Meat and Muscle Biology™

Determination of Consumer Color and Discoloration Thresholds for Purchase of Representative Retail Ground Beef[1]

Katie R. Lybarger[2], Erin S. Beyer[2], Kaylee J. Farmer[2], Lane A. Egger[2], Lindsey N. Drey[3], Melvin C. Hunt[2], Jessie L. Vipham[2], Morgan D. Zumbaugh[2], Michael D. Chao[2], and Travis G. O'Quinn[2]*

[2]Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506, USA
[3]Cargill, Wichita, KS, USA
*Corresponding author. Email: travisoquinn@ksu.edu (Travis G. O'Quinn)
[1]Contribution no. 23-296-J of the Kansas Agriculture Experiment Station, Manhattan, KS 66506, USA.

Abstract: The objective of this study was to identify the threshold for color and discoloration for consumers to purchase ground beef and to determine the best objective measurement to predict consumer purchase intent. This study was designed in 2 phases, with Phase 1 requiring consumers to evaluate ground beef samples of multiple days of display simultaneously, and Phase 2 having consumers evaluate samples of only a single day of display. Ground beef packages (80% lean) were evaluated for overall appearance liking and purchase intent (yes/no) by consumers ($n = 216$ and 318). Additionally, packages were evaluated for L^*, a^*, b^*, calculated percentage of metmyoglobin, oxymyoglobin, chroma, hue angle, and trained sensory panel redness and discoloration scores. Models showed that each of the objective measures evaluated were predictors ($P < 0.05$) of consumer purchasing intent. All logistic regression equations ($P < 0.01$) had high R^2 values of 0.48 to 0.86 (Phase 1) and 0.26 to 0.65 (Phase 2) and correctly classified 78.1% to 90.1% (Phase 1) and 70.5% to 84.0% (Phase 2) of samples as would/would not purchase. Linear regression equations predicting consumer overall appearance ratings with objective measures also resulted in significant ($P < 0.01$) models, with R^2 values of 0.57 to 0.93 and 0.35 to 0.54. The a^* values of 21.6, 24.6, 28.3, and 30.5 (Phase 1) and 20.7, 26.2, 31.7, and 35.4 (Phase 2) correspond with consumers being 50%, 75%, 90%, and 95% likely to purchase the product at full price. However, if the product was discounted, the a^* values were reduced to 17.9, 21.4, 25.0, and 27.4 (Phase 1) and 17.7, 22.7, 27.7, and 31.1 (Phase 2). The models generated from this study provide the ability to predict consumer willingness to purchase ground beef and provide ground beef processors an indication of potential consumer purchasing behaviors based upon objective values that are easy to measure.

Key words: consumer, sensory, color, ground beef, retail display, metmyoglobin
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Introduction

The United States population consumed 10 kg of ground beef per capita in 2020, accounting for more than 46% of total US retail beef consumption (Schulz, 2021). This demand has shifted ground beef from an industry by-product to an increasingly valuable segment of the meat industry (Speer et al., 2015). Although the US has shifted to a "ground beef nation" (Close, 2014), there are many unknowns regarding consumer purchasing intent of ground beef in the retail setting.

Previous research has evaluated myoglobin and the factors controlling beef color (Giddings, 1977; Faustman and Cassens, 1990; Mancini and Hunt, 2005; Suman and Joseph, 2013; Faustman and Suman, 2017). Traditionally, at retail, beef is exposed to oxygen through the use of polyvinyl chloride (PVC) overwrap, and 2 main forms of myoglobin control beef color and the associated consumer perceptions: oxymyoglobin and metmyoglobin (Mancini and Hunt, 2005;

Mancini and Ramanathan, 2020). As beef is exposed to oxygen for extended periods in traditional PVC overwrapped packages, the bright-red color associated with oxymyoglobin begins to transition to the primarily brown color associated with metmyoglobin through the naturally occurring oxidation process of beef (Mancini and Ramanathan, 2020). This browning of fresh beef has been estimated to cost the beef industry $3.73 billion annually (Ramanathan et al., 2022). Numerous authors have previously evaluated strategies and methods to extend shelf life through the use of various ingredients (Smith et al., 1996; Hoyle Parks et al., 2012; Shalaby et al., 2018), packaging methods (Jayasingh et al., 2001; Hunt et al., 2004; Yang et al., 2016), lighting conditions (Cooper et al., 2016; Steele et al., 2016), and storage conditions (Martin et al., 2013; Rogers et al., 2014).

Meat color is commonly identified as one of the most important purchasing motivators for beef consumers (Olson et al., 2019; Farmer et al., 2022; Harr et al., 2022a). Thus, maintaining a desirable bright-red color of ground beef is a priority for retailers. Additionally, understanding consumer perceptions related to both redness and discoloration is critical to fully understanding beef shelf life and how and when consumers will elect to purchase versus not purchase displayed products. Several previous studies have attempted to identify the relationship between meat discoloration and consumer acceptance and willingness to pay, first in an in-store trial (Hood and Riordan, 1973) and then utilizing online surveys and meta-analyses (Holman et al., 2016, 2017; Feuz et al., 2020a; Najar-Villarreal et al., 2021). However, the results of these studies are limited and do not provide a comprehensive understanding of the consumer perceptions of ground beef. Previous work is dated (Hood and Riordan, 1973), utilized color measurement settings nonconforming to American Meat Science Association (AMSA) Color Guidelines (Holman et al., 2016, 2017), or used an online format in which samples may not have been uniformly presented (Holman et al., 2016, 2017; Feuz et al., 2020a), with none requiring consumers to evaluate samples in a meat case setting. Furthermore, many aspects of beef color can easily be measured (L^*, a^*, b^*, hue angle, chroma, calculated oxymyoglobin and metmyoglobin percentage, etc.) and may be suitable indicators of consumer purchasing decisions, but most previous works have only presented models evaluating 1 or 2 of such measures (Hood and Riordan, 1973; Holman et al., 2016, 2017; Feuz et al., 2020a; Najar-Villarreal et al., 2021).

Therefore, the objective of the current study was to evaluate the relationship between consumer color perception, willingness to purchase, and ground beef redness and discoloration measured through objective means and to establish limits at which consumer purchase intent is greatly diminished.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board (IRB) approved all procedures for use of human subjects in the sensory panel evaluations used in this study (IRB 7740.7, February 2021).

Sample collection

This study was designed in 2 phases, with Phase 1 requiring consumers to evaluate ground beef samples of multiple days of display simultaneously, and Phase 2 having consumers evaluate samples of only a single day of display. Each phase was conducted on separate weeks, approximately a month apart. The week prior to each phase of the study, 180 to 454 g ground beef packages (80% lean) were obtained from Cargill Meat Solutions in Wichita, KS, and transported under refrigerated temperatures (2°C to 4°C) to the KSU Meat Laboratory. Packages were randomly assigned to 1 of 10 d of retail display (d0 to d9), with d0 representing the day samples were placed in the case. All packages were stored in their mother bag (tri gas, 69.6% nitrogen, 30% carbon dioxide [CO_2], 0.4% carbon monoxide), under refrigeration (2°C to 4°C), in the absence of light until scheduled display in the retail case. Samples were placed in the retail cases for display at approximately 10 to 14 d of age, which is consistent with commercially produced ground beef sold at retail.

On the designated day, ground beef packages were displayed in random order in 3 coffin-style cases (model DMF8; Tyler Refrigeration, Niles, MI) at 2°C to 4°C under continuous fluorescent lights (32 W Del-Warm White 3,000 K; Philips Lighting Company, Somerset, NJ) averaging a 2,143 ± 113 lx emission case-wide. Each case was divided into 3 sections separated with distinct barriers. Samples entered the case in the afternoon on each day, with trained sensory panels taking place an hour later and consumer sensory panels following 2 h after samples entered the case. The cases were programmed to defrost twice per day and never reach a temperature above 10°C. For Phase 1, samples within each section represented each day of retail display (d0 to d9) and the entire range of discoloration from extremely fresh (d0) to extremely discolored (d9). For Phase 2, samples within each section represented only 1 d of retail display, with consumers evaluating the entire case of a single day (d0 to d9). Samples were rotated within their designated case section every 24 h to ensure equal distribution of light upon the packages.

Consumer sensory panel evaluation

For both phases of the study, consumer sensory panelists ($n = 216$ [Phase 1] and 318 [Phase 2]) were recruited from Manhattan, KS, and surrounding communities and monetarily compensated for their involvement. For Phase 1 of the study, each consumer evaluated 20 samples, consisting of 2 samples from each day of display. For Phase 2 of the study, consumers evaluated 20 ground beef samples from a single day of display (d0 to d9). Consumers assessed the overall appearance and desirability of each sample on a 100-point continuous line scale with descriptive anchors at 0, 50, and 100. The scale anchor of 0 corresponded to extremely undesirable, 50 neither desirable nor undesirable, and 100 extremely desirable. Furthermore, consumers responded to a yes/no question related to whether or not they would purchase the sample if it was full-priced at retail. If a “no” response was recorded, then the survey was directed to have consumers respond to a yes/no question related to whether or not they would purchase the product if it was discounted at retail. The consumer panelists were provided an electronic tablet (TB-8505F; Lenovo, Morrisville, NC) to record their responses utilizing a digital survey (Qualtrics, Provo, UT).

Trained sensory panel evaluation

For both phases of the study, a trained descriptive panel evaluated each sample for redness and percentage discoloration using 100-point continuous line scales prior to consumer evaluation. Trained sensory panelists were trained according to the AMSA Meat Color Measurement Guidelines (King et al., 2023). Prior to the beginning of the study, each panelist was subjected to the Farnsworth Munsell 100 Hue Color Vision Test (Munsell, Grand Rapids, MI) to screen for color blindness and participated in 3 or more 30 min training sessions to familiarize panelists with the scales. Panelists were trained leading up to the panels with scales visually anchored at 0 for packages with an extremely dark red color, 50 for a slightly dark red color, and 100 for a bright, cherry red color (Figure 1), as previously described by Van Bibber-Krueger et al. (2020). Panelists were trained to assess percentage discoloration through the use of photos of 5 ground beef packages representing differing levels of discoloration, along with the use of multiple ground beef packages in the retail case during training. The photos serving as anchors representing ground beef packages at 0%, 50%, and 100% discoloration are presented in Figure 1. For each day, a varying number of panelists ($n = 8$ to 17) visually evaluated 180 samples in a randomized order. The trained sensory panelists were given an electronic tablet (Lenovo TB-8505F) to record their responses utilizing a digital survey (Qualtrics Software, Provo, UT).

