



Oxygen Scavengers affect Gas Mixture and Color Stability of Master Packed Ground Beef

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Abstract: This study investigated the effect of storage time, display time, oxygen scavengers, and carbon dioxide concentration on master packed ground beef color and package characteristics. Samples were stored at 0.5°C for up to 28 d in 20% CO₂/80% N₂ and 30% CO₂/70% N₂. Results indicated that red meat color was maintained for up to 28 d of storage. Nevertheless, a* values (meat redness) decreased during display as storage time increased ($p < 0.05$). Master packs with 2 types of oxygen scavengers showed comparable total carbon dioxide absorbed. However, differences between oxygen scavengers were noticed in packages that did not include meat. Carbon dioxide significantly decreased by 14 d of storage in packages with oxygen scavengers ($p < 0.05$), and remained low for the duration of the study. Carbon dioxide absorption by an oxygen scavenger is an important factor when considering the headspace gas and specific oxygen scavenger used in a modified atmosphere packaging system.

Keywords: color stability, ground beef, master pack, oxygen scavengers

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Introduction

The main objective of meat packaging is to maintain quality attributes throughout the shelf life of the product, while providing an attractive, fresh product. Master pack is a commonly used, centralized packaging system that provides benefits to meat packers, retailers, and consumers (Jeyamkondan et al., 2000; Tewari et al., 1999). Use of Master packs is an effective method at prolonging meat shelf-life, but also has economic advantages when compared to traditional packaging systems (Jeyamkondan et al., 2000; Tewari et al., 1999). Master packs utilize a dual packaging system with individual retail packages enclosed in a large outer package. Extended shelf life is maintained by a modified atmosphere in the outer package. The gas permeable, retail packages are removed from the outer package just prior to being placed in retail display. An anoxic atmosphere is typically used in the outer package to avoid oxidation reactions and color fading (Jayasingh et al., 2002; Kim et al., 2010), as well as to control the growth of aerobic, spoilage bacteria (Sørheim et al., 1999). Caution must

be taken since residual oxygen that is present in the headspace gas can trigger meat discoloration (Gill and McGinnis, 1995a; Sørheim et al., 2009; Venturini et al., 2006). For this reason, oxygen scavengers in the retail package play a key role in controlling oxygen concentrations (Gill and McGinnis, 1995b; Jeyamkondan et al., 2000; Limbo et al., 2013; Tewari, et al., 2002). Headspace atmospheres usually include carbon dioxide to suppress microbial growth (Kennedy et al., 2005; Martínez et al., 2005; Tewari et al., 1999), allowing fresh meat to be stored for longer periods of time (Wilkinson et al., 2006). Silliker et al. (1977) showed that carbon dioxide has a bacteriostatic effect during storage and a residual effect after meat is exposed to air. Venturini et al. (2010) emphasized the importance of having enough carbon dioxide in the package, so that it could saturate the meat and reach equilibrium during the entire storage time. Previous work in this laboratory has shown that oxygen scavengers can affect not only oxygen concentration, but also carbon dioxide concentration (Arteaga et al., 2016). These findings have increased our interest in investigating different

oxygen scavengers. Previous studies involving oxygen scavengers did not compare different brands (Beggan et al., 2006; Buys, 2004; Gill and McGinnis, 1995b; Isdell et al., 1999; Limbo et al., 2013; Venturini et al., 2006; Venturini et al., 2014). In a few studies, multiple oxygen scavengers were compared, but the focus was on oxygen kinetics (Charles et al., 2006; Miltz and Perry, 2005; Tewari et al., 2002). For this reason, the current study compares 2 of the most commonly used commercial oxygen scavengers and 2 carbon dioxide concentrations in the headspace gas mixture to show the changes in gas concentrations while meat is master packed, as well as the effect of these treatments on meat color during master pack storage and retail display.

Materials and Methods

Experimental plan

The study was performed to show the effect of storage time, different oxygen scavengers, and headspace gas on package and meat characteristics. Master packs were stored in the dark at $0.5 \pm 0.5^\circ\text{C}$ for 0, 14, 21, or 28 d. At the end of each storage time, headspace gas concentrations (Pac Check 333, Mocon Inc., Minneapolis, MN) and film deflation were measured. The overwrap package was removed from the master pack and ground beef color was measured immediately after removal from the master pack and again after 1 h of bloom time in the dark at 0.5°C . Overwrapped packages were displayed in an open top, illuminated retail display case (Tyler Refrigeration, Niles, MI) at $4 \pm 1^\circ\text{C}$ and stored under continuous fluorescent lighting (GE F40SP35-ECO, 3500 K, 40W, Lux 920–1000, General Electric, East Cleveland, OH) for 2 and 4 d. Storage and display temperatures were chosen based on commonly used settings across studies with master packs. Retail temperature was standardized since it varies within industry. A thermometer on the display cases monitored temperature.

