1.07</td>
<td>49.05</td>
<td>0.72</td>
<td>57.41</td>
<td>0.07</td>
<td>0.08</td>
<td>0.00</td>
<td>42.51</td>
<td>6.07</td>
</tr>
<tr>
<td>B</td>
<td>20.33</td>
<td>0.80</td>
<td>24.62</td>
<td>4.07</td>
<td>55.65</td>
<td>4.79</td>
<td>53.24</td>
<td>4.12</td>
<td>1.30</td>
<td>1.00</td>
<td>40.61</td>
<td>23.35</td>
</tr>
<tr>
<td>C</td>
<td>5.22</td>
<td>0.94</td>
<td>42.10</td>
<td>3.07</td>
<td>52.64</td>
<td>2.16</td>
<td>33.23</td>
<td>1.56</td>
<td>0.63</td>
<td>0.05</td>
<td>75.61</td>
<td>16.93</td>
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<tr>
<td>D</td>
<td>0.03</td>
<td>0.91</td>
<td>37.77</td>
<td>3.84</td>
<td>62.22</td>
<td>3.85</td>
<td>0.03</td>
<td>0.03</td>
<td>2.04</td>
<td>1.40</td>
<td>96.86</td>
<td>0.99</td>
</tr>
<tr>
<td>E</td>
<td>5.42</td>
<td>2.10</td>
<td>23.90</td>
<td>3.00</td>
<td>46.69</td>
<td>1.70</td>
<td>17.34</td>
<td>1.96</td>
<td>1.58</td>
<td>1.38</td>
<td>45.78</td>
<td>15.53</td>
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<td>F</td>
<td>0.16</td>
<td>0.10</td>
<td>52.84</td>
<td>4.35</td>
<td>64.52</td>
<td>4.45</td>
<td>0.06</td>
<td>0.00</td>
<td>0.12</td>
<td>0.03</td>
<td>98.79</td>
<td>1.05</td>
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<td>G</td>
<td>2.01</td>
<td>1.80</td>
<td>21.80</td>
<td>7.50</td>
<td>76.70</td>
<td>8.22</td>
<td>2.11</td>
<td>1.82</td>
<td>5.65</td>
<td>2.92</td>
<td>92.24</td>
<td>1.62</td>
</tr>
<tr>
<td>H</td>
<td>0.00</td>
<td>0.00</td>
<td>31.90</td>
<td>3.38</td>
<td>68.60</td>
<td>3.38</td>
<td>7.83</td>
<td>4.46</td>
<td>12.71</td>
<td>8.39</td>
<td>78.46</td>
<td>8.03</td>
</tr>
<tr>
<td>I</td>
<td>0.00</td>
<td>0.00</td>
<td>21.00</td>
<td>2.25</td>
<td>78.90</td>
<td>2.35</td>
<td>2.60</td>
<td>1.07</td>
<td>7.13</td>
<td>1.00</td>
<td>90.48</td>
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<td>0.00</td>
<td>0.00</td>
<td>28.76</td>
<td>4.67</td>
<td>71.26</td>
<td>4.16</td>
<td>2.25</td>
<td>1.80</td>
<td>5.20</td>
<td>4.65</td>
<td>92.55</td>
<td>1.79</td>
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<td>K</td>
<td>0.00</td>
<td>0.00</td>
<td>23.50</td>
<td>3.22</td>
<td>74.40</td>
<td>3.32</td>
<td>37.25</td>
<td>16.24</td>
<td>3.78</td>
<td>1.48</td>
<td>58.93</td>
<td>17.71</td>
</tr>
<tr>
<td>L</td>
<td>6.82</td>
<td>5.90</td>
<td>27.83</td>
<td>7.27</td>
<td>65.58</td>
<td>3.78</td>
<td>0.00</td>
<td>0.00</td>
<td>8.53</td>
<td>4.32</td>
<td>91.47</td>
<td>4.23</td>
</tr>
</tbody>
</table>

1 % oxy = (% met - % deoxy)

* Means in the same column bearing a common letter do not differ significantly (p>0.05).
** Standard errors of difference.
*** Oscavengers inside the retail tray.
**** Oscavengers outside the retail tray.
Fig. 1 Influence of oxygen partial pressure on the three chemical states of myoglobin.
Microbial growth on centrally prepared, retail-ready lamb chops in foam trays (Growth was negative for E. coli, Listeria, and Salmonella)
FIG 5B

Microbial growth on centrally prepared, retail-ready lamb chops in plastic trays

(Growth was negative for E.coli, Listeria and Salmonella)
FIG 5C-1

Average odor acceptability scores of centrally prepared, retail-ready lamb chops in plastic trays

Time of retail display (h)

0 24 48 72 96

Scores

0 2

Odor acceptability
FIG 5C-II

Average odor acceptability scores of centrally prepared, retail-ready lamb chops in plastic trays

<table>
<thead>
<tr>
<th>Time of retail display (h)</th>
<th>Odor acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>72</td>
</tr>
<tr>
<td>48</td>
<td>96</td>
</tr>
</tbody>
</table>

Storage day: 48, 72, 96
Average off-odor intensity scores of centrally prepared, retail-ready lamb chops in foam trays.
Average off odor intensity scores of centrally prepared, retail-ready lamb chops in foam trays.

FIG. S D-II
Average retail appearance scores of centrally prepared, retail-ready lamb chops in plastic trays
FIG 5F

Average retail appearance scores of centrally prepared, retail-ready lamb chops in foam trays
Average surface discoloration scores of centrally prepared, retail-ready lamb chops in plastic trays.

**FIG 5G**

- **Discoloration scores** vs. **Time of retail display (h)**
- **Storage day = 2**
- **Storage day = 8**
- **Storage day = 20**
- **Storage day = 27**
- **Storage day = 41**
- **Storage day = 48**
- **Storage day = 55**
Average surface discoloration scores of centrally prepared, retail-ready lamb chops in foam trays

Time of retail display (h)

Discoloration scores

FIG 54
Average color scores of centrally prepared, retail ready lamb chops in plastic trays

Time of retail display (h)

Color scores

Storage day = 2
Storage day = 6
Storage day = 13
Storage day = 20
Storage day = 27
Storage day = 34
Storage day = 41
Storage day = 48
Storage day = 55

FIG 51
PROCEDURE I

1. SELECT/ PREPARE MASTER BAG
2. CALCULATE HALF-LIFE OF O₂ IN MASTER BAG
3. O₂ SCAVENGER CHOSEN
4. DETERMINE PLACEMENT OF O₂ SCAVENGER
5. 0.5 – 4 LBS OF MEAT PLACED ON TRAY

PROCEDURE II

1. OVERWRAP MEAT TRAY
2. MASTER BAG MEAT TRAYS
3. STORAGE

PROCEDURE III

1. DISTRIBUTE
2. DISPLAY

FIG. 7
METHOD FOR EXTENDING SHELF-LIFE AND PREVENTION OF DISCOLORATION OF MEAT

BACKGROUND OF THE INVENTION

[0001] Meat production and packaging is well known in the industry. Traditionally, once a primal cut of meat has been made, it is placed in a package containing ambient air and the lidding material is fed from a roll and over the tray covering the meat cut. The tray edges are typically sealed to form the finished product. However, since the air allows the meat to become discolored due to the onset of metmyoglobin, the meat normally undergoes vacuum skin packaging in order to maintain freshness and reduce spoilage of the meat cut.

[0002] The conventional vacuum packaging process normally does not allow the meat cut to exhibit a deep red pigment desired by retailers and consumers. Subsequently, once these vacuum-packed meat cuts reach the supermarkets or meat distribution centers, the primal cuts are cut into smaller cuts. These smaller cuts are then repackaged or displayed in a case for sale. In a very short time, the meat cuts lose the desired red color and start to brown or otherwise become discolored, losing its aesthetic fresh, healthy appearance and often not sold as a result.

[0003] Specifically, meat cuts lose their healthy color due to metmyoglobin (aka browning of meat). Metmyoglobin occurs because of oxidation of deoxymyoglobin, and this chemical reaction of the meat is irreversible. Under a reduced oxygen condition, the rate of the metmyoglobin is high. Transient discoloration can occur in a reduced oxygen environment, because meat muscle possesses a limited enzymatic activity known as metmyoglobin reducing activity (MRA) which converts metmyoglobin back to deoxymyoglobin. However, this process, which can decrease and possibly reverse discoloration, takes several days and is detrimental to centralized meat operations. Furthermore, the MRA is extremely limited and once consumed by the meat cannot be rejuvenated.

[0004] Despite the inherent drawback, centralized packaging of retail meat cuts is gaining in popularity in the food industry due to its economies and the potential to maintain quality, enhance safety, and extend the shelf-life of fresh meat. However, the general requirements to optimize shelf-life of centrally prepared retail-ready meat cuts are slightly different from those needed to extend shelf-life of fresh chilled meat for periods of up to fifteen weeks. Deterioration of chilled meats primarily takes place at the cut or uncut muscle surface. In long term storage at a centralized packaging and storage operation, primal cuts are placed in an atmosphere saturated with carbon dioxide (CO₂) (100%) which contains very low residual oxygen (O₂), and these primal cuts stored at -1.5±0.5°C.

[0005] At the end of required storage, meat is removed and fabricated into retail or food service cuts. New fresh surfaces are created in the process, revitalize the appearance of the meat cuts; and when the new surfaces of the meat cuts are prepared for retail display the normal expectation is a further four days of shelf-life. Depending on the variability of the meat species, the shelf-life is usually limited by development of undesirable organoleptic changes, where defects in color are usually independent of the microbial presence. The latter has a lactic acid bacterial population, which maximizes under storage conditions at levels about 10⁶ cfu/cm² well before the shelf-life expiration.

[0006] However, with centralized distribution of retail-ready fresh meat, circumstances and storage requirements are different. The wholesale storage period following initial packaging of the retail cuts is in the range of 20-30 days and prepared products must withstand the rigor of retail display for up to two days thereafter without further manipulation of the contents of the package. Retail packages are simply moved from their storage container (usually a unit or over-wrap containing a modified atmosphere) to retail display where desirable meat color develops upon exposure to air. The present commercial centralized meat operations only provide one to two weeks of shelf-life. Whereas, in North America, total shelf-life of several weeks (i.e., at least greater than four weeks) is desired because of distant markets and intent of North American meat industry to export to distant countries. Hence, the goal is to extend the shelf-life of retail-ready meat cuts.

[0007] A number of approaches have been taken to extend the shelf-life of meat. The basic approach is to package meat cuts with an inert gas atmosphere after the meat has been shipped from a processing facility to a retail outlet. Thereafter, when the retail outlet receives the packaged meat, the inert gas within the package is replaced with an oxygen-containing atmosphere.

[0008] One example of such a packaging system is depicted in U.S. Pat. No. 4,055,672 issued in 1977. The ‘672 patent provides for a system in which a meat product is packaged with one of the package walls formed from a gas impermeable material and another package wall formed as an inner gas permeable layer and an outer gas impermeable layer. The meat cut is initially packaged in an inert gas atmosphere which is maintained within the package by the package walls including the outer gas impermeable wall layer. If the outer gas impermeable layer is removed, this enables the oxygen-containing ambient air to flow into the package through the permeable layer. However, the ‘672 patent allows the meat to deteriorate after the impermeable layer has been removed, unless an additional impermeable layer is added. Nevertheless, placing a gas impermeable film layer over a gas permeable film layer is expensive to produce and difficult to seal to a container.

[0009] Another example of packaging containing an inert gas atmosphere is depicted in U.S. Pat. No. 6,302,324 issued in 2001. The ‘324 patent provides for packaging a food product in a receptacle containing an inert gas atmosphere and sealing a film to the receptacle. The receptacle includes a sealing flange and a tab portion extending from the sealing flange to which the film is sealed. The tab and the film are removed from the package to form an opening between the film and the receptacle when the food product is ready to be displayed to consumers. An atmosphere exchange operation is carried out through the opening, by inserting a nozzle through the opening and introducing an oxygen-containing gas into the receptacle cavity through the opening. The inert gas atmosphere initially contained within the receptacle is exhausted through the opening and the nozzle is withdrawn from the opening. The opening is closed by sealing the film to the receptacle. The ‘324 patent allows an inert gas atmosphere within the interior of the package to be easily and quickly replaced with an oxygen-containing atmosphere.
Another patent for extending the shelf-life of meat has been described in the process for pre-packing fresh meat seen in U.S. Pat. No. 4,683,139. The '139 patent describes a process wherein the meat is treated with an aqueous solution containing three active components, namely phosphate compounds, a reducing agent and a sequestering agent, and then packaging the meat in a controlled gaseous atmosphere containing from about 20% to 80% carbon dioxide and from about 2% to 30% oxygen, with the balance being nitrogen. Specifically, the process includes (1) placing at least one pork chop on each of a plurality of semi-rigid trays; (2) placing a gaseous mixture over and around the chops on each of the trays; (3) sealing the trays with a gas permeable film; (4) placing a plurality of the trays on a thermoformed tray; and (5) covering and sealing the thermoformed tray with a gas impermeable film. However, the '139 patent concentrates on the centralized pre-packing of fresh meats at the meat packing plant prior to shipment to the point of storage or retail sale. Further, the '139 patent fails to include 100% nitrogen gas filling a master bag before the placement of the tray.

Other examples of inventions desiring to extend the shelf-life of food products are U.S. Pat. Nos. 5,527,105 and 5,705,215 issued to Rinch, Jr. The '105 and '215 patents provide for a magnetic method for extending the shelf-life of food products wherein magnetic strips, matting formed from the strips and pads having magnetic north sides and magnetic south sides. Here, the negative magnetic north sides of the magnetic strips or pads are arranged to impinge on the fresh food products stored in a low-temperature environment. However, the '105 and '215 patents achieve a wetter condition thereby establishing a longer shelf-life condition for foods which are stored in a combined environment to include a north magnetic field and a selected low temperature.

Another example of a shelf-life extender for food use is described in U.S. Pat. No. 5,985,305 issued to Okada in 1999. The '305 shelf-life extender incorporates an isothiocyanic acid compound being supported on a matrix, where the compound is packaged in synthetic resin film or non-woven fabric. However, the '305 patent concentrates on acidic chemical compounds and gelling agents as opposed to integrating a zero oxygen packaging system as described by the present invention.

U.S. Pat. No. 6,153,241 describes another method and a package for extending the shelf-life of a food. Specifically, the method of achieving an extended shelf life for a food includes enclosure of the food in a discrete container having a first and a second container position, treating the food in the discrete container with heat in a treatment chamber while the container maintains the first container position and raising the container to the second container position under which the container is distributed, sold or used. However, contrary to the present invention, the '241 patent describes a method of heat treating a pumpable food carried out in a treatment chamber.

U.S. Pat. No. 6,183,790 to Delducca et al and U.S. Pat. No. 6,666,988 to Carr et al utilize an external oxygen accelerator to activate an oxygen scavenger to reduce the oxygen concentration to 500 parts-per-million (ppm) within 90 minutes. However, even at these low oxygen levels metmyoglobin formation remains very high (See FIG. 1). This stems from the fact that transient discoloration occurs because of limited metmyoglobin reducing activity (MRA) with the meat muscle, and these patents fail to address this process.

U.S. Pat. No. 6,269,946 to Colombo includes use of a meat tray over-wrapped with a gas permeable film. This patent uses metal chloride inside a meat tray to combine with water and acid to produce chlorine dioxide to help preserve meat cuts packaged therein. The disclosed invention also claims oxygen absorbers packaged within a barrier bag, but the patent fails to discuss the importance and advantages of sealing oxygen scavengers inside the meat tray or the need to quickly obtain a zero-oxygen gas environment for long-term cold storage of meat cuts both within the meat tray and the barrier (e.g. master) bag. The patent only provides for very low oxygen environment of about less than 0.05% volume of oxygen and does not attain zero oxygen levels. Further, the meat tray adds a receptacle for injecting carbon dioxide into the meat tray, and does not recommend a nitrogen-rich gas environment for storage, instead favoring carbon dioxide. Carbon dioxide is not preferred for several reasons.