Objective color measurements

Prior to each panel for both phases, within a 2-h period before consumer evaluation, L^*, a^*, and b^* values were collected utilizing a HunterLab MiniScan spectrophotometer (Illuminant A, 2.54 cm aperture, 10° observer; HunterLab, Reston, VA) using methods outlined by the AMSA Color Guidelines (King et al., 2023). Three scans were taken from the surface of the ground beef sample package, and the readings were averaged. Spectral data were also recorded for the calculation of hue angle, chroma, percent oxymyoglobin, and percent metmyoglobin according to the AMSA Meat Color Measurement Guidelines (King et al., 2023).

pH

On d0 of each phase, pH measurements of 8 ground beef packages were obtained using a Mettler Toledo (Columbus, OH) pH meter calibrated according to the manufacturer’s specification, as

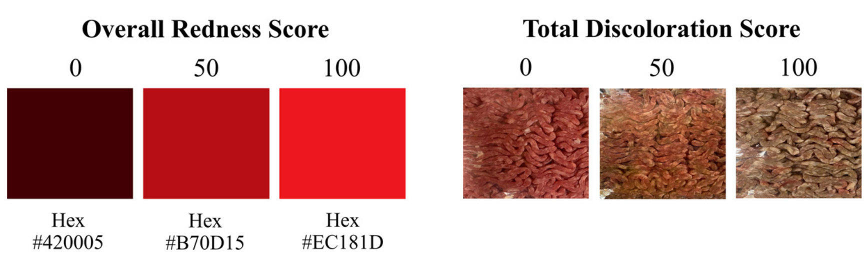

Figure 1. References used for training of panelists for redness and discoloration scores.

previously described by Hammond et al. (2022). Five grams of each sample, in duplicate, were weighed into 100 mL beakers, and 50 mL of Milli-Q water (MilliporeSigma, Burlington, MA) was added to each beaker. Each sample was then mechanically homogenized (Homogenizer 850; Fisher Scientific International, Waltham, MA), and the pH of each sample was then measured and recorded at approximately room temperature.

Microbiological analysis

For both phases of the study, microbiological analysis was conducted on d0 and d9, with aerobic plate counts (APCs) measured on 8 ground beef packages per day of evaluation. Upon arrival at the laboratory, 10 g sample cores of ground beef were weighed and stomached with 90 mL of buffered peptone water (BPW). Serial dilutions were produced for each sample using BPW. Duplicate Aerobic Count (AC) Petrifilms were plated with 1 mL of each dilution. The AC Petrifilms were then incubated at 35°C ± 1°C for 48 h. ACs were determined according to the manufacturer's protocol to confirm the ground beef utilized in this study was within the typical range and observed color differences were not due to microbial contamination.

Statistical analysis

The statistical analyses were performed using the procedures of SAS (SAS Institute, Cary, NC), with α set at 0.05. Logistic regression models were calculated for the probability of a sample being identified as "would purchase" for both full-priced and discounted responses by consumer sensory panelists using PROC LOGISTIC with the ctable, rsquare, and lackfit options specified. The PROC REG program was utilized to determine the simple linear regressions for consumer overall appearance ratings. PROC CORR was used to calculate Pearson correlation coefficients for sensory and objective measures.

Results

Demographics

Demographic information regarding the consumer panelists who participated in both phases of the study can be found in Table 1. Because of an additional day of sampling, Phase 2 had a larger number of participants than Phase 1. An additional day of evaluation was added because of the increased number of samples available and case scheduling. Phase 1 had a mostly even split of women and men (51.4% vs. 48.6%), whereas Phase 2 had a higher number of men than women (62.9% vs. 37.1%). In both phases, the majority of consumers (57.9% and 63.9%) resided in 1 or 2 person households, with more than a third being married. Phase 1 had 47.2% of consumers over the age of 30, whereas Phase 2 reported 42.8% in the same age bracket. Caucasian consumers represented the highest ethnic origin in both phases (89.8% and 87.4%), with the majority making more than 50,000 USD per year (54.2% and 50.0%). The population was educated, with college and post-college graduates making up 51.8% and 55.1% of the population in Phase 1 and Phase 2, respectively. Consumers in this study reported regular beef consumption at a rate of 1 to 3 times weekly in 59.7% of people in Phase 1 and 59.4% of people in Phase 2. The top purchasing motivators in both phases were "lean/fat ratio," "price," and "color" (Table 1).

Logistic regression equations

The average pH of the ground beef product in Phase 1 was 6.01 with a standard deviation of 0.05, and in Phase 2 it was 6.07 with a standard deviation of 0.07. The microbiological analysis resulted in a 3 log CFU/g increase in average APCs between d0 and d9 for both phases of the study.

A summary of the overall mean, minimums, maximums, and variation for all independent variables evaluated in both phases of the study are provided in Table 2. Because of the study objectives, a large range within the variables was created and measured within both phases. Such a range was required for the calculation of robust statistical models for the prediction of consumer purchase intent and sensory ratings.

Tables 3 and 4 present the logistic regression equations calculated for the prediction of consumer sensory panel purchase intent of retail ground beef for Phases 1 and 2. The objective measurements evaluated during the study were utilized to create logistic regression models to predict the likelihood a consumer would respond as "yes" or "would purchase" to the full-priced and discounted survey questions. Overall, the models showed that each of the objective measurements evaluated was a predictor of consumer purchasing intent, and all of the logistic regression equations were predictive ($P < 0.01$) of consumer purchase intent. Phase 1 presented models with high R^2 values ($R^2 > 0.48$; most models with $R^2 > 0.78$). Furthermore, the models generated from Phase 1 correctly classified more than 78% of samples as would/would not purchase, with the

Table 1. Demographic characteristics of consumers who participated in consumer visual sensory panels

		Phase 1 ($N = 216$)	Phase 2 ($N = 318$)
Characteristic	Response	Percentage of consumers	
Gender	Male	48.6	62.9
	Female	51.4	37.1
Household size	1 person	22.7	29.9
	2 people	35.2	34.0
	3 people	14.4	8.2
	4 people	14.8	16.0
	5 people	7.9	5.4
	6 people	2.8	3.8
	Greater than 6 people	2.3	2.8
Marital status	Married	44.9	37.7
	Single	55.1	62.3
Age	Under 20	9.7	7.9
	20–29	43.1	49.4
	30–39	5.1	8.8
	40–49	12.5	10.4
	50–59	13.4	12.0
	Over 60	16.2	11.6
Ethnic origin	African American	0.5	0.9
	Asian	1.9	1.6
	Caucasian/white	89.8	87.4
	Hispanic	4.2	4.4
	Mixed race	1.9	2.2
	Native American	0.9	0.9
	Other	0.9	2.5
Household income level	Under $25,000	27.8	35.5
	$25,000–$34,999	8.3	6.3
	$35,000–$49,999	9.7	8.2
	$50,000–$74,999	14.4	11.6
	$75,000–$99,999	14.8	11.0
	$100,000–$149,999	13.9	13.8
	$150,000–$199,999	6.0	8.2
	Greater than $199,999	5.1	5.4
Education level	Non-high school graduate	0.0	0.3
	High school graduate	13.9	12.9
	Some college/technical school	34.3	31.8
	College graduate	34.7	32.1
	Post-college graduate	17.1	23.0
Weekly beef consumption	0 times	1.4	1.3
	1 to 3 times	59.7	59.4
	4 to 6 times	25.5	29.3
	7 to 9 times	7.4	5.4
	10 or more times	6.0	4.7
Most important factor when purchasing ground beef	Color	19.4	17.3
	Lean/fat content	44.4	44.0
	Packaging content	1.9	2.2
	Price	26.4	29.6
	Primal	3.7	3.1
	Production practices	2.8	3.1
	Other	2.3	0.6

Table 2. Summary statistics for independent variables evaluated in the study for 80% lean retail ground beef

	Phase 1				Phase 2			
Measurement	Mean	Minimum	Maximum	Standard deviation	Mean	Minimum	Maximum	Standard deviation
L*	51.60	44.90	56.11	0.08	54.19	48.53	58.30	0.08
a*	24.94	11.32	36.92	0.33	26.00	14.89	37.90	0.23
b*	22.06	15.94	28.14	0.14	22.81	17.67	34.15	0.10
Metmyoglobin[1]	35.28	21.22	63.30	0.58	30.89	20.32	52.50	0.35
Oxymyoglobin[1]	61.27	32.96	75.50	0.58	65.85	42.23	76.68	0.35
Chroma[1]	33.45	19.55	46.42	0.34	34.66	23.32	51.02	0.24
Hue angle[1]	0.75	0.63	0.99	<0.01	0.73	0.65	0.89	<0.01
Trained sensory panel redness score[2]	65.70	7.50	99.54	1.28	76.73	30.17	98.73	0.74
Trained sensory panel discoloration score[3]	28.64	0.00	98.63	1.57	18.07	0.00	85.33	0.97
Consumer appearance score[4]	60.74	2.98	96.61	1.17	61.04	8.91	99.72	0.65

[1]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[2]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[3]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[4]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

Table 3. Logistic regression equations for predicting consumer sensory panel purchase intent of 80% lean retail ground beef for Phase 1 of the study