Packaging

Ground beef, with approximately 18% fat, was obtained from the Pennsylvania State University Meats Laboratory. Percent fat was determined by the modified Babcock method (Sebranek et al., 1989). Following fat determination, meat was portioned into $150 \text{ g} \pm 1 \text{ g}$, placed on polystyrene trays (Bunzl Koch Supplies, N. Kansas City, MO) and overwrapped with a PVC, gas permeable stretch film (PMS 15, Prime Source, St. Louis, MO, Oxygen Transmission Rate (OTR) 16639 cc/m^2 per

24h at 23°C). One overwrap package was master packed in a rigid, high barrier, multilayer polypropylene with Ethylene Vinyl Alcohol tray [OTR 0.1cc to 1cc/tray/24h at 23°C and 0% Relative Humidity (RH); Coextruded Plastic Technologies, Inc., Edgerton, WI] and filled with a gas mixture of 80% N_2 /20% CO_2 or 70% N_2 /30% CO_2 . The rigid tray was then lidded with a 60 μm , high barrier film HB-60 (O_2 -TR 3.1 and CO_2 TR 9.2 cc/m^2 per 24h at 23°C and 0% RH; Ultravac Solutions LLC, Kansas City, MO) using a Rhino 4 tray sealer (UltraSource LLC, Kansas City, MO). Packages not containing ground beef, but using the same treatments, were included in the study to account for changes in gas concentrations and film deflation. Samples were packaged in duplicate for each package type. Overwraps were packaged in high barrier, 76 μm vacuum pouch bags (UltraSource LLC) instead of rigid trays and filled with a 70% N_2 /30% CO_2 gas mixture using a Minipack Torre (Minipack America Inc., Orange, CA). Designated master packs included 1 oxygen scavenger A, 500cc absorption capacity (osA; Mitsubishi Gas Chemical America, Inc., New York, NY), 1 oxygen scavenger B, 800 cc absorption capacity (osB; Multisorb Technologies, Buffalo, NY) or no oxygen scavenger. Similarly, packages without ground beef, but using the same treatments were included in the study to account for changes in gas concentrations. Samples were packaged in duplicate for each package type.

Film deflation

Film deflation in master packed products represents a decrease in gas volume in the package. For rigid trays used in this research, film deflation is observed as the top layer of film changes from flat to concave. Data for film deflation were collected for each master pack as described by Rotabakk et al. (2006). Film deflation was measured using a straight edge and a caliper. The top of the tray was considered as the reference plane from which the distance to the film was obtained. Measurements were taken in triplicate at the center of the tray.

Volume of carbon dioxide lost/absorbed

Volume of carbon dioxide lost and absorbed was calculated based on volume differences between d 0 and the day of storage using film deflation of the master pack, carbon dioxide concentrations, master pack volume, and overwrapped ground beef volume. Master pack and overwrapped ground beef volumes were obtained through water volume displacement. Empty master packs were used to measure the amount of carbon dioxide that was lost due to package permeability.

In the case of ground beef and oxygen scavenger absorption, carbon dioxide absorbed was calculated based on the volume lost in master packs with ground beef or oxygen scavenger, respectively, with adjustments for volume lost due to package permeability. Total carbon dioxide volume for scavenger A or scavenger B oxygen scavengers refers to the carbon dioxide lost/absorbed in master packs with ground beef and 1 oxygen scavenger, scavenger A or scavenger B, respectively.

Gas concentration

Headspace gas concentration (O_2 , CO_2 , and CO) of master packs at the end of their selected storage time was analyzed using a gas analyzer with reporting limit of 0.01% (Pac Check Model 333, Mocon Inc.). A foam rubber septum was applied over the cover film of the master pack to avoid headspace gas leakage. A needle was inserted through the septum into the package headspace gas where an 8 cc aliquot was collected and analyzed.

Color

Color, reported as Commission internationale de l'éclairage (CIE) L^* , a^* , and b^* values, was evaluated on each overwrap package using a reflected color measurement spectrophotometer (MiniScan EZ, HunterLab, Reston, VA) with an 8mm port size, 2° observer, and illuminant A. The spectrophotometer was standardized using a white ceramic tile covered by the same PVC overwrap film used in the overwrap package. Measurements were taken at three different positions from each sample of ground beef. Color was recorded immediately after opening master packs, after 1 h to allow meat to bloom, and after 2 and 4 d of display.

Myoglobin forms

Percentage of oxymyoglobin, deoxymyoglobin, and metmyoglobin were calculated according to the American Meat Science Association guidelines (AMSA; American Meat Science Association, 2012). Reflectance values collected at 400 to 700 nm were converted to K/S values (S is the scattering coefficient and K the absorbance coefficient) and ratios of different wavelengths were used for the calculations (MiniScan EZ, HunterLab). In cases where negative percentages were calculated, those were converted to zero. Similarly, values over 100 were converted to 100 (Mancini et al., 2003). Proportions of the three forms of myoglobin were transformed to sum 100. Three readings were taken at different locations on each package of ground

beef. To obtain the pure form of oxymyoglobin, ground beef was packaged in high oxygen atmosphere, 80% $O_2/20\%$ CO_2 , and stored for 2 h before taking the reading. The reference values for the other 2 forms of myoglobin were obtained as indicated in the AMSA guidelines (American Meat Science Association, 2012).

