Project Title:

Impact of Ground Beef Packaging Systems and Temperature Abuse on the Safety and Quality of Ground Beef

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Project Summary

The objectives of this study were to:

1. Determine the impact of packaging methods and temperature abuse on the pathogen loads in ground beef inoculated with *E. coli* O157 and *Salmonella*.
2. Determine the effect of packaging methods and temperature abuse on the spoilage characteristics and shelf life of ground beef.

These objectives were accomplished with two studies – a pathogen study conducted at the BSL II Food Safety Laboratory at Texas Tech University-Experimental Sciences Building and a shelf life study conducted at the GW Davis Meat Science Laboratory. Coarse-ground beef was obtained from a commercial processor located 45 miles from Lubbock, TX. Ground beef patties were produced and allotted randomly to five packaging treatments. The five packaging treatments evaluated were: **1**) control (foam tray with film over-wrap); **2**) high-oxygen (80% O_2 / 20% CO_2) modified atmosphere package (MAP); **3**) low-oxygen MAP without carbon monoxide; **4**) low-oxygen carbon monoxide (0.4% CO, 30% CO_2, 69.6% N_2) MAP; and **5**) vacuum (clear pouch/bag). Packaged patties were stored in the dark for 5 days, displayed under retail lighting for 5 days at abusive temperatures, transferred to additional retail display cases maintained at 0°C and displayed for 10 days. Samples were removed from the test at regular intervals throughout the study to evaluate the effects of packaging treatment on pathogen levels and spoilage characteristics.

Executive Summary of Results

- Increases in numbers of *E coli* O157:H7 in ground beef were higher in the OW and OX packaging treatments than CO, NO, and VAC during temperature abuse.
- *Salmonella* counts did not differ among packaging treatments during temperature abuse.
- Ground beef packaged in CO exhibited an extended shelf, less odor development, greater color stability and less oxidative rancidity development compared to OW, OX, NO and VAC packaging treatments.

- In general, all low oxygen packaging techniques resulted in extended shelf life, less odor production and reduced oxidative rancidity development compared to oxygenated packaging techniques.
- 97% of the trained panel detected some type of off-odor in the packages after the 20-day storage and display period. Conversely, 20% of consumers were unable to detect off-odors in all packages and indicated they would consume the ground beef based on its odor regardless of packaging type.
- With the exception to meat color, CO and VAC packaged exhibited similar color, odor, TBA and microbial characteristics
- A significant percentage of consumers would purchase and consume ground beef packaged in CO after 5 days of temperature abuse and 15 days of lighted display.

Project Description

Introduction

Recent petitions to FDA and USDA have requested the re-evaluation of carbon monoxide gas as an approved packaging component. The Food and Drug Administration (FDA) and USDA FSIS requires that approved processes and/or ingredients do not in any way result in the product becoming adulterated or misbranded, which includes making the meat product look better or of greater value than untreated products and the normal spoilage indicators can not be masked (FSIS, 2003). Thus, research is needed to provide industry and government officials with scientific data regarding the safety and spoilage characteristics of modified atmosphere packaging systems containing carbon monoxide gas.

Pactiv Corporation received approval by the Food and Drug Administration in 2002 to use carbon monoxide (0.4%) as a component of a gas mixture in a modified atmosphere packaging systems to maintain wholesomeness, provide flexibility in distribution and reduce shrinkage in meat (FDA, 2002). Carbon monoxide use in MAP systems has been shown to reduce aerobic plate counts (Brewer et al., 1994 and Luno et al., 2000), psychrotrophic bacteria counts (Brewer et al., 1994 and Luno et al., 1998), and *Brochothrix thermosphacta* levels (Luno et al., 2000 and Sorheim et al., 1999) on the surface of beef steaks. Similar reductions in psychrotrophic bacteria counts were also observed in ground beef samples (Luno et al., 1998), while the effect of carbon monoxide gas on lactic acid bacteria counts seems to be dependent on application (Brewer et al., 1994 and Luno et al., 2000). Nissen et al. (2000) reported that packaging atmospheres containing 0.4% carbon monoxide could increase the growth of certain strains of *Salmonella* at abusive temperatures in ground beef. However, Brashears et al. (2006) recently reported that a MAP environment consisting of 0.4% carbon monoxide/30% carbon dioxide/69.6% nitrogen reduced *E. coli* O157:H7 and *Salmonella* spp in ground beef patties stored under simulated retail display by **1×10^2 log cfu/g** compared to traditional packages. This research contradicts concerns expressed by several authors (Hintlian and Hotchkiss, 1986; Sivertsvik et al., 2002; Farber, 1991; O'Connor-Reyes and Shaw, 2000) who feared MAP atmospheres may inhibit organisms that are typical indicators of spoilage to consumers while promoting the growth of pathogens. However, most research suggesting a relationship between MAP and pathogen growth/survivability was performed by inoculating samples through a septum placed on the packaging film. Palmore (2005) showed this approach was very difficult to control and resulted in leaks, which caused the package environment to change during the course of the study. Therefore, pre-packaged inoculation studies examining carbon monoxide effects on the survival of *E. coli* O157:H7 and *Salmonella* spp on ground beef stored at abusive temperatures are limited.

Materials and Methods

Objective 1: Coarse ground beef was obtained from a commercial processor immediately after its release from the company's "test and hold" program, and transported to the Texas Tech University BSL 2 pathogen processing area for sample preparation under simulated industry conditions. The coarse ground beef was placed in a mixer and blended with either a cocktail mixture of *E. coli* O157 or *Salmonella* prior to a final grind (separate batches for each pathogen). Five packaging treatments were evaluated: **1**) control (foam tray with film over-wrap); **2**) high-oxygen (80% O_2 / 20% CO_2) modified atmosphere package (MAP); **3**) low-oxygen MAP without carbon monoxide; **4**) low-oxygen carbon monoxide (0.4% CO, 30% CO_2, 69.6% N_2) MAP; and **5**) vacuum (clear pouch/bag).

Beef patties were produced, packaged and stored in the dark at 0-2°C for 5 days. Following dark storage, packages were placed in multi-deck retail cases under continuous fluorescent lighting (approximately 1900 lux using high-output bulbs with a color temperature rating of 3500°K) at 10^{o}C for 5 days. Ground beef intended for overwrap packages was stored in chubs during dark storage. On day 5, patties were inoculated and produced from the chub-packed ground beef and subjected to temperature abuse with the other packaging treatments. Following temperature abuse, all packages were placed in additional multi-deck cases under similar lighting for 10 days at 0-2°C. Packaged beef patties were evaluated for total pathogens on days 0, 5, 6, 7, 8, 9, 10, 15 and 20 of the study.

A cocktail mixture of 4 *E. coli* O157:H7 Strains (A4 966, A5 528, A1 920, 966) and 3 *Salmonella* strains (14028, 3347-1, phage 13) were used in this study. Individual strains were propagated in trypicase soy broth at 37°C for 18-24 h. After growth, a concentrated culture was prepared containing all 3 strains of *Salmonella* and a separate one containing all 4 strains of *E. coli*. Concentrated cultures were prepared to allow for inoculation levels of 1 x 10^4 cfu/g in the ground beef.

On each day of sampling, packages were aseptically opened and subjected to serial dilutions in peptone dilution water. Samples inoculated with *Salmonella* were plated on XLD agar overlayed with TSA using the thin-layer agar method to allow for recovery of injured cells. Samples containing *E. coli* O157 were plated onto MacConkey Agar overlayed with TSA using the thin-layer agar method as well. Samples were plated using a spiral plating system and counted using a Q count automated counting system. All plates were incubated for 24-28 h at 37°C prior to counting.

The project was a split-plot design with meat block serving as the main plot, and blocked by retail display case. Data were analyzed using the GLM procedures of SAS (Cary, NC). Least-square means were computed for each dependent variable, and statistically separated by pair-wise t-test (PDIFF option of SAS) with predetermined $\alpha = 0.05$.

Objective 2 Coarse ground beef (81/19 lean:fat) was obtained from a commercial processor immediately after its release from the company's "test and hold" program, and transported to the Gordon W Davis Meat Science Laboratory for preparation and packaging under simulated industry conditions. The coarse ground beef was placed in a mixer and blended prior to a final grind for each packaging treatment. The final grind was then be transferred to a patty forming machine and portioned into 150 g patties of uniform thickness prior to packaging. Five packaging treatments were evaluated: **1**) control (foam tray with film over-wrap); **2**) high-oxygen (80% O_2 / 20% CO_2) modified atmosphere package (MAP); **3**) low-oxygen MAP without carbon monoxide; **4**) low-oxygen carbon monoxide (0.4% CO, 30% CO_2, 69.6% N_2) MAP; and **5**) vacuum (clear pouch/bag).

Beef patties were evaluated for changes in color and odor by trained and consumer panelists over time (Days 0, 5, 6, 7, 8, 9, 10, 15 and 20). On day 0 of the study, packaged beef patties were stored in the dark at 0-2°C for 5 days. Following dark storage, packages were placed in multi-deck retail cases under continuous fluorescent lighting (approximately 1900 lux using high-output bulbs with a color temperature rating of 3500°K) at 10^{o}C for 5 days. Following temperature abuse, packages were placed in additional multi-deck cases under similar lighting for 10 days at 0-2°C. Ground beef intended for overwrap packages were stored in chubs during dark storage. On day 5, patties were produced from the chub-packed ground beef and subjected to temperature abuse with the other packaging treatments.

Both trained and consumer panelists were used to detect differences in color and odor. Panelists were trained in multiple sessions using representative samples prior to the start of the project. Trained panelists evaluated the color of ground beef patties using a five-point, verbally anchored scale (1 = very bright red; 5 = very dark red or brown) and surface discoloration (1 = no discoloration; 5 = severe discoloration, 61-100%) according to AMSA color guidelines. Consumer panelists were recruited from the surrounding area and paid to participate in the study. Consumers were asked to determine if the ground beef patties had good color (1 = very strongly agree; 7 = very strongly disagree) and how likely they would be to purchase (1 = definitely would purchase; 5 = definitely would not purchase) the package based on the color (AMSA, 1991). CIE L*, a*, and b* values were taken at each sampling time using a Hunter Miniscan XE Plus (Hunter Laboratories Model MSXP-4500C, Reston, VA).

Odor panels were conducted on packages removed from the cases at each sampling interval. Odor samples were presented to trained and consumer panelists under red lighting. Trained panelists were asked to determine if an off-odor was present (1 = no off-odor; 5 = extreme off-odor) and to characterize the off-odor if present (1 = rancid; 2 = arid; 3 = sweet; 4 = sour; 5 = acid; and 6 = putrid). Consumer panelists were asked if the meat in the package smells fresh (1 = very strongly agree, 7 = very strongly disagree) and how likely they would be to consume the meat (1 = definitely would consume; 5 = definitely would not consume) based upon the odor.

Microbial loads were determined using standardized methods. Total Aerobic Plate Counts (APC) were determined by plating on total plate count agar, Lactobacilli was determined by plating on LBS agar and total coliforms was determined by plating on VRBA agar. All plates were incubated at 37 °C for 48 h, except those used to measure psychrophillic bacteria. Total aerobic psychrophilic bacteria were determined by plating onto APC agar and incubating at 7 °C for 7 d. Finally, oxidative rancidity development in samples was evaluated using the procedures of Buege and Aust (1978).

The project was a split-plot design with meat block serving as the main plot, and blocked by retail display case. Data were analyzed using the GLM procedures of SAS (Cary, NC). Least-square means were computed for each dependent variable, and statistically separated by pair-wise t-test (PDIFF option of SAS) with predetermined $\alpha = 0.05$.

Results and Discussion

Pathogen Growth; Figures 1-4

During times of temperature abuse, *E. coli* O157 increased over time in ground beef in all packages. The initial inoculation levels were not different on day 0 ranging from 5.38 $\log_{10}$ cfu/g to 5.84 $\log_{10}$ cfu/g (Figure 1). On the 5th day of sampling, just prior to starting temperature abuse, the numbers had not increased and they again were not significantly different comparing among the treatments. On day 7 (2 days of temperature abuse) the ground beef in the carbon monoxide (CO) packages and in the no oxygen (NO) packages had significantly fewer *E. coli* O157:H7 cells compared to the amount detected in other packages. On day 8 the ground beef from CO, NO, vacuum (VAC) and high oxygen (OX) packages had significantly fewer *E. coli* O157:H7 compared to the overwrap (OW) packages. On days 9 and 10, the ground beef in the CO, NO and VAC packages had fewer cells while the OX and the OW samples contained 1-2 log cycles more *E. coli* O157:H7. On day 10, the ground beef was removed from temperature abuse conditions and returned to normal storage temperatures. After an additional 5 days of storage at normal holding temperatures (total of 15 days) and another additional 5 days (total of 20 days), the amount of *E. coli* O157:H7 remained lower in the ground beef packaged in CO, NO, and VAC packaging compared to the samples collected from traditional OW packages and OX packages.

In general, over time, the total numbers of *E. coli* O157:H7 increased significantly in all ground beef samples in all packages during temperature abuse. However, the increase in CO,. NO and VAC packaged samples was less than that in OX and OW samples. During times of abuse the CO, NO and VAC samples increased approximately 1 log cycle. In the OW and OX samples, we observed at least a 2 log cycle increase.

The *Salmonella* in the ground beef samples did not differ among treatments during temperature abuse. There are some numerical differences which indicate a similar trend as the *E. coli* O157:H7 differences with the amount of *Salmonella* detected in ground beef packaged in CO, VAC, and NO packages being numerically lower during times of temperature abuse, but the differences were no statistically significant (Figure 2). As observed with the *E. coli* O157:H7, the total amount of *Salmonella* in all packaged increased during temperature abuse with increases in ground beef in all packages being more than 2 log cycles during the abuse. At the end of the abuse period and during extended storage it is likely that the pathogens entered the decline phase of the growth cycle.