Measurement	Intercept	Slope	Adjusted R^2	*P* value	*C* statistic[1]	% Correct[2]
Product sold at full price						
L*	−50.10	0.99	0.58	<0.01	0.88	82.2
a*	−7.13	0.33	0.83	<0.01	0.95	90.1
b*	−15.93	0.78	0.82	<0.01	0.94	89.6
Metmyoglobin[3]	6.81	−0.17	0.81	<0.01	0.94	89.3
Oxymyoglobin[3]	−9.94	0.17	0.81	<0.01	0.94	89.4
Chroma[3]	−9.76	0.32	0.84	<0.01	0.94	90.0
Hue angle[3]	18.11	−23.44	0.79	<0.01	0.95	88.4
Trained sensory panel redness score[4]	−4.29	0.08	0.82	<0.01	0.94	90.0
Trained sensory panel discoloration score[5]	2.27	−0.06	0.77	<0.01	0.94	88.4
Consumer appearance score[6]	−4.98	0.10	0.86	<0.01	0.95	90.1
Product sold at discounted price						
L*	−39.58	0.80	0.48	<0.01	0.86	78.1
a*	−5.54	0.31	0.79	<0.01	0.93	88.1
b*	−14.15	0.75	0.76	<0.01	0.92	86.0
Metmyoglobin[3]	7.17	−0.15	0.78	<0.01	0.93	87.6
Oxymyoglobin[3]	−7.51	0.15	0.78	<0.01	0.93	87.3
Chroma[3]	−8.26	0.32	0.79	<0.01	0.93	87.9
Hue angle[3]	16.25	−19.45	0.77	<0.01	0.93	87.6
Trained sensory panel redness score[4]	−2.86	0.07	0.77	<0.01	0.93	87.1
Trained sensory panel discoloration score[5]	3.20	−0.05	0.76	<0.01	0.93	88.3
Consumer appearance score[6]	−3.32	0.09	0.83	<0.01	0.95	88.4

[1]Measure of goodness of fit for binary outcomes in a logistic regression model, ranging from 0 to 1 and poor model to strong model, respectively.

[2]Percentage of correctly classified events and nonevents by the model.

[3]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[4]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[5]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[6]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

Table 4. Logistic regression equations for predicting consumer sensory panel purchase intent of 80% lean retail ground beef for Phase 2 of the study

Measurement	Intercept	Slope	Adjusted R^2	P value	C statistic[1]	% correct[2]
Product sold at full price						
L*	−22.44	0.43	0.28	<0.01	0.74	70.5
a*	−4.14	0.20	0.42	<0.01	0.78	74.6
b*	−8.69	0.43	0.37	<0.01	0.76	71.7
Metmyoglobin[3]	4.54	−0.12	0.41	<0.01	0.78	74.6
Oxymyoglobin[3]	−6.37	0.11	0.40	<0.01	0.77	74.9
Chroma[3]	−5.65	0.19	0.41	<0.01	0.78	73.8
Hue angle[3]	12.87	−16.27	0.41	<0.01	0.78	74.0
Trained sensory panel redness score[4]	−3.03	0.05	0.41	<0.01	0.79	74.3
Trained sensory panel discoloration score[5]	1.61	−0.04	0.39	<0.01	0.79	75.1
Consumer appearance score[6]	−4.36	0.09	0.65	<0.01	0.86	80.4
Product sold at discounted price						
L*	−21.49	0.43	0.26	<0.01	0.75	77.3
a*	−3.89	0.22	0.42	<0.01	0.80	78.0
b*	−9.18	0.48	0.37	<0.01	0.78	78.4
Metmyoglobin[3]	5.42	−0.12	0.40	<0.01	0.80	78.3
Oxymyoglobin[3]	−5.85	0.12	0.39	<0.01	0.79	77.7
Chroma[3]	−5.68	0.22	0.42	<0.01	0.79	77.9
Hue angle[3]	13.81	−16.49	0.39	<0.01	0.80	78.2
Trained sensory panel redness score[4]	−2.28	0.05	0.39	<0.01	0.80	79.8
Trained sensory panel discoloration score[5]	2.37	-0.03	0.38	<0.01	0.81	79.1
Consumer appearance score[6]	−3.49	0.09	0.63	<0.01	0.87	84.0

[1]Measure of goodness of fit for binary outcomes in a logistic regression model, ranging from 0 to 1 and poor model to strong model, respectively.

[2]Percentage of correctly classified events and nonevents by the model accuracy of a logistic regression model.

[3]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[4]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[5]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[6]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

majority of the models correctly classifying more than 87% of samples. Phase 2 presented effective models with R^2 values of 0.26 to 0.65 (most models with $R^2 > 0.40$) and correctly classified more than 70% of samples as would/would not purchase.

In Phase 1, *a** value was among the best objective measurements evaluated with R^2 values of 0.83 and 0.79 for full-priced and discounted models, respectively (Figure 2). Calculated metmyoglobin percentage (Figure 3) was determined from spectral data and resulted in high R^2 values of 0.81 in full-priced models and 0.78 in discounted models. Also in Phase 1, trained sensory panel discoloration was a noteworthy predictor, with R^2 values of 0.81 in the full-priced model, and 0.78 in the discounted model (Figure 4). Trained sensory panel redness scores were also good predictors ($R^2 > 0.77$) in Phase 1.

Phase 2 presented similar results among the objective measurements. Values for *a** continued to be the strongest predictor, with R^2 values of 0.42 for both full-priced and discounted models (Figure 5). Calculated metmyoglobin percentage (Figure 6) also resulted in strong R^2 values of 0.41 and 0.40 for full-priced and discounted models, respectively. The trained sensory panel discoloration score models (Figure 7) had R^2 values of 0.39 in the full-priced models and 0.38 in the discounted models. Overall, the Phase 2 models accounted for less variation among the variables than the Phase 1 models because of the phase setup and project design of product in the retail cases.

Using the logistic regression models, specific thresholds for consumer likeliness to purchase were identified for both phases of the study (Tables 5 and 6). Common threshold values for the likeliness for a consumer to purchase (50%, 75%, 90%, and 95% likely) were identified based on the values of the independent variables measured. In Phase 1, the model showed *a** values (Figure 1) of 21.6, 24.6, 28.3, and 30.5 related to 50%, 75%, 90%, and 95% likelihood

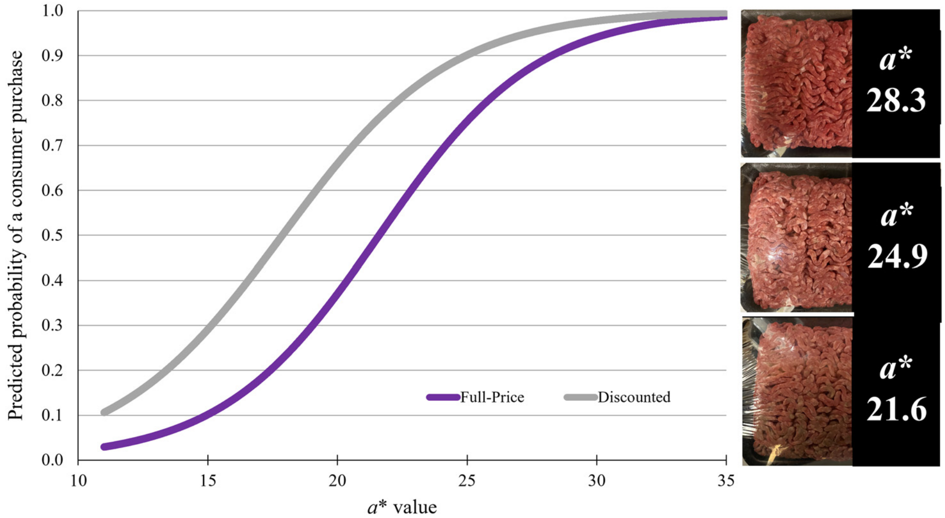

Figure 2. Probability of a consumer purchasing an 80% lean ground beef package based on *a** value and pricing: Phase 1.

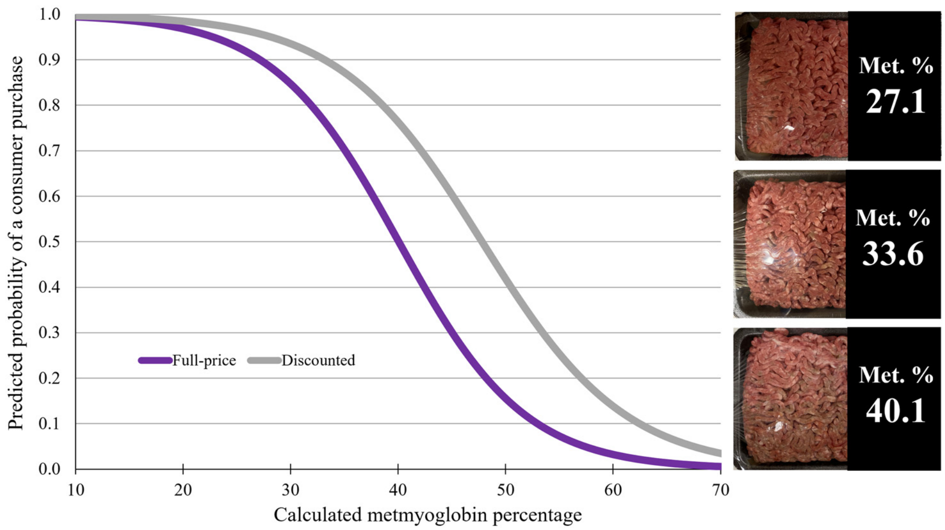

Figure 3. Probability of a consumer purchasing an 80% lean ground beef package based on calculated metmyoglobin percentage and pricing: Phase 1; metmyoglobin percentage calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

of consumers purchasing the product at full price. If the product was discounted, then the values shifted substantially to 17.9, 21.4, 25.0, and 27.4 for the corresponding 50%, 75%, 90%, and 95% likelihood thresholds for purchase. The trained sensory panel discoloration scores (Figure 4), which were a measure of the percentage of metmyoglobin (brown color) on the surface of the product, provided insight regarding the amount of discoloration present on a product that would still result in a consumer to purchase. For consumers to be 50%, 75%, and 90% likely to purchase the product, the percentage of discoloration was determined to be 37.8%, 19.5%, and 1.1% in Phase 1. Discounted product again shifted these values, with consumers willing to purchase product with a greater amount of discoloration if discounted, with the models showing discoloration percentages of 64.0, 42.0, 20.1, and 5.2 corresponding with 50%, 75%, 90%, and 95% likely to purchase.