Statistical analysis

Statistical analyses for package characteristics were conducted using a multi-way ANOVA performed with General Linear Model (GLM) of Minitab 16.2.4 software (Minitab Inc., State College, PA). Gas concentrations and film deflation used storage time, headspace gas, presence of ground beef, and type of oxygen scavenger as factors in a 4 way ANOVA. Volume of carbon dioxide lost/absorbed used headspace gas, storage time, and package component as factors in a 3 way ANOVA. Color results, CIE L^* , a^* , and b^* values and myoglobin forms, were analyzed using storage time and display time as repeated measures along with headspace gas, and type of oxygen scavenger as fixed factors using the mixed procedure of SAS (SAS Inst. Inc., Cary, NC) for serial repeated measures. The effect of bloom on ground beef color and myoglobin forms was analyzed separately through serial repeated measures using the mixed procedure of SAS. For the interaction between oxygen scavengers and storage time after 1 h bloom, a factorial design was applied using GLM in Minitab 16.2.4 software. Effects were considered significant at $p < 0.05$. When ANOVA indicated significant differences among treatment means Tukey Means Separation Test was used to discern the significant differences ($p < 0.05$). A total of 96 samples were used in the study.

Results and Discussion

Film deflation

Headspace gas ($p < 0.0001$), storage time ($p < 0.0001$), presence of ground beef ($p < 0.0001$), and oxygen scavenger ($p < 0.0001$) had significant effects on film deflation. Film deflation was greater in packages with 30 versus 20% carbon dioxide ($p < 0.05$). This observation agrees with other reports showing a relationship between carbon dioxide absorption and film deflation (Al-Nehlawi et al., 2013; Rotabakk et al., 2006). The low solubility of nitrogen in meat is important for its function as a filler gas that maintains the package volume and prevents package collapse (Al-Nehlawi et al., 2013; Rotabakk et al., 2007). The volume of carbon dioxide lost was greater in 30%

carbon dioxide ($p < 0.05$). As expected, packages with ground beef had greater film deflation compared to empty packages ($p < 0.05$). This finding is consistent with numerous studies pertaining to carbon dioxide absorption by meat (Al-Nehlawi et al., 2013; Gill and Penney, 1988; Gill, 1988; Jakobsen and Bertelsen, 2004; Rotabakk et al., 2006, 2007; Rotabakk et al., 2010). Film deflation was greater for packages with oxygen scavenger B compared to oxygen scavenger A. In addition, film deflation was greater in packages with either oxygen scavenger A or oxygen scavenger B than packages without an oxygen scavenger ($p < 0.05$). This finding correlates with the changes in carbon dioxide concentration in each scenario. Storage time increased film deflation. Table 1 shows how the interaction of oxygen scavengers, storage time, and presence of ground beef affects film deflation. Packages on d 0 had minimal film deflation compared to packages after 14, 21, or 28 d of storage ($p < 0.05$). Oxygen scavenger B, with or without ground beef had greater film deflation values ($p < 0.05$), than packages with oxygen scavenger A and ground beef ($p > 0.05$). The lowest film deflation values were obtained in packages without oxygen scavengers and packages on d 0 ($p < 0.05$).

Volume of carbon dioxide lost/absorbed

Each package component (meat, oxygen scavenger, initial carbon dioxide concentration) provides a mechanism through which carbon dioxide could be absorbed or lost. Figure 1 shows the volume of carbon dioxide lost due to package permeability or absorbed by the oxygen scavenger or ground beef. Statistical results show that initial headspace gas ($p < 0.0001$), storage time (p

< 0.0001), package component ($p < 0.0001$), and their interactions ($p < 0.0001$) have significant effects on the loss of carbon dioxide from the master pack headspace. Master packs with 30% initial CO₂ concentration had greater absorption/loss of carbon dioxide ($p < 0.05$) than those with 20% CO₂. It has been shown that carbon dioxide partial pressure is the main factor affecting carbon dioxide absorption by meat (Jakobsen and Bertelsen, 2004). Therefore, it is expected that higher initial carbon dioxide concentration would increase its absorption by meat due to a greater partial pressure difference between the headspace gas and the meat (Gill, 1988; Jakobsen and Bertelsen, 2004; Rotabakk et al., 2007). Increasing storage time in master packs with ground beef and/or oxygen scavengers, increased the amount of carbon dioxide lost/absorbed ($p < 0.05$; Fig. 1). Package permeability was not included in the statistical analysis, since its values were used to calculate losses due to each of the other components. Nevertheless, knowing the permeability of the tray and film is important to avoid overestimating the amount of dissolved carbon dioxide. As carbon dioxide concentration decreases, due to package permeability, less carbon dioxide is available for absorption (Rotabakk et al., 2007). It is important to note that the total amount of carbon dioxide lost/absorbed during storage from ground beef master packs with oxygen scavenger A or oxygen scavenger B was the same in master packs with 20% CO₂/80% N₂ ($p > 0.05$). However, with 30% CO₂/70% N₂ the addition of oxygen scavenger B resulted in significantly greater losses after 14 and 21 d of ground beef master pack storage when compared to those with oxygen scavenger A ($p < 0.05$). Nonetheless, oxygen scavenger A absorbed less carbon dioxide compared to oxygen scavenger B for both 20% and 30% CO₂, when considering master packs with no meat present ($p < 0.05$). This difference in carbon dioxide absorption may result from dissimilar oxygen absorption capacities between the 2 oxygen scavengers. As reported by Charles et al. (2006), the carbon dioxide absorption by oxygen scavengers results from a reaction with iron hydroxide (i.e., a product of the oxidation reaction that consumes oxygen). Therefore, it is expected that the amount of carbon dioxide absorbed will be dependent on the amount of oxygen that reacts with an oxygen scavenger. In fact, Charles et al. (2006) found that the absorption capacity for these 2 gases was related, reporting 85 ± 2 cc of carbon dioxide and 116 ± 4 cc of oxygen absorbed simultaneously. For oxygen scavengers used in this study, scavenger A had an oxygen absorption capacity of approximately 500 cc, while scavenger B had a nominal oxygen absorption capacity of 800 cc (Limbo

