Prevention of Transient Discoloration of Beef

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ABSTRACT: Oxygen absorbent technology in conjunction with controlled atmosphere packaging(CAP) was used to prevent transient discoloration in master-packaged beef steaks. Two types of commercial O_2 scavengers were used in the study. The master packs were stored at 1± 0.5 °C. The steaks from master packs were presented in a display-case for visual evaluation. Reflectance spectra from each steak-surface were obtained to estimate metmyoglobin content. Steaks packaged without O_2 scavengers showed more discoloration, and had significantly higher proportions of metmyoglobin when compared to steaks with O_2 scavengers, after most storage intervals ($p < 0.05$). Prevention of metmyoglobin formation was influenced by the number but not the type of O_2 scavenger employed ($p > 0.05$).

Keywords: oxygen scavengers, centralized meat operations, transient discoloration

Introduction

CENTRALIZED PACKAGING OF RETAIL MEAT CUTS IS BECOMING of greater interest to the retail sector and meat industry because of its economic advantages, ability to maintain quality and safety, and potential to extend shelf life (Farris and others 1991). Although substantial research has been completed on the microbiological and sensory aspects of meat during centralized meat packaging under various modified atmospheres (Gill and Jones 1994a, b, 1996; Jeremiah and Gibson 1997a, b, c; Tewari and others 1999), transient color instability of centrally prepared retail beef cuts remains to be resolved. Color deterioration of fresh meat is the most important factor limiting its storage life (Shay and Egan 1986, 1990). Its color is dependent on the oxidation state of the muscle pigment myoglobin and metmyoglobin is the major pigment responsible for meat discoloration (Penney and Bell 1993). Centrally-prepared retail beef cuts stored in controlled atmospheres containing nearly 100% carbon dioxide (CO_2) or nitrogen (N_2) can be susceptible to the formation of metmyoglobin, if there is any residual O_2 present (Ledward 1970; Gill 1989; Gill and Jones 1994a). If the O_2 concentration is not excessive, the meat will absorb the residual O_2 and any metmyoglobin formed will be reduced to deoxymyoglobin as a result of metmyoglobin reducing activity (MRA) within the muscle tissue (O'Keeffe and Hood 1980-81a, b, 1982). Gill and Jones (1994a) reported that in packaged fresh beef 2-4 d are required for this reduction to occur. 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 (Gill 1990). The MRA of muscle tissue is limited and once exhausted cannot convert any metmyoglobin formed back to myoglobin (Gill 1991).

Transient discoloration of meat is not a major concern when the product is in storage, transit, or both for periods longer than 2 d (Gill and McGinnis 1995a). However, such discoloration can be problematic when commercial conditions require rapid distribution and display of product. Centrally prepared beef steaks and ground beef packaged under controlled atmospheres were shown to be susceptible to very low O_2 concentrations (Gill and Jones 1994a, b). Gill andMcGinnis (1995a) reported that *longissimus dorsi* (LD) samples stored at -1.5 °C for 48 h (O_2 concentrations < 400 ppm) showed lower metmyoglobin formation than when stored at other temperatures. In contrast, myoglobin in beef of low color stability (*psoas major*, PM) oxidized even at lower O_2 concentrations (< 100 ppm) irrespective of temperatures. The authors concluded that beef with high color stability (LD) was least susceptible to metmyoglobin formation if atmospheres contained < 600 ppm of O_2 at temperatures < 0 °C; however, beef with poor color stability (PM) was highly susceptible to metmyoglobin formation even at very low O_2 concentrations and sub-zero temperatures.

