

Determination of consumer purchase thresholds for discoloration of beef steaks in retail display

by

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Abstract

The objective of this study was to evaluate and determine similar purchasing tendencies and develop predictive models for consumer purchase likelihood based on objective measures of steak redness and discoloration to identify thresholds for consumer purchase of beef strip loin steaks. To accomplish this, the study was designed in two phases. Phase 1 required consumers to evaluate steak samples from various days of display ranging in discoloration from fresh to 100% discolored. Phase 2 required consumers to evaluate samples from all the same day of display with similar discoloration. Commercially packaged steaks were procured from a major beef processor in a case-ready format, identical to packages that would otherwise be displayed and sold at retail. Steaks were all the same USDA quality grade (upper 2/3 Choice), and were packaged and stored identically prior to the simulated retail display period. For each phase, steaks were removed from their mother-bag and placed in coffin-style retail cases and displayed under florescent lights for the pre-planned display period (0 – 14 days) in order to create differences in both steak color and discoloration. Consumers ($N = 200$ phase 1; 176 phase 2) evaluated steaks for overall appearance liking and identified whether or not they would purchase the product (yes/no) if it was fully-priced as well as if it was sold at a discount. Additionally, numerous objective color measures (L^* , a^* , b^* , chroma, hue angle) were assessed on each sample and each was evaluated by a trained descriptive sensory panel for overall redness, % discoloration, and fat color. Results showed that in both phases of the study, all of the objective measures evaluated were predictors ($P < 0.05$) of consumer purchase intent. The predictive models accounted for 30 – 78% of the variation in consumer purchase intent for steaks sold at full-price and 27 – 72% of the variation when sold at a discount for Phase 1. In Phase 2, the models were less predictive, with models only accounting for 11 – 57% of the variation in

consumer purchase likelihood in both full-priced and discounted samples. α^* value and trained sensory panel discoloration scores were some of the best predictors evaluated. These models showed that even minimal discoloration has a large impact on consumer purchasing likelihood, with steaks that have 12 to 22 percent discoloration only having a 50% chance of being purchased at full-price. These results underscore the importance of insuring steaks sold at retail are maintained at a bright red level and free of discoloration, with the developed models proving some guidance to the requirements expected by consumers for purchase of beef steaks related to color characteristics.

Keywords: beef, color, consumer, discoloration, retail, sensory

Table of Contents

List of Figures	vii
List of Tables	viii
Acknowledgements	ix
Chapter 1 - Review of Literature	1
Biochemistry of Meat Color	1
Physics of Color	3
Instrumental Color Analysis	4
Visual Color Analysis	6
Factors Influencing Meat Redness	7
Muscle Variation	8
Animal Age	8
Water Holding Capacity	8
PSE	9
Factors Influencing Meat Discoloration	10
Packaging Type	10
Light Source	12
Lipid Oxidation	12
Color Stability	13
Mitochondria	14
Microbiological Impact	14
Impact of Meat Color on Consumer Purchasing Decisions	15
Economic and Environmental Impact of Meat Discoloration	18
Chapter 2 - Determination of Consumer Purchase Thresholds for Discoloration of Beef Steaks	21
Introduction	21
Materials and Methods	22
Sample display	22
Objective color measurement	23
Trained sensory panel evaluation	23
Consumer sensory panel evaluation	24

Proximate and pH analysis	25
Statistical analysis	25
Results	26
Demographics	26
Logistic regression models	26
Pearson correlations	28
Linear regression equations	29
Discussion	30
References	53
Appendix A - Sensory Panel Evaluation Forms	60
Consumer Sensory Panel Ballot.....	60
Trained Sensory Panel Ballot.....	65
Appendix B - Sample Photos with Corresponding Likelihood to Purchase Thresholds	67
a^* Value – Full Price – Phase 1	67
a^* Value – Discount – Phase 1	68
a^* Value – Full Price – Phase 2	69
a^* value – Discount – Phase 2	70
Trained Panel Discoloration Score – Full Price – Phase 1	71
Trained Panel Discoloration Score – Discount – Phase 1.....	71
Trained Panel Discoloration Score – Full Price – Phase 2	72
Trained Panel Discoloration Score – Discount – Phase 2.....	72