Phase 2 likeliness to purchase threshold values are summarized in Table 6. In this phase, *a** values of 20.7, 26.2, 31.7, and 35.4 corresponded with 50%, 75%, 90%, and 95% likely to purchase, respectively. Similar to Phase 1, consumers indicated a willingness to purchase ground beef with lower *a** values (Figure 5), with values of 17.7, 22.7, 27.7, and 31.1 resulting in 50%, 75%, 90%, and 95% likely to purchase if the product was discounted. Phase 2 resulted

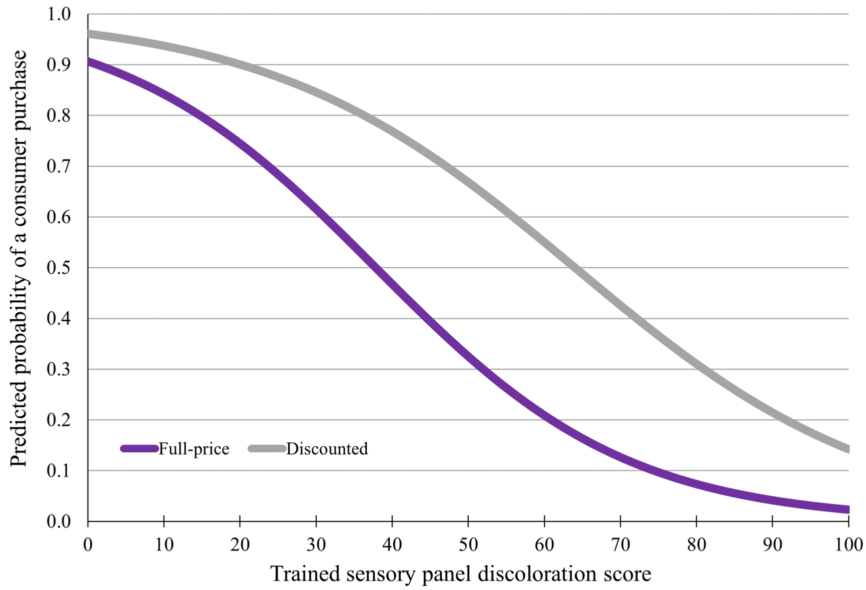

Figure 4. Probability of a consumer purchasing an 80% lean ground beef package based on trained sensory panel discoloration score and pricing: Phase 1; sensory discoloration scores: 0 = no visible discoloration, 100 = complete discoloration.

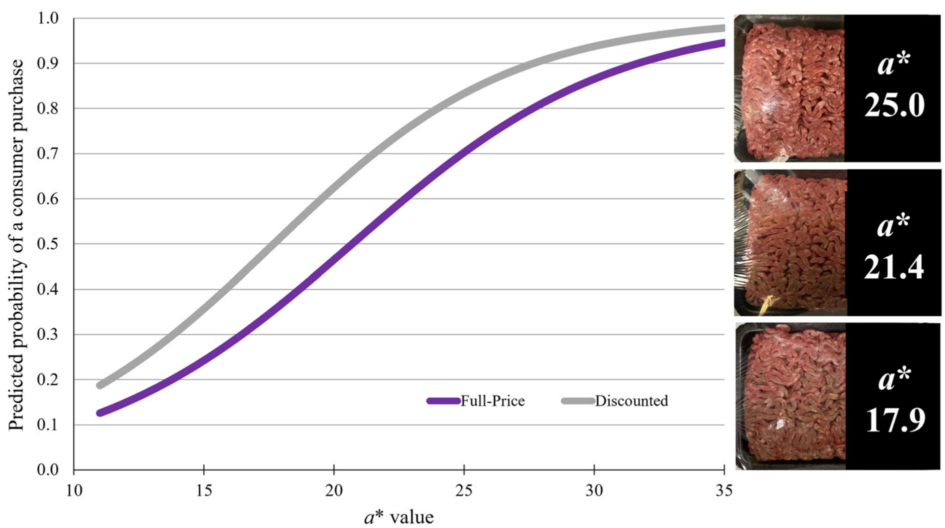

Figure 5. Probability of a consumer purchasing an 80% lean ground beef package based on *a** value and pricing: Phase 2.

in a higher percentage of discoloration accepted by consumers. In this phase, trained sensory panel discoloration values (Figure 7) of 40.3% and 12.8% correspond to 50% and 75% likely to purchase. Meanwhile, trained sensory panel discoloration values of 79.0%, 42.4%, and 5.8% correspond with consumers being 50%, 75%, and 90% likely to purchase if the product was discounted.

Pearson correlation coefficients

Pearson correlation coefficients were calculated utilizing the objective measurements collected in both phases of the study (Table 7). All of the variables were related ($P < 0.01$), with many highly correlated ($r > 0.90$). In Phase 1, trained sensory panel redness and consumer appearance scores were closely related to a^* values ($r > 0.96$), with Phase 2 also showing a close relationship between trained sensory panel redness scores and a^* values ($r = 0.90$). However, the relationship between consumer appearance score and a^* value in Phase 2 was weaker ($r = 0.71$).

In Phase 1, consumer overall appearance presented a strong relationship to almost all of the objective measurements ($r > 0.93$ for all but L^*). However, the relationship was not as strong in Phase 2 ($r = 0.64$ to 0.74).

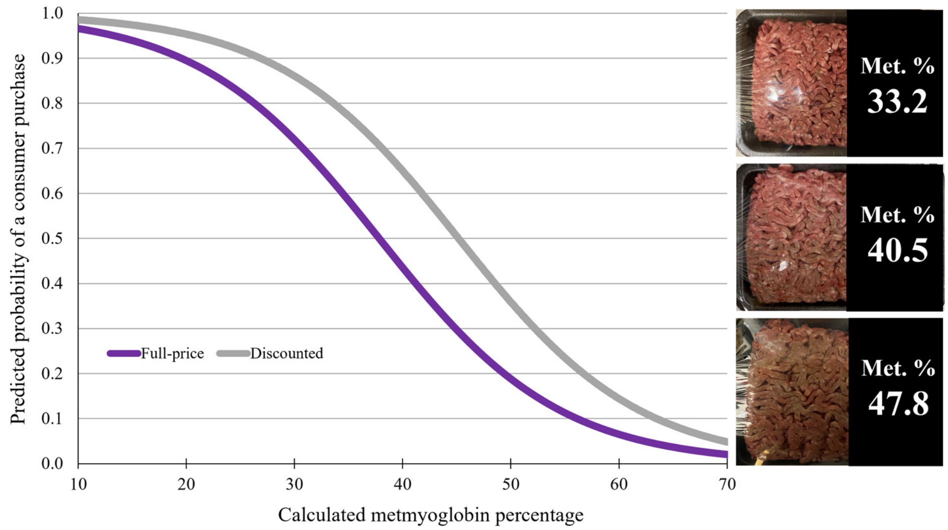

Figure 6. Probability of a consumer purchasing an 80% lean ground beef package based on calculated metmyoglobin percentage and pricing: Phase 2; metmyoglobin percentage calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

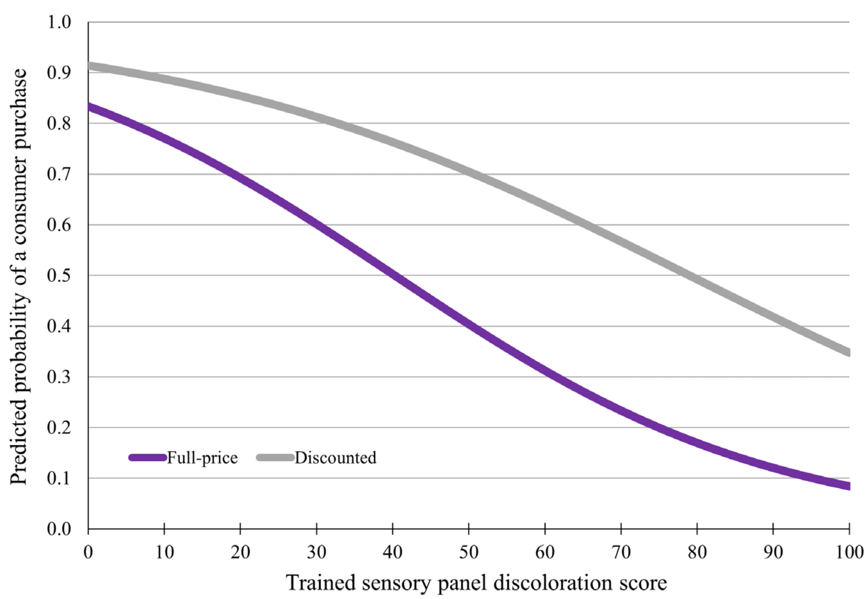

Figure 7. Probability of a consumer purchasing an 80% lean ground beef package based on trained sensory panel discoloration score and pricing: Phase 2; sensory discoloration scores: 0 = no visible discoloration, 100 = complete discoloration.

The relationship between consumer overall appearance score and all other objective measurements was strong in both phases but differed between the 2 phases because of the differences in design.

The trained sensory panel discoloration score resulted in a very strong relationship ($r = 0.98$) with the calculated metmyoglobin score in Phase 1. Results in Phase 2 were similarly high ($r = 0.93$), indicating the trained sensory panel discoloration scores were an accurate indicator of the percentage of metmyoglobin on the surface of the ground beef product.

Hue angle also showed potential as an objective measurement to assess discoloration, with strong relationships reported between almost all other measurements ($r > 0.91$ for all but L^*) in Phase 1. Although slightly lower values were found in Phase 2, the relationship between hue angle and all other measurements was still strong ($r > 0.71$; most $r > 0.93$).