Transient discoloration may be prevented if O_2 absorbents are used in conjunction with controlled atmosphere packaging (CAP). Next to PM, ground beef is most sensitive to discoloration. To understand temporary degradation of ground beef color, Gill and McGinnis (1995b) performed an O_2 absorption kinetics study with a commercial O_2 scavenger and reported that they could prevent discoloration if large numbers were used in each pack to bring residual O_2 to < 10 ppm within 2 h at a storage temperature of -1.5 °C. However, this may not be commercially feasible. Numbers required might be reduced by more effective placement inside retail trays. In addition, there is a need to examine O_2 absorption kinetics of a variety of new scavengers available using low initial O_2 concentrations. These results would clarify controversy which exists in the literature regarding usefulness of O_2 scavengers in different meat packaging systems (Rousset and Renerre 1990; Sorheim et al. 1995a, b; Allen and others 1996; Doherty and Allen 1998). Therefore, we examined scavenger performance under the above conditions (Tewari and others 2000a) and during use in retail-packaging systems (Tewari and others 2000b) in our lab. Based on the results from these studies, additional work was initiated to prevent transient discoloration of PM steaks. The objective of this study was to determine whether O_2 absorbent technology might be used in conjunction with CAP to prevent inevitable transient discoloration of PM beef.

Materials and Methods

Oxygen scavengers

Ageless® FX-100 (Mitsubishi Gas Chemical Co. Inc., Tokyo, Japan) and FreshPax® R-2000 (Multisorb Technologies Inc., Buffalo, N.Y.,U.S.A.) O_2 scavengers were used in the study. Both O_2 scavengers have iron-based chemical reactions. Ageless® FX-100 requires moisture (> 70% relative humidity) for activation, which prevents O_2 absorption during handling in air, whereas FreshPax® R-2000 is self-activating as soon as it is exposed to air.

Master-packaging, storage, and sampling of steaks

Twenty fresh beef tenderloins (*psoas major*, PM) from animals slaughtered within 24 h, were obtained from a local beef-packing plant. Four 2- cm thick steaks were prepared from each tenderloin and were randomly distributed. Each steak was placed on an absorbent pad of dimensions 152 × 114 mm (MP-30620, Paper Pak® Corp., La Verne, Calif.,U.S.A.) in a 216 × 133 × 25 mm solid polystyrene tray (clear plastic tray # 2D, Western Paper & Food Distributors Ltd., Calgary, Alberta). Eight Ageless® FX-100 O_2 scavengers were placed underneath the absorbent pad. Each retail tray was over-wrapped with a shrinkable film having an O_2 transmission rate of 8000 mL/(m^2 24 h) at 23 °C and 70% r.h. (Vitafilm 'Choice Wrap', Goodyear Canada Ltd., Calgary, Alberta). After sealing, the film was shrink-wrapped 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 595 × 447 mm bimetalized, plastic laminate pouch (SecureFresh® Pacific Ltd., Auckland, NewZealand). The master packs were evacuated, filled with 4.5 L N_2, and sealed using a CAP machine (CAPTRON, SecureFresh Pacific Ltd., Auckland, New Zealand). Eight such master packs were prepared. Similarly, 8 master packs, each having 4 retail trays containing 2 FreshPax® R-2000 O_2 scavengers underneath the absorbent pads; and an additional 8 master packs, each containing 4 retail trays with no O_2 scavengers (controls), were prepared. Each pack was labeled accordingly. During initial packaging, the O_2 concentration was measured in every 5th master pack using an O_2 analyzer (Mocon MS-750, Modern Controls Inc., Minneapolis, Minn., U.S.A.). The analyzer response is based on the use of a solid state O_2 ion conduction material, zirconium oxide. The analyzer had an accuracy of ± 5 ppm in the 0 to 1000 ppm range, ± 0.05% in the 0.1 to 10% range, and ± 1% in the 10 to 100% range for O_2 concentrations. The resolution of the analyzer was smaller than the accuracy, that is, in the 0 to 1000 ppm O_2 concentration range the resolution was 1 ppm.

The master-packaged steaks were stored at 1 ± 0.5 °C. On day 0, 4 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 Ageless® FX-100, one having FreshPax® R-2000 O_2 scavengers, and one having no O_2 scavenger), were opened at 1 d intervals for 8 d and placed in a retail display case. The O_2 concentration in each pack was measured immediately before being opened.

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 (Model LPM12T, Hill Refrigeration, Barrie, Ontario). The case was illuminated for 12 h/d with incandescent lamps giving a light intensity of 750 lux at the display shelf surface. Detailed information about the display case has been previously presented (Gill and Jones 1994a). A temperature data logger (Tru-Test, Auckland, New Zealand) was placed at the center of the display case to record air temperatures surrounding the product.

The PM steaks on display were examined for color and discoloration 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.