Other U.S. Patents and publications (U.S. Pat. No. 6,230,883, U.S. Pat. No. 6,447,826, U.S. Pat. No. 6,586,651, U.S. Pat. No. 6,592,919) recommend using an atmospheric mixture containing carbon dioxide or discuss methods to create an atmosphere of carbon dioxide. However, in these inventions, although carbon dioxide has anti-microbial activity, solubility increases at low temperature and it is absorbed into the meat cuts, and after long storage the meat starts to discolor from the inside out. For this reason, carbon dioxide is only successful for long-term storage of primal or sub-primal meat cuts or uncleared carcasses. However, for retail ready cuts, use of carbon dioxide is detrimental to the meat color if long-shelf life of case-meat is desired. Solubilization of carbon dioxide into the meat prevents and/or delays meat cuts from re-blooming when master bags containing retail meat cuts are opened and the meat exposed to air.

In other systems utilizing activated oxygen scavengers as mentioned by Delducca et al and Carr et al, the presence of carbon dioxide hinders the rate of oxygen absorption by oxygen scavengers due to formation of carboxylic acid (carbon dioxide reacting with residual oxygen), hence the lowest oxygen concentrations obtained with these
Present commercial centralized meat operations employ master packaging in which three or more trays, each containing retail-ready meat cuts, are placed in a gas-impermeable master bag. However, residual oxygen may be present inside the packages due to the entrapment of oxygen during controlled atmosphere packaging (CAP). Specifically, the residual oxygen may be present due to any one of the following factors: (1) insufficient oxygen eva- cuation; (2) insufficient flushing times during CAP-machine operations; (3) use of an improper ratio of meat-mass to package atmosphere resulting in dead space in the master bag; (4) oxygen entrapment in the retail trays themselves, in absorbent pads or under the meat cut; (5) oxygen ingress through seams of a film used to over-wrap a master pack; (6) film defects; or (7) oxygen release from meat muscle. Since some of these factors are inevitable in commercial meat packaging operations, the plain use of master packaging has found limited application in commercial centralized meat operations. Therefore, a system is needed to reduce the oxygen concentration in a relatively short period of time in order to restore the metmyoglobin reducing activity.

Previously issued patents and prior art procedures reduce the oxygen concentration to at best 500 ppm within 90 minutes. These processes can result in some extension of shelf-life of case-ready meat cuts for retail sale, however these oxygen concentrations still lead to transient meat discoloration. For meat packaging implementing national and international centralized meat packaging operations, extremely long shelf life in the range of 8-10 weeks is desired. This long of a shelf-life can only be obtained if the transient meat discoloration can be avoided. Consequently, premature temporary discoloration limits the advantages of centrally packaged retail ready meat cuts using current oxygen depleted master packaging methods because a zero-oxygen storage environment is not attained.

Discoloration is also dependent on the specific muscle packaged since tissue vary in capacity to withstand low oxygen concentrations (<500 ppm). Centrally prepared beefsteaks and ground beef packaged under controlled atmospheres are shown to be susceptible to very low oxygen concentrations. Beef muscle with high color stability are least susceptible to metmyoglobin formation if the atmosphere is maintained at <600 ppm O₂ at temperatures <0° C. However, beef with poor stability is highly susceptible to metmyoglobin formation even at very low O₂ concentrations and subzero temperatures, and these cuts require a zero-storage environment for long-term storage.

If the enzymes causing MRA are retained in the meat, longer shelf life of meat cuts is possible. To accomplish this, the oxygen concentration in the master-bags used to ship meat from a central meat operation containing groups of meat trays must be zero. Under zero-oxygen concentration, meat color will go to the de-ox state and will come back to ox-state with the master-bags containing trays are opened and exposed to atmosphere. By doing this procedure, the enzymes causing MRA are retained and the meat does not go through a transient discoloration and long shelf-lives can be attained. The present invention has been developed to alleviate the above-identified drawbacks and provide further benefits to the meat distribution centers, supermarkets and the consumer.

The goal of the invention is to provide packers with an integrated packaging system that incorporates oxygen scavengers along with automatic formation of master-bags to fit the size of meat-trays, family size or multi-individual trays, and gas-flushing and sealing. The packaging system reduces the oxygen concentration to 0 ppm within a short period of time after pack closure. The invention uses modified horizontal, form, fill, and seal equipment with different packaging size options. The packaging equipment is intended to operate exclusively in meat operations utilizing oxygen scavengers, but may be adapted for operations with long-term storage in a carbon dioxide environment.

SUMMARY OF THE INVENTION

The present invention in its several disclosed embodiments alleviates the drawbacks described above with respect to traditional meat packaging and incorporates several additionally beneficial features. The process of packaging meat, namely retail-ready meat, is known in the prior art. Disclosed herein is a packaging system and method of same developed to prevent meat discoloration of prepared fresh meat cuts, such as beef, pork, lamb, and chicken. Specifically, different packaging configurations use self-activated oxygen scavengers and structures to extend the shelf life of fresh meat cuts by attaining a zero oxygen-packaged environment.

When fresh meat is exposed to oxygen, two effects normally occur. First, bacteria begins to grow and subsequently the fresh meat color disappears. By eliminating exposing the meat to oxygen, the chances of reducing bacteria and extending the fresh meat color improve dramatically. As a result, the present invention effectively removes oxygen very rapidly from a sealed package thereby increasing the shelf-life of the meat up to 12 weeks or more for different meat types.

The disclosed packaging system extends the shelf-life of centrally prepared retail-ready meat cuts by restoring metmyoglobin reducing activity of the meat-muscle through zero oxygen packaging. This achieves extremely long shelf-life for storage of retail-ready meat cuts. A retail-ready meat cut is placed in a tray having an activated oxygen scavenger based upon an iron chemical system and an absorbent pad. Several of these trays are placed in a master bag that is filled with a high nitrogen gas mixture and sealed. Several different combinations of placing scavengers (based upon iron chemical systems) and optimization of the oxygen scavenging capacity in each tray are achieved.

The tray or the master bag containing optimum oxygen scavenging capacity results in 0.6-2.0 hour half-life for oxygen in the master bag (depending upon the initial oxygen concentration and meat-type) and is one desired for centrally prepared retail-ready meat cuts. Such a packaging system under 100% nitrogen atmosphere resulted in at least a ten week storage life for centrally prepared meat cuts, such as beef tender loin steaks, with a subsequent display life of at least three days.

Thus, the use of an activated oxygen scavenger and an absorbent pad inside a master bag having 100% nitrogen introduced therein provides a significant increase in profit by reducing spoilage. By reducing the partial pressure of oxygen to zero ppm in the master bags, the growth of the
aerobic spoilage and pathogenic microorganisms is inhibited thereby extending the storage and display life of retail-ready fresh meat packages. Additionally, this process preserves the vivid, bright cherry red color of red meats, whereby longer shelf life and better looking meat products translate into higher sales and higher profits. Moreover, the master package will reduce purge due to temperature changes and will actually enhance the natural aging process producing more flavorful and tender cuts of fresh meat.

0029] Another advantage of the present invention is that a retailer is capable of unpackaging a days’ supply of fresh meat cuts at a time. The master package is protected from oxygen exposure until the seal is released and the individual packages are placed in the retail case. In essence, the shelf life clock does not begin ticking until the fresh meat is placed in the retail case. For central packaging operations, by utilizing the master packages, the shrinking of meat cuts due to handling, transportation and temperature fluctuations is greatly reduced to virtually zero shrinkage.

0030] The main advantage of the invention is the zero-oxygen system gas environment in the master bag stops the formation of metmyoglobin, the agent that causes fresh meat to become discolored. By stopping metmyoglobin's formation, the metmyoglobin reducing activity (MRA) of the meat muscle is retained. Because the oxygen concentration in the master bag is zero ppm, metmyoglobin cannot form and the discoloration process never occurs. Further, under the zero-oxygen system, only lactic acid and other slow growing anaerobic bacteria will grow; and the growth of faster growing aerobic bacteria causing rapid spoilage is restricted.

0031] Shelf-life in the retail case is increased by one to seven additional days, depending upon the type of meat cut. The present packaging system preserves the enzymatic activities of meat-muscle that maintains the bright cherry red color of each meat cut, the retail display life of the meat is extended dramatically. The addition of carbon monoxide as part of the gas mixture environment also helps preserve the reddish color of the meat as a layer of carbon monoxymyoglobin is formed on the meat surface.

0032] The apparatus used in the invention will automatically package meat trays into a single master bag containing oxygen scavengers with appropriate oxygen absorption capacity to reduce the half-life of oxygen inside the master bags and meat packages to between 0.6 and 2.0 hours. The master bags are formed around the meat trays and the ambient air is flushed from the bag. The bag is then injected with the desired gas mixture environment that is preferably 100% nitrogen or nitrogen rich (>50%) with the balance a mixture of other gases, preferably carbon monoxide and carbon dioxide. Some small quantity of carbon monoxide (≥0.1%) is preferred. The master bags can then be stored for several weeks at freezing or below freezing temperatures (28°F–32°F) until needed for placing into a retail display for several days before meat discoloration occurs.

DESCRIPTION OF THE DRAWINGS

0033] The objects and features of the invention will become more readily understood from the following detailed description and appended claims when read in conjunction with the accompanying drawings in which like numerals represent like elements and in which:

[0034] FIG. 1 is a x-y graph depicting the influence of oxygen partial pressure on three chemical states of myoglobin;

[0035] FIG. 1A is a table displaying the half-life of oxygen in bags containing scavengers based upon enzymes and iron chemical systems in an air or nitrogen atmosphere as described in Example 1;

[0036] FIG. 1B is a table showing constants of first order kinetics equation for various scavengers;

[0037] FIG. 2A is a table describing treatments for beef steaks and pork chops as described in Example 2;

[0038] FIG. 2B is a table depicting oxygen concentration in master bags containing beef and pork stored at 2°C in 100% nitrogen atmosphere over the course of seven days as described in Example 2;

[0039] FIG. 2C is a table displaying mean color, surface discoloration and retail appearance scores and standard errors for pork chops and beef steaks after various treatments;

[0040] FIG. 2D is a table depicting mean values of the chemical states of myoglobin (% met-, % deoxy-, and % oxy-myoglobin) and standard errors of difference for pork chops and beef steaks after various treatments;

[0041] FIG. 2E is an x-y graph depicting a discoloration score given to bags undergoing various treatments as described in Example 2;

[0042] FIG. 2F is an x-y graph depicting a retail appearance score given to bags undergoing various treatments as described in Example 2;

[0043] FIG. 2G is an x-y graph showing different treatments given a discoloration score during retail display times as described in Example 2;

[0044] FIG. 2H is an x-y graph illustrating different treatments given a retail appearance score during retail display times as described in Example 2;

[0045] FIG. 2I is an x-y graph showing different treatments having a certain percentages of metmyoglobin during retail display times as described in Example 2;

[0046] FIG. 3A is an x-y graph depicting a control and two experimental types given a discoloration score within storage intervals as described in Example 3;

[0047] FIG. 3B is an x-y graph illustrating the control and two experimental types given a retail appearance score within storage intervals as described in Example 3;

[0048] FIG. 3C is an x-y graph illustrating the control and two experimental types having a percentage of metmyoglobin taken during storage intervals as described in Example 3;

[0049] FIG. 4A is an x-y graph showing different weeks receiving color scores during retail display times as described in Example 4;

[0050] FIG. 4B is an x-y graph showing different weeks receiving discoloration scores during retail display times as described in Example 4;
[0051] FIG. 4C is an x-y graph showing different weeks receiving retail appearance scores during retail display times as described in Example 4;

[0052] FIG. 4D is an x-y graph showing different weeks receiving off-odor intensity scores during a course of days of retail display as described in Example 4;

[0053] FIG. 4E is an x-y graph showing different weeks receiving odor acceptability scores during a course of days of retail display as described in Example 4;

[0054] FIG. 4F is an x-y graph depicting different weeks showing a microbial count during a course of days of retail display as described in Example 4;

[0055] FIG. 5A is an x-y graph depicting a microbial plate count for meats, namely lamb chops stored on foam trays over a period of time as described in Example 5;

[0056] FIG. 5B is an x-y graph illustrating microbial plate count for meats, namely lamb chops stored on plastic trays over a period of time as described in Example 5;

[0057] FIG. 5C-I to 5C-II is an x-y graph detailing odor acceptability of meat, namely lamb chops, based on the amount of time the chops are displayed as described in Example 5;

[0058] FIGS. 5D-I and 5D-II is an x-y graph showing scores of off-odor intensity based on the amount of time the chops are displayed as described in Example 5;

[0059] FIG. 5E is an x-y graph depicting scores of retail appearance of meat, namely lamb chops based on time of retail display in plastic trays as described in Example 5;

[0060] FIG. 5F is an x-y graph depicting scores of retail appearance of meat, namely lamb chops based on time of retail display in foam trays as described in Example 5;

[0061] FIG. 5G is an x-y graph illustrating surface discoloration of meat, namely lamb chops in plastic trays based on time of retail display as described in Example 5;

[0062] FIG. 5H is an x-y graph detailing surface discoloration of meat, namely lamb chops, in foam trays based on time of retail display as described in Example 5;

[0063] FIG. 5I is an x-y graph showing color scores of meat, namely lamb chops in plastic trays, based on time of retail display as described in Example 5;

[0064] FIG. 5J is an x-y graph showing color scores of meat, namely lamb chops in foam trays, based on time of retail display as described in Example 5;

[0065] FIG. 6A is an x-y graph showing color score of meat, namely pork chops, based on time of retail display over a period of time as described in Example 6;

[0066] FIG. 6B is an x-y graph showing discoloration of meat, namely pork chops, based on time of retail display as described in Example 6;

[0067] FIG. 6C is an x-y graph depicting scores of retail appearance of meat, namely pork chops based on time of retail display as described in Example 6;

[0068] FIG. 6D is an x-y graph showing scores of off-odor intensity of meat, namely pork chops, based on the time of retail display as described in Example 6;

[0069] FIG. 6E is an x-y graph detailing odor acceptability of meat, namely pork chops, based on the amount of time the chops are displayed as described in Example 6;

[0070] FIG. 6F is an x-y graph depicting microbial plate count for meats, namely pork chops, based on time the chops are displayed as described in Example 6;

[0071] FIG. 6G is a schematic flow chart showing the method of the process used for packaging meat under the invention;

[0072] FIG. 6H is an embodiment of the arrangement of the elements of a meat tray;

[0073] FIG. 6I is another embodiment of the arrangement of the elements of a meat tray;

[0074] FIG. 6J is an embodiment of the arrangement of meat trays inside a master bag;

[0075] FIG. 6K is an embodiment of a master bag containing a large primal or sub-primal meat cut;

[0076] FIG. 6L is another embodiment of the arrangement of meat trays and oxygen scavengers inside a master bag; and

[0077] FIG. 6M is a schematic drawing of an apparatus to package meat according to the disclosed method and process.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0078] As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiment(s) are merely exemplary of the invention that may be embodied in various and alternative forms. Specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention. Further, the particular materials and amounts thereof, as well as other conditions and details, recited in these examples should not be used to unduly limit this invention.

[0079] The present invention in its several disclosed embodiments alleviates the drawbacks described above with respect to traditional meat packaging and incorporates several additionally beneficial features. The process of packaging meat, namely retail-ready meat, is known in the prior art. Disclosed herein is a packaging system and method of the same developed to prevent meat discoloration of prepared fresh meat cuts, such as beef, pork, lamb, and chicken. Specifically, different packaging configurations of components of the system use self-activated oxygen scavengers and structures to extend the shelf life of fresh meat cuts. A number of different options have been tested.