List of Figures

Figure 1.1 Myoglobin and oxygen reactions occurring to determine visual surface color (Mancini and Hunt, 2005)	3
Figure 1.2 White light is passed through a prism and split into its different color components (King et al., 2023)	4
Figure 1.3 Graphic showing the CIE L*, a*, b* color space (King et al., 2023)	6
Figure 1.4 Approximate economic impact of discolored ground beef and steaks on the beef industry (Ramanathan et al., 2022)	19
Figure 2.1 Probability of a consumer purchasing a beef strip loin steak based on a^* value and pricing - Phase 1.....	37
Figure 2.2 Probability of a consumer purchasing a beef strip loin steak based on a^* value and pricing - Phase 2.....	38
Figure 2.3 Probability of a consumer purchasing a beef strip loin steak based on trained sensory panel discoloration score and pricing - Phase 1	39
Figure 2.4 Probability of a consumer purchasing a beef strip loin steak based on trained sensory panel discoloration score and pricing - Phase 2	40
Figure 2.5 Linear regressions for predicting consumer overall appearance rating based on a^* value	41
Figure 2.6 Linear regressions for predicting consumer overall appearance rating based on trained sensory panel discoloration score	42
Figure 2.7 Visual guide provided to trained sensory panelists for fat color score evaluation	43
Figure 2.8 Visual guide provided to trained sensory panelists for percent discoloration evaluation	44

List of Tables

Table 2.1 Demographic characteristics of consumers who participated in consumer visual sensory panels	45
Table 2.2 Summary statistics for independent variables evaluated in the study for beef strip steaks	46
Table 2.3 Logistic regression equations for predicting consumer sensory panel purchase intent of beef strip steaks for Phase 1	47
Table 2.4 Logistic regression equations for predicting consumer sensory panel purchase intent of beef strip steaks for Phase 2 of this study	48
Table 2.5 50, 75, 90, and 95% likeliness thresholds for various objective quality measures for consumer purchase intent of beef strip steaks for Phase 1	49
Table 2.6 50, 75, 90, and 95% likeliness thresholds for various quality measures for consumer purchase intent of beef strip steaks for Phase 2	50
Table 2.7 Pearson correlation coefficients for objective color measurements, trained sensory panel color ratings, and subjective consumer ratings ¹	51
Table 2.8 Linear regression equations for predicting consumer sensory panel overall liking scores for beef strip steaks	52

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Chapter 1 - Review of Literature

It has been documented that meat color is one of the most important factors influencing consumer purchasing decisions (Olson et al., 2019; Farmer et al., 2022; Harr et al., 2022). Numerous studies have shown that consumers are less willing to purchase discolored meat; however, the impact of discoloration of steaks on consumer purchase thresholds is not deeply understood and has not been widely explored in the literature. Thus, the objective of this review is to discuss the discoloration of beef steaks, the influence on consumer purchasing decisions, and how it impacts the beef industry.

Biochemistry of Meat Color

Lean color plays a vital role in consumer purchasing decisions of meat. For beef, consumers view a bright cherry-red color as an indicator for fresh products, however, brown and discolored is typically viewed negatively and consumers willingness to pay decreases as meat discolors (Greibitus et al., 2013). The protein primarily responsible for the determination of meat color is myoglobin. Myoglobin is a sarcoplasmic protein present in muscle tissue that is responsible for storing oxygen. The state of the heme iron in addition to what ligand is bound at the sixth coordination site of myoglobin influences meat color development (King et al., 2023).

There are four main forms of myoglobin: deoxymyoglobin, oxymyoglobin, metmyoglobin, and carboxymyoglobin (King et al., 2023). Deoxymyoglobin exists when there is no ligand bound to the sixth coordination site and iron is in the ferrous (Fe^{2+}) state which results in a purplish color (King et al., 2023). Deoxymyoglobin typically occurs in an oxygen free environment such as in a vacuum package or immediately after cutting, such as ribbing a carcass. After being exposed to oxygen, oxymyoglobin is formed. Oxymyoglobin occurs when oxygen is bound to the sixth coordination site and iron is in the ferrous (Fe^{2+}) state which results in the

desirable bright cherry-red color (King et al., 2023). When meat is exposed to an oxygen rich environment and turns bright cherry-red it is referred to as bloom. When the iron oxidizes and is in the ferric state, metmyoglobin can occur. Metmyoglobin occurs when no ligand is bound to myoglobin, similar to deoxymyoglobin; however, the iron is oxidized and in the ferric (Fe^{3+}) state resulting in a tan or brown pigment (King et al., 2023). This is typically viewed as a negative pigment by consumers. Finally, carboxymyoglobin occurs when carbon monoxide is bound to the sixth coordination site which results in a bright cherry-red, very stable pigment, similar to the bright cherry-red color that occurs with oxymyoglobin (Faustman and Suman, 2017). This occurs commonly in modified atmosphere (MAP) packaging to preserve the color and prevent the formation of metmyoglobin.