Table 1—The oxygen (O_2) concentration in master packs* containing beef steaks stored under a nitrogen atmosphere for up to 8 d at 1 ± 0.5 °C

Day	Oxygen concentration (ppm)		
	Control[a]	FX-100[b]	R-2000[c]
0	78	78	78
1	477	31	0
2	340	7	0
3	328	0	0
4	110	0	0
5	56	0	0
6	37	0	0
7	50	0	0
8	243	0	0

* 4 over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with 4 retail trays, without O_2 scavengers.
[b]Master pack with 4 retail trays, each containing 8 Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c]Master pack with 4 retail trays, each containing 2 FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.

Visual assessment of master-packaged steaks

A 5-member trained panel was used for the subjective evaluation of the steaks (Jeremiah and Gibson 1997b; Jeremiah 1998). Color scores were assessed using a 8-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=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% (Jeremiah and Gibson 1997a).

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 (Macbeth Color Eye 1500/Plus, Kollmorgen Corp., Newburg, N.J., U.S.A.). 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 (AMSA 1991). The ratios and wavelengths used for the calculations were: K/S 474) K/S 525 for % deoxymyoglobin, K/S 575 ÷

K/S 525 for % metmyoglobin, and K/S 610 ÷ K/S 525 for % oxymyoglobin. Further information concerning calculation of deoxy-, met-, and oxy-myoglobin is available elsewhere (AMSA 1991).

Table 2—Sensory panel scores (average scores of 5 panelists) for beef (PM) steaks stored in master packs* under a nitrogen atmosphere for up to 8 d at 1 ± 0.5 °C

	Color†, **			Discoloration††, **		
Day	Control[a]	FX-100[b]	R-2000[c]	Control	FX-100	R-2000
0	5.6 ± 0.5***,E,F,D,G			1.0 ± 0.0^{K}		
1	5.3 ± 0.5^{I,H,G}	5.8 ± 0.7^{E,F,D,C}	5.7 ± 0.9^{E,F,D,G}	2.5 ± 1.1^{E,F,D}	1.8 ± 1.1^{H,I,J,G}	1.4 ± 0.6^{H,I,J,K}
2	5.9 ± 0.5^{E,D,C}	5.8 ± 0.8^{E,F,D,C}	5.2 ± 0.5^{I,H}	2.7 ± 1.6^{E,C,D}	1.2 ± 0.8^{H,I,J,K}	1.4 ± 0.5^{H,I,J,K}
3	5.6 ± 0.5^{E,F,D,G}	5.9 ± 0.6^{E,D,C}	5.6 ± 0.7^{E,F,H,G}	3.6 ± 1.3^{B}	1.9 ± 1.5^{H,F,G,I}	1.9 ± 0.8^{H,F,G}
4	5.6 ± 0.5^{E,F,G,H}	5.5 ± 0.5^{E,F,G,H}	6.2 ± 0.4^{B,A,C}	3.6 ± 0.8^{A,B}	1.4 ± 0.6^{H,I,J,K}	1.4 ± 0.5^{H,I,J,K}
5	5.1 ± 0.3^{I}	5.6 ± 0.6^{E,F,G,H}	5.4 ± 0.5^{I,F,H,G}	1.8 ± 0.9^{H,I,G}	1.9 ± 1.0^{H,F,G,I}	1.6 ± 0.8^{H,I,J,K}
6	5.5 ± 1.5^{E,D,C}	6.5 ± 0.5^{A}	5.3 ± 0.8^{I,H,G}	4.3 ± 1.5^{A}	1.6 ± 0.5^{H,I,J,K}	1.1 ± 0.3^{J,K}
7	6.3 ± 0.5^{A,B}	6.0 ± 0.4^{B,D,C}	4.4 ± 0.5^{J}	3.2 ± 2.1^{B,C,D}	1.0 ± 0.0^{K}	2.4 ± 0.7^{E,F,G}
8	5.7 ± 0.7^{E,F,D,G}	6.0 ± 0.4^{B,D,C}	5.7 ± 0.7^{E,F,D,G}	3.3 ± 1.0^{B,C}	1.3 ± 0.5^{H,I,J,K}	1.3 ± 0.6^{I,J,K}