Table 1. Film deflation (mm) of master packs with oxygen scavengers, storage time, and with or without ground beef¹

Oxygen scavenger ²	Ground beef ³	N	Storage time, days ⁴			
			0	14	21	28
A	Yes	4	0.87 ^{fg}	9.91 ^{ab}	9.04 ^{ab}	9.95 ^{ab}
	No	4	0.72 ^g	6.16 ^d	6.44 ^d	7.26 ^{cd}
B	Yes	4	1.19 ^{fg}	10.25 ^{ab}	9.14 ^{ab}	9.55 ^{ab}
	No	4	1.16 ^{fg}	10.61 ^a	9.74 ^{ab}	9.29 ^{ab}
None	Yes	4	1.08 ^{fg}	2.50 ^{ef}	2.46 ^{ef}	3.66 ^c
	No	4	1.14 ^{fg}	1.40 ^{fg}	0.13 ^g	0.44 ^g

^{a-g}Means without a common letter are significantly different ($p < 0.05$).

¹SEM = 0.32.

²One oxygen scavenger A, B, or no oxygen scavenger was added in the master pack.

³150g of ground beef in gas permeable package enclosed in master pack when "Yes".

⁴Master packs were stored in the dark at 0.5 ± 0.5°C.

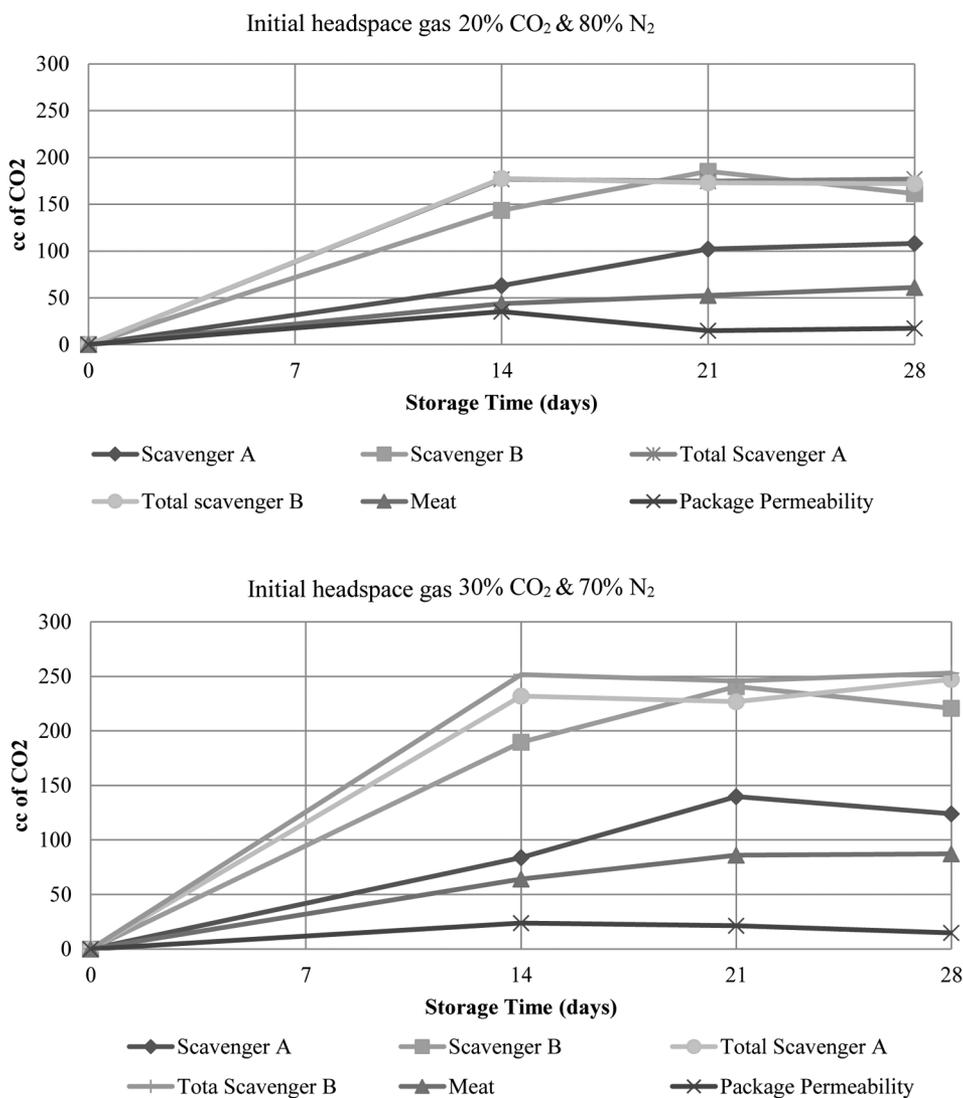


Figure 1. Carbon dioxide volume lost from the master pack headspace gas due to package permeability, oxygen scavenger absorption, and ground beef solubility. ^aCarbon dioxide volume loss calculated from package volume and gas concentration. Total volume observed refers to master packs with ground beef and an oxygen scavenger. SEM = 3.0.