Oxygen Scavengers

[0080] Oxygen scavengers based on iron chemical systems were employed. A sachet placed within the packaging bag contains chemical granules ranging from 0.001 mm to 1.5 mm in diameter. The half-life of oxygen in a bag containing these oxygen scavengers was in the range of 30 to 1500 minutes, with the quantity of oxygen absorption material ranging from 1 gram to 300 grams. The oxygen
absorption material was placed in a package, which was either laminated or un laminated with porosity levels ranging from 20 to 120 gurly a second, and an active surface area of 4 to 64 square inches. The preferred material for the bag is type. The scavengers are typically formed from iron (<25%, preferably 15-20%), carbon (<35%, preferably 20-30%), vermiculite (<20%, preferably 10-15%), and de-ionized water (<10%, preferably 5%), salt [NaCl] (<10%, preferably 5%). A small amount (<10%) of zeolites can also be added for increased oxygen absorption rates. Oxygen scavengers can also be based on manganum, copper, and enzymes. The oxygen scavengers are activated upon exposure to air and/or oxygen in an atmosphere greater than 60% relative humidity, and work under a temperature range of 28° to 45° F.

Meat Characteristics

The meat can be of any type such as pork, lamb, beef, veal, chicken, fish, turkey, venison, or any other meat type. In the actual meats studied developing the invention, meats used included beef, veal, pork, and chicken. The cuts used were primal and/or sub-primal, and the grades of fresh meat cuts were prime, choice, and/or select. The meats included both boned and boneless cuts, and the size of fresh cut meat product was in the range of 1 to 5 lbs. The meat carcass was cooled either through blast cooling and/or cold room storage, with a cooling temperature of between 5° to 40°F. The time between slaughter and packaging was in the range of 24 hours to 120 hours. Packaging temperatures were less than 40°F.

Retail Tray Characteristics

The retail tray composition was of plastic and/or polystyrene and/or combination of both. The inherent oxygen content of the retail tray was in the range of 10 to 23,000 ppm. The surface of the retail tray exhibited either a grid or ridged pattern, or a flat surface upon which to place the fresh meat product. The retail tray core was either fiddled or over-wrapped. The retail tray surface area was in the range of 15,000 to 325,000 square mm. A moisture absorbent pad was either placed in the retail tray before the fresh meat product or was not included. The oxygen scavenger pads were placed in the retail tray or exterior to the retail tray.

The retail tray overwrap used has an oxygen permeability in the range of 3,000 to 10,000 cc of oxygen per square meter per 24 hours at 73° F and 70% relative humidity. Additional atmospheric permeability of the retail tray overwrap consisted of additional ambient atmosphere flow with multiple holes, each having a diameter of less than 5 mm, punched through the overwrap or a single needle hole with a diameter of less than 5 mm.

Master Bag Characteristic

The meat trays containing different meat cuts in different numbers (one to six retail trays) are placed in a master bag possessing good seal strength. The master bag possesses good seal strength with either a foil lining or an ethyl vinyl alcohol (EVOH) lining. The oxygen permeability of the master bag was less than 13 cc of oxygen per square meter per 24 hours at 73° F and 70% relative humidity. The master bag was gas-flushed with different gas-compositions and sealed.

The modified atmosphere characteristics were composed of different gas mixtures of carbon dioxide, carbon monoxide, and nitrogen/inert gas. Typical gas mixtures either consisted of 100% nitrogen and/or any inert gas or contained 100% carbon dioxide or different percentages of gases generally in the concentrations of <1% carbon monoxide, <40% carbon dioxide, and the balance either nitrogen and/or some other inert gas. The oxygen scavengers of different characteristics were placed in the master bags or in the retail trays or both. The residual oxygen content in the master bag after gas flushing using single or multiple cycles was less than 6%. The storage temperature of the master bags was less than 40° F, and the master bags were stored for up to 15 weeks.

Display and Sampling of Retail-Trays

Upon removal from primary storage at weekly intervals, and on day 0 of retail display, master packaging was removed and retail trays placed in the center of the display shelf. The displayed meat cuts were examined for discoloration, retail acceptability, off odor intensity, and odor acceptability, and odor description for every 24 hours for up to nine days. A similar procedure was repeated for all storage intervals for up to 15 weeks.

Visual Assessment of Master-Packaged Meat Cuts

A five-member panel was used for the subjective evaluation of the meat cuts. Surface discoloration was evaluated using a seven-point descriptive scale: 1=Extremely undesirable, 2=Unacceptable, 3=Neither desirable nor undesirable, 4=Desirable, and 5=Extremely desirable.

Odor Assessment of Master-Packaged Meat Cuts

A five-member panel was used for odor assessment. Off odor intensity scores were assessed using a four-point descriptive scale: 1=No off odor, 2=Light off odor, 3=Moderate off odor, 4=Prevalent off odor. Odor acceptability scores were assessed using a five-point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=slightly unacceptable, 5=Unacceptable.

Microbial Analysis

A 10 cm2 sample was obtained at each sampling time (on day 0 and last day of each storage interval) from each meat cut using a sterile cork borer. The sample was placed into a stomacher bag with 10 mL of 0.1% peptone solution and was massaged for 120 seconds using a commercial stomacher, yielding a dilution of 106. The homogenate was further diluted 10-, 100-, and 10,000-fold, after which 0.1 mL volumes of undiluted homogenate. Each dilution prepared was spread on duplicate plates of All Purpose Tween (APT). The plates were then incubated aerobically for 3 days at 25° C. The micro flora was determined from plates bearing 20-200 colonies.

Results Summary

The oxygen concentration was 0 ppm (zero) after 24 hours of storage, and was 0 ppm throughout the storage period of up to 15 weeks. Based on sensory and microbial analysis:

1) Beef cuts were acceptable for 10 weeks storage plus 5 days at the retail display,
2) Pork chops were acceptable for 15 weeks during storage plus 9 days at the retail display.

3) Lamb chops were acceptable for 8 weeks during storage plus 7 days at the retail display, and

4) Chicken pieces were acceptable for 8 weeks storage plus 6 days at the retail display.

Discussion

Referring to FIG. 1, there are three chemical states for myoglobin. Metmyoglobin is at a peak level at low oxygen pressures of about 2 mm of mercury. At sea-level, the atmospheric pressure of oxygen is approximately 160 mm of mercury, while the total atmospheric pressure is approximately 760 mm of mercury. As can be observed graphically, in order to begin minimizing formation of metmyoglobin, the atmospheric partial pressure needs to be reduced to less than 1 mm of mercury, or an oxygen content at sea level of less than 0.13%. To have no metmyoglobin formation, the atmospheric partial pressure of oxygen needs to be reduced to 0 mm mercury for an O_2 content at sea-level of 0 ppm (e.g. zero oxygen).

Example 1 shown in Table 1A depicts the first phase of the present invention involving a detailed oxygen absorption study of oxygen scavengers based upon an iron chemical system and enzymatic activity. The iron chemical system based scavengers are dependent upon the chemical reaction of ferrous iron to ferric oxide or ferric hydroxide. Specifically, Example 1 indicates that oxygen scavengers modified based upon the iron chemical system have the potential for reducing the oxygen concentration to 0 ppm within a few hours of munter packaging, provided an appropriate selection of oxygen scavengers is combined with appropriate placement in the package.

Two factors restricting the activity of the oxygen scavengers are sub-zero temperatures such as -1.5°C and a low oxygen concentration. Thus, the rate of the iron chemical reaction is greatly reduced at subzero temperatures, and low oxygen concentrations prevent random movement of oxygen molecules due to diffusion, which results in lower oxygen absorption rates. Therefore, the activation of a custom-designed oxygen scavenger of an appropriate capacity is capable of providing short half-life of oxygen, i.e. a high rate of oxygen absorption. Furthermore, the packaging film, preferably having a high oxygen permeability, acts as an oxygen barrier under sub-zero temperatures and low oxygen concentrations. Thus, the first phase of the invention concentrates on the placement of oxygen scavengers positioned inside the tray and surrounded by the packaging film.

In the second phase as illustrated in Example 2, the scavengers were interiorly placed within the trays containing meat muscles. Here, the meat muscles had poor color stability since the packaging films covering the trays (seen in Example 1) act as oxygen barriers under sub-zero temperatures and low oxygen concentrations. Hence, the presence of O_2 scavengers of appropriate capacity (at least 10 cc per pound of meet) is required. During the second phase, several experiments concentrated on the effect of varying the oxygen-absorbing capacities on the display life. Further, the need for knowing the initial concentration of oxygen in the package, calculating the needed half-life of oxygen in the package and subsequently designing the oxygen scavenger required to obtain the desired half life of oxygen.

Example 3 depicts the third phase of the present invention whereby preventing transient discoloration of the meat cuts, namely the retail-ready meat cuts. Lastly, the fourth phase as shown in Example 4 shows that the restoration of metmyoglobin reducing activity will result in extending the shelf-life of retail ready meat cuts. For example, the shelf-life of the retail-ready beef tender loin cuts was ten weeks with a display life of three days after each weekly storage differing from the conventional one to two weeks with a display life of one and half days.

EXAMPLE 1

Oxygen Absorption Kinetics of Enzymatic and Iron Chemical Systems Based Oxygen Scavengers

The current uses of O_2 scavengers generally involve packs in which the atmosphere contains some substantial fraction of O_2, if not air, at the time of pack sealing and the inhibition of chemical reactions or proliferation of microorganisms that proceed relatively slowly. Consequently, commercial O_2 scavengers are designed to remove a specified amount of O_2 from a relative high O_2 atmosphere over periods of a day or more. The rate of O_2 absorption has then not been a principal concern in the design of commercial O_2 scavengers. However, there are applications such as centralized meat operations where the rate of O_2 absorption is of prime importance.

The O_2 absorption rates of O_2 scavengers vary with the natures of their reactants and other materials used in their construction. Rates of absorption may also be affected by factors such as temperature and the compositions of the atmospheres to which they are exposed. Therefore, the objective of this study was to design an oxygen scavenger for centralized meat operation after studying the O_2 absorption kinetics of O_2 scavengers based upon enzymes and iron chemical systems.

Materials and Methods

1. O_2 Scavengers

2. Absorption of O_2 by Scavengers

O_2 scavengers were placed in gas impermeable bags composed of a laminate of polyester, oriented nylon, and an EVOH/EVA co extrusion with an O_2 transmission rate of 0.55 ml per m² per 24 hours at 23°C, 70% relative humidity. Bags containing scavengers were either emptied of air by flattening each bag around the scavengers it contained, or were evacuated then filled with a known volume of N_2 or CO_2, using a controlled atmosphere packaging (CAP) machine, before being sealed. Then, a quantity of air was injected into each bag using a gas-tight syringe inserted through a stick-on septum (Modem Controls, Inc., Minneapolis, Minn., USA).
Immediately after the injection of air, the puncture point was sealed using a hot iron. Each filled bag was stored at room or a constant temperature. Samples (8 mL) of the atmosphere in each bag were obtained every hour for 8 hours by means of a gas tight syringe inserted through a stick-on septum. If no substantial O₂ absorption was noticed within 8 hours, samples were taken after every 12 hours for up to 96 hours. Immediately after each sampling, the O₂ concentration in the sample was determined using an O₂ analyzer (Mocron MS0750, Modern Controls, Inc., Minneapolis, Minn., USA) with a zirconium oxide sensor, and the puncture point was then sealed using a hot iron. Residual air in the emptied bag was measured as the volume of water displaced by the emptied bag, and was used in the calculation.

To examine the effects of temperature and initial O₂ concentrations on O₂ absorption rates, scavengers were placed in bags after the scavengers, in their original sealed package, had been held overnight at the temperature at which O₂ absorption was to be measured. For each of the two scavengers at each temperature, six bags were prepared. Three of the bags were emptied of air, and sealed, and then 240 mL of air was injected into each. The other three were each filled with 4.5 L of N₂ before being sealed, and then 15 mL of air was injected into each. For each of the two scavenger types based upon scavenging mechanism, two sets of six bags were prepared, with one set being stored at each of the temperatures 25, 12, 2 or −1.5°C.

To characterize O₂ absorption when O₂ scavengers were placed inside over-wrapped retail trays with master packs, a 216x133x25 mm (LxWxH) retail tray over-wrapped with a film of O₂ transmission rate of 8000 mL per m per 24 hours at 23°C, 70% relative humidity, containing scavengers, based upon iron chemical system, was placed in each of the six bags. A 5 mm hole was made at one corner of the over-wrapped film to allow free exchange of atmospheres during gas flushing, three bags were emptied of air and sealed, and then 240 mL of air was injected into each. The other three bags were each filled with 4.5 L of N₂ to which 15 mL of air was added by injection.

3. Data Analysis

The half-life of O₂ in a pack atmosphere was calculated as the time required for the O₂ concentration in the pack atmosphere to be reduced to half the initial value. The half-life was calculated from the volumes of O₂ at successive time intervals during the storage of the pack. In calculating the volumes of O₂ absorbed from each atmosphere of air by the scavenger, the initial volume of air was taken to be the 240 mL added to the pack plus the measured volume of residual air. The volume of O₂ in a pack at the end of any period was calculated as the volume of atmosphere at the end of the period multiplied by the concentration of O₂ in the atmosphere at that time. The volume of atmosphere at the beginning of each period was taken to be the volume of atmosphere at the beginning of the previous period less the volume of the atmosphere removed as a sample at the end of the period and the volume of O₂ calculated to have been absorbed during the previous period.

The volume of O₂ absorbed during a period was calculated as the volume of atmosphere at the start of the previous period multiplied by the concentration of O₂ in the atmosphere at the beginning of the period less the volume of atmosphere at the start of the period multiplied by the concentration of O₂ at the end of the period. In calculating the volumes of O₂ remaining in the pack of atmospheres of N₂ or CO₂ to which air was added, the volumes of the atmosphere removed during sampling and the volumes of O₂ absorbed during a period were neglected.

To determine the order of reaction, plots were prepared of the natural logs (ln) and the reciprocals of the volumes of O₂ remaining in the pack atmosphere against time. If the ln plot approximated a straight line, the reaction was regarded as first order. If the reciprocal plot approximated a straight line, the reaction was regarded as second order. Rate-constants were calculated using the following equations:

for first-order reactions—ln[A]=−kt−ln[A₀], and
for second-order reactions—1/[A]=kt+1/[A₀],

where, [A] = amount of reactant A at time t(h),
k = the rate-constant (hour⁻¹), and
[A₀] = the initial amount of reactant.

Frequency factors and activation energies were calculated from the Arrhenius Equation of the form: ln(k)=−E_a/R(1/T)+ln(A)

where,

A = frequency factor (frequency of collisions),
E_a = activation energy (J mol⁻¹),
R = universal gas constant (8.314 J mol⁻¹K⁻¹), and
T = temperature (K).

4. Results

Using scavengers based upon iron chemical system in bags containing air, the O₂ half-life was four times longer at −1.5°C than at 25°C, but with a N₂ atmosphere, the O₂ half-life at −1.5°C was only double that at 25°C. (Table 1A) The O₂ half-life in bags containing air and scavengers based upon enzymes was seven times longer at −1.5°C than at 25°C, but was only two and a half times longer at −1.5°C than at 25°C, with a N₂ atmosphere. (Table 1B) The O₂ absorption reaction was first order for all the O₂ scavengers. (Table 1B)

Discussion

The O₂ concentrations affected the O₂ half-lives substantially for any scavenger type resulting in longer O₂ half-lives for the low initial O₂ concentration of 500 ppm in N₂ atmospheres than for the high initial O₂ concentration of 200,000 ppm in air at the same temperature. Scavengers based upon iron chemical systems have shorter O₂ half-lives than the scavengers based upon enzymes. The kinetic data of the present study showed that the O₂ absorption reaction was first-order at both high (20%) and low (500 ppm) initial O₂ concentrations and included O₂ concentration as a limiting factor.