* Four over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with 4 retail trays, without O_2 scavengers.
[b] Master pack with 4 retail trays, each containing 8 Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c] Master pack with 4 retail trays, each containing 2 FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.
† Color 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=extremely dark red.
††Discoloration scale: 1=0% (none), 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-99%, 7= 100% (complete).
** Means within the same category (color, discoloration, appearance) having the same superscript letter are not significantly different ($p > 0.05$).
*** Standard Deviation

Statistical analysis

The effects of treatment differences (control, Ageless® FX-100, and FreshPax® R-2000 O_2 scavengers) were examined statistically using analysis of variance (proc ANOVA, SAS 1990) at an α level of 0.05. Only the main effects were analyzed.

Results

Measurement of O_2 concentration

The O_2 concentration increased from 78 to 477 ppm on the 1st d of storage in the master pack without O_2 scavengers, whereas in packs containing Ageless® FX-100 or FreshPax® R-2000 O_2 scavengers, O_2 decreased to 31 and 0 ppm, respectively (Table 1). Oxygen concentration decreased continuously until d 6 in master packs with no O_2 scavengers, and reached 0 ppm in master packs containing FreshPax® R-2000 and Ageless® FX-100 O_2 scavengers after 1 and 2 d storage, respectively. An increase in O_2 concentration was observed in master packs containing controls on d 7, and 8 of storage.

Visual assessment of steaks

At day 0, steaks serving as fresh controls were given color scores of 6 (slightly dark red). After subsequent daily storage intervals, steaks packaged with no O_2 scavengers received color scores of 5 (bright cherry red) or 6 (slightly dark red) and steaks packaged with Ageless® FX-100 and FreshPax® R-2000 O_2 scavengers received color scores of 6 and 5 or 6, respectively (Table 2). Steaks packaged with FreshPax® R-2000 were a little less dark than the steaks packaged with Ageless® FX-100 O_2 scavengers.

At day 0, all steaks received discoloration scores of 1 (0% discoloration). After subsequent daily storage intervals, steaks packaged with no O_2 scavengers had discoloration scores of either 2 (1-10% discoloration), 3 (11-25% discoloration) or 4 (26-50% discoloration) (Table 2). Steaks packaged with Ageless® FX-100 O_2 scavengers received a discoloration score of 1 (0% discoloration) after 2, 4, 7, and 8 d, and 2 (1-10% discoloration) after 1, 3, 5, and 6 d. Steaks packaged with FreshPax® R-2000 O_2 scavengers received discoloration scores of 1 (0% discoloration) at storage intervals of 1, 2, 4, 6, and 8 d , and discoloration scores of 2 (1-10% discoloration) at storage intervals of 3, 5, and 7 d (Table 2).

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 d. Metmyoglobin content increased from 3.5 on d 0 to 22.8 % on d 3, then decreased to 4.7% on d 4, and again increased to 16.1% on d 7 but decreased to 5.2% on d 8 (Table 3). 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.

Metmyoglobin content of steaks packaged with Ageless® FX-100 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 d of storage. Also, the metmyoglobin content was comparable with that of the fresh control for all storage intervals ($p > 0.05$) (Table 3).

The metmyoglobin content of steaks packaged with FreshPax® R-2000 O_2 scavengers was not different when compared with fresh controls and steaks packaged with Ageless® FX-100 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 FreshPax® R-2000 O_2 scavengers after 3, and 7 d of storage ($p < 0.05$). Differences were most noticeable at 2, 3, 6, and 7 d of storage, where the metmyoglobin content of steaks packaged with FreshPax® R-2000 O_2 scavengers was reduced to zero (Table 3).

Discussion

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 (Gill and McGinnis 1995a). 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

Table 3—Mean values for the oxidized states of myoglobin obtained from the surfaces of beef (PM) steaks, stored in master packs* under a nitrogen atmosphere for up to eight days at 1±0.5°C. Steaks were prepared from beef tenderloins within 24 h of slaughter.