Linear regression equations

Linear regression equations predicting consumer overall appearance ratings with objective measures

Table 5. The 50%, 75%, 90%, and 95% likeliness thresholds for various objective quality measures for consumer purchase intent of 80% lean retail ground beef for Phase 1

Measurement	50%	75%	90%	95%
Product sold at full price				
L*	50.6	51.7	52.8	53.6
a*	21.6	24.9	28.3	30.5
b*	20.4	21.8	23.2	24.2
Metmyoglobin[1]	40.1	33.6	27.1	22.7
Oxymyoglobin[1]	58.5	64.9	71.4	75.8
Chroma[1]	30.5	33.9	37.4	39.7
Hue angle[1]	0.77	0.73	0.68	0.65
Trained sensory panel redness score[2]	53.6	67.4	81.1	90.4
Trained sensory panel discoloration score[3]	37.8	19.5	1.1	-
Consumer appearance score[4]	49.8	60.8	71.8	79.3
Product sold at discounted price				
L*	49.5	50.8	52.2	53.2
a*	17.9	21.4	25.0	27.4
b*	18.9	20.3	21.8	22.8
Metmyoglobin[1]	47.8	40.5	33.2	28.2
Oxymyoglobin[1]	50.1	57.4	64.7	69.7
Chroma[1]	25.8	29.2	32.7	35.0
Hue angle[1]	0.84	0.78	0.72	0.68
Trained sensory panel redness score[2]	40.9	56.6	72.3	82.9
Trained sensory panel discoloration score[3]	64.0	42.0	20.1	5.2
Consumer appearance score[4]	36.9	49.1	61.3	69.6

[1]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[2]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[3]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[4]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

Table 6. The 50%, 75%, 90%, and 95% likeliness thresholds for various quality measures for consumer purchase intent of 80% lean retail ground beef for Phase 2

Measurement	50%	75%	90%	95%
Product sold at full price				
L*	52.2	54.7	57.3	59.0
a*	20.7	26.2	31.7	35.4
b*	20.2	22.8	25.3	27.1
Metmyoglobin[1]	37.8	28.7	19.5	13.3
Oxymyoglobin[1]	57.9	67.9	77.9	84.7
Chroma[1]	29.7	35.5	41.3	45.2
Hue angle[1]	0.79	0.72	0.66	0.61
Trained sensory panel redness score[2]	60.6	82.6	–	–
Trained sensory panel discoloration score[3]	40.3	12.8	–	–
Consumer appearance score[4]	48.4	60.7	72.9	81.2
Product sold at discounted price				
L*	50.0	52.5	55.1	56.8
a*	17.7	22.7	27.7	31.1
b*	19.1	21.4	23.7	25.3
Metmyoglobin[1]	45.2	36.0	26.9	20.6
Oxymyoglobin[1]	48.8	57.9	67.1	73.3
Chroma[1]	25.8	30.8	35.8	39.2
Hue angle[1]	0.84	0.77	0.70	0.66
Trained sensory panel redness score[2]	45.6	67.6	89.6	–
Trained sensory panel discoloration score[3]	79.0	42.4	5.8	-
Consumer appearance score[4]	38.8	51.0	63.2	71.5

[1]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[2]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[3]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[4]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

also resulted in significant ($P < 0.01$) models, with R^2 values of 0.57 to 0.93 in Phase 1 (Table 8) and R^2 values of 0.35 to 0.54 in Phase 2 (Table 9). Therefore, these models were able to account for a large amount of variation within the consumer overall appearance scores. The strongest relationships included *a** (Figure 8) and calculated metmyoglobin percentage (Figure 9) in their prediction of consumer overall appearance ratings.

The linear regression equations for *a** resulted in robust R^2 values of 0.92 and 0.50 for Phases 1 and 2, respectively (Figure 8). This linear regression equation generated in Phase 1 accounted for 92% of the variation within the data points collected. Moreover, Figure 8 demonstrates that as *a** (sample redness) increases, there is a linear increase in consumer overall appearance ratings of 3.39 units for every unit change in *a** value for Phase 1 and 2.04 units for each unit change in *a** for Phase 2.

The linear regression equations for calculated metmyoglobin percentage presented strong R^2 values of 0.92 and 0.54 for Phases 1 and 2, respectively (Figure 9). The linear regression equation generated in Phase 1 accounted for 92% of the variation within the data points collected and indicated a decrease of close to 2% in consumer appearance rating for every 1% increase in calculated metmyoglobin percentage.

Finally, Figure 10 presents the linear regression for predicting trained sensory panel discoloration scores based upon calculated metmyoglobin percentage.

Table 7. Pearson correlation coefficients for objective color measurements, trained sensory panel color ratings, and subjective consumer ratings[1] ($N = 600$ samples)

	L^*	a^*	b^*	Metmyoglobin[2]	Oxymyoglobin[2]	Chroma[2]	Hue angle[2]	Trained sensory panel redness score[3]	Trained sensory panel discoloration score[4]
Phase 1									
a*	0.79								
b*	0.76	0.98							
Metmyoglobin[2]	−0.75	−0.98	−0.93						
Oxymyoglobin[2]	0.73	0.96	0.93	−0.99					
Chroma[2]	0.78	0.10	0.99	−0.96	0.95				
Hue angle[2]	−0.73	−0.96	−0.91	0.99	−0.98	−0.95			
Trained sensory panel redness score[3]	0.80	0.97	0.95	−0.97	0.96	0.97	−0.95		
Trained sensory panel discoloration score[4]	−0.72	−0.94	−0.88	0.98	−0.98	−0.92	0.98	−0.95	
Consumer appearance score[5]	0.76	0.96	0.93	−0.96	0.96	0.95	−0.95	0.96	−0.94
Phase 2									
a*	0.80								
b*	0.72	0.97							
Metmyoglobin[2]	−0.84	−0.96	−0.88						
Oxymyoglobin[2]	0.82	0.93	0.86	−0.98					
Chroma[2]	0.78	0.10	0.99	−0.94	0.92				
Hue angle[2]	−0.83	−0.95	−0.86	0.99	−0.97	−0.93			
Trained sensory panel redness score[3]	0.84	0.90	0.81	−0.93	0.92	0.87	−0.93		
Trained sensory panel discoloration score[4]	−0.80	−0.85	−0.73	0.93	−0.93	−0.81	0.94	−0.93	
Consumer appearance score[5]	0.59	0.71	0.64	−0.74	0.74	0.69	−0.73	0.71	−0.72

[1]All reported correlation coefficients were significant ($P < 0.01$).

[2]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[3]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[4]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

[5]Sensory scores: 0 = extremely undesirable, 100 = extremely desirable.

The linear regression equations for both phases of the study were almost identical: Phase 1: trained sensory panel discoloration score = −61.8 + 2.6 × calculated percentage metmyoglobin; Phase 2: trained sensory panel discoloration score = −65.0 + 2.6 × calculated percentage metmyoglobin. This indicates the trained sensory panel's discoloration scores were not impacted by the varied methods between Phase 1 and Phase 2 of the study. This is further evidenced by R^2 values of 0.96 and 0.87 for Phase 1 and Phase 2, respectively.

Discussion

Ground beef color

Consumers in this study reported "lean/fat ratio," "price," and "color" as the most important motivators when purchasing ground beef at the retail level. Recent studies involving customer purchasing motivators also reported "color" to be among the top 3 purchasing motivators (Olson et al., 2019; Prill et al., 2019; Davis et al., 2021; Farmer et al., 2022; Harr et al., 2022a, 2022b). Lucherk et al. (2017) reported fresh beef steak color was of more importance to female consumers and Californian consumers, whereas it was less important to consumers categorized as "heavy beef eaters." Also, Pohlman (2017) reported ground beef color, fat, and price to be significantly more important than the product label. Ramanathan et al. (2022) reported 2.55% of beef is discarded at the retail level because of discoloration. Furthermore, these authors reported a 1% decrease in discarded beef because of discoloration would save the wasted 23.95 billion liters of water, 96.88 billion megajoules of energy, and 0.40 million tons of CO_2 emissions required to produce this

Table 8. Linear regression equations for predicting consumer sensory panel overall liking scores for 80% lean retail ground beef ($N = 600$ samples)

Measurement	Intercept	Slope	Adjusted R^2	P value
Phase 1				
L*	−494.51	10.76	0.57	<0.01
a*	−23.90	3.39	0.92	<0.01
b*	−109.22	7.70	0.87	<0.01
Metmyoglobin[1]	129.05	−1.94	0.92	<0.01
Oxymyoglobin[1]	−57.52	1.93	0.91	<0.01
Chroma[1]	−50.43	3.32	0.91	<0.01
Hue angle[1]	249.86	−252.40	0.89	<0.01
Trained sensory panel redness score[2]	2.56	0.89	0.93	<0.01
Trained sensory panel discoloration score[3]	80.84	−0.70	0.88	<0.01
Phase 2				
L*	−214.75	5.09	0.35	<0.01
a*	8.13	2.04	0.50	<0.01
b*	−32.76	4.11	0.42	<0.01
Metmyoglobin[1]	103.29	−1.37	0.54	<0.01
Oxymyoglobin[1]	−28.15	1.35	0.54	<0.01
Chroma[1]	−5.40	1.92	0.48	<0.01
Hue angle[1]	202.59	−193.54	0.53	<0.01
Trained sensory panel redness score[2]	13.30	0.62	0.50	<0.01
Trained sensory panel discoloration score[3]	69.78	−0.48	0.52	<0.01

[1]Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

[2]Sensory scores: 0 = extremely dark red, 100 = bright cherry red.