Overall, it appears that CO, NO and VAC packaging had a detrimental effect on the growth of *E. coli* O157:H7 during extended times of temperature abuse and may improve the safety these products. Even though there was no impact on the growth of *Salmonella*, the suppression of *E. coli* O157 is enough of a benefit to warrant exploration of this packaging technology as a viable intervention in ground beef for processors wanting to control *E. coli* O157:H7.

Quality Evaluations

Consumer odor scores are presented in Figures 5 and 6. Consumer responses when asked if they would consume the meat in the package, considering its odor, are presented in Figure 5. Odor evaluation began on day 5 after samples had been held in dark storage under refrigerated conditions. During the abuse period, an increasing number of consumers would not consider consuming the meat packaged in OW or OX packages. Throughout the 20-d display period, consumers indicated they probably would consume samples packaged in the NO and CO environments, while most consumers were unsure whether or not they would consume meat stored in VAC packages. Consumer agreement to the statement: *The meat in this package smells fresh* are presented in Figure 6. After three days of temperature abuse, consumers indicated the ground beef packaged in OW and OX environments was no longer fresh. Throughout the 15 and 20 day display period, consumers were neutral or in agreement that ground beef packaged in

VAC, and CO or NO environments, respectively, smelled fresh. To better understand consumer rankings for these traits, frequency distributions for each packaging type and each day of display were generated. These frequency tables are presented in the appendix and will be discussed further.

Trained panels scores for off odor are presented in Figures 7 and 8. Figure 7 depicts the presence of off odors in samples during lighted display. Data reveals panelists detected slight off odors in OX and OW samples on the first day of lighted display. After three days of temperature abuse, trained panelists began to detect off odors in ground beef packaged in NO and CO packaging. After five days of temperature abuse and lighted display, significant off odors in the ground beef can be detected in the OW and OX package treatments; whereas slight off odors are present in a clear majority of the ground beef samples from the NO CO and VAC packaging. The frequencies of "no off odor" scores made by trained panelists are presented in Figure 8. The frequency of "no off odor" scores was highest among the VAC, NO and CO packaging throughout lighted display. The frequency of the score began to decline after 4 days of temperature abuse, and was almost non-existent at the end of the study – indicating most of the samples had an off odor after 20 days of storage.

Trained panels scores for meat color and percent surface discoloration are presented in Figures 9 and 10, respectively. CO packaging stabilized meat color throughout the 20 day storage period, and prevented surface discoloration from developing. Samples stored in OX and OW packagings began to brown and discolor after 1-2 days of temperature abuse. Samples packaged in NO and VAC environments were ranked higher than OX and OW packaged samples but lower than CO packaged samples. Surprising, the color of VAC packages samples tended to improve during display. Surface discolor scores followed a similar pattern to meat color scores (Figure 10) with the exception of NO packaged samples, which showed a sharp increase in lean discoloration after the 5-day temperature abuse period.

Consumer color scores supported the findings of the trained panelist and are presented in Figures 11 and 12. Consumers agreed that ground beef packaged in CO had good color throughout temperature abuse and lighted display. Consumers also gave no indication they would not purchase the ground beef in CO packages throughout the trial. Ground beef packaged in OX and OW treatments would not be purchased by consumers after 1-2 days of temperature abuse.

Non-pathogen microbial counts for Aerobic plate counts, coliforms, Lactobacillus and psychrophillic aerobic plate counts are presented in Figures 13-16, respectively. In general, all micorobial counts increased during temperature abuse. Little change occurred in APC and coliforms counts during the 5 days prior to temperature abuse, however, bacteria counts began to increase immediately for Lactobacillus and psychrophillic APC in all packaging treatments. All microbial counts had a tendency to platau after the temperature abuse period. Psychrophillic APC counts, however, plateau at approximate 10^8 log cfu/g in the CO, VAC and NO packaging treatments after 8 days of storage (three days of temperature abuse). APC exceeded 10^7 log cfu/g for all packaging treatments after 3-4 days of temperature abuse.

Thiobarbituric acid test for each packaging treatment are presented in Figure 17. TBA values indicate an increase in oxidative rancidity that occurred simultaneously with temperature abuse. However, ground beef packaged in CO, NO or VAC environment stabilized quickly and showed little oxidative rancidity development throughout the abuse and display period – remaining stable throughout the trial with little day-to-day variation. Ground beef stored in OX environments showed significant oxidation early in the abuse period and continued to develop oxidation byproducts throughout the trial. Samples stored in OW were intermediate in TBA values.

Objective color values (L*, a* and b*) are presented in Tables 1-3, respectively. Generally, the objective color values support the color observations made by the trained and consumer panelists.

Tables 4 and 5 show changes that occur in diameter or girth of MAP (CO, NO and OX) packages during display. These data indicate no changes in package size occurred due to the accumulation of gases.

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Figure 1. Changes in the total numbers of *E. coli* O157:H7 in ground beef packaged in traditional and modified atmosphere packaging subjected to storage at 2 C on day 0-5 then temperature abused on days 5-10 at 10 C and again subjected to 2 C storage for days 10-20. A significant interaction between treatment and day was detected (P=0.05). Treatment effects were detected (P<0.05) on days 7, 8, 10, and 20 (See Figure 2).

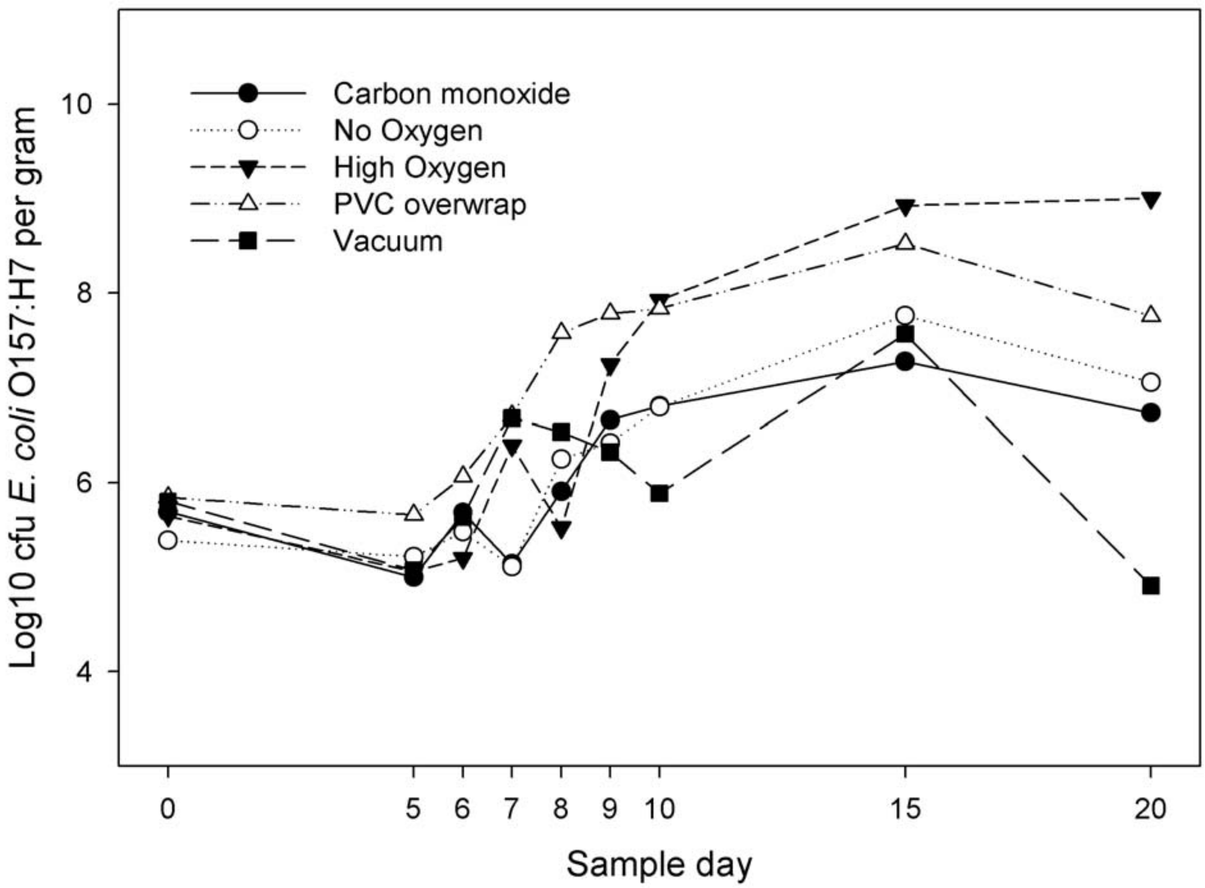


Figure 2. Days on which a significant treatment effect was detected for *E. coli* O157:H7 concentration in inoculated ground beef. Bars with different subscripts different at $\alpha = 0.05$ for each pairwise comparison.

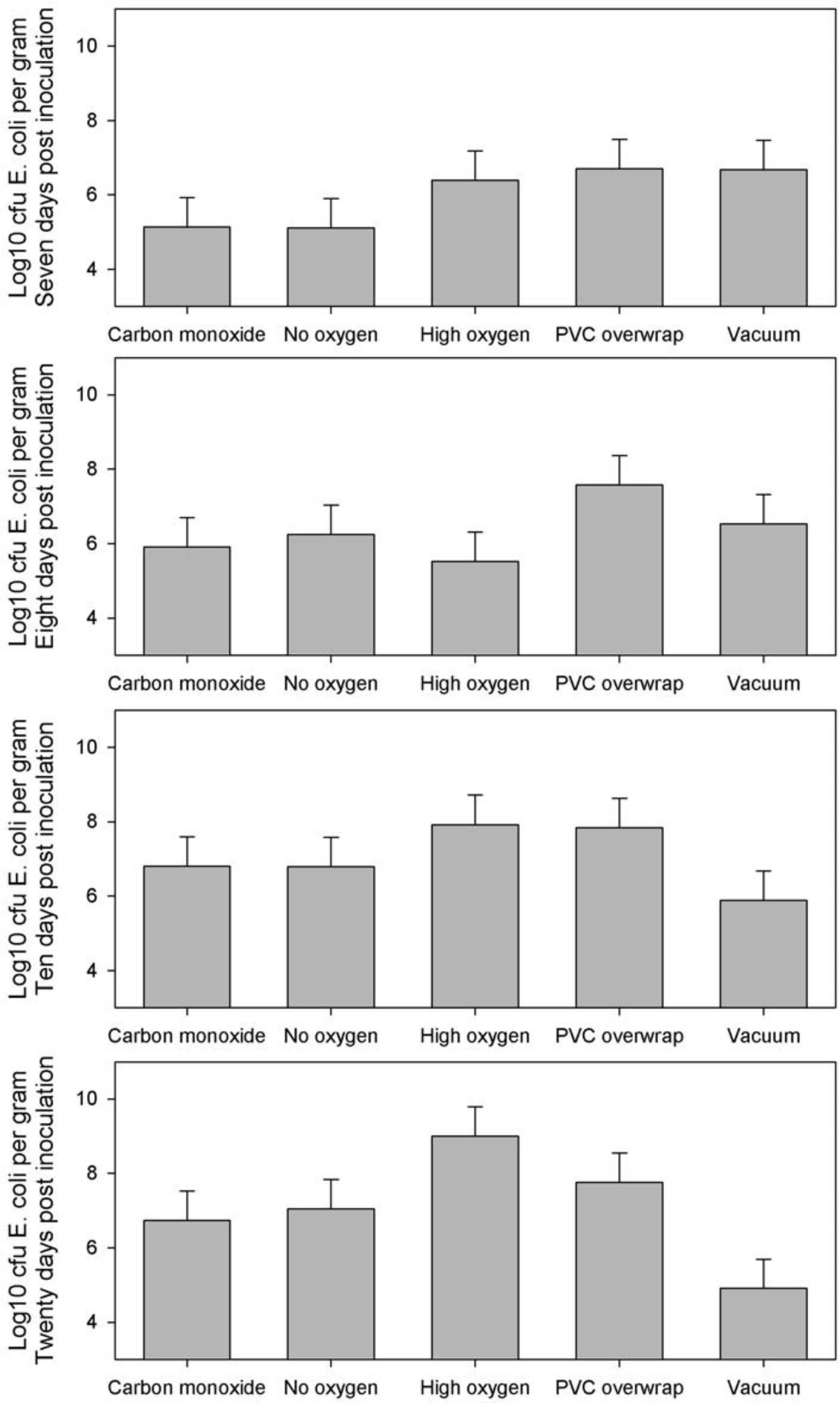


Figure 3. Changes in the total numbers of *Salmonella* in ground beef packaged in traditional and modified atmosphere packaging subjected to storage at 2 C on day 0-5 then temperature abused on days 5-10 at 10 C and again subjected to 2 C storage for days 10-20. An interaction between treatment and day was not detected (P=0.46). There was no main effect of treatment averaged across time (P<0.43).