At high initial O₂ concentration, other factors, such as the scavenger surface area and environment, may also affect the O₂ absorption rates. However, at low initial O₂ concentrations a diffusion-phenomenon, which is a derivative of O₂ concentration, was the dominant influence and
resulted in low O₂ absorption. A threshold O₂ concentration existed where there was a dramatic decrease in O₂ absorption rate and O₂ concentration became the primary limiting factor for the O₂ absorption rate. Consequently, different rate-constants were observed for the same O₂ absorption curve at the same temperature, depending upon initial O₂ concentration. Therefore, the overall O₂ absorption curve produced by the scavenger was bi-phasic.

[0124] The effect of the positioning of scavengers within packs was also substantial which suggests that despite its high O₂ permeability, the barrier film acted as an O₂ barrier at low O₂ concentrations. Additionally, its barrier effect may increase with decreasing temperature. Consequently, the size of the hole in the hidding film is likely the limiting factor for O₂ absorption when retail trays were placed in a bog.

[0125] Due to significant variation in O₂ absorption rates of O₂ scavengers based upon iron chemical systems and enzymes, appropriate selection of O₂ scavengers is of importance in situations where high O₂ absorption is initially required. For centralized meat operations, scavengers based upon iron chemical system should be employed. Also, total oxygen absorbing capacity of these oxygen scavengers should be such that resulting oxygen half-life is less than two hours. However, due to significant positioning effects, they should be placed either inside the retail trays containing O₂ sensitive products, inside the retail trays as well as in the surrounding gas-impermeable bags, or outside the retail tray depending on the oxygen sensitivity of the meat cut.

EXAMPLE 2

Testing of Different Master Packaging Options for Centralized Meat Operations

Materials and Methods

[0126] 1. Oxygen (O₂) Scavengers

[0127] O₂ scavengers, based on iron-chemical systems, were used. These scavengers require moisture for activation and operating in air of N₂ atmospheres but not in CO₂ atmospheres.

[0128] 2. Master Packaging and Storage of Steaks and Chops

[0129] Experiment 1: Ten fresh beef tenderloins (psosas major, PM) and twenty fresh pork loins (longissimus dorsi, LD) from animals slaughtered 24 hours previously, at local commercial beef- and pork-abattoirs, respectively, were obtained. The meat cuts were vacuum-packaged and stored at 2°C for 14 to 21 days and then used in the experiments. A total of 39 steaks and 39 pork chops were prepared from the stored samples.

[0130] Each steak or pork chop was placed on a solid polystyrene tray with dimensions of 216x133x25 mm (LxWxH) containing O₂ scavengers with O₂ absorbing capacity of at least 10 mL per pound of meat and a single absorbent pad. Each retail tray was hidded with a shrinkable film with an O₂ transmission rate of 8000 mL per m² per 24 hours at 23°C, 70% relative humidity, using commercial glue. Two 3 mm holes were burned through the film in opposite corners of each tray using a soldering iron to allow free exchange of atmospheres during gas flushing. Three retail trays were placed on a plastic cafeteria tray, which as then placed in a 595x447 mm bi-metalized, plastic laminate bag with an O₂ transmission rate of 0.55 m² per 24 hours at 25°C, 70% relative humidity. The bag was then evacuated, filled with 2.5 L of N₂, and heat-sealed using a controlled atmosphere packaging (CAP) machine. Twelve master packs each containing three steaks or three pork chops, were prepared and randomly allocated within species to different treatments including treatments where scavengers were placed either in retail trays or in the master package (Table 2a). Three retail trays containing steaks or pork chops were not stored and served as controls.

[0131] Master-packaged steaks and pork chops were stored at 2°C for one week. The O₂ concentration in each master pack was then measured. The retail trays were then placed on retail display and evaluated for visual characteristics by a 4-member trained sensory panel.

[0132] Experiment 2: Twenty-five beef rib-eyes (longissimus thoracis, LT) from animals slaughtered 24 hours previously were obtained from a local commercial beef-abattoir and were vacuum-packaged and stored at 2°C. Following storage for 3 weeks, steaks (96, 2 cm thick) were placed in solid polyethylene trays with dimensions of 216x133x25 mm containing O₂ scavengers with O₂ absorbing capacity of at least 10 mL per pound of meat underneath an absorbent pad. Retail trays were hidded with a shrinkable permeable film and were prepared as in Experiment 1. Four retail trays were placed on a cafeteria tray, which in turn was placed into a master-pack bag. The master-pack bags were evacuated, filled with 3.25 L of N₂, and heat-sealed using the CAP machine. Six such packs were prepared containing one of four treatment combinations (G, H; Table 2a) and G2 and H2 (not given in Table 2a), which were over-wrapped instead of hidded. Please note treatments, G2 and H2, differ from other treatments (G and H), by having retail trays over-wrapped instead of hidded. The master-packs were stored and evaluated using procedures similar to those used in Experiment 1.

[0133] Experiment 3: Twenty-five Beef tenderloins (psosas major, PM) from animals slaughtered 24 hours previously were obtained from a local commercial beef-abattoir. Steaks (2 cm thick) were placed in 216x133x25 mm solid polyethylene trays containing O₂ scavengers with O₂ absorbing capacity of 200 mL (S2), 400 mL (S4), 600 mL (S6), or 800 mL (S8) underneath an absorbent pad. Each retail tray was over-wrapped with a highly O₂ permeable and shrinkable film as previously described. Containing the same treatment combination (S2, S4, S6, or S8), four retail trays were placed in a master pack, which was evacuated, filled with 4.5 L of N₂, and heat-sealed using the CAP machine. Three retail trays served as un-stored controls.

[0134] Following one week of storage at ~1.5°C, the O₂ concentration in each master pack was measured as previously described. All master bags were removed and the retail trays were placed on retail display and evaluated for visual characteristics daily for four days.

[0135] 3. Display and Evaluation of Retail Trays

[0136] All retail trays were placed at the center of the display shelf. Displayed steaks (PM or LT) and pork chops (LD) were evaluated for color, extent of discoloration, and retail appearance 30-45 min after master pack opening by a 4-5 member trained sensory panel. The details of the eight-point descriptive scale for the color of beef, the six-point
descriptive scale for the color of pork, the seven-point descriptive scale for discoloration of both beef and pork, and the seven-point hedonic scale for retail appearance for both beef and pork are given in Table 2c. Reflectance spectra from the meat surfaces were obtained to estimate the proportions of metmyoglobin, deoxymyoglobin, and oxymyoglobin.


[0138] Each retail tray containing a steak or a chop was evaluated by reflectance spectrophotometry (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, N.Y., USA), at three anatomical locations on each cut. Proportions of the different chemical states of myoglobin (deoxy-, met-, and oxy-) were estimated using standard procedures, by converting the readings (R) to K/S values [K is the absorption coefficient and S is the scattering coefficient, determined at selected wavelengths using the formula: K/S=(1−R)^2/2R]. Ratios of wavelengths used for calculations are: K/S 474+K/S 525 for % deoxymyoglobin, K/S 572+K/S 525 for % metmyoglobin, and K/S 610+K/S 525 for % oxymyoglobin.

[0139] 5. Statistical Analysis

[0140] The influences of different treatments on factors influencing meat color were compared statistically for significant differences (p<0.05) using Analysis of Variance (proc ANOVA and LSD means) in SAS (SAS Institute Inc., Cary, N.C., USA).

Results

Experiment 1

[0141] a. Oxygen Concentration

[0142] The O2 concentration in every fifth bag at initial packaging was 150-200 ppm. After being stored for one week at 2°C, the O2 concentration in most bags with O2 scavengers was 0 ppm, except for bags with treatments H, G, and G1 with beef (Table 2b). Bags without O2 scavengers contained small amounts of O2, occasionally up to 1150 ppm.

[0143] b. Visual Properties

[0144] Pork color scores in all treatments ranged from 2.4 to 3.3, and would be considered normal except in treatment D1, where the chops were slightly pale. (Table 2c) Chops in all treatments could be considered to be without discoloration, except in treatments A and B, where the chops were slightly discolored. Chops in all treatments were rated desirable to extremely desirable except in treatments A, B, and D1. Chops in treatment A were rated slightly undesirable and chops in treatments B and D1 were rated slightly desirable. (Table 2c) Beef steaks in all treatments were perceived to be bright cherry red to moderately dark red, except in treatments E and G1, where color scores were reduced due to complete discoloration of one or more steaks. Steaks in all treatments without O2 scavengers either inside the retail tray or in the master pack were moderately discolored. Steaks in treatments H and G1 were also moderately discolored, undoubtedly as a result of apparent O2 ingress through the pack. Steaks in all treatments with O2 scavengers inside the retail tray were perceived to be at least slightly desirable, except in treatments H and G1, due to extensive discoloration as a result of apparent O2 ingress. (Table 2c and FIG. 2A)

[0145] Comparison of retail appearance scores for beef steaks stored with and without O2 scavengers indicates the necessity of including O2 scavengers in master packaged, display ready meat cuts, stored in controlled atmospheres. Comparison of treatments D and F with D1 and F1 for beef clearly demonstrates the O2 scavengers should be positioned inside the retail tray. (Table 2c)

[0146] c. Chemical States of Myoglobin

[0147] Pork chops in all treatments previously stored with O2 scavengers had 62.0% or more oxymyoglobin and essentially 0.0% metmyoglobin when displayed in air, except in treatments G and H1. Chops in treatment G had 2.1% and chops in treatment H1 had 6.8% metmyoglobin. (Table 2d) Beef steaks in treatments containing O2 scavengers had >90.0% oxymyoglobin, and <2.5% metmyoglobin, except in treatment H and G1. Steaks in treatment H had 78.5% oxymyoglobin and 7.8% metmyoglobin; and steaks in treatment G1 had 58.9% oxymyoglobin and 37.3% metmyoglobin, presumably as a result of O2 ingress into the package. (Table 2d) This data confirm the visual data and the requirement for O2 scavengers inside the retail tray when master packing display-ready meat cuts in controlled atmospheres.

Experiment 2

[0148] a. Oxygen Concentration

[0149] The initial O2 concentration in every fifth bag was about 120 ppm. After one week of storage, the O2 concentration in all bags was 0 ppm, except for one bag (Bag 2, treatment H) which contained 2650 ppm O2 and was a “leaker” and was consequently eliminated from further evaluation.

[0150] b. Visual and Reflectance Properties

[0151] Although significant (p<0.05) differences existed between treatments in visual color ratings, all steaks were perceived to be bright cherry red and no differences of practical importance existed. Retail trays containing grids resulted in steaks with greater amounts of surface discoloration. However, no differences in surface discoloration attributable to lidding or over-wrapping were detected. (Table 2c) Consequently, steaks in retail trays containing grids were rated less desirable in retail appearance (p<0.05). However, the magnitudes of these differences in retail appearance were approximately 0.8 of a panel unit making them of only marginal practical importance. (FIG. 2B)

[0152] Steaks in over-wrapped trays containing a grid had the highest proportions of oxymyoglobin and the lowest proportions of metmyoglobin (p<0.05). Despite this finding, the visual data clearly indicates inclusion of a grid in the tray is not so productive, and the overall data clearly demonstrates similar advantages for either lidding or over-wrapping the trays. Consequently, the most feasible retail packaging system for use with controlled atmosphere, master packaging is the over-wrapped tray containing O2 scavengers underneath an absorbent pad. (Table 2c)

Experiment 3

[0153] a. Oxygen Concentration

[0154] The O2 concentration at packaging was approximately 80 ppm. After 7 days of storage at -1.5°C, the O2 concentration in all bags was 0 ppm.
b. Visual and Reflectance Properties

Steaks in retail trays containing O₂ scavengers with absorbing capacity of <600 mL were more discolored than the un-stored controls at all display intervals, but discolored essentially the same rate as the un-stored controls. (FIG. 2C) Steaks in retail trays containing O₂ scavengers with 800 mL of absorbing capacity also discolored at essentially the same rate as the un-stored controls, but did not discolor as extensively. Un-stored controls deteriorated rapidly in retail appearance and had a retail case-life of 2.5 days. (FIG. 2D)

Steaks stored with less than or equal to six O₂ scavengers resulting in O₂ absorbing capacity of less than 600 mL also deteriorated rapidly in retail appearance and had shorter retail-case lives than un-stored controls. Steaks stored with O₂ scavengers having absorbing capacity >600 mL deteriorated more slowly in retail appearance and had retail-case lives in excess of 4 days. (FIG. 2D) The rate of metmyoglobin and oxymyoglobin (% oxymyoglobin= 100-% metmyoglobin) formation during retail display (FIG. 2E) clearly demonstrates the advantage of using O₂ scavengers and indicates a minimum requirement for O₂ scavengers with absorbing resulting in an O₂ half-life of 0.6-0.7 hours in the pack atmosphere, where the O₂ concentration could otherwise remain less than or equal to 500 ppm at any time during storage (a deficiency noted in prior art methods).

c. Discussion

At low temperatures pork color is stable at several hundred ppm of O₂. The present study confirmed this finding. (Table 2c) Beef, especially PM, discolors even at very low O₂ concentrations, which is also evident from the results of the present study. The present results clearly demonstrate O₂ scavengers are essential to prevent and/or reduce discoloration in master-packaged meats. The use of O₂ scavengers in master packing of pork should provide protection to complement the intrinsic ability of pork muscle tissue to resist oxidative discoloration and may provide increased display life. The use of O₂ scavengers reduced O₂ concentrations to 0 ppm in most treatments in the present study. The appropriate absorbing capacity of O₂ scavengers to be used appears to be >600 mL based upon present results.

Steaks and chops used in the present study were vacuum-packaged and stored for two to three weeks at 2°C before master packaging, which lowers their metmyoglobin-reducing capacity, and therefore presented a worst-case scenario for centralized packaging operations.

Therefore, greater storage ability should be expected with fresh, un-stored beef or pork. Although pork can probably be master packaged using any treatment-combination with O₂ scavengers, the presence of O₂ scavengers inside the retail tray appears to be imperative when master packaging beef. Treatments G, G2, H, and H2 were selected as retail packaging systems, which may be commercially adaptable. Additional replicates of each of these treatments were evaluated in part II of the present study to determine the importance of a grid inside the retail tray and to obtain a comparison of lidded and over-wrapped retail trays. Results indicated a grid was not required and there was little difference between lidded and over-wrapped trays. (Table 2c) With CAP master-packages, selection of an appropriate retail packaging system should include an assessment of the number of O₂ scavengers required in each retail tray to minimize residual O₂ concentrations.

High O₂-permeable film over-wrap has been shown to act as an O₂ barrier at low O₂ concentrations. Consequently, two isolated systems affect the O₂ concentration in the overall package-atmosphere of master packs. The probability of having O₂ entrapped inside the retail tray is high due to the absorbent pad and space between over-wrap and edges of the tray.