Figure 1.1 depicts the meat color triangle showing the four main reactions that occur to determine visual surface color of meat. Reaction 1 depicts the oxygenation of myoglobin where oxygen is binding to the ligand at the sixth coordination site. Deoxymyoglobin is transitioning to oxymyoglobin as would occur during bloom. Reaction 2a depicts the oxidation of the heme iron to convert oxymyoglobin to metmyoglobin. Reaction 2b depicts the oxidation of the heme iron similar to 2a; however 2b shows the conversion of deoxymyoglobin to metmyoglobin. Reaction 3 depicts oxidation of the iron in oxymyoglobin transitioning to metmyoglobin then reduction of iron transitioning again to deoxymyoglobin. This reaction occurs since reaction 1 is not reversible, however reaction 3 makes it possible to convert back to deoxymyoglobin in an instance where oxygen is no longer present such as vacuum packaging. Reaction 4 depicts the formation of carboxymyoglobin when carbon monoxide is the ligand bound at the sixth coordination site. This forms a very stable bright pigment. Understanding the chemical reactions that cause meat to discolor is critical to potential next steps or solutions to the problem of meat discoloration.

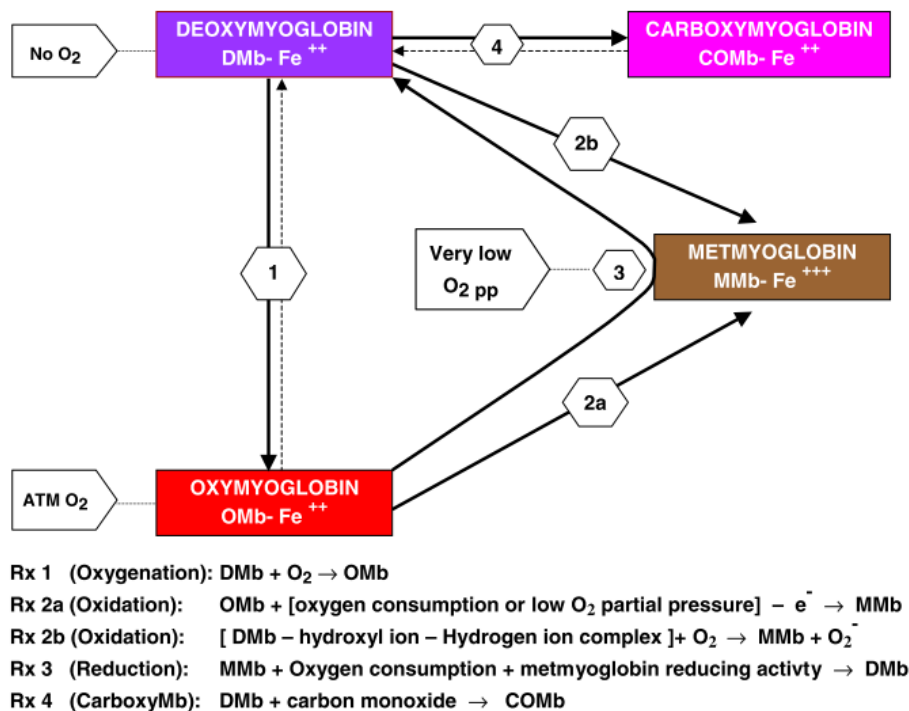


Figure 1.1 Myoglobin and oxygen reactions occurring to determine visual surface color (Mancini and Hunt, 2005)

Physics of Color

Color is a physical phenomenon that is perceived when white light interacts with an object and is either absorbed, transmitted, or reflected. Figure 1.2 (King et al., 2023) shows white light passing through a prism to be reflected and split into its different color components. Each visual color has a specific wavelength it measures (Figure 1.2). In the case of meat, the perceived color is a result of light reflecting off the surface of the meat and the interaction of light with the pigments and structures within the tissue. Light is made up of electromagnetic waves that are characterized by their wavelengths, measured in nanometers (nm). The visible spectrum, which can be perceived by the human eye, ranges from approximately 400 nm (violet) to 700 nm (red). When light strikes the surface of meat, the interaction between the light and the molecular structures of the meat determines the wavelengths of light that are absorbed or reflected (King et

al., 2023). The wavelengths that are reflected back to the human eye are perceived as the meat's color. Understanding the physics of color provides critical insights into how meat color is developed, perceived, and evaluated by both consumers and researchers.