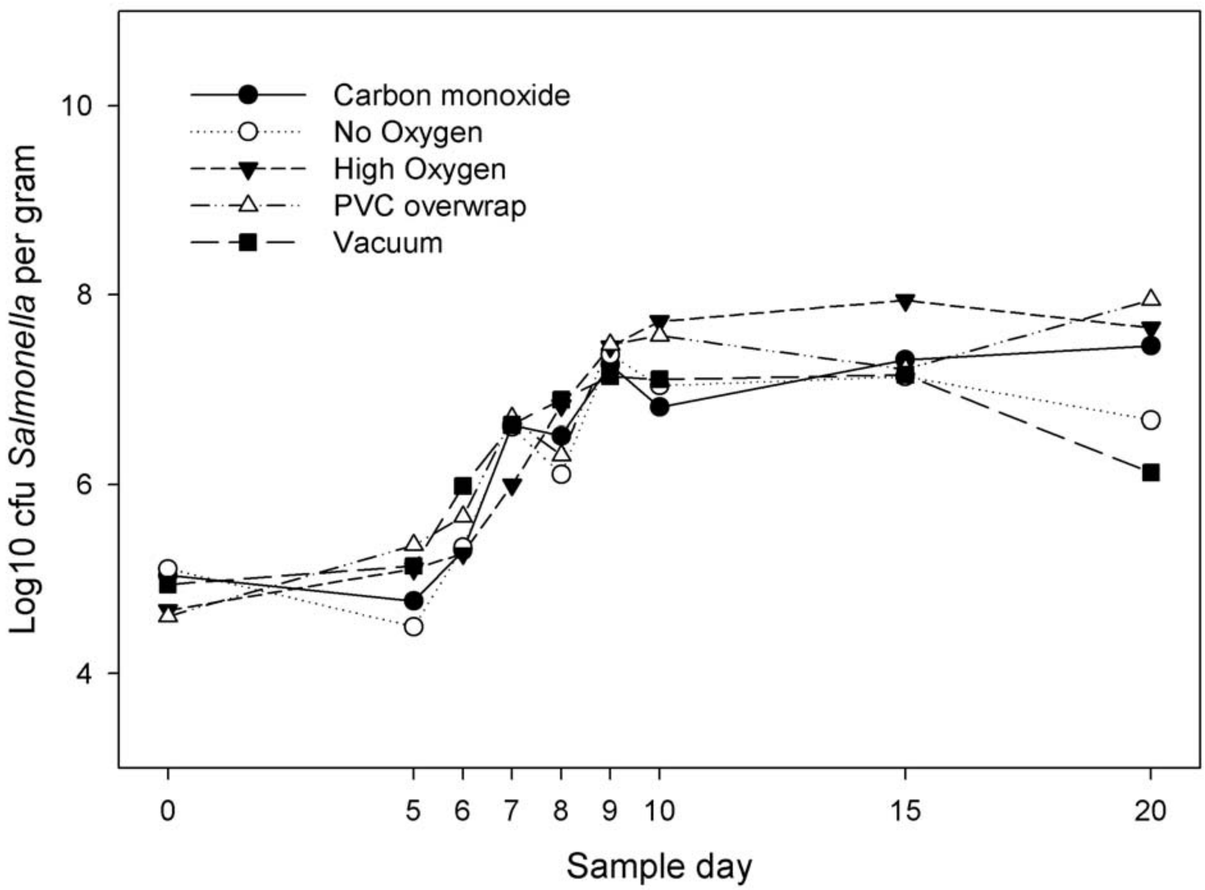


Figure 4. Model-predicted concentration of *Salmonella* averaged over sample day. No treatment effect was evident (P=0.43).

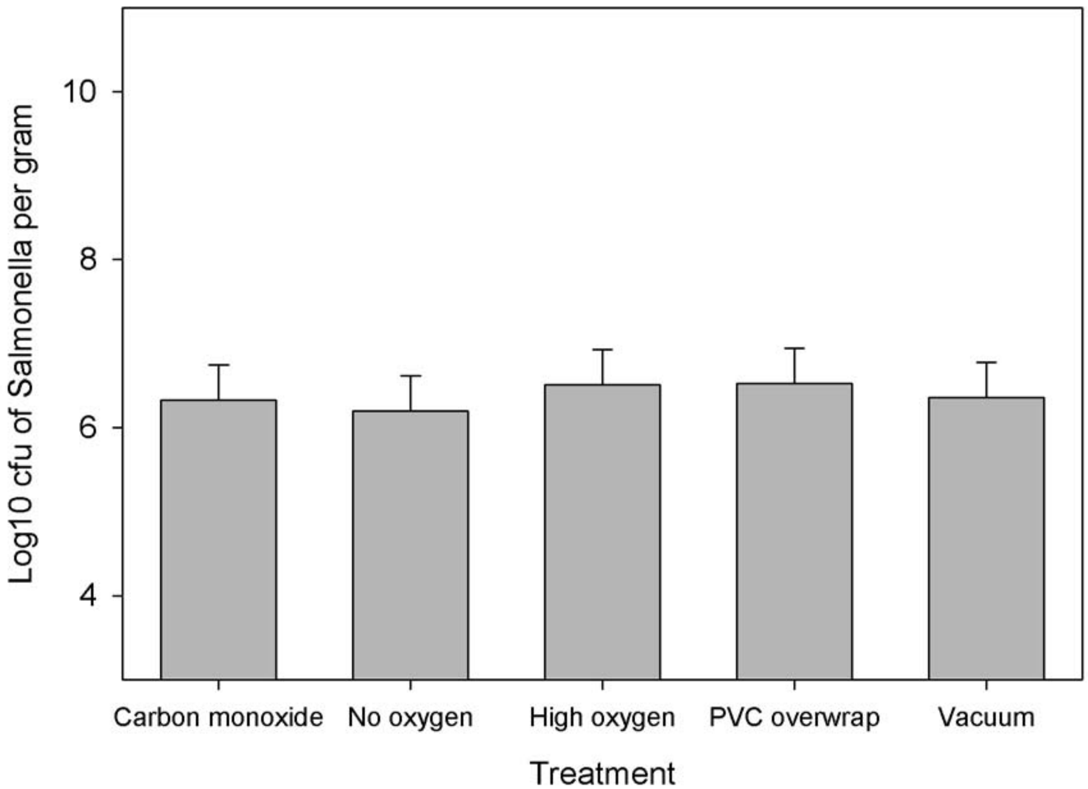
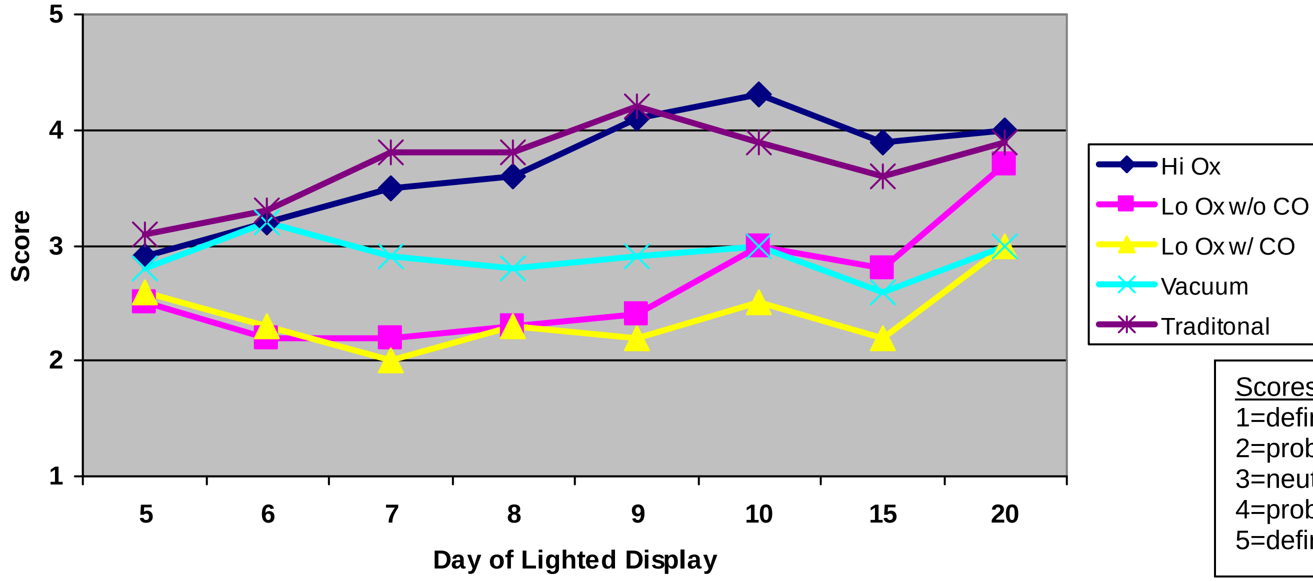


Figure 5- Consumer Responses to their Likelihood to Consume Based on the Odor

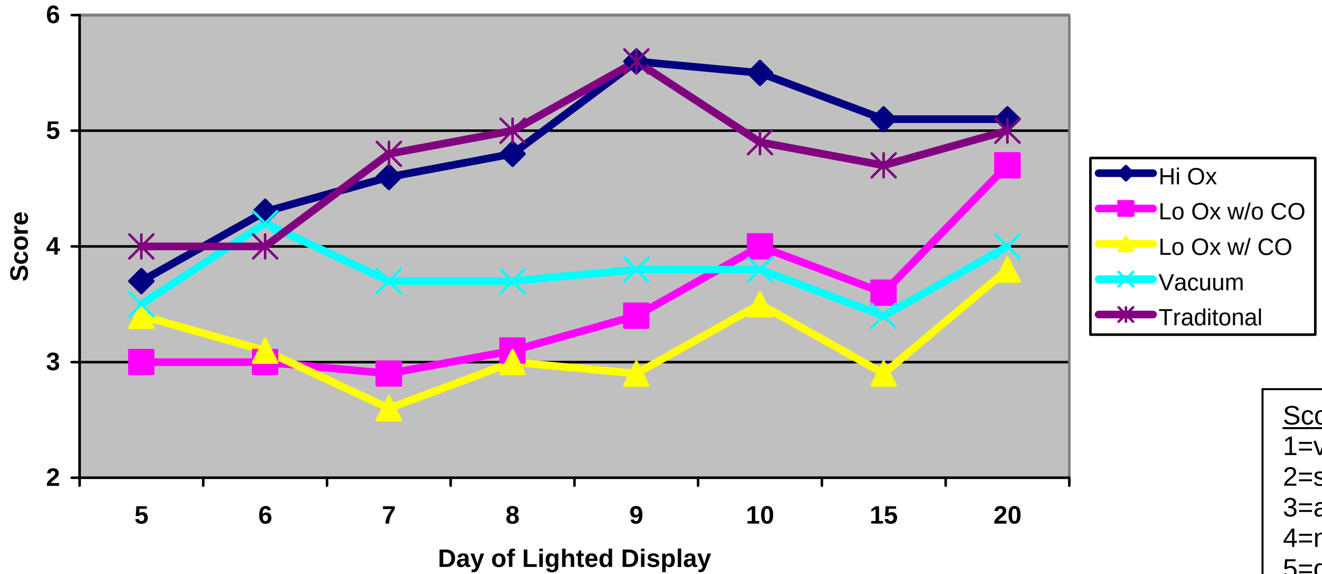


Scores
1=definitely would consume
2=probably would consume
3=neutral
4=probably would not consume
5=definitely would not consume

Data for Figure 5 – Consumer Responses to their Likelihood to Consume Based on the Odor

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	2.9^{bc}	3.2^{b}	3.5^{c}	3.6^{c}	4.1^{c}	4.3^{c}	3.9^{c}	4.0^{b}	0.14
70%N_2 / 30% CO_2	2.5^{a}	2.2^{a}	2.2^{a}	2.3^{a}	2.4^{a}	3.0^{b}	2.8^{b}	3.7^{b}	0.14
0.4% CO / 30% CO_2 / 69.6% N_2	2.6^{ab}	2.3^{a}	2.0^{a}	2.3^{a}	2.2^{a}	2.5^{a}	2.2^{a}	3.0^{a}	0.14
Vacuum Package	2.8^{abc}	3.2^{b}	2.9^{b}	2.8^{b}	2.9^{b}	3.0^{b}	2.6^{ab}	3.0^{a}	0.14
Traditional	3.1^{c}	3.3^{b}	3.8^{c}	3.8^{c}	4.2^{c}	3.9^{c}	3.6^{c}	3.9^{b}	0.14

Figure 6 - Consumer Agreement with the Statement: The ground beef in this package smells fresh.



Scores
1=very strongly agree
2=strongly agree
3=agree
4=neutral
5=disagree
6=strongly disagree
7=very strongly disagree

Data for Figure 6 – Consumer Agreement with the Statement: The ground beef in this package smells fresh.

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	3.7[ab]	4.3[b]	4.6[c]	4.8[c]	5.6[c]	5.5[d]	5.1[c]	5.1[b]	0.19
70%N_2 / 30% CO_2	3.2[a]	3.0[a]	2.9[a]	3.1[ab]	3.4[ab]	4.0[b]	3.6[b]	4.7[b]	0.19
0.4% CO / 30% CO_2 / 69.6% N_2	3.4[a]	3.1[a]	2.6[a]	3.0[a]	2.9[a]	3.5[a]	2.9[a]	3.8[a]	0.19
Vacuum Package	3.5[ab]	4.2[b]	3.7[b]	3.7[b]	3.8[b]	3.8[ab]	3.4[ab]	4.0[a]	0.19
Traditional	4.0[b]	4.0[b]	4.8[c]	5.0[c]	5.6[c]	4.9[c]	4.7[c]	5.0[b]	0.19