The amount of O₂ absorbing capacity in each retail tray will also dictate the retail display life of meat cuts. Steaks packaged with higher absorbing capacity, i.e., with a high absorbing capacity O₂ scavengers tend to have more retail display life than those packaged with low absorbing capacity O₂ scavengers. As the present study demonstrated, longer retail display life for steaks packaged with O₂ scavengers of absorbing capacity >600 mL are achieved relative to O₂ scavengers of low capacity. The higher the absorbing capacity, the shorter the O₂ half-life is in the pack atmosphere, resulting in faster removal of residual O₂ which in turn prevents transient discoloration. With prevention of transient discoloration, the limited metmyoglobin reducing capacity of the muscle is preserved. This activity further delays development of discoloration during retail display and yields acceptable retail appearance even after four days of retail display, as shown in the present study. (Table 2c)

The present study further demonstrated little importance for placing meat cuts on a grid and little advantage for lidding retail-trays. However, O₂ scavengers based upon iron chemical system with oxygen absorbing capacity ≥600 mL must be placed inside the retail trays to attain an O₂ concentration of 0 ppm in the pack atmosphere of a master pack of the size 595x447 mm. The number of O₂ scavengers can vary provided they can provide an O₂ half-life of 0.3-0.4 hours in the master pack. Another combination, depending upon the color stability of meat cuts, can be placing some oxygen scavengers in the master pack (outside the retail tray) and only a few in the retail tray. However, the commercial system that can deliver a total storage and shelf-life of retail-ready cut cuts should have clear plastic tray with oxygen scavengers underneath the absorbent pad, and the meat cuts placed on top of the absorbent pad. (Table 2c and FIG. 2D)

EXAMPLE 3

Prevention of Transient Discoloration of Retail-Ready Beef Cuts

Centrally-prepared retail beef cuts stored in controlled atmospheres containing nearly 100% carbon dioxide (CO₂) or nitrogen (N₂), which may have small amounts of O₂, are susceptible to the formation of metmyoglobin due to the presence of the residual O₂. If the O₂ concentration is not excessive, the meat will absorb the residual O₂ and any metmyoglobin formed will be reduced to deoxymyoglobin as a result of metmyoglobin reducing activity (MRA) within the muscle tissue. In packaged fresh beef 2-4 days are required for reduction of metmyoglobin to deoxymyoglobin. When stored meat is removed from the controlled atmosphere, it blooms to the desirable, bright, red color associated with freshly cut meat, but this will not occur if a substantial amount of metmyoglobin is present. The MRA of muscle tissue is limited and once exhausted cannot convert any metmyoglobin formed back to myoglobin. This results in inevitable transient discoloration problem.
Transient discoloration of meat is not a major concern when the product is in storage, transit, or both for long periods. However, such discoloration is highly undesirable when commercial conditions require periodic rapid distribution and display of centrally packaged meat. Consequently, premature temporary discoloration limits the advantages of centrally packaged retail ready meat cuts using O₂-depleted master packaging technology. Such discoloration is also dependent upon the specific muscle packaged since tissues vary in their capacity to withstand “low” O₂ concentrations (<500 ppm). Central preparation beefsteaks and ground beef packaged under controlled atmospheres were shown to be susceptible to very low O₂ concentrations. Beef muscles with high color stability (LD) are least susceptible to metmyoglobin formation if atmospheres contained <600 ppm of O₂ at temperatures <0°C; however, beef with poor color stability (PM) was highly susceptible to metmyoglobin formation even at very low O₂ concentrations and sub-zero temperatures.

The objective of this study was to determine whether O₂ absorbent technology might be used in conjunction with CAP to prevent inevitable transient discoloration of PM beef.

Materials and Methods

1. Oxygen Scavengers

O₂ scavengers, based on iron chemical systems, and having O₂ absorbing capacity of at least 10 cc per pound of meat product were used in the study.

2. Master Packaging, Storage, and Sampling of Steaks

Twenty fresh beef tenderloins (psosas major PM) from animals slaughtered within 24 hours were obtained from a local beef-processed plant. Four 2 cm thick steaks were prepared from each tenderloin and were randomly distributed. Each steak was placed in an absorbent pad of dimensions 152x114 mm in a 216x133x25 mm solid polystyrene tray. O₂ scavengers with O₂ absorbing capacity of at least 10 cc per pound of meat product were placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable film having an O₂ transmission rate of 8000 mL/(m²24 hour) at 23°C and 70% relative humidity.

After sealing, the film was shrunk to the tray using a hot-air gun. Two 3-mm holes were made in the film at the corners of the tray to allow free exchange of atmospheres during gas flushing. Four such retail trays were placed in a 595x447 mm bimetalized, plastic laminate pouch. The master packs were evacuated, filled with 4.5L N₂, and sealed using a CAP machine. Eight such master packs were prepared. Similarly, eight master packs, each having four retail trays containing two of another type of O₂ scavengers underneath the absorbent pads; and an additional eight master packs, each containing four retail trays with no O₂ scavengers (controls), were prepared. Each pack was labeled accordingly.

The master-packaged steaks were stored at 1±0.5°C. On day 0, four retail trays served as fresh controls and were kept for visual evaluation in the retail-display case and to obtain reflectance spectra of the steak surfaces. Three master packs (one having one type and another one having another type of O₂ scavengers, and one having no O₂ scavenger), were opened at 1 day intervals for 8 days and placed in a retail display case. The O₂ concentration in each pack was measured immediately before being opened.

3. Display and Sampling of Retail Trays

All retail trays were placed in the center of the display shelf of a horizontal, fan-assisted retail display case. The PM steaks on display were examined for color, discoloration, and retail appearance at 30-45 min after opening of the master-packs, and reflectance spectra of the steak surfaces were obtained to estimate metmyoglobin, deoxymyoglobin, and oxymyoglobin content.

4. Visual Assessment of Master-Packaged Steaks

A five-member trained panel was used for the subjective evaluation of the steaks. Surface discoloration was evaluated using a seven-point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7=100%. Retail appearance was assessed using a seven-point hedonic scale: 1=extremely undesirable, 2=undesirable, 3=slightly undesirable, 4=neither desirable nor undesirable, 5=slightly desirable, 6=desirable, 7=extremely desirable.

5. Estimation of Myoglobin States

The average reflectance spectrum was obtained from three locations of the steak covered with a shrinkable film using a reflectance spectrophotometer. Reflectance values (R) of the different myoglobin oxidation states were estimated at specified wavelengths, and converted to K/S values (K is the absorption coefficient and S is the scattering coefficient). The K/S values are used for quantifying the proportion of deoxy-met-, and oxy-myoglobin, and are calculated using selected wavelengths (474, 525, 575, and 610 nm) for fresh meat color. The ratios and wavelengths used for the calculations were: K/S 474=K/S 525 for percent deoxymyoglobin, K/S 575+K/S 525 for percent metmyoglobin, and K/S 610+K/S 525 for percent oxymyoglobin.

5. Statistical Analysis

The effects of treatment differences (control and both types of O₂ scavengers) were examined statistically using analysis of variance (proe ANOVA, SAS Institute, Inc., Cary, N.C.) at a level of 0.05. Only the main effects were analyzed.

6. Visual Assessment of Steaks

Discoloration: On day 0, all steaks received discoloration scores of 1 (0% discoloration). After subsequent daily storage intervals, steaks packaged with no O₂ scavengers had discoloration scores of either 2 (1-10% discoloration), 3 (11-25% discoloration) or 4 (26-50% discoloration) (Table 2c). Steaks packaged with type-one O₂ scavengers received a discoloration score of 1 (0% discoloration) after 2, 4, 7, and 8 days, and 2 (1-10% discoloration) after 1, 3, 5, and 6 days. Steaks packaged with type-two O₂ scavengers received discoloration scores of 1 (0% discoloration) at storage intervals of 1, 2, 4, 6 and 7 days, and discoloration scores of 2 (1-10% discoloration) at storage intervals of 3, 5, and 7 days (FIG. 3A).

Retail Appearance (RA): On day 0, control steaks received retail appearance scores of 7 (extremely desirable).
After subsequent daily storage intervals, steaks packaged with no \( O_2 \) scavengers received RA scores of 5 (slightly desirable) or 6 (desirable) after 1, 2, 5, and 7 days. However, these scores were down to 3 (slightly undesirable) or 4 (neither desirable nor undesirable) after 3, 4, 6, and 8 days of storage. Steaks packaged with type-I \( O_2 \) scavengers received RA scores of 6 (desirable) or 7 (extremely desirable) for all storage intervals, and steaks packaged with type-II \( O_2 \) scavengers received RA scores of 6 or 7 for all storage intervals, except after 7 days when they received RA scores of 5 (slightly desirable) (FIG. 3B).

**[0185]** b. Metmyoglobin on the Steak Surface

Metmyoglobin content was not significantly different for control steaks (with no \( O_2 \) scavengers) after most storage intervals when compared to fresh controls (\( p<0.05 \)), except after 3 and 7 days. Metmyoglobin content increased from 3.5% on day 0 to 22.8% on day 3, then decreased to 4.7% on day 4, and again increased to 16.1% on day 7 but decreased to 5.2% on day 8. (FIG. 3C) Discoloration was visible at the edges of these steaks for all storage intervals. However, these areas were not exposed during reflectance spectrophotometry; and thus, the reflectance spectra did not report this discoloration, which would have undoubtedly increased the proportion of metmyoglobin. (FIG. 3C)

**[0187]** Metmyoglobin content of steaks packaged with type-I \( O_2 \) scavengers was not significantly different when compared to control steaks (steaks packaged with no \( O_2 \) scavengers), for all storage intervals (\( p<0.05 \)), except after 3 and 7 days of storage. Also, the metmyoglobin content was comparable with that of the fresh control for all storage intervals (\( p<0.05 \)). (FIG. 3C).

**[0188]** The metmyoglobin content of steaks packaged with type-II \( O_2 \) scavengers was not different when compared with fresh controls and steaks packaged with type-II \( O_2 \) scavengers, for all storage intervals (\( p<0.05 \)). However, steaks packaged with no \( O_2 \) scavengers had higher metmyoglobin content than the steaks packaged with type-II \( O_2 \) scavengers after 3 and 7 days of storage (\( p<0.05 \)). Differences were most noticeable at 2, 3, 6, and 7 days of storage, where the metmyoglobin content of steaks packaged with type-II \( O_2 \) scavengers was reduced to zero. (FIG. 3C)

**Discussion**

**[0189]** Reduced \( O_2 \) concentration has been demonstrated to have an adverse effect on meat color, and PM has been shown to have the least color stability, discoloring rapidly even at very low \( O_2 \) concentrations (<100 ppm) irrespective of the storage temperature. Consequently, \( O_2 \) absorbent technology might be used in conjunction with CAP to prevent inevitable transient discoloration, and this constituted the hypothesis of the present study. On day 0, the \( O_2 \) concentration was 78 ppm and this rose to 477 ppm in master packs without \( O_2 \) scavengers after 1 day of storage.

**[0190]** Master packs containing \( O_2 \) scavengers had no measurable \( O_2 \) at most storage times, except after 1 and 2 days in the case of type-I \( O_2 \) scavengers. As a consequence, steaks with \( O_2 \) scavengers had low metmyoglobin content and almost no discoloration, which resulted in significantly higher RA scores. Steaks packaged without \( O_2 \) scavengers had an increase in metmyoglobin content from day 0 to day 3 of storage. After 4 days storage, metmyoglobin content decreased, but then gradually increased until after 7 days storage, when it decreased again. This indicated these steaks underwent two cycles of transient discoloration, regaining color due to MRA or other reducing factors.

**[0191]** Steaks packaged with \( O_2 \) scavengers did not undergo such transient discoloration. Moreover, steaks packaged with type-II \( O_2 \) scavengers had lower metmyoglobin content than the fresh control after all storage intervals, and metmyoglobin content was reduced to zero in some cases.

**[0192]** In the present study, PM steaks expected to have poor color stability were used, but, very low metmyoglobin contents and high RA scores were observed in samples packaged with \( O_2 \) scavengers. Thus, the hypothesis of combining \( O_2 \) absorbent technology with CAP to prevent transient discoloration was proven. (FIGS. 3B and 3C)

**[0193]** The \( O_2 \) concentration during initial packaging was 78 ppm, and it went up to 477 ppm after 1 day of storage. Therefore, the amount of time required to reduce the \( O_2 \) concentration from 477 ppm to 0 ppm would be almost four times the half-life of \( O_2 \) in the package atmosphere. For type-I and type-II \( O_2 \) scavengers, incorporating the number of scavengers used in the study, the \( O_2 \) half-life is 0.31 and 0.65 hours, respectively (Example 1). Steaks will also contribute to the total \( O_2 \) absorbing capacity to some extent (<10%). Thus, at 1x0.5° C, transient discoloration of PM steaks can be prevented if residual \( O_2 \) is reduced to 0 ppm within 3 hours of pack closure.

**[0194]** Selection of a suitable retail-packaging system is another critical aspect of master packaging technology using CAP. It is evident from the results of the present study that the \( O_2 \) concentration in the master pack may initially increase drastically after packaging. Such an increase may be attributed to \( O_2 \) entrainment either in the absorbent pad or under the over-wrap film during evacuation. In addition, meat tissue initially releases dissolved, unreacted \( O_2 \) causing reduction of oxyhemoglobin to deoxymyoglobin in the presence of low partial pressures of \( O_2 \) in the head space during CAP storage. This increase is inevitable. Therefore, \( O_2 \) entrainment must be minimized to prevent \( O_2 \) concentrations increasing in the pack to the point where transient discoloration may occur.

**[0195]** It has been found that over-wrap film with high \( O_2 \) permeability acts as an \( O_2 \) barrier at low initial \( O_2 \) concentrations (Example 1), and the barrier property increases at low storage temperatures. It is also evident that \( O_2 \) concentration may increase due to entrainment of \( O_2 \) in either the absorbent pad or the over-wrap. It is recommended that each retail tray within the master pack contain \( O_2 \) scavengers to absorb any \( O_2 \) entrapped inside the tray, which may affect meat color. Less discoloration occurs on steak surfaces in a system where \( O_2 \) scavengers are placed in the master pack. Placing \( O_2 \) scavengers directly inside the retail tray will also reduce the number of \( O_2 \) scavengers required.

**[0196]** The present work was designed to examine meat samples with the highest pigment instability stored under conditions conducive to discoloration during centralized distribution. Beef (PM) was placed in over-wrapped retail trays (which may have \( O_2 \) entrapped in the absorbent pad or over-wrap or both). Although a storage temperature of 1x0.5° C is not recommended to optimize storage life of fresh meat cuts in centralized systems, it is closer to the
optimum (~-1.5°C) than the commercial norm. Rates of myoglobin oxidation and metmyoglobin reducing activity increase and decrease, respectively, at temperatures above 0°C. Thus, better results can be expected at ~-1.5°C. Nevertheless, under worst-case conditions, the use of O₂ scavengers in conjunction with CAP prevented transient discoloration of PM beefsteaks. It is probable that the system used in the present study will easily prevent transient discoloration in beef steaks with higher color stability, such as L.D., especially if stored below 0°C. Oxygen scavengers should prevent transient discoloration of all centrally prepared beef cuts, but, factors such as selection of packaging systems, O₂ scavenger type, and package atmospheres (N₂/CO₂) may affect results.

EXAMPLE 4

Total Shelf Life of Retail-Ready Meat Cuts Using the Designed Packaging System and Optimized Oxygen Absorption Technology

[0197] Exploration of an appropriate master-packaging system, which will minimize both color instability and microbial spoilage, is imperative for centralized meat operations. Although research has been done on microbiological and sensory aspects of meat during centralized meat packaging under various modified atmospheres, meat discoloration due to residual O₂ in controlled atmospheres remains a challenge as the rate of metmyoglobin formation increases at low partial pressures of O₂.

[0198] Beef steaks made from muscles of poor color stability, such as psoas major (PM), discolor rapidly even at O₂ concentrations of <100 ppm and sub-zero temperatures, resulting in short storage life in CAP followed by short display life. Consequently, application of oxygen absorption technology in conjunction with CAP became an attractive option. In addition, a suitable retail packaging system is required to reduce residual O₂ in the controlled atmospheres due to the possibility of O₂ entrapment within retail trays. The objective of the present study was to examine the storage and retail display life of master packaged beef steaks (PM) stored under 100% nitrogen atmosphere along with O₂ absorbents at -1.5°C.

Materials and Methods

[0199] 1. Oxygen Scavengers

[0200] O₂ scavengers, based on iron chemical system, were used in the study. The O₂ absorbing capacity was at least 10 mL per pound of meat.