[3]Sensory scores: 0 = no visible discoloration, 100 = complete discoloration.

discarded beef (Ramanathan et al., 2022). However, Ramanathan et al. (2022) did not provide any data regarding the point at which beef products become unacceptable to consumers, leading to this wastage. The consumer purchasing motivators reported in recent work, along with the results from Ramanathan et al. (2022), illustrate the importance of determining the point at which beef reaches an unacceptable state at retail to consumers and the impact that this has on the beef industry.

pH

The pH of fresh beef is commonly reported to be below 6.0 in order to be considered "normal" (Page et al., 2001). However, these measurements are typically reported from whole-muscle beef cuts. Today, ground beef that is sold at retail may undergo numerous processes, including the inclusion of lean finely textured beef, the inclusion of antioxidants, and the use of multiple antimicrobial interventions including organic acid sprays, as well as be composed of a mix of lean sources from both fed beef and mature unfed beef. Additionally, these production practices may vary by processor, market, or season. This creates variation within the pH of products sold at retail. Previous published reports detailing the pH of ground beef purchased in retail markets have reported a pH of 6.0 for 80% lean commodity ground beef (Najar-Villarreal et al., 2019) and 6.2, 6.1, and 6.1 for 90%, 80%, and 70% lean ground beef (Davis et al., 2021). In both of these studies, ground beef was purchased from local supermarkets, indicating the observed mean pH of product in the current work was similar to that of

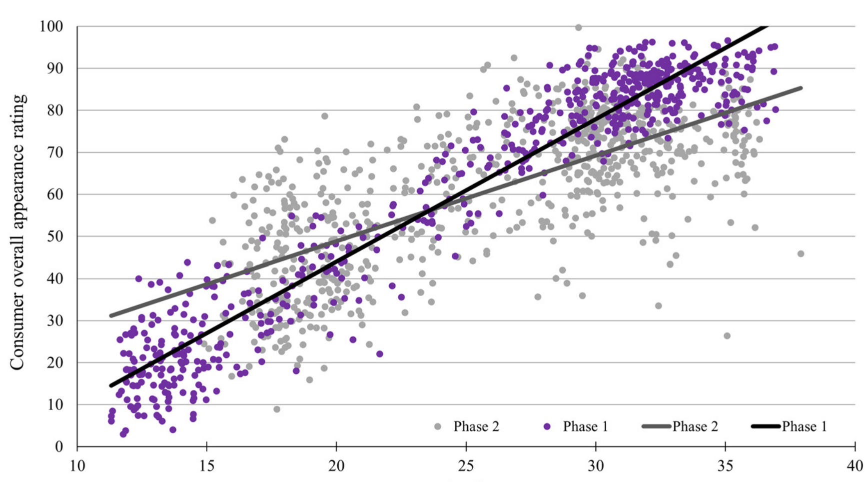

Figure 8. Linear regressions for predicting consumer overall appearance rating based on a^* value; consumer overall appearance scores: 0 = extremely undesirable, 100 = extremely desirable.

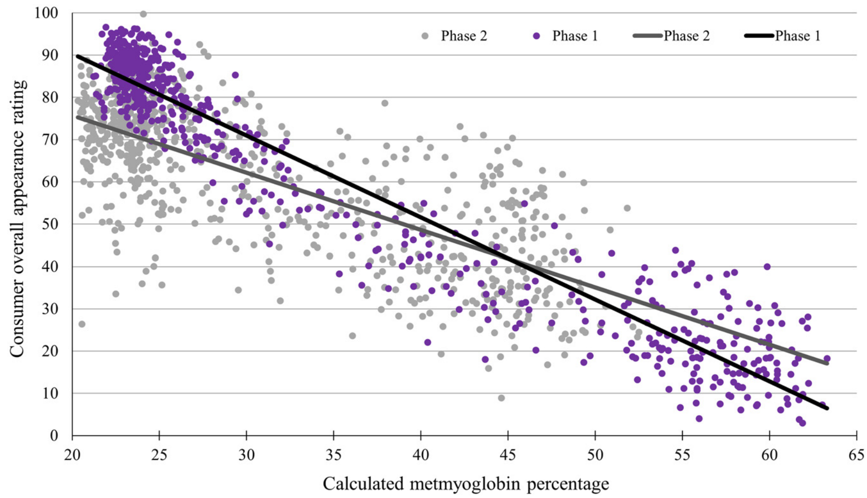

Figure 9. Linear regressions for predicting consumer overall appearance rating based on calculated metmyoglobin percentage; consumer overall appearance scores: 0 = extremely undesirable, 100 = extremely desirable; metmyoglobin percentage calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

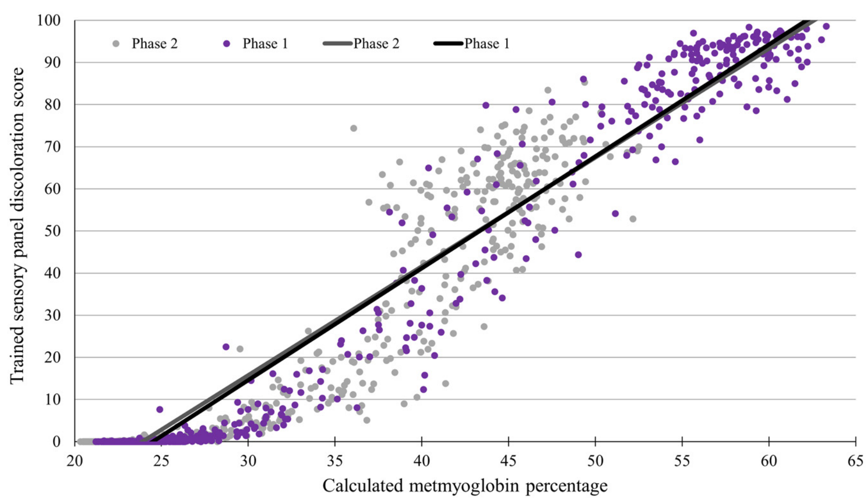

Figure 10. Linear regressions for predicting trained sensory discoloration score based on calculated metmyoglobin percentage; trained sensory panel discoloration scores: 0 = no visible discoloration, 100 = complete discoloration; metmyoglobin percentage calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

commercially available ground beef and thus was representative of ground beef sold at retail.

Impact of color on consumer perceptions of ground beef

Several studies have attempted to evaluate the impact of meat discoloration on consumer purchasing intent, but results have been limited and inconsistent. The first study with this objective was Hood and Riordan (1973), which established a linear regression model (proportion of discolored meat in total sales = 45.5 to 0.56 × level of metmyoglobin in discolored meat) to predict the likelihood of consumer purchase at different levels of metmyoglobin in beef steak products. The linear regression equations from the current work differed greatly. Hood and Riordan (1973) reported that every unit increase in metmyoglobin in discolored beef resulted in a 0.56% decrease in meat sales. Meanwhile, our study found the slope of the similar model to be much steeper, with every percentage increase in metmyoglobin to result in a corresponding 1.94 or 1.37 unit decrease in consumer appearance liking scores. Many factors and differences between the 2 studies are likely responsible for the observed differences in the models. Hood and Riordan (1973) did not include the entire range of metmyoglobin discoloration (0% to 100%) and only included samples with 5% to 33% discoloration because of the in-store trial nature of their study. The current work was able to include the entire range of discoloration for consumer consideration and therefore more precisely identify the points in which consumers reported ground beef products to be unacceptable. Additionally, the dependent variable evaluated by Hood and Riordan (1973) (retail sales) differed from the current work (consumer appearance liking score), and thus, the models were used to predict different outcomes, hence a different relationship should be expected. It is also noteworthy that Hood and Riordan (1973) was conducted 50 y ago, and consumer preferences may have shifted over time.

In a more recent study utilizing an online survey format, Holman et al. (2016) reported an upper and lower limit to b^* (13.0 and 22.0) as an accurate predictor of consumer acceptance of beef steaks while not finding a^* to be meaningful. This contrasts with the current work, in which a^* value was among the best predictors and b^* was among the poorest for predicting consumer sensory panel overall liking scores. However, the initial Holman et al. (2016) study was limited in sample size ($N = 10$), severely limiting the power and accuracy of such modeling. In a follow-up study with a greater sample size ($N = 80$), the authors contradicted their previous study's results, finding a^* to be an important indicator of consumer beef color acceptability (Holman et al., 2017). Furthermore, Holman et al. (2017) established a threshold a^* value of >12.5 for consumer acceptability. This supports the findings from the current work, but a true comparison cannot be made between the current work and the Holman et al. (2017) study because the authors utilized illuminant D_{65} in contrast to illuminant A used in the current work. The current study utilized illuminant A as recommended by the AMSA Meat Color Guidelines because it allows for better detection of redness differences among samples within a study and is thus the preferred method for studies with the objective of establishing the importance of meat redness as a tool to predict consumer purchasing intent (King et al., 2023). Although Holman et al. (2017) collected data to calculate the percentage of metmyoglobin present in the samples, regression models for this variable were not reported and thus cannot be compared with the current work. Additionally, Holman et al. (2016, 2017) included instructions for respondents to set their computer monitors to select true color and the highest screen resolution, but it is unknown if all respondents followed these directions. Therefore, it cannot be guaranteed that survey respondents evaluated the photo samples under the same conditions necessary to ensure that the true color and discoloration of the samples were accurately represented for each panelist, thus highlighting a limitation of utilizing web-based survey tools for consumer color evaluation versus utilizing centralized testing, as was done in the current work.

Carpenter et al. (2001) evaluated consumer preferences for beef color and its impact on consumer taste scores. These authors packaged beef steaks and ground beef in differing packaging types to allow for each beef color (red, purple, brown) to be achieved (Carpenter et al., 2001). Consumers evaluated each sample and were asked to identify the product color (red, purple, brown) and describe their liking of the color and their likelihood to purchase the product. Following the visual analysis, consumers participated in taste panels in which they consumed 3 samples labeled the same as the ones they visually appraised. However, the samples consumed were all identical. This allowed the researchers to understand the impact of visual appearance scores on taste scores. Results from this study complement the current work, as consumers preferred the samples identified as "red" (a^* value = 14.7), with a correlation ($r = 0.90$) between appearance scores and consumer likelihood to purchase. Moreover, the authors reported color and packaging did not influence taste scores (Carpenter et al., 2001). Unfortunately, it is challenging to directly compare these results to the current work because the authors utilized illuminant D_{65} for a^* measurement.

Najar-Villarreal et al. (2021) conducted a meta-analysis of 13 papers from peer-reviewed journals to establish acceptability thresholds for the color life of beef *longissimus lumborum* and *psoas major* steaks. This study presented an upper and lower limit to a^* value of 24.07 and 20.24, respectively, for *longissimus lumborum* steaks, and 23.75 and 20.99, respectively, for *psoas major* steaks (Najar-Villarreal et al., 2021). These findings complement the current work, as an a^* value of 24.9 corresponded with a 75% purchasing likelihood and an a^* value of 21.6 corresponded with a 50% purchasing likelihood in the current models. However, it is important to note that Najar-Villarreal et al. (2021) used data from trained sensory panels to determine product acceptability, which is not in accordance with the AMSA Color Guidelines (King et al., 2023), which reinforce consumer sensory panels as the only suitable way to determine acceptability thresholds. Moreover, the authors chose an arbitrary point on the various scales used by the cited studies to assess acceptability, as opposed to panelists answering a yes/no question regarding acceptability or having an identified point on the scales related to acceptability for the panelists to consider. In total, the results from the Najar-Villarreal et al. (2021) analysis should be considered with these limitations and may provide only limited information related to how a^* value relates to consumer perceptions.