Figure 7 - Trained Panel Scores for the Presence of Off-Odor

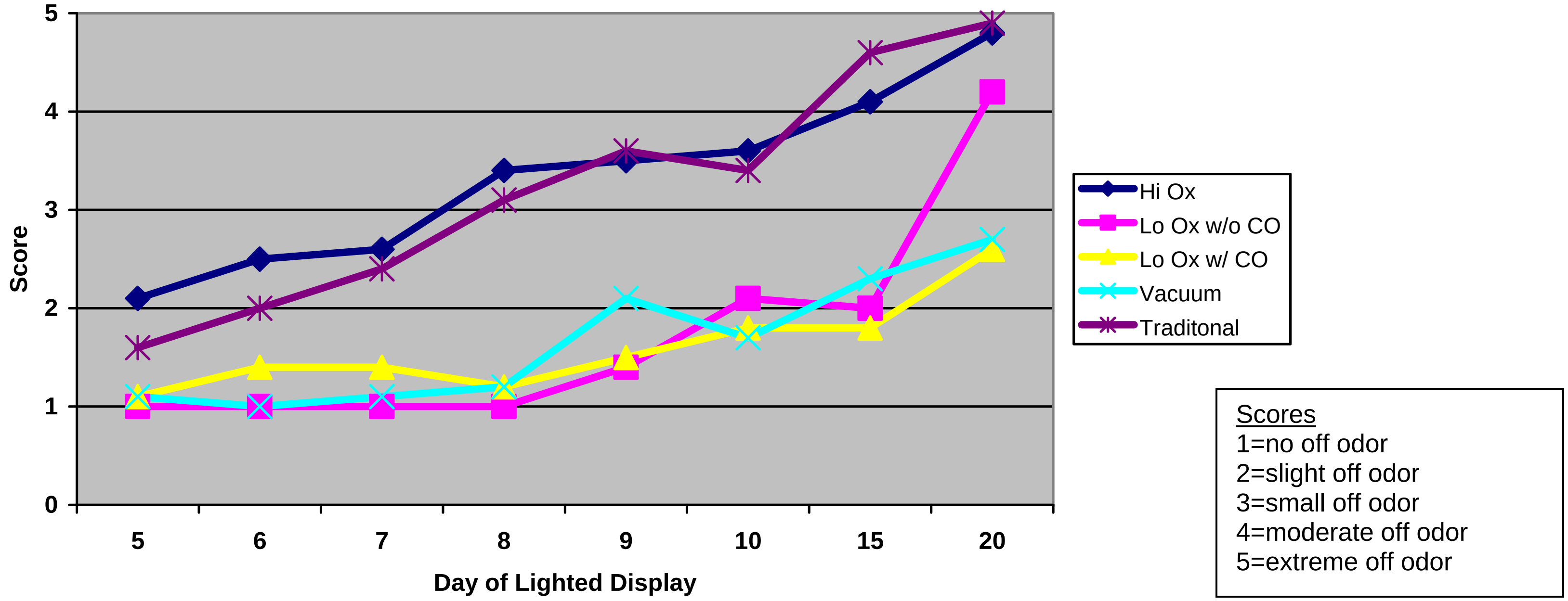


Figure 7 - Trained Panel Scores for the Presence of Off-Odor

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	2.1[c]	2.5[d]	2.6[c]	3.4[b]	3.5[c]	3.6[c]	4.1[c]	4.8[c]	0.10
70%N_2 / 30% CO_2	1.0[a]	1.0[a]	1.0[a]	1.0[a]	1.4[a]	2.1[a]	2.0[a]	4.2[b]	0.10
0.4% CO / 30% CO_2 / 69.6% N_2	1.1[a]	1.4[b]	1.4[b]	1.2[a]	1.5[a]	1.8[a]	1.8[a]	2.6[a]	0.10
Vacuum Package	1.1[a]	1.0[a]	1.1[a]	1.2[a]	2.1[b]	1.7[b]	2.3[b]	2.7[a]	0.10
Traditional	1.6[b]	2.0[c]	2.4[c]	3.1[b]	3.6[c]	3.4[c]	4.6[d]	4.9[c]	0.10

Figure 8 - Frequency of "No Off Odor" Characterization by Trained Panelists (n = 981 total observations)

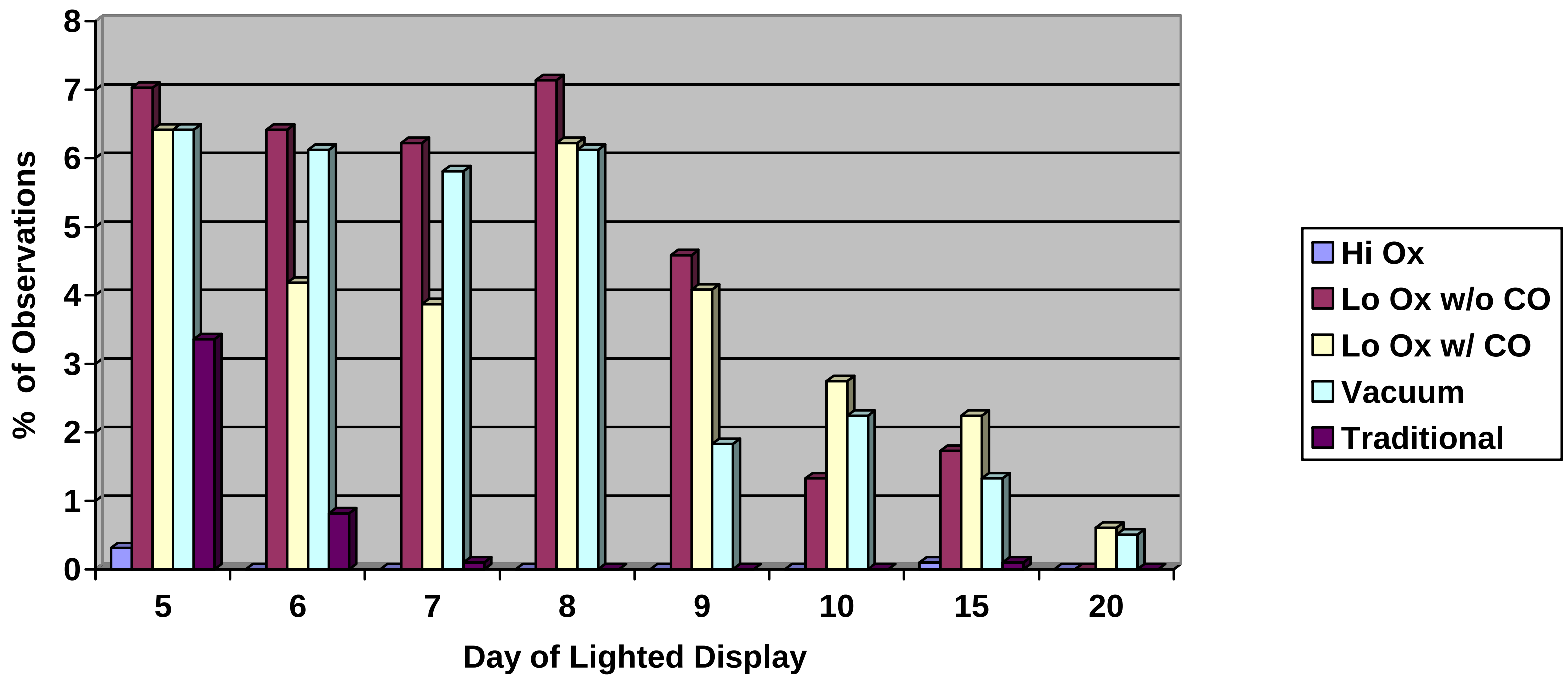
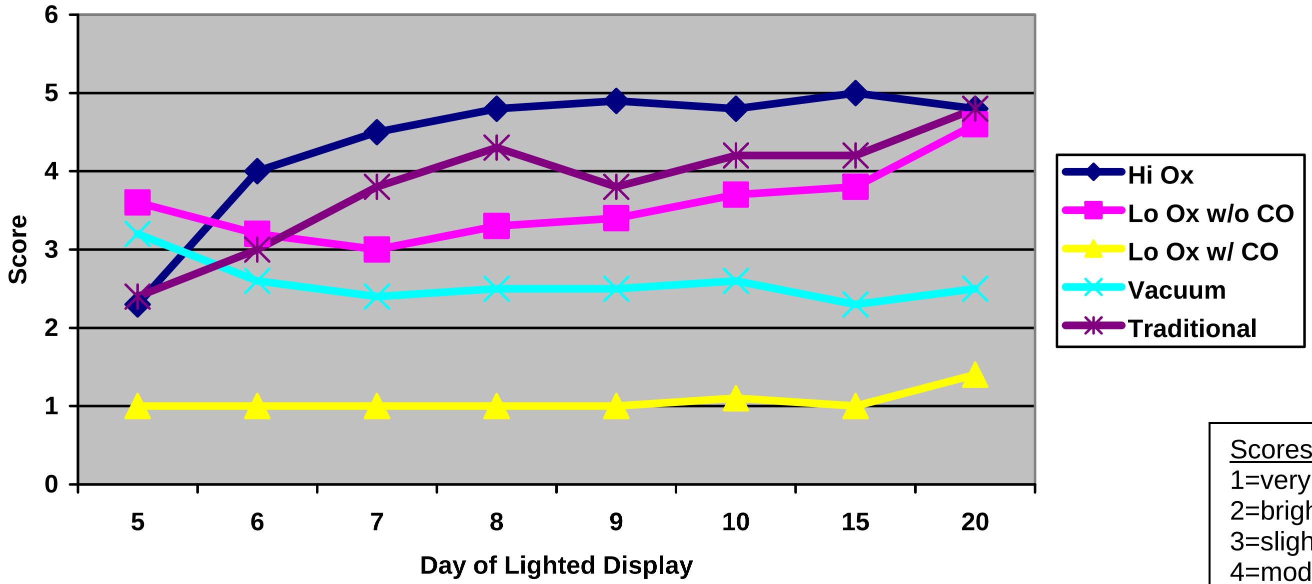


Figure 9 - Trained Panel Color Scores for Meat Color

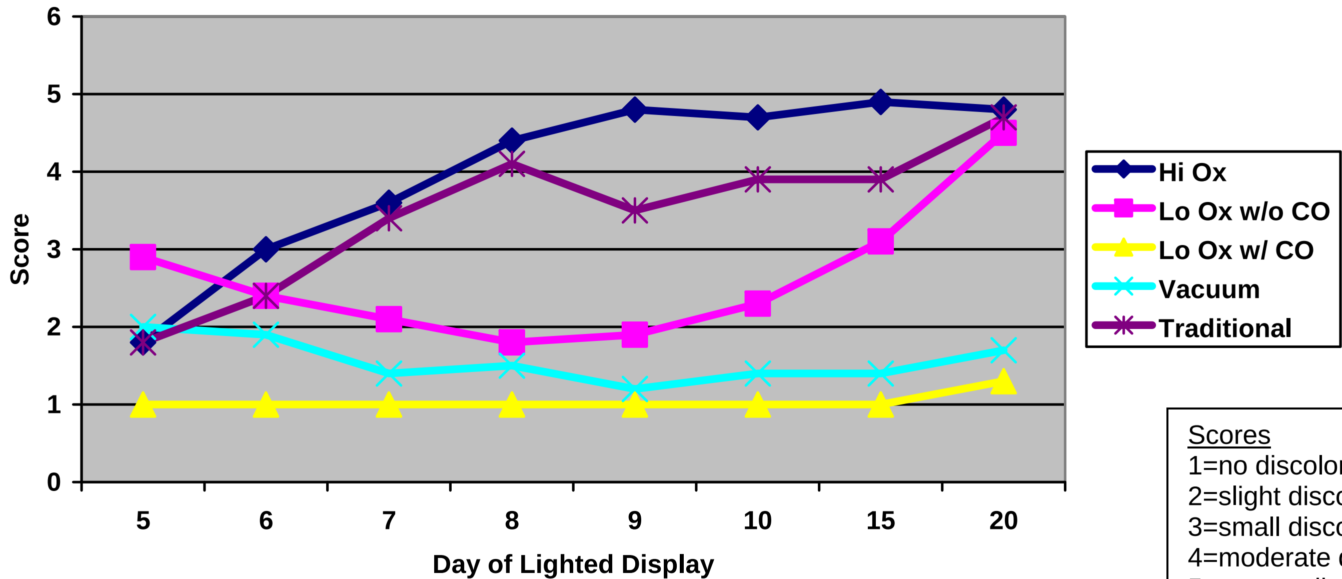


Scores
1=very bright red
2=bright red
3=slightly dark red or brown
4=moderate dark red or brown
5=very dark red or brown

Data for Figure 9 - Trained Panel Color Scores for Meat Color

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	2.3^b	4.0^d	4.5^e	4.8^e	4.9^e	4.8^e	5.0^e	4.8^c	0.09
70%N_2 / 30% CO_2	3.6^d	3.2^c	3.0^c	3.3^c	3.4^c	3.7^c	3.8^c	4.6^c	0.09
0.4% CO / 30% CO_2 / 69.6% N_2	1.0^a	1.0^a	1.0^a	1.0^a	1.0^a	1.1^a	1.0^a	1.4^a	0.09
Vacuum Package	3.2^c	2.6^b	2.4^b	2.5^b	2.5^b	2.6^b	2.3^b	2.5^b	0.09
Traditional	2.4^b	3.0^c	3.8^d	4.3^d	3.8^d	4.2^d	4.2^d	4.8^c	0.09

Figure 10 - Trained Panel Color Scores for Meat Discoloration

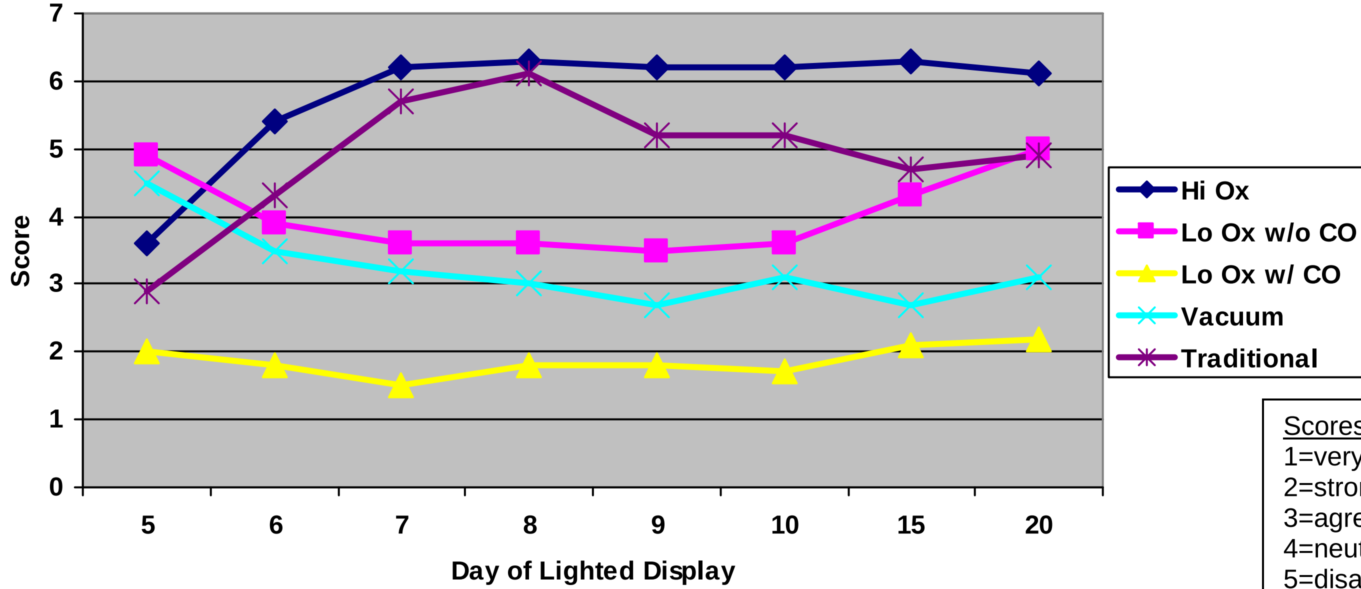


Scores
1=no discoloration
2=slight discoloration (1-10%)
3=small discoloration (11-20%)
4=moderate discoloration (21-60%)
5=severe discoloration (61-100%)