[0201] 2. Master Packaging, Storage, and Sampling of Steaks

[0202] Fresh beef tenderloins (psoas major, PM) from animals slaughtered 24 hours previously were obtained from a local beef abattoir. Eighty steaks of 2 cm thickness were prepared from these tenderloins. Each steak was placed on a 152x114 mm absorbent pad in a 216x133x25 mm (LxWxH) solid polyethylene tray with O₂ scavengers having O₂ absorbent capacity of at least 10 mL per pound placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable O₂ permeable film with an O₂ transmission rate of 9.000 mL/m² per 24 hours at 23°C, 70% relative humidity, and atmospheric pressure. After sealing, the film was shrunk to the tray using a hot-air gun. Then, two 3-mm holes were made at the opposite corners of the tray to allow for exchange of atmospheres during gas flushing. Four such retail trays were placed in an EVA co-extruded master pack with O₂ transmission-rate of 0.55 mL/m² per 24 hours at 23°C, 70% relative humidity, and atmospheric pressure. The bags were evacuated, filled with 4.5 L of N₂, and sealed using a CAP machine. Twenty such bags were prepared. Additionally, 8 retail trays were prepared and treated as un-stored controls.

[0203] The master packs were stored at ~-1.5±0.5°C. On week 0 and day 0 of retail display, four steaks in retail trays, serving as fresh, un-stored controls, were analyzed for visual, odor, taste, and microbial characteristics. Also, reflectance spectra were obtained from the surface of these steaks. The visual analysis was done daily for 4 days, and similarly reflectance spectra were obtained daily. On day 4 of retail display, odor, taste, and microbial analyses were done in addition to visual examination and reflectance spectrum measurements. Two master packs were opened at subsequent 1 week storage intervals for 10 weeks. The O₂ concentration in each bag was measured immediately before opening the bag.

[0204] Master-bags containing meat cuts and oxygen scavengers having oxygen absorbing capacity of at least 10 mL per pound of meats, placed only outside the meat-trays, were also prepared. The over-wrap film of the meat-trays had at least one hole of less than 5 mm diameter. Such master-bags were flushed-back with a gas-mixture containing 64.6% Nitrogen, 0.4% CO, and 35% CO₂.

[0205] 3. Display and Sampling of Retail Trays

[0206] Upon removal from primary CAP storage at weekly intervals, and on day 0 of retail display, master packaging was removed and each group of 8 retail trays was placed in the center of the display shelf.

[0207] The displayed PM steaks were examined for color, discoloration, retail-acceptability, off odor intensity, odor acceptability, and odor description, 45 min after opening of the master-packages. Also, reflectance spectra from the meat surfaces were obtained to estimate metmyoglobin, deoxymyoglobin, and oxymyoglobin. After visual scores and reflectance spectra were obtained, two steaks (one from each master bag) were removed from the display case, and samples were taken for microbial analysis. Then the steaks were cooked and analyzed for flavor acceptability and off-flavor intensity.

[0208] The remaining six steaks were left in the display case, and were examined for visual characteristics at subsequent intervals of 24 hours and reflectance spectra at 12 hours for 96 hours. After 96 hours of retail display, the steaks were analyzed in a similar fashion as on day 0 of retail display. During sensory evaluation, the samples remained in the display case and the well-trained panelists made judgments independently. A similar procedure was repeated for all storage intervals.

[0209] 4. Visual Assessment of Master-Packaged Steaks

[0210] A five-member panel was used for the subjective evaluation of the steaks. Color scores were assessed using an eight-point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Pale red, 5=Bright cherry red, 6=slightly dark red, 7=Moderately dark red, 8=Ex-
extremely dark red. Surface discoloration was evaluated using a seven-point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7=100%. Retail appearance was assessed on a seven-point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5=Slightly desirable, 6=Desirable, 7=Extremely desirable.

[0211] 5. Odor Assessments of Master-Packaged Steaks

[0212] A five-member panel was used for the odor assessment. Odor intensity scores were assessed using a four-point descriptive scale: 1=No off odor, 2=Light off odor, 3=Moderate off odor, 4=Prevalent off odor; odor acceptability scores were assessed using a five-point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable; and off odor description scores were assessed using a six-point scale: 1=Sour-sulfur rotten eggs, 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=Other.

[0213] 6. Microbial Analysis

[0214] A 10 cm² sample was obtained at each sampling time (on day 0 and 4 of each storage interval) from each of the two steaks using a sterile cork borer. Then, the sample was placed into a stomacher bag with 10 mL of 0.1% peptone solution and was massaged for 120 seconds using a commercial stomacher, yielding a dilution of 10⁶. The homogenate was further diluted 10⁵, 10⁶, 10⁷, 10⁸, and 10⁹, fold, after which 0.1 mL volumes of undiluted homogenate and of each dilution were prepared and were spread on duplicate plates of APT. The plates were incubated aerobically for 3 days at 25°C. The micro flora was determined from plates bearing 20-200 colonies.

[0215] 7. Statistical Analysis

[0216] The main effects of storage interval and retail display period were examined statistically using analysis of variance (proc ANOVA, SAS Institute Inc., Cary, N.C.) at an a level of 0.05.

Results

[0217] a. Measurement of O₂ Concentration

[0218] The O₂ concentration was <100 ppm at initial packaging, and after any CAP storage interval it was reduced to 0 ppm, except after 8 weeks storage when 24 ppm of O₂ was measured in one bag.

[0219] b. Evaluation of Steaks

[0220] Although significant (p<0.05) differences existed between CAP storage intervals in visual color rating on day 0 of retail display, that is, when steaks were removed from storage, all steaks were perceived to be bright cherry red or slightly dark red and no differences of practical importance existed. Generally, steaks remained stable in color until they became extremely dark (FIG. 4A) or completely discolored (data not shown) on the fourth day of retail display for any storage interval. Due to a leak in the master pack, steaks were completely discolored on day 1 of retail display after 1 week of storage. These steaks were removed from retail display and not analyzed further.

[0221] On day 0 of retail display for any CAP storage interval, no significant (p<0.05) surface discoloration was reported on the steaks. The retail display period significantly (p<0.05) increased the amount of surface discoloration on the steaks for any CAP storage interval. However, the steaks discolored at a faster rate than the unstored controls for all storage intervals, and were relatively extensively discolored (p<0.05). (FIG. 4B)

[0222] Steaks were extremely desirable in retail appearance on day 0 of retail display for any storage interval (p<0.05). Despite the fact that they deteriorated more rapidly in retail appearance than the unstored controls, they were still in the acceptable range (about 3.5) on the third day of retail display. (FIG. 4C)

[0223] From a practical perspective, steaks were perceived to have no off-odors on day 0 of retail display for any storage interval, however, significant differences existed between storage intervals with respect to off-odor intensity ratings (p<0.05). The maximum difference in ratings was 0.3 of a panel unit, which is of marginal practical importance. Even on day 4 of retail display, only slight off odors were reported. (FIG. 4D) Generally, odor of steaks was acceptable on day 0 of retail display. (FIG. 4E) Maximum differences of 0.3 of a panel unit were noticed after 7 and 8 weeks of CAP storage, which has little practical significance. Despite significant (p<0.05) differences between storage intervals on odor acceptability ratings of day 4 of retail display, all steaks were perceived to be slightly acceptable. (FIG. 4E)

[0224] Despite differences (p<0.05) between CAP storage intervals on microbial numbers at day 0 of retail display, steaks had <10⁵ cfu/cm² of total organisms, and no differences of practical importance existed. In most cases, microbial numbers were comparable with those of unstored controls. (FIG. 4F) On day 4 of retail display, microbial numbers were <10⁴ cfu/cm² in all cases. (FIG. 4F) When opened, meat-cuts in master-bags containing 0.4% CO bloomed quickly when compared with meat-cuts in master-bags containing 100% nitrogen.

[0225] e. Discussion

[0226] Centrally prepared retail beef cuts stored in controlled atmospheres containing nearly 100% carbon dioxide (CO₂) or nitrogen (N₂), which may have small amounts of residual O₂, are susceptible to the formation of metmyoglobin due to the presence of the residual O₂. If the O₂ concentration is not excessive, the meat tissue will metabolize some of the residual O₂ and any metmyoglobin formed will be reduced to deoxymyoglobin as a result of metmyoglobin reducing activity (MRA) within the muscle tissue.

[0227] In packaged fresh beef, 2-4 days are required for reduction of metmyoglobin to deoxymyoglobin. When stored meat is removed from the controlled atmosphere, it blooms to the desirable, bright red color associated with freshly cut meat, but this will not occur if a substantial amount of metmyoglobin is present. The MRA of muscle tissue is limited in stability and once exhausted is not available to convert metmyoglobin back to deoxymyoglobin.

[0228] To overcome this disadvantage and address the issue of transient discoloration during CAP storage of fresh beef, the present work was undertaken to combine the efficacies of CAP storage of fresh beef and O₂ absorbent technology and demonstrate the shelf life extension of retail-ready fresh beef under these conditions. Tenderloins are known to have very poor color stability and discolor
rapidly even at very low O₂ concentrations and at a storage temperature of −1.5±0.5° C. The effect of intermuscular differences on color stability adds another variable that complicates continuous prevention of meat discoloration. Biochemical factors, such as oxygen consumption rate (OCR) and MRA, have been reported to be different for different muscles. Therefore, the system was tested using a beef muscle type that had poor color stability and represented a worst-case challenge for centralized meat operations.

[0229] The performance of O₂ absorbent technology was also put on test during this study for its ability to prevent transient discoloration by rapidly reducing the residual O₂ concentration to essentially 0 ppm, and thereby preserving the limited MRA of muscle. Retained MRA may further enhance retail display life of steaks. It is also true that steaks packaged with an optimum O₂ absorbing capacity have more retail display life when compared with steaks packaged without such capacity. Thus, the system used in the present study was believed to have the capability to provide solutions for the major problems of residual O₂ concentrations encountered in centralized fresh meat distribution.

[0230] For all CAP storage intervals, the steaks had acceptable visual, odor, and flavor scores on day 0 of retail display. Additionally, metmyoglobin content and microbial growth were minimal and in some cases even lower than in fresh controls on the day packs were opened and displayed. Along with a low storage temperature of −1.5±0.5° C., an important factor influencing microbial content was low initial microbial load. Beef tenderloins were used in the study, and these muscles are internally located and do not undergo much handling by meat-cutters as compared to other cuts. This protects them to some extent from cross-contamination, and hence yields low initial microbial load. The meat cuts used in the present study had very low initial bacterial numbers, which would have delayed onset of spoilage levels of microorganisms, and thus may have reduced the occurrence of off-odors. It was not surprising that microbial growth and odor did not limit CAP storage and retail display life of steaks.

[0231] Due to the increased solubility of O₂ and reduction in the partial pressure of O₂ required for maximal metmyoglobin formation at sub-zero temperatures, maximum discoloration occurred several millimeters below the meat surface. Since meat is translucent, such discoloration is normally visible. The deeper in the tissue metmyoglobin occurs, the lower is its visibility, and this resulted in low levels of discernable discoloration and higher retail appearance scores during retail display. Also, use of optimum O₂ absorbing capacity in each retail tray prevented transient discoloration of beefsteaks, which probably retained MRA and delayed discoloration further. Prevention of such transient discoloration has been reported above. The combination of these hurdles resulted in reduced discoloration even on day 3 of the retail display period. Since the bright-red color of meat was restored, the steaks received acceptable retail appearance scores on day 3 of retail display for any CAP storage interval, after which the meat was in an unacceptable range. Thus, visual characteristics seem to be the limiting factor for acceptability of steaks.

[0232] Steaks had a slight off-flavor on day 0 of retail display after 8 weeks CAP storage and onwards. Considering the intrinsic variability in meat cuts, such slight deterioration of flavor and odor may be of no practical importance.

[0233] The relative success of the system used in the present study is noteworthy considering the poor color stability of PM muscle. The system is able to deliver longer CAP storage with longer subsequent retail display life if beef muscles with higher color stability are used. It can be conservatively concluded that the present system has the capability of providing a 10 week CAP storage life with a subsequent 3 day retail display life for centrally prepared beef tenderloin steaks. Master-bags filled with 0.4% CO will certainly need oxygen scavengers placed outside the meat-trays.

EXAMPLE 5

Shelf Life Extension of Lamb Chops Utilizing Zero-Oxygen Tech

[0234] 1. Master-Packaging, Storage, and Sampling of Steaks

[0235] Fresh lamb primal cuts from animals slaughtered 24 hours previously, were obtained from a lamb abattoir. Eighty chops of 2-cm thickness were prepared from these cuts. Each chop was placed on an absorbent pad and a foam tray, with O₂ scavengers having an absorption capacity of at least 10 cc (e.g. 10 mL) per pound placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable O₂ permeable film with an O₂ transmission rate of 8000 mL per m² per 24 hours at 23° C., 70% relative humidity, and atmospheric pressure. After sealing, the film was shrink to the tray using a hot-air gun. One 3-mm hole was made at the opposite corners of the tray. Four such retail trays were placed in a master pack with O₂ transmission rate of 0.55 mL per m² per 24 hours at 23° C., 70% relative humidity, and atmospheric pressure. Master bags containing O₂ scavengers outside the meat trays and inside the master bag were also prepared.

[0236] The bags were evacuated, filled with 4.5 L. of N₂ and sealed using a CAP machine. Ten such bags were prepared. Similarly, ten such packages were prepared by using plastic trays instead of foam trays. During initial packaging, the O₂ concentration was measured in every fifth bag by using an O₂ analyzer (Mocon MS-750, Modern Controls Inc., Minneapolis, Minn.), which uses a solid state O₂ ion conduction material, zirconium oxide. The O₂ analyzer had an accuracy of ±0.05% in the 0 ppm to 1000-ppm range, ±0.05% in the 0.1% to 10% range, and ±0.1% in the 10% to 100% ranges for O₂ concentrations. The resolution of the analyzer was smaller than the accuracy; that is, in the 0 to 1000 ppm O₂ concentration range the resolution was 1 ppm.

[0237] The master packs were stored at −1.5° C. Two master packs (one containing foam trays and the other containing plastic trays) were opened at subsequent 1 week storage intervals for 8 weeks. The O₂ concentration in each bag was measured immediately before opening the bag. Master bags containing meat cuts and oxygen scavengers having oxygen absorbing capacity of at least 10 cc per pound of meats, placed only outside the meat-trays, were also prepared. The over-wrap film of the meat-trays had at least
one hole of less than 5 mm diameter. Such master-bags were flushed-back with a gas-mixture containing 64.6% Nitrogen, 0.4% CO, and 35% CO2.

[0238] 2. Display and Sampling of Retail Trays

[0239] Upon removal from primary CAP storage at weekly intervals, and on day 0 of retail display, master packaging was removed and each group of 8 retail trays was placed for sensory analysis. The displayed chops were examined for color, discoloration, retail-acceptability, off odor intensity, odor acceptability, and odor description, 20 min after opening of the master-packages. After visual and odor scores were obtained, two chops (one from each master bag) were removed from the display case, and samples were taken for microbial analysis. A similar procedure was repeated for all storage intervals.

[0240] 3. Visual Assessment of Master-Packaged Lamb Chops

[0241] A three-four-member panel was used for the subjective evaluation of the steaks. Color scores were assessed using an eight point descriptive scale: 0=Completely discolored, 1=White, 2=Pale pink, 3=Pink, 4=Red, 5=Bright cherry red, 6=Slightly dark red, 7=Moderately dark red, 8=Extremely dark red. Surface discoloration was evaluated using a seven point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7=100%. Retail appearance was assessed on a seven point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=Slightly undesirable, 4=Neither desirable nor undesirable, 5=Slightly desirable, 6=Desirable, 7=Extremely desirable.