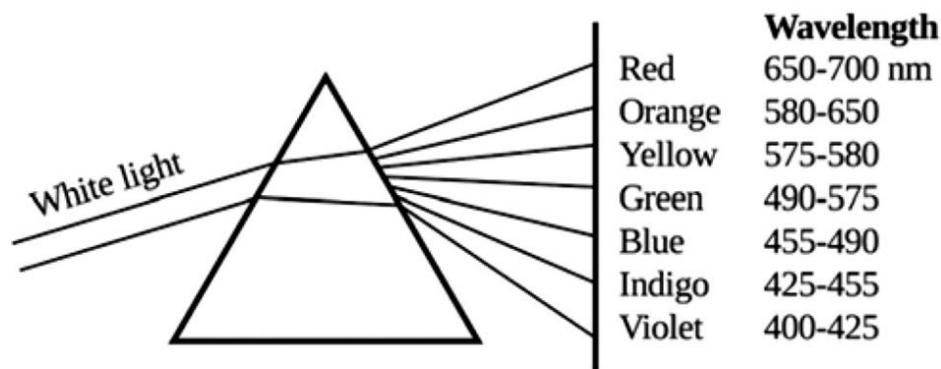


Figure 1.2 White light is passed through a prism and split into its different color components (King et al., 2023)

Human Perception of Color

When light reflected from the meat enters the eye, the brain interprets the combination of wavelengths as a specific color. Factors like ambient lighting, the surrounding environment, and individual differences in vision can influence how color is perceived. For example, fluorescent lighting in retail settings may enhance or distort the appearance of meat color compared to natural light. Inside the human eye, the cornea contains rod and cone cells called photoreceptors which are able to capture the light and transmit a signal to the optic nerve and brain which then translates that into a color (King et al., 2023). In a person with color blindness, their rod and cone cells are missing or malfunctioning which impacts how the person perceives the color.

Instrumental Color Analysis

In meat science, color is often measured using instruments such as spectrophotometers or colorimeters, which quantify the light reflected from the surface of the meat. Instrumental

measurements eliminate subjectivity and provide standardized data for evaluating meat color under different conditions. A spectrophotometer measures the reflectance or absorbance of light at specific wavelengths. It provides a spectral profile that can be used to calculate the state of myoglobin in the meat based on the wavelength (King et al., 2023). The selection of illuminants and observer is important to ensure uniform data collection for samples. The three illuminants that are the most common for meat research are illuminant A, C, and D⁶⁵ (King et al., 2023). Illuminant A is recommended for meat samples since it places emphasis on red wavelengths and can better evaluate differences in red. Illuminant C and D⁶⁵ are better suited for non-red objects as these place less emphasis on red wavelengths (King et al., 2023). The 10° observer is recommended for evaluation of meat products since it captures a wider portion of the surface sample. While it may seem minor, it is critical that data collected using different illuminants or observers are not compared with each other.

Colorimeters measure color based on the CIE Lab* color space. *L** measures lightness (0 = black, 100 = white), *a** measures red/green (-60 = green, 60 = red), and *b** measures yellow/blue (-60 = blue, 60 = yellow). These measurements can be used to calculate the hue and chroma which are also valuable when discussing meat color. Hue angle refers to the basic color or shade of an object, such as red, blue, yellow, or green. It is determined by the dominant wavelength of light reflected from the surface of the object. Chroma measures the intensity or saturation of a color, representing how vivid or dull the color appears. Figure 1.3 represents the CIE color space. Hue angle is shown by the angle around the sphere that the color is and chroma is represented by how far or close to the center of the sphere the color is.