Data for Figure 10 - Trained Panel Color Scores for Meat Discoloration

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	1.8[b]	3.0[d]	3.6[d]	4.4[d]	4.8[d]	4.7[e]	4.9[e]	4.8[d]	0.09
70%N_2 / 30% CO_2	2.9[c]	2.4[c]	2.1[c]	1.8[c]	1.9[b]	2.3[c]	3.1[c]	4.5[c]	0.09
0.4% CO / 30% CO_2 / 69.6% N_2	1.0[a]	1.0[a]	1.0[a]	1.0[a]	1.0[a]	1.0[a]	1.0[a]	1.3[a]	0.09
Vacuum Package	2.0[b]	1.9[b]	1.4[b]	1.5[b]	1.2[a]	1.4[b]	1.4[b]	1.7[b]	0.09
Traditional	1.8[b]	2.4[c]	3.4[d]	4.1[d]	3.5[c]	3.9[d]	3.9[d]	4.7[d]	0.09

Figure 11 - Consumer Agreement to the Statement: The ground beef in this package has good color

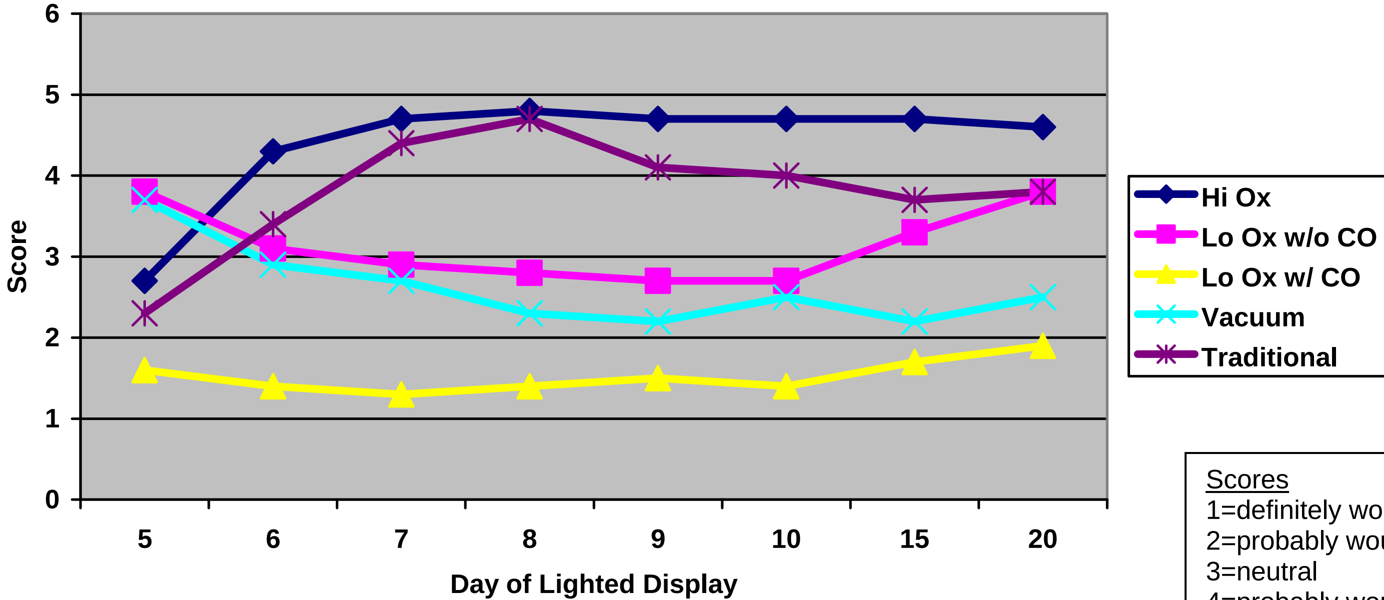


Scores
1=very strongly agree
2=strongly agree
3=agree
4=neutral
5=disagree
6=strongly disagree
7=very strongly disagree

Data for Figure 11 – Consumer agreement scores to the statement: The ground beef in this package has good color

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	3.6^c	5.4^d	6.2^e	6.3^e	6.2^e	6.2^e	6.3^e	6.1^d	0.13
70%N_2 / 30% CO_2	4.9^d	3.9^b	3.6^c	3.6^c	3.5^c	3.6^c	4.3^c	5.0^c	0.13
0.4% CO / 30% CO_2 / 69.6% N_2	2.0^a	1.8^a	1.5^a	1.8^a	1.8^a	1.7^a	2.1^a	2.2^a	0.13
Vacuum Package	4.5^d	3.5^b	3.2^b	3.0^b	2.7^b	3.1^b	2.7^b	3.1^b	0.13
Traditional	2.9^b	4.3^c	5.7^d	6.1^d	5.2^d	5.2^d	4.7^d	4.9^c	0.13

Figure 12 - Consumer Scores for Likelihood to Purchase Based on the Color of the Meat



Scores
1=definitely would purchase
2=probably would purchase
3=neutral
4=probably would not purchase
5=definitely would not purchase

Data for Figure 12 – Consumer Scores for Likelihood to Purchase Based on the Color of the Meat

	Day of Lighted Display								
Package Treatment	5	6	7	8	9	10	15	20	SEM
80% O_2 / 20% CO_2	2.7^c	4.3^d	4.7^d	4.8^d	4.7^e	4.7^d	4.7^e	4.6^d	0.10
70%N_2 / 30% CO_2	3.8^d	3.1^b	2.9^b	2.8^c	2.7^c	2.7^b	3.3^c	3.8^c	0.10
0.4% CO / 30% CO_2 / 69.6% N_2	1.6^a	1.4^a	1.3^a	1.4^a	1.5^a	1.4^a	1.7^a	1.9^a	0.10
Vacuum Package	3.7^d	2.9^b	2.7^b	2.3^b	2.2^b	2.5^b	2.2^b	2.5^b	0.10
Traditional	2.3^b	3.4^c	4.4^c	4.7^d	4.1^d	4.0^c	3.7^d	3.8^c	0.10

Figure 13 - Aerobic Plate Counts

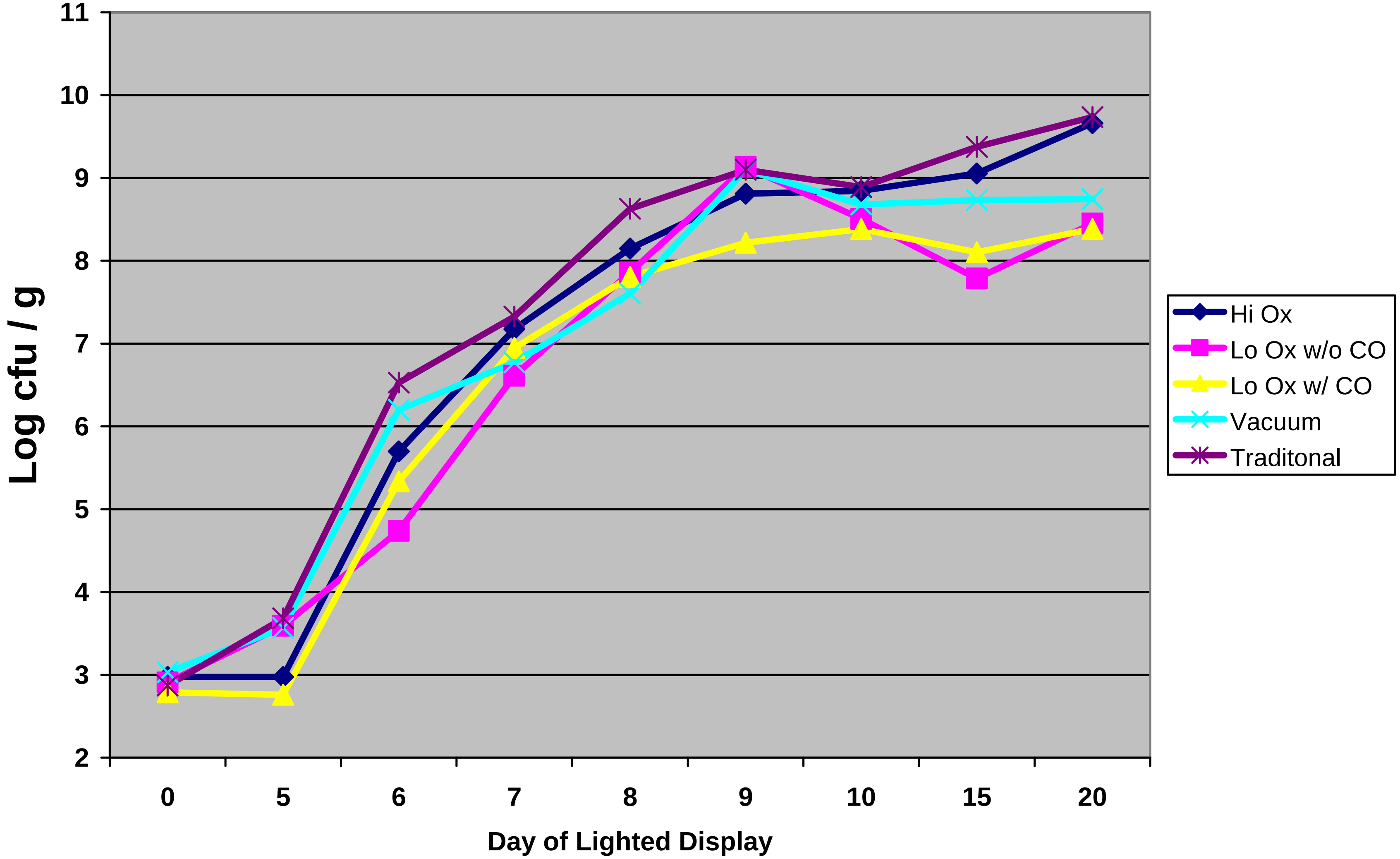
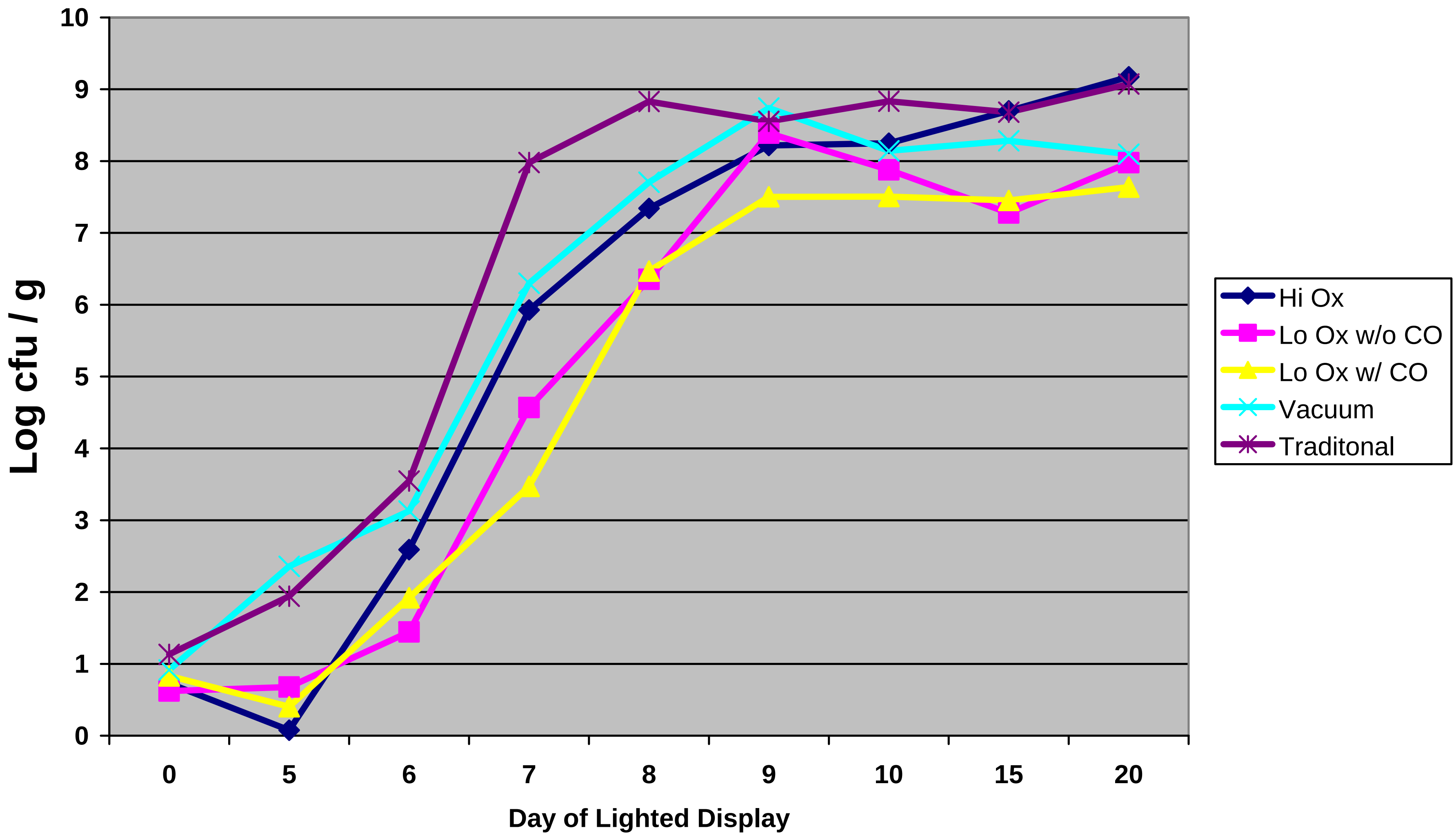