et al., 2013). Considering each master pack component alone, ground beef or oxygen scavenger, provides an indication of the maximum carbon dioxide that could be absorbed by those 2 components separately. In the current work, the sum of these 2 maximum quantities is greater than the amount of carbon dioxide lost/absorbed in master packs with ground beef and oxygen scavengers. This finding may indicate that ground beef and/or oxygen scavengers do not exhibit their maximum carbon dioxide absorption capacity when they are in the same system. With limited oxygen in the master pack the ability of the scavenger to absorb carbon dioxide is muted. Because of the complexity of the system of master packs with ground beef and oxygen scavengers, it is difficult to know how much of that total carbon dioxide absorbed/lost is attributable to each component alone.

Gas concentrations

Oxygen concentration in the master pack atmosphere was affected by headspace gas ($p < 0.0001$), storage time ($p < 0.0001$), presence of ground beef ($p = 0.023$), and oxygen scavenger ($p < 0.0001$). Oxygen concentration was greater in packages with 30% carbon dioxide ($p < 0.05$). This was a result of higher oxygen concentrations on the day of packaging. Oxygen concentrations in master packs decreased during the first 2 wk of storage ($p < 0.05$) and remained similar throughout 28 d of storage ($p > 0.05$). The initial concentration of O₂ was 3.54% for both oxygen scavengers A and B. The first measurement of the reduction in O₂ concentration was recorded on d 14. Oxygen levels were barely detectable with an average concentration of 0.02% for

each of the oxygen scavengers through d 28 of storage. It is important to note that work by several other investigators showed that O₂ concentration in a modified atmosphere package with an oxygen scavenger drops rapidly after a few hours of storage (Charles et al., 2006; Gill and McGinnis, 1995b; Limbo et al., 2013; Miltz and Perry, 2005; Tewari et al., 2002).

The presence of ground beef also increased the average oxygen concentration compared to packages without meat ($p < 0.05$). This increase in oxygen concentration in master packs may be related to entrapped oxygen in the meat, in the overwrap tray headspace or in the tray matrix in cases where polystyrene foam trays are used (Limbo et al., 2013; Tewari et al., 2002; Venturini et al., 2006, 2014). The use of oxygen scavengers, A and B effectively reduced oxygen concentration during master pack storage ($p < 0.05$). Similar results by Venturini et al. (2006) and Limbo et al. (2013) showed that oxygen scavengers rapidly reduced oxygen concentration in master packs during storage and that these concentrations were lower when compared to packages without oxygen scavengers. There were significant interactions

of oxygen scavenger with ground beef ($p < 0.0001$) and oxygen scavenger with storage time for headspace oxygen concentrations ($p < 0.0001$). Although the presence of ground beef affected oxygen concentration, concentrations were similar ($p > 0.05$), independent of ground beef, when an oxygen scavenger was present.

Presence of ground beef ($p < 0.0001$), oxygen scavengers ($p < 0.0001$), initial carbon dioxide concentration in the headspace atmosphere ($p < 0.0001$), and storage time ($p < 0.0001$) each affected carbon dioxide concentration in the headspace of master packs. Since carbon dioxide dissolves in ground beef (Gill, 1988), headspace concentrations were reduced when ground beef was present in the package ($p < 0.05$). Figure 2 shows changes in carbon dioxide concentration in the different master packaging conditions. Master packs with ground beef and an oxygen scavenger exhibited a decreased carbon dioxide concentration by 14 d of storage to nearly 0% ($p < 0.05$), with no difference between the 2 types of oxygen scavengers ($p > 0.05$). As explained before, iron-based oxygen scavengers are found to absorb not only oxygen, but also carbon