Evaluation of objective measurements

Results from our study show that all objective measurements evaluated are predictors of consumer purchasing intent. Previous work from Holman et al. (2017) identified a^* as the "most simple and robust prediction of beef color acceptability." However, the current work indicates many other measures are suitable as well. Calculated percentage metmyoglobin and chroma were similar to a^* value at indicating consumer purchase intent. Our results indicate a multitude of objective measurements could be utilized to predict consumer purchasing intent of ground beef in a retail setting and would allow for the research group to select variables that provide the greatest convenience for collection.

Trained sensory panels are a tool commonly used to describe and quantify color characteristics of meat products (Mancini and Ramanathan, 2020). Seyfert et al. (2007) reported trained sensory panel visual color was correlated with a^* and chroma ($r = 0.84$ and 0.87, respectively), which were weaker correlations than those in current study ($r = 0.97$, 0.90 and 0.97, 0.87) for a^* and chroma, respectively, for Phase 1 and 2. These relationships reported by Seyfert et al. (2007) were weaker than those found by Mancini et al. (2022), who reported a^* and chroma to both be highly correlated ($r > 0.97$) to trained sensory panel redness scores, as well as many of the other objective measures closely associated with visual color scores. These results are in close agreement with the relationships identified in the current work. In another study, the trained sensory panel conducted by Colle et al. (2015) classified *gluteus medius* steak color as "dull" with an a^* value of 27.1. However, the trained sensory panel in that study consisted of only 2 people (Colle et al., 2015). Additionally, Kim et al. (2016) reported a^* values of 14.0 corresponded to trained sensory panel visual color as moderately dark red. In our work, consumers were not asked to classify redness of samples into categories of dullness or darkness, but the a^* value reported by Kim et al. (2016) would have corresponded with samples with less than a 50% likelihood for purchase. Finally, Brewer and Wu (1993) reported a negative correlation ($r = -0.52$) between calculated percentage metmyoglobin and trained sensory panel acceptability scores, which was much weaker than the correlation between trained panel discoloration scores and percentage metmyoglobin reported in the current work ($r = 0.98$ and 0.93). Also, these authors reported a correlation ($r = 0.54$) between a^* and trained panel acceptability scores (Brewer and Wu, 1993). As previously discussed, utilizing trained sensory panels to assess acceptability is not supported by the AMSA Color Guidelines (King et al., 2023) and should be interpreted accordingly.

Impact of retail case layout and discounts

Numerous intentional differences existed between Phase 1 and Phase 2 of the current study pertaining to the layout of the retail cases. In Phase 1, consumers evaluated samples representing the entire range of discoloration from each day of retail display, whereas Phase 2 consumers evaluated samples from only 1 d of retail display. This deliberate design allowed consumers in Phase 1 to identify the point at which the color of ground beef progressed from acceptable to unacceptable. Therefore, this study captured and evaluated any differences related to how consumers evaluated the samples when a variety of discolored packages were presented at once and when the entire retail case was of similar appearance.

The changes in methods between phases did lead to some differences in results, as well. All of the objective measurements in Phase 2 were significant, but the extent to which the variables were able to account for variation in the consumer intent to purchase was much lower than Phase 1. Because Phase 2 consumers were evaluating samples from only 1 day of display, it would be expected that they would give the same responses for each sample evaluated, but consumers did not do so. Hood and Riordan (1973) noted that consumer reactions to discolored meat would likely be less discriminatory if all meat being compared contained similar amounts of discoloration. They predicted that discolored meat displayed next to bright-red meat, similar to the design of Phase 1, would lead to a heightened negative reaction toward the discolored meat. Our results would support this. A more recent study reported 58% of consumers indicated that the presence of discolored steaks in the retail case makes nondiscolored steaks appear more appealing (Feuz et al., 2020b), helping to again explain some of the differences observed between the 2 phases in the current work. Although discrepancies among the data gathered from the 2 phases exist, each provide different perspectives to make decisions with.

The current work did observe consumers to be more willing to purchase ground beef later in shelf life if the product was discounted. Similarly, Feuz et al. (2020a) reported consumers would require willingness-to-pay discounts of $6.71 for discolored beef with 25% of its surface area discolored. However, these authors did not report their parameters for their assessment of discoloration, so it is challenging to make comparisons between their study and ours. Additionally, the current work allowed for the meat to discolor naturally, whereas in the previously mentioned study, images of the samples were modified to represent discoloration using a photo editing software. Moreover, Feuz et al. (2020a) utilized a web-based survey, again allowing for the possibility of differences in monitor resolution and color settings to potentially impact their results. Finally, the current work did not ask consumers to assign a monetary value to "discounted" but left it open for interpretation by the consumers, thus providing no insight as to the actual discount amount needed for consumers to purchase packages when discounted.

Conclusion

Overall, our models showed that each of the objective measures evaluated were predictors of consumer purchasing intent. Objective measurements shown to be the best included a^* value and calculated metmyoglobin percentage. The models generated from this study provide the ability to predict consumer willingness to purchase ground beef of varying days of retail display and provide ground beef producers an indication of potential consumer purchasing behaviors based upon multiple objective measures. These results also indicate that the use of labor-intensive trained sensory panels is not required for all studies and that the use of objective measures, which are often easier to collect, will provide a comparably good representation of consumer purchasing likelihood. Thus, future studies may be designed to collect the color data that are the easiest for the research teams without sacrificing the ability to draw meaningful conclusions related to consumer perceptions.

Literature Cited

Brewer, M. S., and S. Y. Wu. 1993. Display, packaging, and meat block location effects on color and lipid oxidation of frozen lean ground beef. J. Food Sci. 58:1219–1236. https://doi.org/10.1111/j.1365-2621.1993.tb06152.x

Carpenter, C. E., D. P. Cornforth, and D. Whittier. 2001. Consumer preferences for beef color and packaging did not affect eating satisfaction. Meat Sci. 57:359–363. https://doi.org/10.1016/S0309-1740(00)00111-X

Close, D. 2014. Ground beef nation: The effect of changing consumer tastes and preferences on the U.S. cattle industry. Rabobank International, Food and Agribusiness Research and Advisory.

Colle, M. J., R. P. Richard, K. M. Killinger, J. C. Bohlscheid, A. R. Gray, W. I. Loucks, R. N. Day, A. S. Cochran, J. A. Nasados, and M. E. Doumit. 2015. Influence of extended aging on beef quality characteristics and sensory perception of steaks from the *gluteus medius* and *longissimus lumborum*. Meat Sci. 110:32–39. https://doi.org/10.1016/j.meatsci.2015.06.013

Cooper, J. V., B. R. Wiegand, A. B. Koc, L. Schumacher, I. Grün, and C. L. Lorenzen. 2016. Rapid communication: Impact of contemporary light sources on oxidation of fresh ground beef. J. Anim. Sci. 94:4457–4462. https://doi.org/10.2527/jas.2016-0728

Davis, S. G., K. M. Harr, K. J. Farmer, E. S. Beyer, S. B. Bigger, M. D. Chao, A. J. Tarpoff, D. U. Thomson, J. L. Vipham, M. D. Zumbaugh, and T. G. O'Quinn. 2021. Quality of plant-based ground beef alternatives in comparison with ground beef of various fat levels. Meat Muscle Biol. 5:38, 1–15. https://doi.org/10.22175/mmb.12989

Farmer, K. J., E. S. Beyer, S. G. Davis, K. M. Harr, K. R. Lybarger, L. A. Egger, M. D. Chao, J. L. Vipham, M. D. Zumbaugh, and T. G. O'Quinn. 2022. Evaluation of the impact of bone-in versus boneless cuts on beef palatability. Meat Muscle Biol. 6:15488, 1–13. https://doi.org/10.22175/mmb.15488

Faustman, C., and R. G. Cassens. 1990. The biochemical basis for discoloration in fresh meat: A review. J. Muscle Foods 1:217–243. https://doi.org/10.1111/j.1745-4573.1990.tb00366.x

Faustman, C., and S. P. Suman. 2017. Chapter 11 - The eating quality of meat: I—Color. In: F. Toldrá, editor, Lawrie's meat science. Woodhead Publishing, Duxford, UK. p. 329–356. https://doi.org/10.1016/B978-0-08-100694-8.00011-X

Feuz, R., F. B. Norwood, and R. Ramanathan. 2020a. Do consumers have an appetite for discolored beef? Agribusiness 36:631–652. https://doi.org/10.1002/agr.21651

Feuz, R., F. B. Norwood, and R. Ramanathan. 2020b. The spillover effect of marketing discolored beef on consumer preferences for nondiscolored beef. Journal of Agricultural and Applied Economics 52:160–176. https://doi.org/10.1017/aae.2019.39

Giddings, G. G. 1977. The basis of color in muscle foods. Crit. Rev. Food Sci. 9:81–114. https://doi.org/10.1080/10408397709527231

Hammond, P. A., C. K. Y. Chun, W. J. Wu, A. A. Welter, T. G. O'Quinn, G. Magnin-Bissel, E. R. Geisbrecht, and M. D. Chao. 2022. An investigation on the influence of various biochemical tenderness factors on eight different bovine muscles. Meat Muscle Biol. 6:13902. https://doi.org/10.22175/mmb.13902

Harr, K. M., E. S. Beyer, K. J. Farmer, S. G. Davis, M. D. Chao, J. L. Vipham, M. D. Zumbaugh, and T. G. O'Quinn. 2022a. Impact of disclosing fat content, primal source, and price on consumer evaluation of ground beef. Meat Muscle Biol. 6:15482, 1–17. https://doi.org/10.22175/mmb.15482

Harr, K. M., E. S. Beyer, K. J. Farmer, S. G. Davis, M. D. Chao, J. L. Vipham, M. D. Zumbaugh, and T. G. O'Quinn. 2022b.