Figure 14 - Coliform Counts



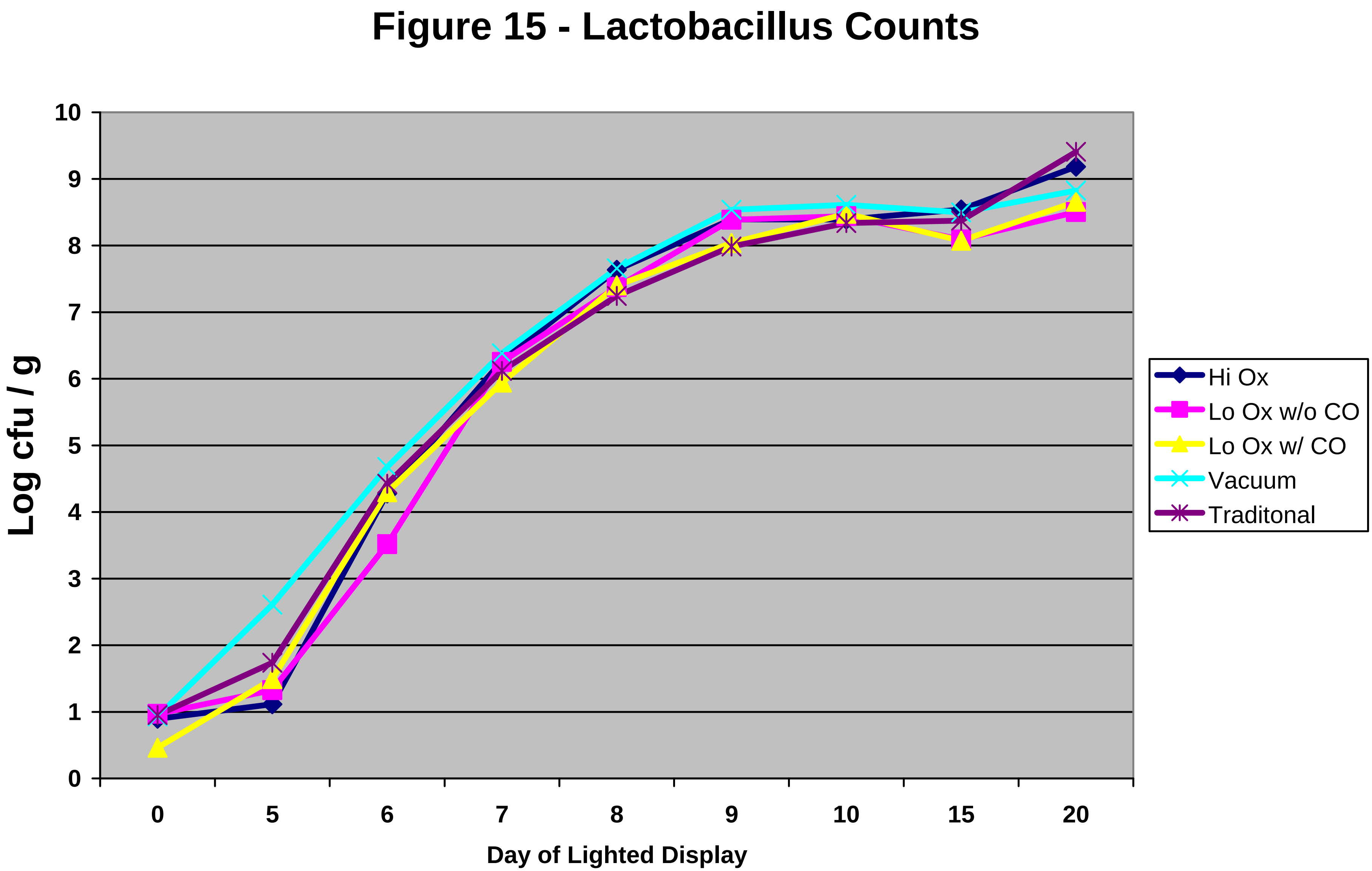


Figure 15 - Lactobacillus Counts
Log cfu / g
10
9
8
7
6
5
4
3
2
1
0
0
5
6
7
8
9
10
15
20
Day of Lighted Display
Hi Ox
Lo Ox w/o CO
Lo Ox w/ CO
Vacuum
Traditonal

Figure 16 - Psychrophilic Aerobic Plate Counts

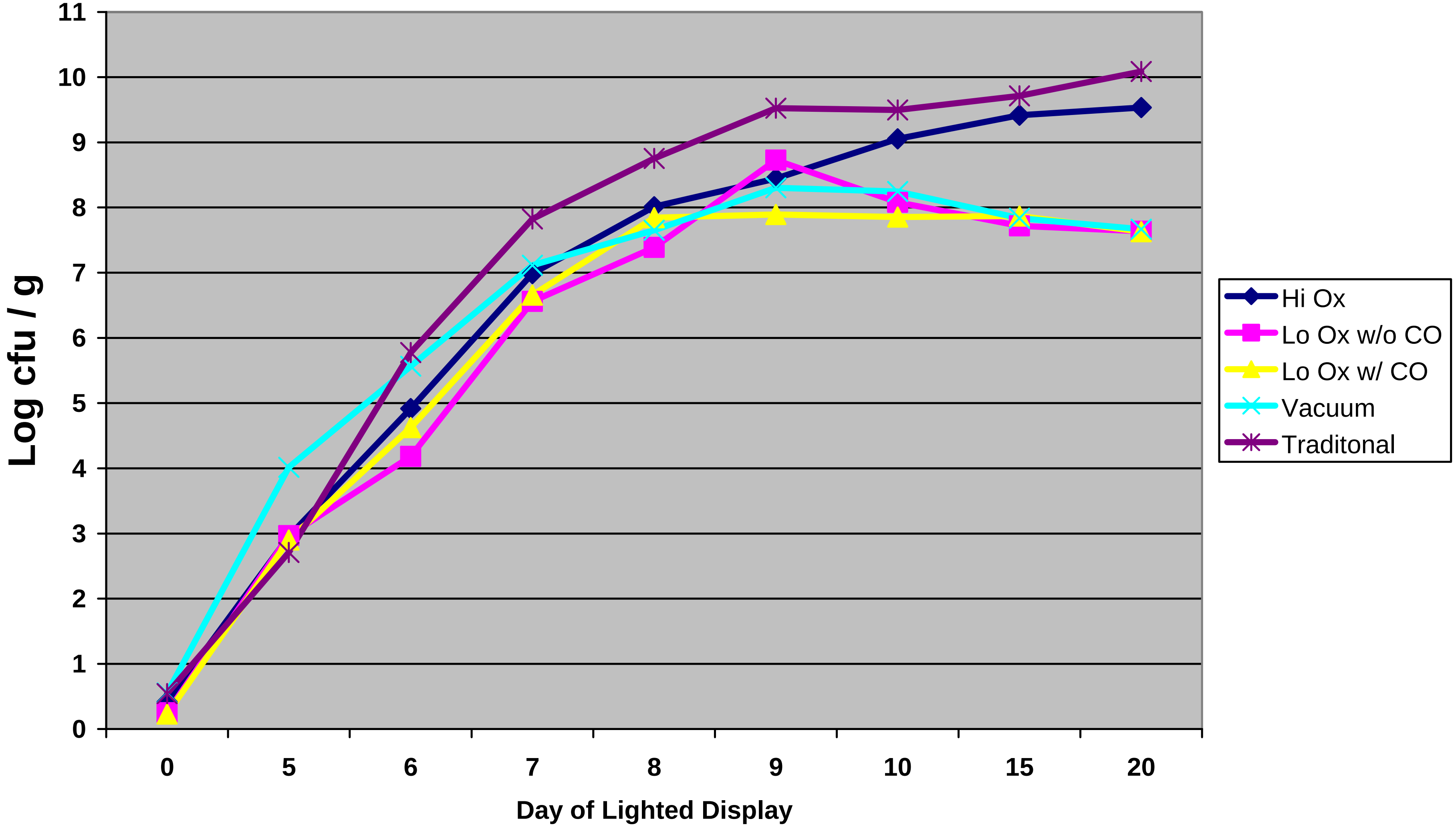
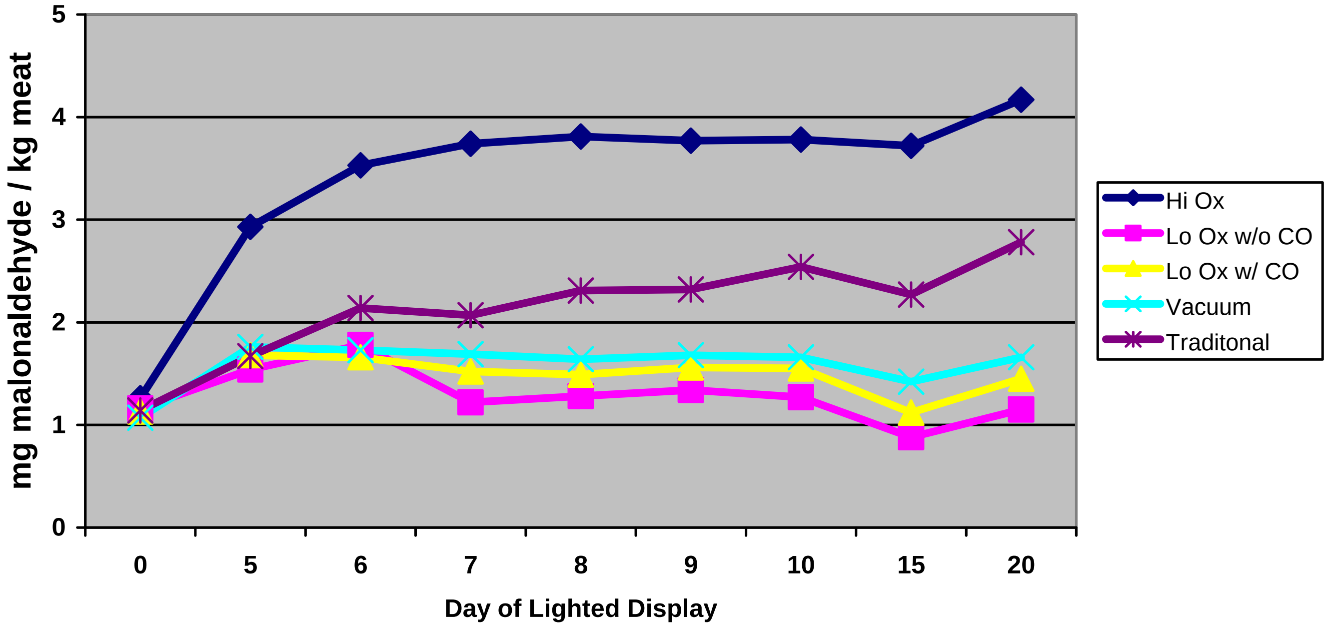


Figure 17 - Thiobarbituric Acid Oxidative Rancidity Values



Data for Thiobarbituric Acid Oxidative Rancidity Values

	Day of Display								
Package Treatment	0	5	6	7	8	9	10	15	20
80% O_2 / 20% CO_2	1.26^a	2.93^b	3.53^c	3.74^d	3.81^d	3.77^d	3.78^d	3.72^d	4.17^d
70%N_2 / 30% CO_2	1.16^a	1.54^a	1.78^a	1.22^a	1.28^a	1.34^a	1.27^a	0.88^a	1.15^a
0.4% CO / 30% CO_2 / 69.6% N_2	1.13^a	1.68^a	1.66^a	1.52^b	1.49^{ab}	1.56^{ab}	1.55^b	1.12^a	1.45^b
Vacuum Package	1.07^a	1.76^a	1.73^a	1.69^b	1.64^b	1.68^b	1.66^b	1.42^b	1.66^b
Traditional	1.14^a	1.67^a	2.14^b	2.07^c	2.31^c	2.32^c	2.54^c	2.27^c	2.78^c

[abcd]Least squares means in a column lacking a common superscript letter differ ($P < 0.05$)

Table 1 - Objective color L* Values

	Day of Lighted Display								
Package Treatment	1	5	6	7	8	9	10	15	20
80% O_2 / 20% CO_2	49.2^{bc}	46.3^{bc}	48.6^{b}	50.7^{d}	50.8^{c}	50.6^{b}	51.8^{c}	51.9^{c}	47.8^{c}
70%N_2 / 30% CO_2	47.3^{a}	44.3^{a}	46.1^{a}	45.6^{a}	46.7^{a}	47.6^{a}	45.3^{a}	45.8^{a}	39.9^{a}
0.4% CO / 30% CO_2 / 69.6% N_2	48.5^{ab}	47.0^{c}	48.5^{b}	48.3^{c}	48.1^{ab}	47.6^{a}	48.2^{b}	48.7^{b}	45.1^{b}
Vacuum Package	47.3^{a}	44.6^{a}	46.6^{a}	46.0^{ab}	46.9^{ab}	48.5^{a}	48.0^{b}	48.3^{b}	48.4^{c}
Traditional	50.3^{c}	45.4^{ab}	47.2^{ab}	47.1^{bc}	48.3^{b}	49.1^{ab}	46.1^{a}	45.2^{a}	44.4^{b}