[0242] 4. Odor Assessments of Master-Packaged Lamb Chops

[0243] A three to four-member panel was used for the odor assessment. Off odor intensity scores were assessed using a four point descriptive scale: 1=No off odor, 2=Slight off odor, 3=Moderate off odor, 4=Prevalent off odor; odor acceptability scores were assessed using a five-point scale: 1=Acceptable, 2=Slightly acceptable, 3=Neither acceptable nor unacceptable, 4=Slightly unacceptable, 5=Unacceptable; and off odor description scores were assessed using a six-point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=Other.

[0244] 5. Flavor Assessment of Master-Packaged Lamb Chops

[0245] The lamb chops were cooked the lamb chops after 27 and 55 days of storage for flavor assessment.

[0246] 6. Microbial Assessment

[0247] Analysis of the lamb chops, after weekly storage interval, for aerobic, anaerobic, E. coli, Listeria, and Salmonella was performed.

Results

[0248] a. Oxygen Concentration

[0249] The oxygen concentrations in the master packages were in the range of 0.5% immediately after packaging which went up to 2-5% within a few minutes of gas flushing and sealing. The oxygen concentration was reported to be 0 for each weekly storage interval.

[0250] b. Visual, Odor, Microbial and Flavor Assessment

[0251] The lamb chops had bright red to dark red color, zero to minimal discoloration, extremely acceptable appearance, and no off-odor for all the storage and display time intervals. (FIGS. 5C-1-5) The microbial load showed a gradual increase in the count, with no detrimental effect to the meat quality. Also, pathogen-growth were negative for all storage intervals. (FIGS. 5A-5B) The flavor was assessed to be extremely acceptable after 27 days of storage.

[0252] c. Discussion

[0253] The lamb chops were extremely desirable for all storage intervals and display periods. The testing showed no difference between chops packaged in plastic and foam trays with all having retail acceptability and no odor throughout the display period. (FIGS. 5C-1-5) No substantial difference in desirability was reported for lamb cuts in the master bags with O2 scavengers in meat trays or in master bags with O3 scavengers placed only outside the meat trays; i.e. in the master bags. It is believed this is due to preventing the myoglobin reducing activity of the muscle by absorbing the oxygen rapidly to zero levels. This enhances the display life of centrally prepared retail ready meat cuts. In addition, a nitrogen atmosphere provides an anaerobic atmosphere, and helps in reblooming of the meat once removed from the master package. When opened, meat-cuts in master bags containing 0.4% CO bloomed quickly when compared with meat-cuts in master-bags containing 100% nitrogen. Master bags filled with 0.4% CO will certainly need oxygen scavengers placed outside the meat-trays.

[0254] The zero oxygen packaging system for centralized meat operations extends the available display and storage times for the meat. A storage life of 8+ weeks with a subsequent display life of 4+ days was obtained for centrally prepared retail ready lamb chops by employing zero oxygen storage.

EXAMPLE 6

Shelf Life Extension of Pork Chops by Employing “Zero Oxygen Packaging System”

[0255] 1. Master Packaging of Pork Chops

[0256] Fresh pork loins from animals slaughtered 24 hours previously, were obtained from a local beef abattoir. One hundred and twenty chops of 2 cm thickness, were prepared from these porkloins. Each pork chop was placed on a 152x114 mm absorbent pad in a 216x133x25 mm (LxWxH) solid polystyrene tray with O2 scavengers of O2 absorption capacity of at least 10 mL per pound of meat placed underneath the chop. Master bags where O2 scavengers were placed only outside the meat trays were also prepared. Each retail tray was over-wrapped with a shrinkable O2 permeable film with an O2 transmission rate of 800 mL/m2 per 24 hours at 23° C., 70% relative humidity, and atmospheric pressure. After sealing, the film was shrunk to the tray using a hot-air gun. Then, two 3-mm holes were made at the opposite corners of the tray to allow free exchange of atmospheres during gas flushing. Four such retail trays were placed in an EVA co-extruded master pack with O2 transmission-rate of 0.55 mL/m2 per 24 hours at 23° C., 70% relative humidity, and atmospheric pressure. The bags were evacuated, filled
with 4.5 L of N₂, and sealed using a CAP machine. Thirty such bags were prepared. An additional 8 retail trays were prepared and treated as un-stored controls.

[0257] The master packs were stored at -1.5±0.5°C. On week 0 and day 0 of retail display, four steaks in retail trays, serving as fresh, un-stored controls, were analyzed for visual, odor, taste, and microbial characteristics. The visual analysis was done daily for 6 days. On day 6 of retail display, odor, taste, and microbial analyses were done in addition to visual examination. Two master packs were opened at subsequent 1 week storage intervals for 15 weeks. The O₂ concentration in each bag was measured immediately before opening the bag. Master bags containing meat cuts and oxygen scavengers having oxygen absorbing capacity of at least 10 cc per pound of meats, placed only outside the meat-trays, were also prepared. The over-wrap film of the meat-trays had at least one hole of less than 5 mm diameter. Such master-bags were flushed-back with a gas-mixture containing 64.6% Nitrogen, 0.4% CO₂, and 35% CO₂.

[0258] 2. Display and Sampling of Retail Trays

[0259] Upon removal from primary CAP storage at weekly intervals, and on day 0 of retail display, master packaging was removed and each group of 8 retail trays was placed in the center of the display shelf. The displayed pork chops were examined for color, discoloration, retail-acceptability, off odor intensity, odor acceptability, and odor description, 45 min after opening of the master-packages.

[0260] After visual scores were obtained, two chops (one from each master bag) were removed from the display case, and samples were taken for microbial analysis. The remaining six chops were left in the display case, and were examined for visual characteristics at subsequent intervals of 24 hours and reflectance spectra at 12 hours for 96 hours. After 144 hours of retail display, the chops were analyzed in a similar fashion as on day 0 of retail display. During sensory evaluation, the samples remained in the display case and the well-trained panelists made judgments independently. A similar procedure was repeated for all storage intervals.

[0261] 3. Visual Assessment of Master-Packaged Chops

[0262] A five-member panel was used for the subjective evaluation of the steaks. Color scores were assessed using a five-point descriptive scale: 0=Completely discolored, 1=Extremely pale, 2=Pale, 3=Normal, 4=Dark, 5=Extremely dark. Surface discoloration was assessed using a seven-point descriptive scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7=100%. Retail appearance was assessed on a seven-point hedonic scale: 1=Extremely undesirable, 2=Undesirable, 3=SLightly undesirable, 4=Neither desirable nor undesirable, 5=SLightly desirable, 6=Desirable, 7=Extremely desirable.

[0263] 4. Odor Assessments of Master-Packaged Chops

[0264] A five-member panel was used for the odor assessment. Off odor intensity scores were assessed using a four-point descriptive scale: 1=No off odor, 2=SLight off odor, 3=Moderate off odor, 4=Prevalent off odor, odor acceptability scores were assessed using a five-point scale: 1=Acceptable, 2=SLightly acceptable, 3=Neither acceptable nor unacceptable, 4=SLightly unacceptable, 5=Unacceptable; and off odor description scores were assessed using a six-point scale: 1=Sour-sulfur (rotten eggs), 2=Sour-lactic acid, 3=Putrid, 4=Dirty socks, 5=Floral/Fruity, 6=other.

[0265] 5. Microbial Analysis

[0266] A 10 cm² sample was obtained at each sampling time (on day 0 and 4 of each storage interval) from each of the two chops using a sterile cork borer. Then, the sample was placed into a stomacher bag with 10 mL of 0.1% peptone solution and was massaged for 120 seconds using a commercial stomacher, yielding a dilution of 10⁻⁶. The homogenate was further diluted 10⁻¹, 10⁻², 10⁻³, 10⁻⁴, 10⁻⁵, and 10⁻⁶-fold, after which 0.1 mL volumes of undiluted homogenate and of each dilution were prepared and the spread on duplicate plates of APT. The plates were incubated aerobically for 3 days at 25°C. The micro flora was determined from plates bearing 20-200 colonies. (FIG. 6F)

Results

[0267] a. Measurement of O₂ Concentration

[0268] The O₂ concentration was 5% at initial packing, and after a CAP storage interval it was reduced to 0 ppm. The oxygen concentration was down to 0 ppm within three hours of master pack closure.

[0269] b. Evaluation of Chops

[0270] A storage life of at least 15 weeks and a retail display life of at least six days for pork chops packaged by employing "zero oxygen packaging systems approach" were obtained. (FIGS. 6A-6F) When opened, meat-cuts in master-bags containing 0.4% CO₂ bloomed quickly when compared with meat-cuts in master-bags containing 100% nitrogen. Master bags filled with 0.4% CO₂ will certainly need oxygen scavengers placed outside the meat-trays.

[0271] It is interesting to note that the visual and microbial characteristics of the pork chops remained in an acceptable condition even after such a long storage in cooler and at retail display case.

Demonstrated Principles

[0272] 1. Metmyoglobin reducing activity is capable of being restored provided the oxygen concentration in the master package which contains meat cuts is reduced to zero ppm within a few hours of sealing the package.

[0273] 2. Oxygen absorption kinetics by an oxygen scavenger is bi-phasic where the rate of oxygen absorption varies with the initial oxygen concentration.

[0274] 3. Pre-treating the oxygen scavengers by moisture causes faster activation.

[0275] 4. Oxygen scavengers based on an iron chemical system can be effectively utilized to reduce the oxygen concentration in the master bag.

[0276] 5. The oxygen half-life will be dependent upon the initial oxygen concentration in the package and the ambient temperature.

[0277] 6. The permeability of packaging films having very high oxygen ingress rate is significantly reduced at sub-zero temperatures where the films act as an oxygen barrier.

[0278] Included within the scope of the present invention and the abovementioned examples are compositions comprising various combinations of these substances and mate-
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[0279] The present invention finds specific industrial applicability in the meat distribution and retail industries. The automated machine disclosed herein used to package meat cuts achieves zero oxygen packaging in a central packaging facility for master bag storage and retail display. The storage and display times are significantly increased using the system.

[0280] FIG. 7 shows the basic steps employed in the invention organized in to four separate procedures or processes. Steps 705-715 comprise the first procedure of determining the capacity of the O₂ scavenger to use. Step 720 comprises the second procedure of determining placement of the O₂ scavenger. Steps 725-735 is the third procedure of packaging, and steps 740-750 are the fourth procedure of storage and display of the meat.

[0281] For determining the half-life process, in step 705, the master bag is selected and prepared. The master bag must exhibit low oxygen transmission-rates, preferably <10 cc/m²/day at 23°C. Typically, this will require a master bag composed of high oxygen barriers films such EVOH or foil, and the master bag must have good seal-strength.

[0282] The oxygen permeability of the bag must also be established. A master bag is filled with the appropriate quantity of 100% nitrogen (or any other inert gas) or a combination of >50% nitrogen (or other inert gas) plus other non-inert gases (e.g. CO₂ and/or CO or other gases) and then the residual O₂ level in the bag is measured immediately after sealing, three hours after sealing, and 24 hours after sealing using different sampling sets of bags for each measurement.

[0283] In step 710, residual O₂ concentration in the bag is taken into consideration and an appropriate Arrhenius equation is used to calculate the half-life of oxygen in the master bag, and an appropriate O₂ scavenger with an optimum capacity is designed or selected. In step 715, the O₂ scavenger is chosen. The scavenger chosen must have sufficient capacity (10 cc-1000 cc) to rapidly absorb the O₂ to the required low level and achieve a zero oxygen storage atmosphere within 24 hours of sealing the master bag. The O₂ scavengers must also self-activate in the presence of O₂ at >60% relative humidity (caused by the fresh meat cuts).

[0284] Besides the half-life of residual O₂ concentration in the bag, an important consideration is the type of meat cuts. Beef and lamb/veal muscles, especially tender loins, have very poor color-stability, and metmyoglobin formation, with the concurrent discoloration, has the highest rate for these muscle-types. Hence, a very fast oxygen scavengers (capable of working at 0-4°C) with an optimal capacity of 10-1000 cc (e.g. 10-1000 mL) per pound of meat (depending upon the location of meat muscle, i.e., loins, ribs, etc.) is desired in a master bag with residual oxygen concentration of less than 5%. Also, placement of the O₂ scavengers should be close to the meat cuts to avoid any discoloration due to oxygen-entrapment.

[0285] Pork, on the other hand, has relatively very high color stability. Fast oxygen scavengers (capable of working at 0-4°C) with an optimal capacity of 10-500 cc (e.g. 10-500 mL) per pound of meat is desired in a master-bag with residual oxygen concentration of less than 5%. For pork products, oxygen scavengers can be placed outside the meat-trays within the master bag. For other meats (e.g. beef, lamb, and veal), the oxygen scavengers can either be inside the meat trays, or inside the master bag and outside the meat trays, depending on the muscle type. In either case, oxygen permeability of the meat trays must be sufficient for residual trapped oxygen to diffuse out of the meat trays.

[0286] The primary consideration is to have fast-type oxygen scavengers with the capability to reduce oxygen concentrations to 0 ppm (zero oxygen level) within 24 hours of packaging closure. Optimal oxygen scavenging capacity is between 10 cc to 1000 cc (e.g. 10 mL to 1000 mL) per pound of meat-cuts in a master-bag having residual oxygen concentration of less than 5% and resulting in a half-life for oxygen ranging from 0.6 to 2 hours.

[0287] The desired oxygen scavengers is chemical-based, because enzyme-based scavengers have been shown to have low oxygen absorption rates as shown in the data presented in this and the earlier Ser. No. 10/434,010 application. Iron chemical systems, from the chemical group of ferrous and ferric ions, are the preferred oxygen scavenging materials. However, other chemical groups such as magnesium and copper can be used. The material used is finely granulated to a powdered form and its capacity is determined by the amount of powdered material placed inside a sachet. The preferred composition of the scavenger material follows:

[0288] iron (<25%, preferred range 15-20%)
[0289] carbon (<35%, preferred range 20-25%)
[0290] vermiculite (<20%, preferred range 10-15%)
[0291] deionized water (<10%, preferably 5%)
[0292] salt (preferably NaCl, <10%, preferably 5%)

[0293] The desired capacity of oxygen scavengers used ranges from 10 cc to 1000 cc per pound of meat packaged in a master bag. The exact capacity and half-life is calculated based on the Arrhenius equation found in patent application Ser. No. 10/434,010. The scavengers need to function in the temperature range of ~2.222° to 7.222°C. (28° to 40°F),

[0294] For the next procedure of determining placement of the O₂ scavenger, in step 720 placement of the O₂ scavenger depends primarily on the meat type. Depending on the meat-type, the O₂ scavenger can be placed inside the meat-tray or outside the meat-tray in the master bag. For beef and lamb cuts, placing the O₂ scavenger inside is usually considered optimal. However, O₂ scavengers can be placed outside the meat-trays provided one or more pin-holes are made in the over-wrapping film surrounding the meat-tray, each hole having a diameter of less than 5 mm. It is important for the film over-wrapping to allow exchange and diffusion of atmosphere, or more specifically oxygen, between the interior and exterior of the meat tray when sealed in the master bag.

[0295] For the third procedure of packaging the meat, in step 725 between 0.5-4.0 lbs of meat are placed on appropriate trays. Conventional foam trays can be used in the packaging. Tests performed using foam and plastic trays, both over-wrapped and lidded, showed no substantial difference.
In step 730, the meat trays are over-wrapped for eventual display in a meat case. The over-wrapping film must have high oxygen transmission rates on the order of >8000 cc/m2/24 hours at 23°C. At least one pin-hole of <5 mm diameter must be made on the over-wrapping film that wraps the meat-trays to prevent oxygen entrapment inside the meat-trays or allow diffusion out of oxygen entrapped within the meat-trays (e.g. depending on whether the O2 scavengers are located inside the tray or the master bag). The pin-holes are required because despite the permeability of the film, the film still acts as an oxygen-barrier, and oxygen molecules become entrapped within the meat-tray causing discoloration to the meat. However, for pork, the pin-holes can be eliminated. This diffusion action permits trapped oxygen to diffuse outside the tray and be absorbed by oxygen scavengers outside the tray, or conversely for residual oxygen trapped in a master bag lacking oxygen scavengers to diffuse into a tray for absorption by scavengers within a meat tray.