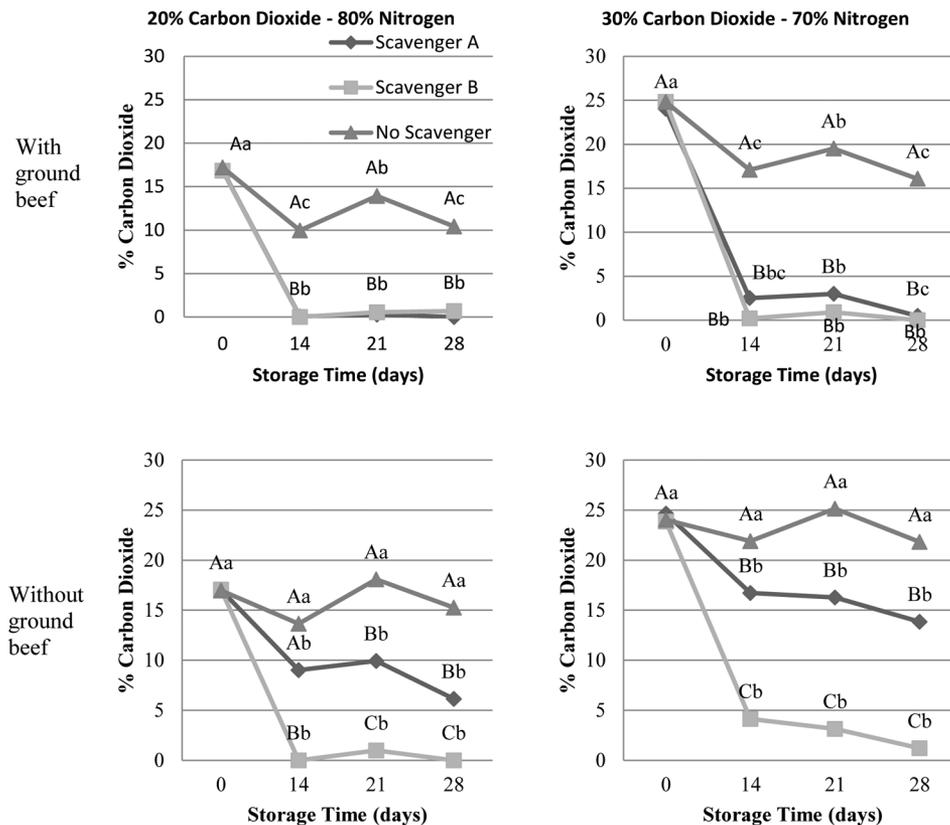


Figure 2. Presence of oxygen scavenger A, B, or none on carbon dioxide concentrations in master packs with and without ground beef packaged in an gas permeable package in 2 headspace atmospheres. ^{A-C}Means within the same storage time without a common letter are significantly different ($p < 0.05$). ^{a-c}Means within the same oxygen scavenger without a common letter are significantly different ($p < 0.05$). SEM for master packs with ground beef is 0.42 and SEM for master packs without ground beef is 0.86.

dioxide from the package headspace (Charles et al., 2006; Miltz and Perry, 2005). On the other hand, master packs without ground beef show that oxygen scavenger A reduced carbon dioxide concentrations by 14 d of storage, but not as much as oxygen scavenger B ($p < 0.05$). As mentioned before, this difference can be explained by the oxygen absorption capacity of each type of oxygen scavenger. From 14 to 28 d of storage, carbon dioxide concentrations did not change in master packs with oxygen scavengers and with or without ground beef ($p > 0.05$). Since carbon dioxide absorption by an oxygen scavenger is a subsequent reaction of iron oxidation in the presence of oxygen (Charles et al., 2006), oxygen is needed for oxygen scavengers to continue the uptake of carbon dioxide. Therefore, when oxygen has been depleted from the package headspace gas, carbon dioxide uptake will end. In the current study, this occurred at 14 d of storage. In addition, studies have shown that during the first few days of storage, equilibrium is reached as meat becomes fully saturated with carbon dioxide (Al-Nehlawi et al., 2013; Jakobsen and Bertelsen, 2002; Møller et al., 2000; Penney and Bell, 1993; Rotabakk et al., 2006). Having 30% carbon dioxide, as compared to 20%, resulted in master packs with higher CO₂ concentrations, regardless of their storage time ($p < 0.05$; headspace gas vs. storage time interaction, $p < 0.0001$).

Color

Following master pack storage, individual retail packages were removed, allowed to bloom and placed in an illuminated retail display. During bloom, meat was exposed to atmospheric oxygen leading to formation of bright red oxymyoglobin due to the high permeability of the primary packaging (Uboldi et al., 2014). Carbon dioxide concentrations in the master pack did not have a significant effect on CIE L* value ($p = 0.0635$), a* value ($p = 0.6157$), and b* value ($p = 0.5965$) following 1 h of bloom. Display time and storage time each had a significant effect on L* value ($p < 0.0001$ and $p = 0.0142$, respectively). After 28 d of storage the L* value for 1 h bloom was less ($p = 0.0085$) than that for 0 d of storage (L* = 53.7 versus 55.0 respectively). However, this difference is probably too small to be of practical importance. Similarly, as display time increased, there was a small decrease in L* values. In addition, presence of an oxygen scavenger did not contribute to changes in L* values ($p = 0.1045$). However, allowing meat to bloom for 1 h increased L* values from 54.3 to 55.4 ($p < 0.0001$). When near zero residual oxygen concentration is pres-

ent in the package headspace gas, deoxymyoglobin is the primary pigment form in meat. When this is the case, meat that is allowed to bloom in air becomes a bright red color (Buys, 2004; O’Keeffe and Hood, 1980; Wilkinson et al., 2006). Similar to our study, Isdell et al. (1999) and Uboldi et al. (2015) found that beef steaks and beef patties of ground meat, respectively, stored in reduced oxygen master packs with oxygen scavengers exhibited typical bloom, showing higher a* values (redness).