Table 2 - Objective color a* Values

	Day of Lighted Display								
Package Treatment	1	5	6	7	8	9	10	15	20
80% O_2 / 20% CO_2	21.1^{c}	12.9^{ab}	8.4^{a}	7.4^{a}	10.0^{ab}	12.3^{a}	7.1^{a}	6.9^{a}	8.1^{a}
70%N_2 / 30% CO_2	9.9^{a}	11.0^{a}	11.5^{b}	12.0^{b}	13.3^{c}	13.1^{a}	12.9^{b}	12.5^{b}	14.1^{c}
0.4% CO / 30% CO_2 / 69.6% N_2	16.6^{b}	24.2^{c}	26.1^{c}	26.5^{c}	25.8^{d}	18.0^{b}	28.1^{c}	27.4^{c}	29.6^{d}
Vacuum Package	11.3^{a}	12.1^{a}	12.4^{b}	13.6^{b}	12.6^{bc}	13.6^{a}	13.2^{b}	13.6^{b}	13.6^{bc}
Traditional	19.0^{bc}	15.1^{b}	11.2^{ab}	9.1^{a}	8.4^{a}	11.8^{a}	11.2^{b}	11.8^{b}	10.8^{ab}

Table 3 - Objective color b* Values

	Day of Lighted Display								
Package Treatment	1	5	6	7	8	9	10	15	20
80% O_2 / 20% CO_2	19.5^{c}	15.5^{c}	14.3^{b}	15.5^{bc}	16.1^{b}	16.9^{b}	16.3^{b}	17.0^{b}	17.8^{c}
70%N_2 / 30% CO_2	14.0^{b}	12.8^{a}	13.3^{a}	13.5^{a}	14.5^{a}	15.6^{a}	13.9^{a}	14.5^{a}	15.3^{a}
0.4% CO / 30% CO_2 / 69.6% N_2	13.0^{a}	15.4^{c}	16.5^{c}	16.9^{d}	17.6^{c}	15.4^{a}	17.8^{c}	17.9^{c}	19.3^{d}
Vacuum Package	14.5^{b}	14.0^{b}	14.7^{b}	15.2^{b}	16.3^{b}	16.0^{a}	15.9^{b}	16.8^{b}	16.8^{b}
Traditional	19.7^{c}	16.9^{d}	15.8^{c}	16.0^{c}	16.9^{b}	16.1^{ab}	17.8^{c}	18.1^{c}	17.2^{bc}

Table 4 - Change in MAP Package Size During Lighted Display

	Duration of Lighted Display, days						
Package Treatment	1	2	3	4	5	6	10
80% O_2 / 20% CO_2	0.14[b]	0.07	-0.07	-0.02	0.00	-0.12	-0.09
70%N_2 / 30% CO_2	-0.09[a]	0.02	-0.05	-0.05	-0.11	-0.05	0.02
0.4% CO / 30% CO_2 / 69.6% N_2	-0.02[ab]	0.07	0.03	0.05	-0.09	-0.04	-0.14

Table 5 - Daily Changes in MAP Package Size During Lighted Display

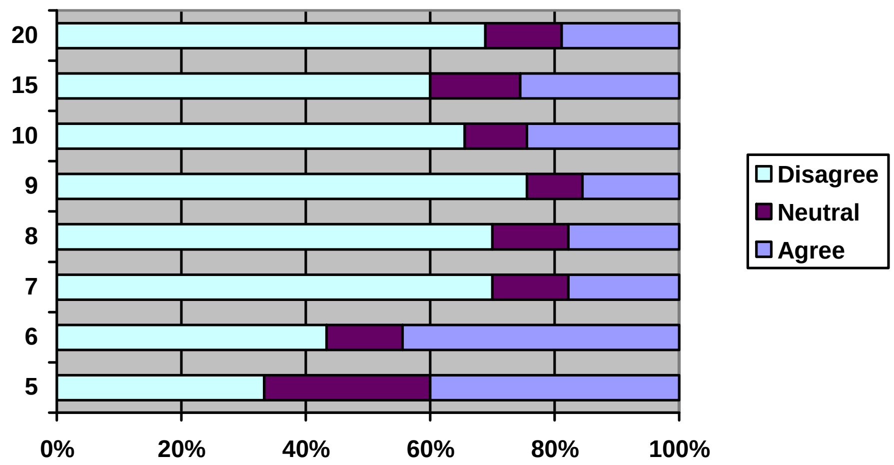
	Day of Lighted Display							
Package Treatment	5	6	7	8	9	10	15	20
80% O_2 / 20% CO_2	39.99	40.02	39.92	39.97	39.97	39.90	39.85	39.81
70%N_2 / 30% CO_2	39.99	40.00	39.92	39.95	40.03	39.92	39.92	39.85
0.4% CO / 30% CO_2 / 69.6% N_2	40.04	40.06	39.94	39.99	40.03	39.96	39.89	39.92

Treatment by Time Interaction (P = 0.9629)

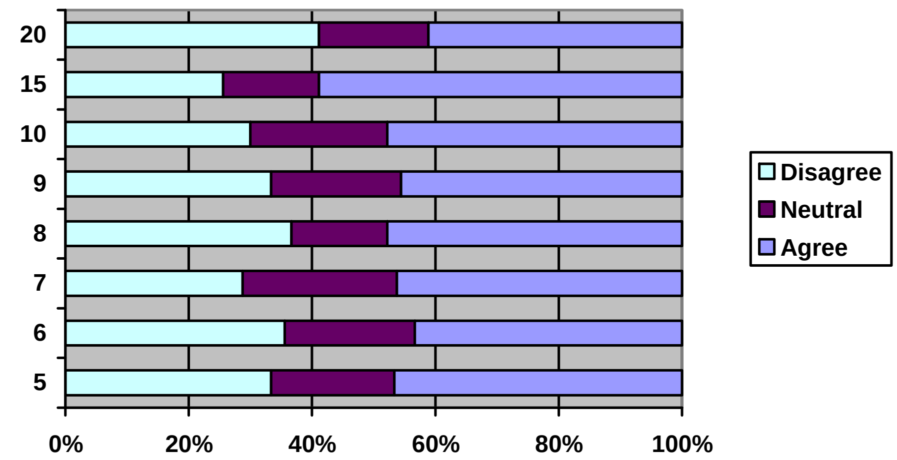
Appendix:

Characterization of Consumer Responses to Odor

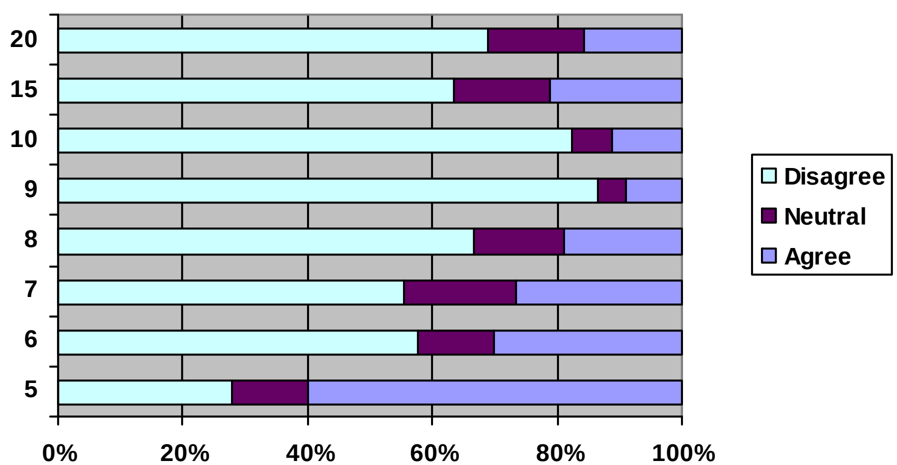
Consumer Opinion Scores to the Statement: "The Ground Beef in this Package Smells Fresh" - Traditional Packages



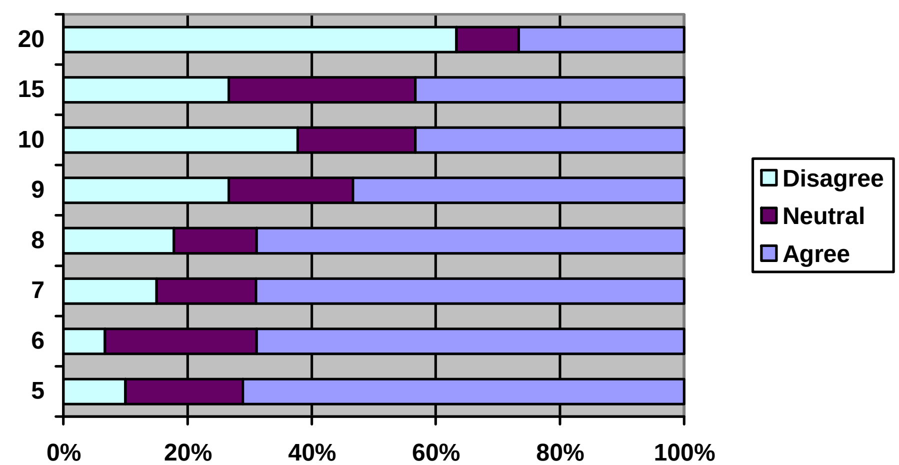
Consumer Opinion Scores to the Statement: "The Ground Beef in this Package Smells Fresh" - Vacuum Packages



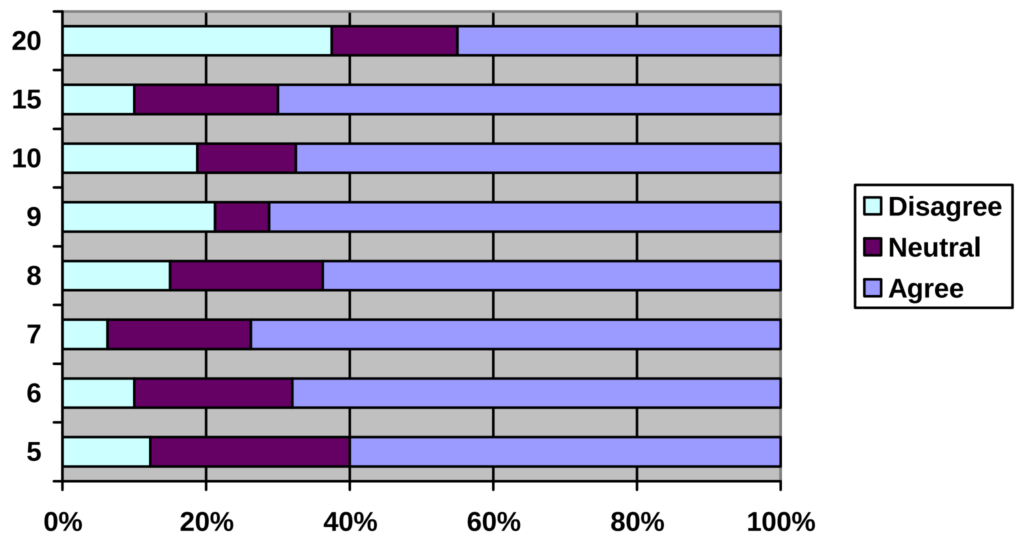
Consumer Opinion Scores to the Statement: "The Ground Beef in this Package Smells Fresh" - High Oxygen Packages

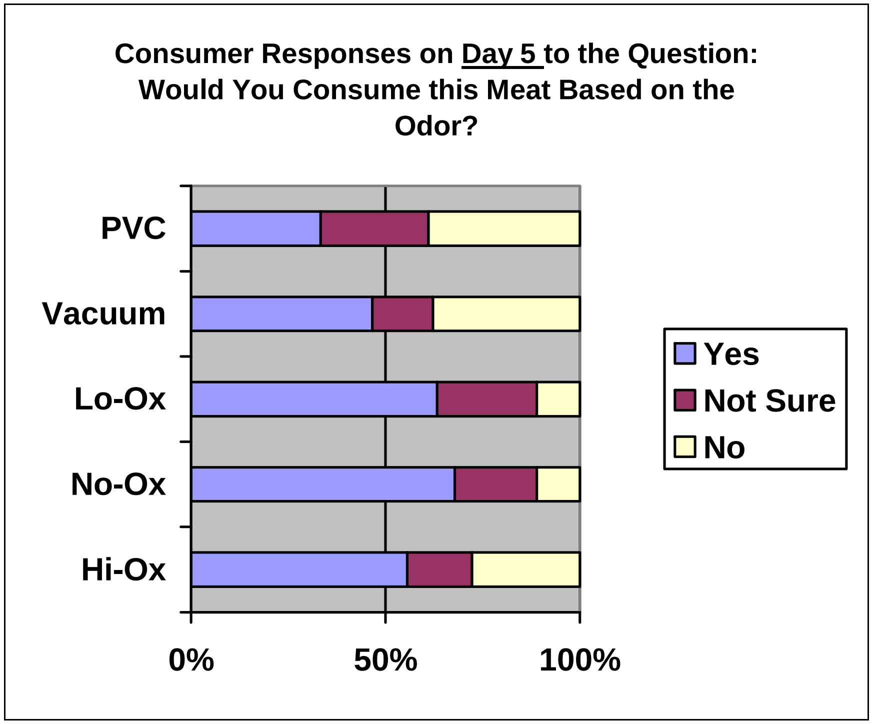


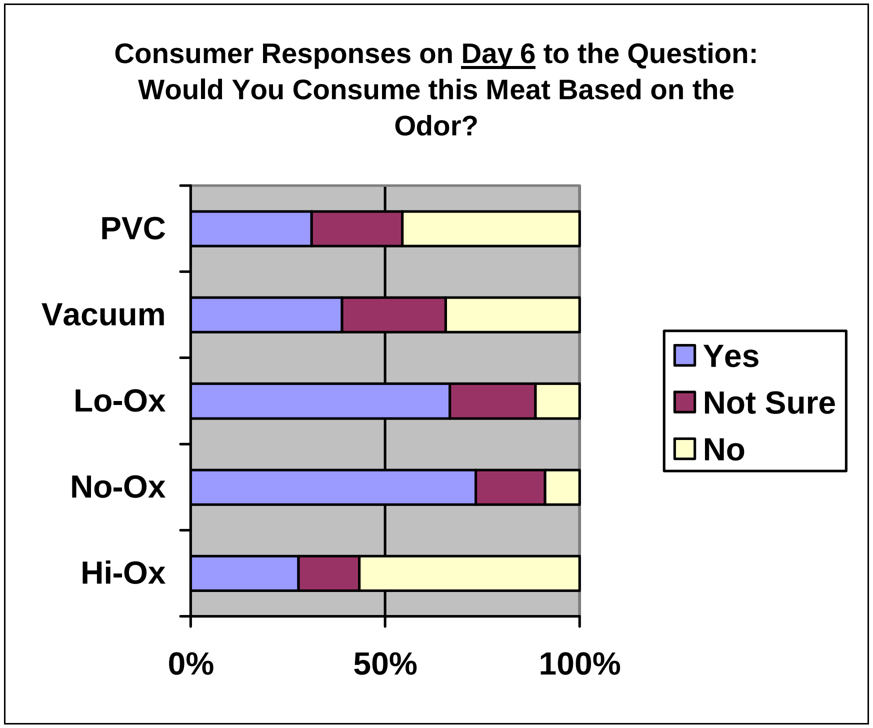
Consumer Opinion Scores to the Statement: "The Ground Beef in this Package Smells Fresh" - No Oxygen Packages