Day	% Metmyoglobin**			% Deoxymyoglobin**			% Oxymyoglobin**		
	Control[a]	FX-100[b]	R-2000[c]	Control	FX-100	R-2000	Control	FX-100	R-2000
0	$3.5\pm3.2^{***,D,C}$			0.0 ± 0.0^{D}			$96.5\pm3.2^{A,B}$		
1	$10.9\pm21.9^{B,D,A,C}$	$6.7\pm2.5^{B,D,C}$	$2.7\pm4.5^{D,C}$	$2.5\pm1.7^{D,C}$	$6.7\pm13.5^{B,D,C}$	$7.3\pm14.6^{B,D,C}$	$86.6\pm10.2^{B,D,A,C}$	$86.6\pm14.1^{B,D,A,C}$	$90.0\pm19.1^{B,D,A,C}$
2	$10.2\pm19.5^{B,D,C}$	$10.5\pm7.7^{B,D,C}$	0.0 ± 0.0^{D}	19.5 ± 14.3^{A}	$1.4\pm2.9^{D,C}$	0.0 ± 0.0^{D}	70.3 ± 8.4^{E}	$88.1\pm5.2^{B,D,A,C}$	100.0 ± 0.0^{A}
3	22.8 ± 15.9^{A}	$6.3\pm4.3^{B,D,C}$	0.0 ± 0.0^{D}	$7.8\pm7.5^{B,D,A,C}$	$3.6\pm4.2^{D,C}$	$6.2\pm6.3^{D,C}$	69.5 ± 10.5^{E}	$90.1\pm2.1^{B,D,A,C}$	$93.9\pm6.3^{B,A,C}$
4	$4.7\pm4.9^{B,D,C}$	$3.1\pm2.9^{D,C}$	$1.8\pm2.1^{D,C}$	$13.1\pm9.6^{B,A,C}$	$18.5\pm19.4^{A,B}$	$8.2\pm5.2^{B,D,A,C}$	$82.1\pm5.9^{B,D,E,C}$	$78.4\pm22.1^{D,E}$	$90.0\pm7.3^{B,D,A,C}$
5	$6.4\pm1.9^{B,D,C}$	$6.1\pm7.1^{B,D,C}$	$2.2\pm2.9^{D,C}$	$4.9\pm9.9^{D,C}$	0.3 ± 0.5^{D}	$2.7\pm4.4^{D,C}$	$88.7\pm9.1^{B,D,A,C}$	$93.6\pm7.3^{B,A,C}$	$95.1\pm7.2^{B,A,C}$
6	$12.4\pm15.2^{B,A,C}$	$8.9\pm5.7^{B,D,C}$	0.0 ± 0.0^{D}	0.3 ± 0.5^{D}	$10.3\pm12.6^{B,D,A,C}$	0.0 ± 0.0^{D}	$87.4\pm15.0^{B,D,A,C}$	$80.8\pm17.8^{D,E,C}$	100.0 ± 0.0^{A}
7	$16.1\pm15.9^{A,B}$	$3.2\pm3.8^{D,C}$	0.0 ± 0.0^{D}	$6.7\pm8.1^{D,C}$	$3.2\pm3.0^{D,C}$	$1.5\pm2.3^{D,C}$	$77.2\pm8.6^{D,E}$	$93.7\pm1.5^{B,A,C}$	98.6 ± 2.3^{A}
8	$5.2\pm4.3^{B,D,C}$	$4.4\pm5.1^{B,D,C}$	$2.5\pm2.3^{D,C}$	$6.7\pm8.8^{D,C}$	0.6 ± 1.3^{D}	$3.3\pm4.4^{D,C}$	$88.1\pm9.3^{B,D,A,C}$	$95.0\pm5.4^{B,A,C}$	$94.2\pm2.4^{B,A,C}$

* Four over-wrapped trays, each containing a PM steak, were placed in a master pack.
[a] Master pack with four retail trays, without O_2 scavengers.
[b] Master pack with four retail trays, each containing eight Ageless® FX-100 O_2 scavengers underneath the absorbent pad.
[c] Master pack with four retail trays, each containing two FreshPax® R-2000 O_2 scavengers underneath the absorbent pad.
** Means within the same category (metmyoglobin, deoxymyoglobin, oxymyoglobin) having same superscript letter are not significantly different (p>0.05).
***Standard deviation.