Labeling terms and production claims influence consumers' palatability perceptions of ground beef. Meat Muscle Biol. 6:15518, 1–11. https://doi.org/10.22175/mmb.15518

Holman, B. W. B., Y. Mao, C. E. O. Coombs, R. J. van de Ven, and D. L. Hopkins. 2016. Relationship between colorimetric (instrumental) evaluation and consumer-defined beef colour acceptability. Meat Sci. 121:104–106. https://doi.org/10.1016/j.meatsci.2016.05.002

Holman, B. W. B., R. J. van de Ven, Y. Mao, C. E. O. Coombs, and D. L. Hopkins. 2017. Using instrumental (CIE and reflectance) measures to predict consumers' acceptance of beef colour. Meat Sci. 127:57–62. https://doi.org/10.1016/j.meatsci.2017.01.005

Hood, D. E., and E. B. Riordan. 1973. Discolouration in prepackaged beef: Measurement by reflectance spectrophotometry and shopper discrimination. Int. J. Food Sci. Tech. 8:333–343. https://doi.org/10.1111/j.1365-2621.1973.tb01721.x

Hoyle Parks, A. R., M. M. Brashears, J. N. Martin, W. D. Woerner, L. D. Thompson, and J. C. Brooks. 2012. Shelf life and stability traits of traditionally and modified atmosphere packaged ground beef patties treated with lactic acid bacteria, rosemary oleoresin, or both prior to retail display. Meat Sci. 90:20–27. https://doi.org/10.1016/j.meatsci.2011.05.020

Hunt, M. C., R. A. Mancini, K. A. Hachmeister, D. H. Kropf, M. Merriman, G. de Lduca, and G. Milliken. 2004. Carbon monoxide in modified atmosphere packaging affects color, shelf life, and microorganisms of beef steaks and ground beef. J. Food Sci. 69:FCT45–FCT52. https://doi.org/10.1111/j.1365-2621.2004.tb17854.x

Jayasingh, P., D. P. Cornforth, C. E. Carpenter, and D. Whittier. 2001. Evaluation of carbon monoxide treatment in modified atmosphere packaging or vacuum packaging to increase color stability of fresh beef. Meat Sci. 59:317–324. https://doi.org/10.1016/S0309-1740(01)00086-9

Kim, H.-W., D. Setyabrata, Y.-S. Choi, and Y. H. B. Kim. 2016. Rapid discoloration of aged beef muscles after short-term/extreme temperature abuse during retail display. Korean J. Food Sci. An. 36:343–351. https://doi.org/10.5851/kosfa.2016.36.3.343

King, D. A., M. C. Hunt, S. Barbut, J. R. Claus, D. P. Cornforth, P. Joseph, Y. H. B. Kim, G. Lindahl, R. A. Mancini, M. N. Nair, K. J. Merok, A. Milkowski, A. Mohan, F. Pohlman, R. Ramanathan, C. R. Raines, M. Seyfert, O. Sørheim, S. P. Suman, and M. Weber. 2023. American Meat Science Association Guidelines for Meat Color Measurement. Meat Muscle Biol. 6:12473. https://doi.org/10.22175/mmb.12473

Lucherk, L. W., T. G. O'Quinn, J. F. Legako, J. C. Brooks, and M. F. Miller. 2017. Fresh beef steak purchasing motivation is affected by demographics and beef preferences of consumers. Meat Muscle Biol. 1:10–11. https://doi.org/10.22175/rmc2017.010

Mancini, R., and M. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. https://doi.org/10.1016/j.meatsci.2005.03.003

Mancini, R. A., and R. Ramanathan. 2020. Molecular basis of meat color. In: A. K. Biswas and P. K. Mandal, editors, Meat quality analysis. Academic Press, London. p. 117–129. https://doi.org/10.1016/B978-0-12-819233-7.00008-2

Mancini, R. A., R. Ramanathan, M. C. Hunt, D. H. Kropf, and G. G. Mafi. 2022. Interrelationships between visual and instrumental measures of ground beef color. Meat Muscle Biol. 6:14040. https://doi.org/10.22175/mmb.14040

Martin, J. N., J. C. Brooks, T. A. Brooks, J. F. Legako, J. D. Starkey, S. P. Jackson, and M. F. Miller. 2013. Storage length, storage temperature, and lean formulation influence the shelf-life and stability of traditionally packaged ground beef. Meat Sci. 95:495–502. https://doi.org/10.1016/j.meatsci.2013.05.032

Najar-Villarreal, F., E. A. E. Boyle, R. D. Danler, T. G. O'Quinn, T. A. Houser, and J. M. Gonzalez. 2019. Fatty acid composition, proximate analysis, and consumer sensory evaluation of United States retail grass-fed ground beef. Meat Muscle Biol. 3:389–398. https://doi.org/10.22175/mmb2019.06.0018

Najar-Villarreal, F., E. A. E. Boyle, C. I. Vahl, Q. Kang, J. J. Kastner, J. Amamcharla, and M. C. Hunt. 2021. Determining the *longissimus lumborum* and *psoas major* beef steak color life threshold and effect of postmortem aging time using meta-analysis. Meat Muscle Biol. 5:41. https://doi.org/10.22175/mmb.12526

Olson, B. A., E. A. Rice, L. L. Prill, L. N. Drey, J. M. Gonzalez, J. L. Vipham, M. D. Chao, and T. G. O'Quinn. 2019. Evaluation of beef top sirloin steaks of four quality grades cooked to three degrees of doneness. Meat Muscle Biol. 3:399–410. https://doi.org/10.22175/mmb2019.07.0022

Page, J. K., D. M. Wulf, and T. R. Schwotzer. 2001. A survey of beef muscle color and pH. J. Anim. Sci. 79:678–687. https://doi.org/10.2527/2001.793678x

Pohlman, F. W., II. 2017. Effects of labeling and consumer health trends on preferred ground beef color characteristics, fat content, and palatability in simulated retail display. B.S. thesis, Univ. of Arkansas, Fayetteville, AR. (https://scholarworks.uark.edu/anscuht/15)

Prill, L. L., L. N. Drey, B. A. Olson, E. A. Rice, J. M. Gonzalez, J. L. Vipham, M. D. Chao, P. D. Bass, M. J. Colle, and T. G. O'Quinn. 2019. Visual degree of doneness impacts beef palatability for consumers with different degree of doneness preferences. Meat Muscle Biol. 3:411–423. https://doi.org/10.22175/mmb2019.07.0024

Ramanathan, R., L. H. Lambert, M. N. Mahesh, B. Morgan, R. Feuz, G. Mafi, and M. Pfeiffer. 2022. Economic loss, amount of beef discarded, natural resources wastage, and environmental impact due to beef discoloration. Meat Muscle Biol. 6:13218. https://doi.org/10.22175/mmb.13218

Rogers, H. B., J. C. Brooks, J. N. Martin, A. Tittor, M. F. Miller, and M. M. Brashears. 2014. The impact of packaging system and temperature abuse on the shelf life characteristics of ground beef. Meat Sci. 97:1–10. https://doi.org/10.1016/j.meatsci.2013.11.020

Schulz, L. 2021. Ground beef demand remains strong. ~https://www.extension.iastate.edu/agdm/articles/schulz/SchMar21.html#:~:text=Ground%20beef%20consumption%20was%20estimated,total%20US%20retail%20beef%20consumption.&text=Many%20muscle%20cuts%20command%20prices,for%20finished%20steers%20and%20heifers. (Accessed 17 May 2023.)

Seyfert, M., R. A. Mancini, M. C. Hunt, J. Tang, and C. Faustman. 2007. Influence of carbon monoxide in package atmospheres containing oxygen on colour, reducing activity, and oxygen consumption of five bovine muscles. Meat Sci. 75:432–442. https://doi.org/10.1016/j.meatsci.2006.08.007

Shalaby, A. R., M. M. Anwar, and E. M. Sallam. 2018. Improving quality and shelf-life of minced beef using irradiated olive leaf extract. J. Food Process. Pres. 42:e13789. https://doi.org/10.1111/jfpp.13789

Smith, G. C., J. B. Morgan, J. N. Sofos, and J. D. Tatum. 1996. Supplemental vitamin E in beef cattle diets to improve shelf-life of beef. Anim. Feed Sci. Tech. 59:207–214. https://doi.org/10.1016/0377-8401(95)00901-9

Speer, N., T. Brink, and M. McCully. 2015. Changes in the ground beef market and what it means for cattle producers. The Angus Foundation, St. Joseph, MO.

Steele, K. S., M. J. Weber, E. A. E. Boyle, M. C. Hunt, A. S. Lobaton-Sulabo, C. Cundith, Y. H. Hiebert, K. A. Abrolat, J. M. Attey, S. D. Clark, D. E. Johnson, and T. L. Roenbaugh. 2016. Shelf life of fresh meat products under LED or fluorescent lighting. Meat Sci. 117:75–84. https://doi.org/10.1016/j.meatsci.2016.02.032

Suman, S. P., and P. Joseph. 2013. Myoglobin chemistry and meat color. Ann. Rev. Food Sci. Technol. 4:79–99. https://doi.org/10.1146/annurev-food-030212-182623

Van Bibber-Krueger, C. L., A. M. Collins, K. J. Phelps, T. G. O'Quinn, T. A. Houser, K. K. Turner, and J. M. Gonzalez. 2020. Effects of quality grade and intramuscular location on beef semitendinosus muscle fiber characteristics, NADH content, and color stability. J. Anim. Sci. 98:skaa078. https://doi.org/10.1093/jas/skaa078

Yang, X., L. Niu, L. Zhu, R. Liang, Y. Zhang, and X. Luo. 2016. Shelf-life extension of chill-stored beef *longissimus* steaks packaged under modified atmospheres with 50% O_2 and 40% CO_2. J. Food Sci. 81:C1692–C1698. https://doi.org/10.1111/1750-3841.13345