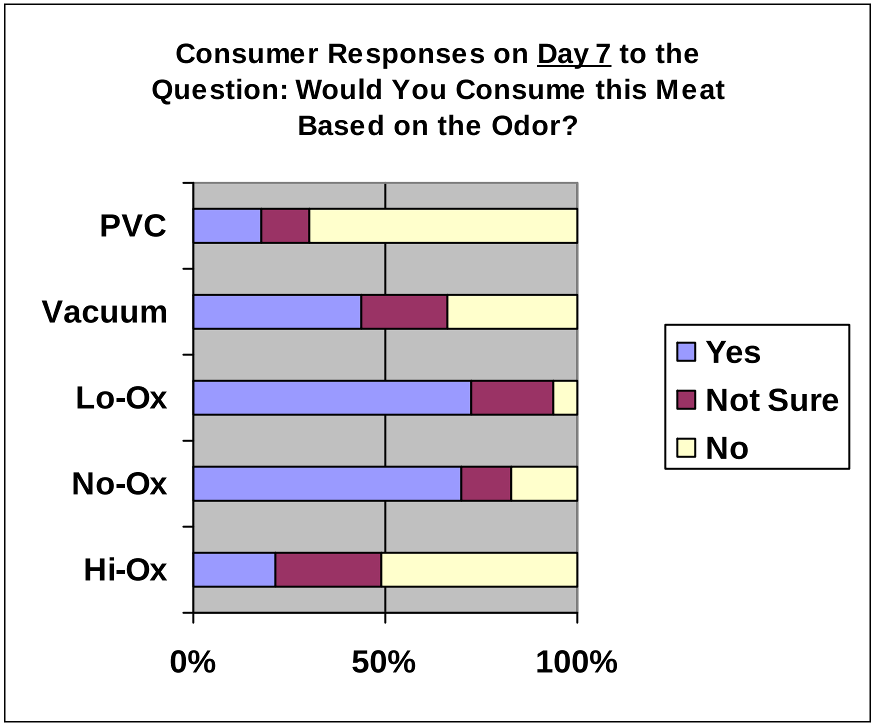


Consumer Opinion Scores to the Statement: "The Ground Beef in this Package Smells Fresh" - Low Oxygen Packages with CO

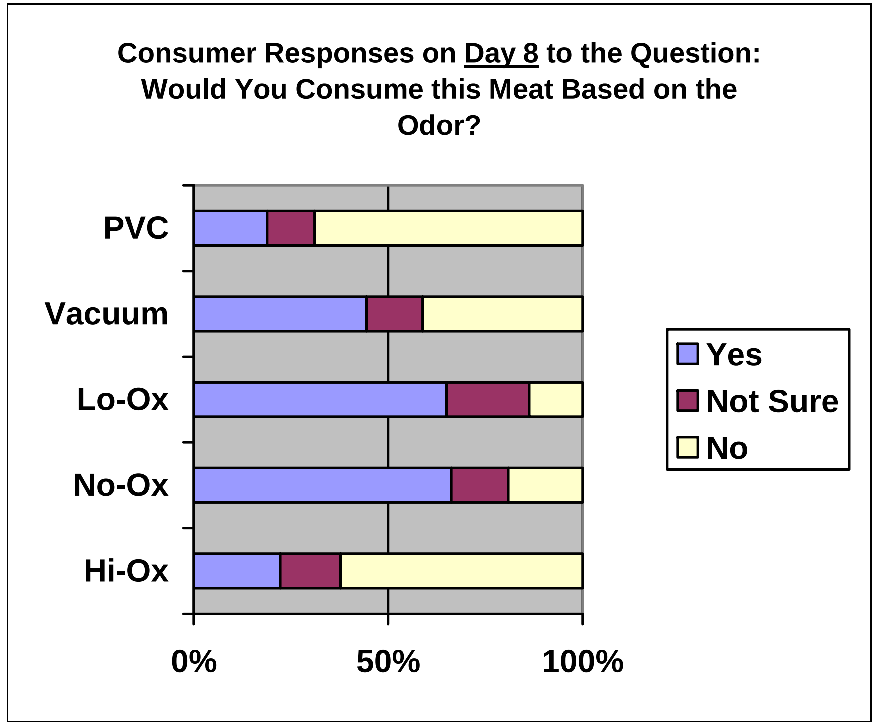



Consumer Responses on Day 5 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No

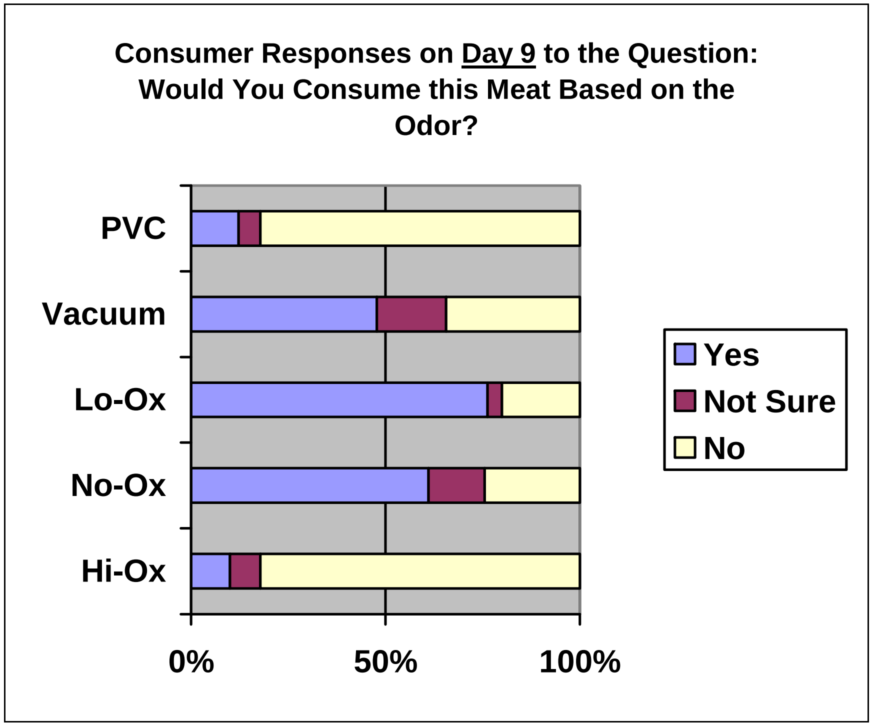

Consumer Responses on Day 6 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No

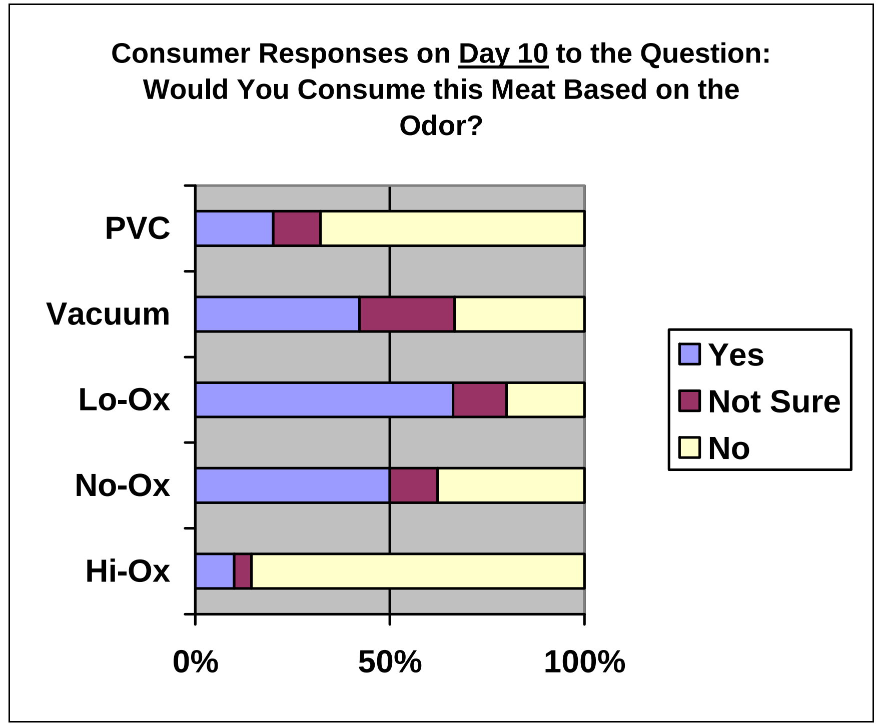


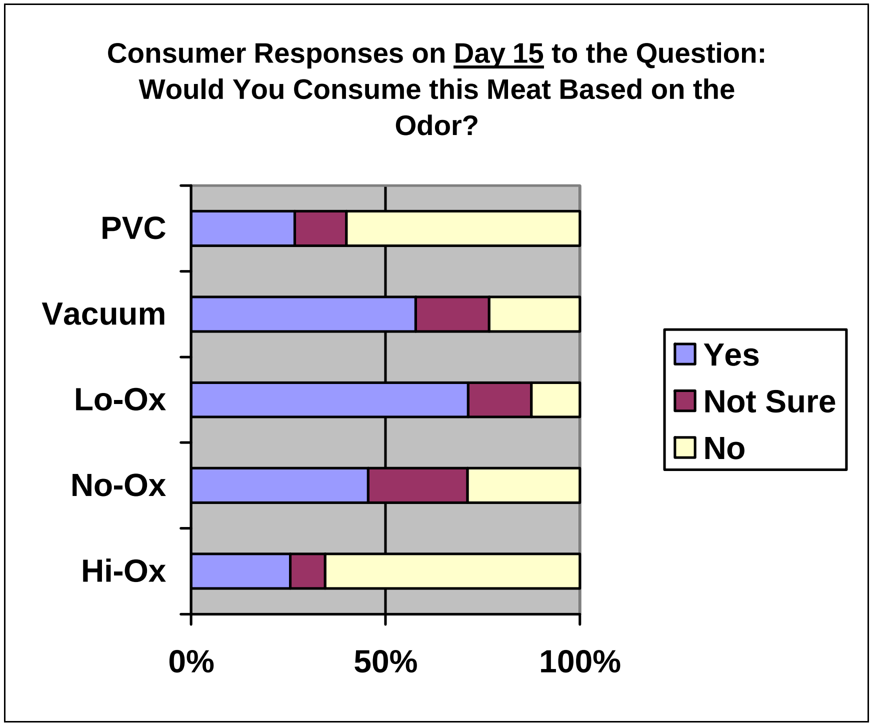
Consumer Responses on Day 7 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No



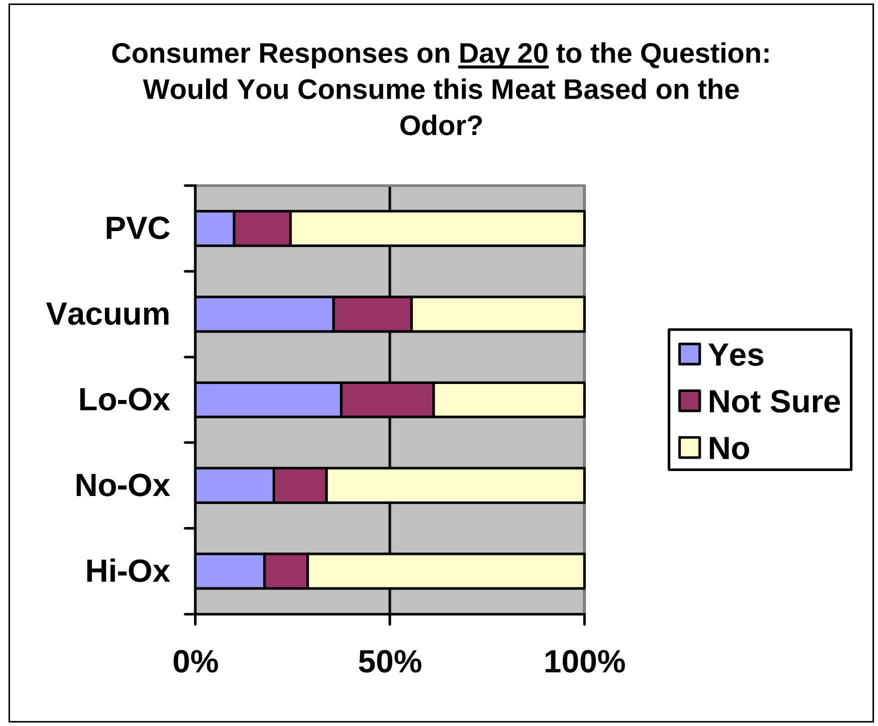
Consumer Responses on Day 8 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No


Consumer Responses on Day 9 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No


Consumer Responses on Day 10 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No



Consumer Responses on Day 15 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No



Consumer Responses on Day 20 to the Question: Would You Consume this Meat Based on the Odor?
PVC
Vacuum
Lo-Ox
No-Ox
Hi-Ox
0%
50%
100%
Yes
Not Sure
No