In step 735, single or multiple meat trays are placed into a master bag, which will include an O2 scavenger of appropriate O2 absorbing capacity. The master bag is gas-flushed (single or multiple flushings either with or without a vacuum to aid removing oxygenated air) using either 100% N2 or >50% N2 and the balance with CO2, CO2 and other trace amounts of non-oxygen gases (e.g. He, H2, H2O, etc) to achieve a residual O2 concentration of less than 5% inside the master bag. The N2 atmospheric content preferably ranges between 50%-100%. A small percentage of CO (<5%) will aid in retaining color of the meat. The preferred CO content ranges between 0.1% to 5%. After the desired gas mixture is injected into the bag, it is sealed and the oxygen scavengers, both inside and outside the trays, absorb any residual oxygen.

The fourth procedure includes steps required for storage and distribution for display. In step 740, the master bags are placed in storage under temperatures in the range of 0°C to –2.2°C. In step 745, the meat is distributed to appropriate grocers or grocer distribution centers with storage maintained under 40°F. Meat can be maintained in this storage and distribution packaging for up to 15 weeks depending on the type of meat. In step 750, the meat is removed from the master bags and placed in meat displays at the appropriate grocer under temperature conditions >0°C, typically up to nine days.

FIG. 8 shows the arrangements of the elements of a meat tray for one embodiment for a meat tray. The tray 705 can be constructed from any acceptable, standard material commonly used for meat trays, preferably styrofoam. The over-wrap 710 likewise can be made from any conventional oxygen permeable plastic wrapping film. In this embodiment, the meat 715 is placed on top of and in direct contact with the oxygen scavenger sachet, with an absorbent pad 725 placed underneath the oxygen scavenger. FIG. 9 shows another embodiment. The meat tray 805 is covered by the plastic over-wrap 810. However, in this embodiment the meat 815 is placed on top of and in direct contact with the absorbent pad 820. The oxygen scavenger sachet 825 is placed underneath the absorbent pad 820. For both of these embodiments, oxygen scavenger sachets used attain enough absorption capacity to achieve an O2 half-life of between 0.6 to 2.0 hours. It is preferred that the oxygen absorption capacity be at least 10 mL per pound of meat and attain a zero oxygen storage atmosphere within 24 hours of packaging.

FIG. 10 shows an embodiment for a master bag containing meat trays with the oxygen scavengers only found inside the meat trays sealed in the master bag. The master bag 905 will contain one or more meat trays 910. The atmosphere within the master bag 905 is flushed of oxygen and injected with a non-oxygen gas consisting primarily of 100% nitrogen or a nitrogen-rich (>50% nitrogen) gas mixture before sealing. FIG. 11 shows an embodiment of a master bag containing a cut of primal or sub-primal meat.

O2 scavengers placed inside the master bag, typically possess O2 absorbing capacity of ≥10 mL/lb (e.g. ≥10 mL/lb) of meat. In this embodiment, the master bag 1005 contains cuts of unwrapped primal or sub-primal meat 1010. The master bag 1005 is flushed of oxygen and injected with a non-oxygen gas consisting primarily of 100% nitrogen (or any other inert gas) or a combination of >50% nitrogen (or other inert gas) plus other non-inert gases (e.g. CO2 and/or CO or other gases) before sealing.

Oxygen scavenger sachets 1015 with appropriate capacity are added to the master bag 1005 before sealing having a total oxygen absorbing capacity of ≥10 mL per pound of meat to achieve an O2 half-life of between 0.6 to 2.0 hours. FIG. 12 shows another embodiment where meat trays and oxygen scavengers are sealed in a master bag. The master bag 1105 contains a plurality of meat trays 1110. Oxygen scavenger sachets 1115 are included inside the master bag 1105 before the master bag 1105 is flushed, injected with the desired gas mixture, (100% nitrogen, nitrogen-rich (>50% nitrogen) with balance of CO2 and CO), and then sealed.

The invention also includes the apparatus used for packaging the master bags. The apparatus consists of horizontal form-fill-seal equipment designed to provide an integrated packaging system for retail-ready meat cuts in meat trays or primal or sub-primal meat cuts of the appropriate size. The preferred maximum size of product packaged by the machine is 28 inches long, 18 inches wide, and 6 inches high. The equipment should be constructed of stainless steel to facilitate cleaning. FIG. 13 shows a basic schematic of the packaging system using the machine.

In the machine schematic of FIG. 13, meat trays 1205 of the preferred maximum size are fed into the apparatus using a conveyor system 1207 powered by a servo motor that moves the meat trays 1205 through the apparatus. For most meat packaging applications, the appropriate oxygen scavenger sachets 1210 will be placed inside the meat tray and outside the meat tray inside the master bag, but for some chosen applications other placement configurations may be used (e.g. scavengers in meat tray only, scavengers outside meat tray only, or no scavengers). A pin-hole of ≤5 mm should be punched in the over-wrap of the meat tray, or multiple holes to facilitate diffusion of trapped oxygen from the retail meat trays.

The meat trays 1205 enter a folding box 1211 which constructs the master bags. One or more 1205 meat trays enter the folding box 1211, which is supplied with the master bag material by a film pulley system 1212 supplying bag film material 1214 from a continuous sheet of material
wrapped onto a roller system 1213. The folding box 1211 folds the fed master bag film material 1214 around the meat trays 1205 to form the master bag by heat-sealing the edges together to form a master bag. Alternatively, the continuous sheet roller system 1213 may consist of a number of prefabricated master bags coupled together by perforations so as to be easily separated and opened by the folding box 1211.

[0306] As the forming master bag passes through the folding box, a wrapper pre-heating mechanism 1215 heats the material to help shrink it onto the meat trays 1205, before reaching a set of propelling and sealing rollers 1216 that seal the end of the master bag. During this process, between the mechanisms of 1215 and 1216, simultaneously with the formation of the master bag, gas flushing is performed to evacuate air out of the master bag while the desired gas mixture is injected. The gas flushing can include applying a vacuum to the master bag to help evacuate ambient air from the master bag.

[0307] The gas mixture is supplied from a gas supply tank 1220 containing pre-mixed gases supported above the conveyor system by a support rack 1217, or the gas can be supplied from multiple tanks, or gas lines leading to an exterior tank of pre-mixed gases. Gas is supplied through a gas supply line 1218, with gas flow regulated by a solenoid valve 1219. The gas tank includes warning devices 1221 that can include pressure, temperature, and composition sensors. It is contemplated that two gas supply lines will flow into the tank. A nitrogen gas line 1222 will supply pure N₂ to the gas tank, and may include a bypass to feed directly into the gas supply line 1218 into the apparatus. The N₂ supply line will provide all the nitrogen for the system, and this nitrogen gas flow may be in a gaseous or liquid state, preferably gaseous as cryogenic temperatures of liquid nitrogen can be problematic and would needlessly complicate the system without any real benefit. The other gas line will supply the mixture of other gases chosen by the user of the system (CO₂, CO, etc.).

[0308] Alternatively, each gas type may use its own gas supply line, but it is contemplated that the gas feed for the other gases will be in a gaseous state and a safety valve 1223 is provided on this gas supply line 1224 for venting in the even that the pressure rises to an unsafe level inside the tank 1220. The preferable gas mixture for most meat packaging will be composed of >50 N₂ and <5% CO and the balance of the mixture CO₂. A safety system may be required for monitoring with these gas mixtures containing CO and CO₂, which can be dangerous at relative low concentrations (e.g. over 50 ppm for CO gas and over 5,000 ppm for CO₂).

[0309] The sides of the master bag are heat-sealed before gas flushing and the ends of the master bag are heat-sealed by a cross-reciprocating seal mechanism utilizing a specific dwell time, speed, pressure, and temperature. A servo motor controls the cross-reciprocating seal. The parameters (speed of the conveyor and cross-sealing speed) depend on the size of the master bag. All of the functional components such as the servo motor, conveyor speed, cross-sealing speed, gas mixture control, bag sizing, and other similar functions, are preferably controlled by a Pentium-based computer control system operated by a windows style touch screen. At the end of the process, a master bag 1226 containing meat trays or primal cuts of meat is produced containing a desired gas mixture reduced to zero oxygen content for long-term storage of the meat cuts.

[0310] While the invention has been particularly shown and described with respect to preferred embodiments, it will be readily understood that minor changes in the details of the invention may be made without departing from the spirit of the invention. Having described the invention, I claim:

1. A packaging system for minimizing meat discoloration comprising:

   a. An apparatus comprising:
      a. A retail meat tray comprised of a tray with one or more oxygen scavenger sachets and an absorbent pad overwrapped with a gas permeable plastic-based film permitting atmosphere exchange between the interior and exterior of the meat tray, said oxygen scavenger sachets containing an iron-based oxygen absorbing material self-activated in an atmosphere of greater than 70% relative humidity;
      b. A sealed master bag containing at least one retail meat tray, said master bag flushed prior to sealing to remove oxygenated air from the interior of the bag to obtain an initial atmosphere equal to or less than 5% oxygen and injected with an oxygen-free, inert gas comprised of greater than 50% inert gas; and
      c. An oxygen absorption capacity of the oxygen scavenger sachets sufficient to achieve a half-life for the 5% residual oxygen of equal to or less than 2.0 hours and reach a zero oxygen storage atmosphere within 24 hours of sealing said master bag.

2. The packaging system for minimizing meat discoloration of claim 1, wherein the oxygen scavenger sachets comprise:

   a. A porous bag with an active surface area of between 4 to 64 square inches and porosity levels ranging from 20 to 120 gurly per second;
   b. Chemical granules ranging from 0.001 mm to 1.5 mm in diameter; and
   c. A total weight of absorbing chemical of between 1 gram to 300 grams.

3. The packaging system for minimizing meat discoloration of claim 2, wherein the chemical granules comprise:

   a. Chemicals less than 25% iron;
   b. Chemicals less than 35% carbon;
   c. Chemicals less than 20% vermiculite;
   d. Chemicals less than 10% de-ionized water; and
   e. Chemicals less than 10% NaCl salt.

4. The packaging system for minimizing meat discoloration of claim 3, wherein the chemical granules comprise less than 10% zeolites.

5. The packaging system for minimizing meat discoloration of claim 1, wherein all the oxygen scavenger sachets sealed within the master bag obtain an absorption capacity of at least 10 mL per pound of meat.

6. The packaging system for minimizing meat discoloration of claim 1, wherein the injected gas comprises nitrogen as the inert gas.
7. The packaging system for minimizing meat discoloration of claim 1, wherein the injected gas comprises less than 5% carbon monoxide.

8. The packaging system for minimizing meat discoloration of claim 1, wherein the injected gas comprises:

- greater than 50% inert gas;
- less than 5% carbon monoxide; and
- carbon dioxide.

9. The packaging system for minimizing meat discoloration of claim 1, wherein the master bag comprises oxygen scavengers placed outside the meat trays.

10. A method for packaging meat to minimize meat discoloration from formation of metmyoglobin comprising the steps of:

- packing a master bag with at least one retail meat tray or a primal or sub-primal cut of meat, said master bag constructed of a material exhibiting gas permeability for oxygen of less than 10 mL/m²/24 hours at 23°C and including oxygen scavenger material self-activated in an atmosphere of greater than 70% relative humidity to reduce the oxygen half-life within said master bag to two hours or less after sealing, achieving a zero oxygen storage atmosphere within 24 hours after sealing, and able to function at a temperature range of between 28°C and 40°F;
- flushing said master bag with a non-oxygen gas to reduce the residual oxygen level within said master bag to 5% or less and injecting an oxygen-free gas mixture containing carbon monoxide into the bag prior to sealing said master bag; and
- storing said master bag at a temperature of between 28°C and 32°C.

11. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 10, further comprising the step of:

- flushing retail cuts of meat in a retail meat tray comprising a tray with an oxygen scavenger contained in a porous sachet and an absorbent pad over-wrapped with a gas permeable plastic-based film perforated by one or more holes.

12. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 11, wherein the meat tray is arranged in the order of the oxygen scavenger sachet on the bottom, the absorbent pad in the middle, and the meat on top.

13. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 11, wherein the meat tray is arranged in the order of the absorbent pad on the bottom, oxygen scavenger sachet in the middle, and the meat on top.

14. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 10, further comprising the step of:

- injecting a gas mixture into the master bag comprised of between 0.1% and 5% carbon monoxide, between 35% and 39% carbon dioxide, and between 56% and 64.9% nitrogen.

15. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 10, further comprising the step of:

- providing oxygen scavengers sealed in the master bag with a total absorption capacity of between 10 mL and 1000 mL of oxygen per pound of meat inside the master bag.

16. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 10, further comprising the step of:

- injecting a gas mixture into the bag comprising between 0.1% and 5% carbon monoxide and between 50% and 99.9% nitrogen.

17. The method for packaging meat to minimize meat discoloration from formation of metmyoglobin of claim 10, wherein the oxygen scavengers comprise:

- between 15% to 20% iron;
- between 20% to 25% carbon;
- between 10% and 15% vermiculite;
- between 5% and 10% de-ionized water;
- between 5% and 10% NaCl salt; and
- between 0% and 10% zeolites.

18. A method for packaging meat for long-term storage, comprising:

- packaging meat cuts, inside or outside of a retail meat tray, inside a sealed master bag used for storage and transport;
- flushing oxygenated air from the master bag to obtain an initial atmosphere containing less than 5% residual oxygen;
- injecting into said master bag a nitrogen gas rich mixture of greater than or equal to 50% nitrogen and further comprising between 0.1% and 5% carbon monoxide;
- sealing said master bag, which contains oxygen scavengers for absorbing the residual oxygen with an absorption capacity of between 10 mL and 1000 mL per pound of meat sealed within the master bag and sufficient for a residual oxygen half-life of less than or equal to 2.0 hours that reduces the residual oxygen level to 0 ppm within 24 hours of sealing; and
- storing said master bag at a temperature of between 28°C-32°C.

19. The method for packaging meat for long-term storage of claim 18, wherein the oxygen scavenger comprises:

- less than 25% iron;
- less than 35% carbon;
- less than 20% vermiculite;
- less than 10% de-ionized water; and
- less than 10% NaCl salt.

20. The method for packaging meat for long-term storage of claim 18, wherein the oxygen scavenger comprises:

- between 15% to 20% iron;
- between 20% to 25% carbon;
- between 10% and 15% vermiculite;
- between 5% and 10% de-ionized water;
- between 5% and 10% NaCl salt; and
- between 0% and 10% zeolites.
21. A method for packaging meat in a zero-oxygen storage environment, comprising:

packaging meat cuts on meat tray having a gas-impermeable film sealed over the top of the meat tray;

sealing said meat tray in a high nitrogen gas rich environment minimizing trapped oxygen to no more than 5% residual oxygen;

sealing within said meat tray an oxygen scavenger for absorbing residual oxygen with an absorption capacity of between 10 mL and 1000 mL per pound of meat sealed within the meat tray and sufficient for a residual oxygen half-life of less than or equal to 2.0 hours that obtains a zero-oxygen storage environment within 24 hours of sealing; and

storing said meat tray at a temperature of between 28°-32° F.

22. The method for packaging meat in a zero-oxygen storage environment of claim 21, wherein the meat tray further comprises an absorbent pad sealed within.

23. The method for packaging meat in a zero-oxygen storage environment of claim 21, wherein the nitrogen gas rich environment is 100% nitrogen.

24. The method for packaging meat in a zero-oxygen storage environment of claim 21, wherein the nitrogen gas rich environment comprises:

   at least 50% nitrogen;

   between 0.1% and 5% carbon monoxide; and

   carbon dioxide.