477 ppm in master packs without O_2 scavengers after 1 d of storage. Master packs containing O_2 scavengers had no measurable O_2 at most storage times, except after 1 and 2 d in the case of Ageless® FX-100 O_2 scavengers. As a consequence, steaks with O_2 scavengers had low metmyoglobin content and almost no discoloration. Steaks packaged without O_2 scavengers had an increase in metmyoglobin content from d 0 to d 3 of storage. After 4 d storage metmyoglobin content decreased, but then gradually increased until after 7 d storage, when it decreased again. This indicated these steaks underwent two cycles of transient discoloration, regaining color due to MRA or other reducing factors. Steaks packaged with O_2 scavengers did not undergo such transient discoloration. Moreover, steaks packaged with FreshPax® R-2000 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. These results are supported by the observation that at no or low partial pressure of O_2, metmyoglobin present in the muscle was reduced to deoxymyoglobin due to MRA (O'Keeffe and Hood 1982). Higher metmyoglobin contents (25 or 23%) were observed after 2 and 4 d of CAP storage on LD steak surfaces, which resulted in transient discoloration (Gill and Jones, 1994a). In the present study, PM steaks expected to have poor color stability were used, but, very low metmyoglobin contents scores were observed in samples packaged with O_2 scavengers. Thus, our hypothesis of combining O_2 absorbent technology with CAP to prevent transient discoloration was proven.

The O_2 concentration during initial packaging was 78 ppm, and it went up to 477 ppm after 1 d of storage. Therefore the amount of time required to reduce the O_2 concentration from 477 to 0 ppm would be almost 4 times the half-life of O_2 in the package atmosphere. For Ageless® FX-100 and FreshPax® R-2000 O_2 scavengers, incorporating the number of scavengers used in the study, the O_2 half-life is 0.57 and 0.65 h, respectively (Tewari and others 2000a). Steaks will also contribute to the total O_2 absorbing capacity to some extent ($< 10\%$). Thus, at 1 ± 0.5°C, transient discoloration of PM steaks can be prevented if residual O_2 is reduced to 0 ppm within 3 h of pack closure.

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 entrapment either in the absorbent pad or under the over-wrap film during evacuation. In addition, meat tissue itself initially releases dissolved, unreacted O_2 causing reduction of oxymyoglobin to deoxymyoglobin in the presence of low partial pressures of O_2 in the headspace during CAP storage. This increase is inevitable. Therefore, O_2 entrapment must be minimized to prevent O_2 concentrations increasing in the pack to the point where transient discoloration may occur. Gill and others (1994) suggested using lidded trays to reduce or eliminate O_2 entrapment within the retail package. Lidded rather than over-wrapped trays could be used with underlying plastic grids instead of absorbent pads to prevent drastic increases in O_2 concentration. However, a study is needed to compare efficacy of using O_2 scavengers in different packaging systems. Such a study was performed in our lab (Tewari and others 2000b).

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 (Tewari and others 2000a), and the barrier property increases at low storage temperatures. It is also evident that O_2 concentration may increase due to entrapment of O_2 in either the soaker 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 tray which may affect meat color. This conclusion was reached during concurrent work (Tewari and others 2000b), which indicated less discoloration occurred on steak surfaces in a system where O_2 scavengers were placed inside the retail tray as compared to a system where O_2 scavengers were placed in the master pack. Perhaps this is the reason Gill and McGinnis (1995b) needed to use 20 scavengers in a master pack stored at -1.5 °C to prevent transient discoloration even when the initial O_2 concentration in the package was 40 ppm. Placing O_2 scavengers directly inside the retail tray will reduce the number of O_2 scavengers required.

The present study 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 1 ± 0.5 °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 (Gill and McGinnis 1995a). Thus, better results can be expected at −1.5 °C. Nevertheless, under worst-case conditions, the use of O_2 scavengers in conjunction with CAP prevented transient discoloration of PM beef steaks. 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 LD, especially if stored below 0 °C. Oxygen scavengers have the potential of preventing transient discoloration of all centrally prepared beef cuts, but, factors such as selection of packaging systems, O_2 scavenger type, and package atmospheres (N_2/CO_2) may affect results. Similar studies on other cuts of retail ready beef and ground beef are warranted.

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