In the current study CIE a* values after 1 h bloom were affected by the presence of an oxygen scavenger, storage time, and display time, as well as their interactions ($p < 0.0001$). The inclusion of an oxygen scavenger increased a* values compared to master packs stored without an oxygen scavenger ($p < 0.0001$). This finding indicates that having an oxygen scavenger present during master pack storage improved meat color stability. Several other investigators have observed meat discoloration during low oxygen storage without the benefit of oxygen scavengers (Buys et al., 1994; Isdell et al., 1999; Limbo et al., 2013; O’Keeffe and Hood, 1980). In general, as storage time in master packs increased, a* values decreased ($p < 0.05$). There was no significant difference in a* value decline due to the type of oxygen scavenger. Redness was maintained through 2 d of display time with an acceptable average of 22.8 and 24.3 a* values, for oxygen scavengers A and B, respectively. It is important to note that redness (a* values) decreased by the fourth day of display, especially in samples with increasing storage time ($p < 0.05$). Commission internationale de l’éclairage b* values for ground beef stored in master packs and then allowed to bloom did not differ ($p > 0.05$) among storage times of 14, 21, or 28 d. However, b* values were significantly greater ($p < 0.0001$) for meat from master packs at Day 0 versus all other storage days.

Ground beef stored without an oxygen scavenger reached lesser a* values during display when compared to ground beef that was master packed with an oxygen scavenger ($p < 0.0001$). This finding emphasizes the necessity of using oxygen scavengers to increase meat color shelf life. Similarly, Isdell et al. (1999) showed that master packed beef steaks without oxygen scavengers presented persistent low a* values during meat display. Conversely, Isdell et al. (1999) discovered that following 6 wk of master pack storage with oxygen scavengers, a* values were acceptable when the retail packages were removed and allowed to bloom but faded during 4 d of retail display. In the current work, an increase in ground beef a* value ($p < 0.05$) after 28 d of storage in a master pack without an

oxygen scavenger may be the result of reducing conditions present in the package due to microbial growth. An increase in bacteria could decrease oxygen tension at the meat surface, causing the observed color changes (Renner, 1990; Seideman et al., 1984).

Myoglobin forms

Oxymyoglobin, deoxymyoglobin, and metmyoglobin concentrations were not affected by initial carbon dioxide concentration in the master packs ($p = 0.93$, $p = 0.54$, and $p = 0.54$, respectively). The use of oxygen scavengers, storage time, display time, and their interactions affected oxymyoglobin and metmyoglobin concentrations ($p < 0.0001$), but did not affect deoxymyoglobin concentration ($p > 0.05$) for samples allowed to bloom following storage. The use of oxygen scavengers helped to maintain myoglobin in its reduced state i.e., deoxymyoglobin during storage. This reduced state of myoglobin allowed ground beef to bloom, increasing oxymyoglobin ($p < 0.0001$) and decreasing deoxymyoglobin ($p < 0.0001$) concentration after exposure to air. Deoxymyoglobin concentrations were consistently low, near 0% for 0 display time and 8.2% on average for other display times in samples that were allowed to bloom for 1 h. Metmyoglobin did

not change after meat bloomed ($p = 0.0805$). Figure 3 shows the interaction between storage time and oxygen scavengers for ground beef stored in a master pack then allowed to bloom for 1 h. After master pack storage and bloom, ground beef without oxygen scavengers, exhibited decreased oxymyoglobin and increased metmyoglobin, as storage time increased ($p < 0.05$). In contrast, the use of oxygen scavengers maintained high oxymyoglobin levels and metmyoglobin levels close to zero during 28 d of master pack storage. As expected, ground beef in master packs with a slight amount of oxygen, i.e., no oxygen scavenger, exhibited meat pigment oxidation making the use of this type of package not feasible. This finding is in agreement with Beggan et al. (2006) and Uboldi et al. (2015) who concluded that the addition of oxygen scavengers reduced metmyoglobin formation in meat compared to packages that did not contain an oxygen scavenger. In that study, metmyoglobin concentration was significantly higher in packages without oxygen scavengers after 7 d of storage. Venturini et al. (2006) also found that the use of oxygen scavengers in master packed beef steaks resulted in decreased pigment oxidation. In their study, a desirable ratio of oxymyoglobin to metmyoglobin was maintained in master packs with oxygen scavenger for up to 42 d of storage. In the

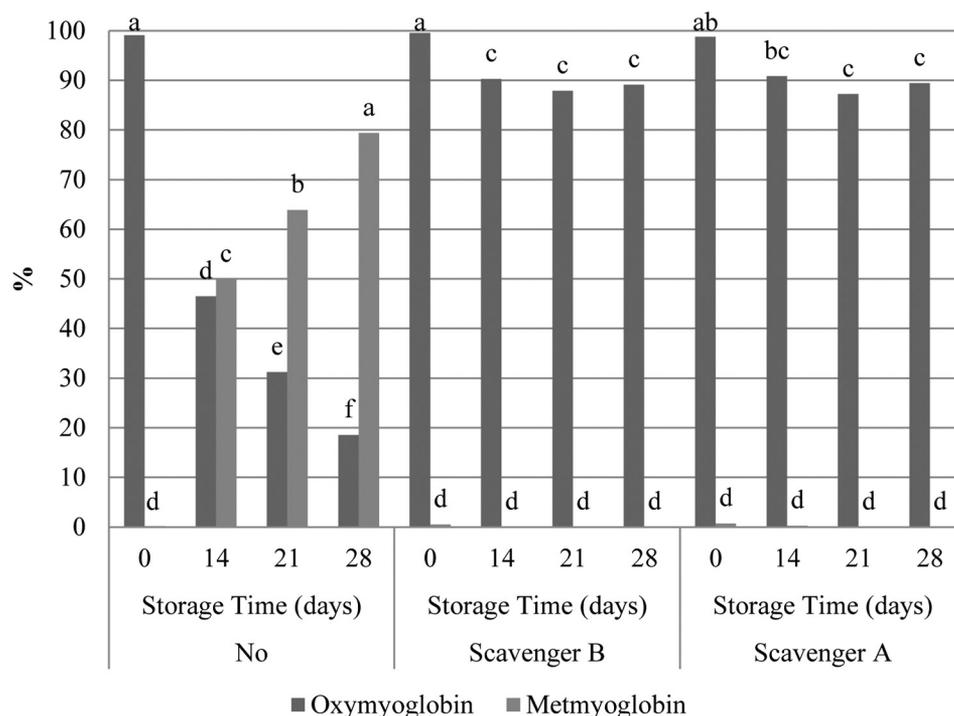


Figure 3. Percentage of myoglobin forms of master packed ground beef after 1-h bloom without or with 1 oxygen scavenger (A or B) over storage time. ^{a-f} Means within the same myoglobin form without a common letter are significantly different ($p < 0.05$). SEM are 1.60 for oxymyoglobin, 1.46 for deoxymyoglobin, and 0.84 for metmyoglobin.

current study, oxymyoglobin decreased ($p < 0.0001$) with display time up to 4 d. The decrease in oxymyoglobin was associated with an increase in metmyoglobin during display ($p < 0.0001$). Still, the addition of an oxygen scavenger showed a clear advantage in color during display, when compared to master packs that did not have an oxygen scavenger. Oxymyoglobin concentration during display (Figure 4) remained above 60% in ground beef that was master packed with oxygen scavengers for up to 28 d and displayed for up to 2 d. It is important to emphasize that oxygen scavengers effectively reduced oxygen levels to a point where meat color stability was improved.

Conclusion

The results of this experiment demonstrate that oxygen scavengers reduce both oxygen and carbon dioxide concentrations in the master pack headspace. By removing residual oxygen, the scavenger allows formation of deoxymyoglobin in master packed ground beef. By 14 d of storage time with the inclusion of oxygen scavengers, CO₂ was reduced to extremely low levels. This eliminates the capability of CO₂ to decrease pH and act as inhibitor of microbial growth. Color analysis clearly shows the advantage of using oxygen scavengers in master packs of ground beef. Even though there were small differences in gas concentrations between the 2 oxygen scavengers used, there were no color differences. An oxygen concentration of 3.79% O₂ during

master pack storage (without oxygen scavenger) was enough to make ground beef color unsuitable for display after 14 d of storage. In contrast, master packed ground beef stored for up to 28 d with an oxygen scavenger and displayed for 2 d produced an oxymyoglobin concentration over 60%. Maintaining oxygen concentration below 0.05% in the master pack headspace gas is important to limit formation of metmyoglobin. This reduction can be achieved by the use of oxygen scavengers. However, changes in headspace carbon dioxide concentration need to be considered when choosing the appropriate oxygen scavenger.

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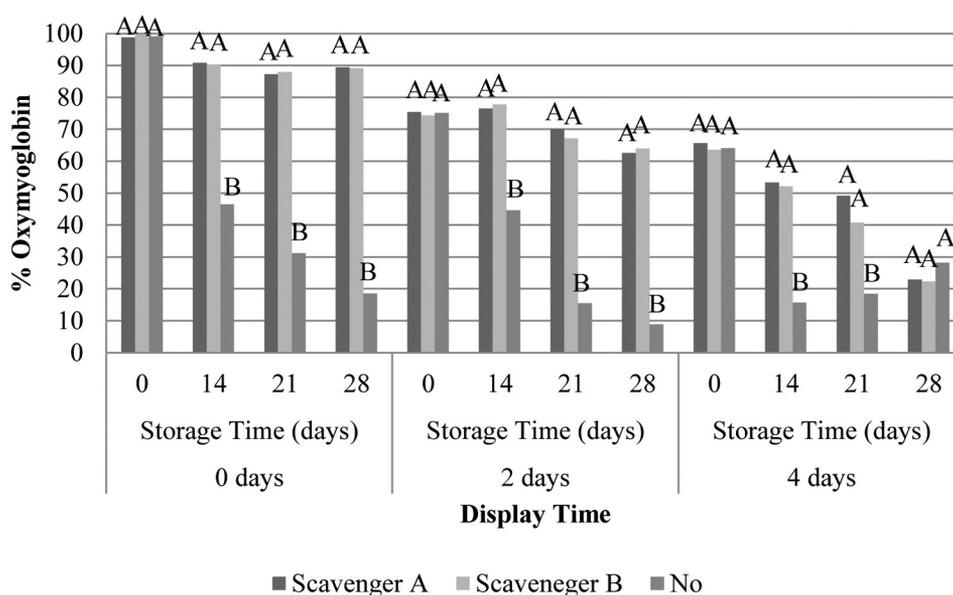


Figure 4. Percent oxymyoglobin of master packed ground beef stored for up to 28 d with or without an oxygen scavenger then displayed for up to 4 d. ^{A-B}Means within the same storage time and display time without a common letter are significantly different ($p < 0.05$) SEM is 3.50.

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