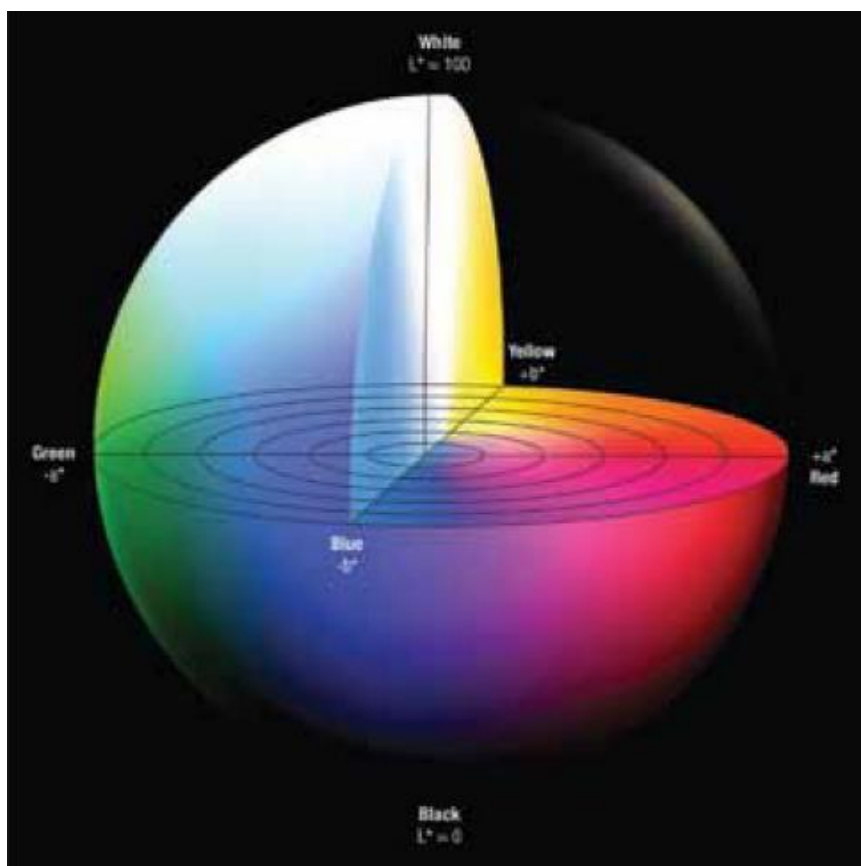


Figure 1.3 Graphic showing the CIE L*, a*, b* color space (King et al., 2023)

Visual Color Analysis

In addition to instrumental methods, trained sensory panels and untrained consumer sensory panels are used to evaluate meat color based on human perception. Visual evaluation of meat color is a critical aspect of color assessment, particularly for understanding consumer preferences. While instrumental methods provide objective data, visual evaluation captures the human perception of color, which plays a significant role in consumer purchasing decisions. Standardized guidelines for meat color measurement emphasize consistency in environmental conditions, panelist training, and evaluation techniques to ensure reliable and reproducible results (King et al., 2023).

Trained sensory panels are widely used for visual color evaluation in research and quality control. Panelists are rigorously trained to identify and score specific attributes of meat color,

such as brightness, redness, and uniformity. Standardized color scales are typically used to guide panelists in assigning numerical scores to meat samples. The AMSA guidelines for meat color measurement (King et al., 2023) emphasize that visual evaluation complements instrumental measurements, providing a holistic understanding of meat color. While instrumental methods quantify attributes like redness (a^* values), lightness (L^* values), and yellowness (b^* values), visual assessment captures the overall impression, which is closer to the consumer's experience. Despite its value, visual color evaluation has inherent challenges. Human visual perception is subjective and can be influenced by fatigue, lighting inconsistencies, or panelist bias (Koculak and Wierzchon, 2023).

Factors Influencing Meat Redness

Meat redness is complex and determined by biological, environmental, and technological factors. From intrinsic qualities like muscle myoglobin content to extrinsic influences such as packaging and lighting, understanding the determinants of meat redness is essential for optimizing product presentation and reducing waste in the meat industry.

Species

The inherent myoglobin concentration varies significantly across species, influencing the redness of muscle tissue. Myoglobin, a heme protein, plays a critical role in oxygen storage and transport in muscle fibers. Beef, among traditional commercial species, possesses the highest myoglobin concentration, resulting in its characteristic deep red color (Mancini and Hunt, 2005). Myoglobin concentration in beef can range from 4-8 mg/g, depending on factors like muscle activity and animal age. Pork, with an intermediate myoglobin level (1-3 mg/g), appears lighter red, while poultry muscle has minimal myoglobin (less than 1 mg/g), resulting in a pale, pinkish hue (Faustman and Cassens, 1990; Mancini and Hunt, 2005).

Muscle Variation

Muscle-to-muscle variation in redness is primarily attributed to differences in muscle fiber types and their metabolic profiles. Oxidative muscles, such as those used for sustained activities, are rich in mitochondria and require higher oxygen storage, leading to elevated myoglobin concentrations. For instance, the *psaos major* a more oxidative muscle, has a higher myoglobin concentration and appears redder compared to glycolytic muscles like the *longissimus dorsi* (Bendall and Wismer-Pedersen, 1962). Glycolytic muscles, which are adapted for short bursts of activity, have fewer mitochondria and thus lower myoglobin levels, resulting in a paler appearance. The fiber type composition—predominantly Type I (slow-twitch oxidative) or Type II (fast-twitch glycolytic)—directly correlates with myoglobin levels and thus meat redness (Aberle et al., 2001).

Animal Age

Animal age is a critical determinant of myoglobin concentration in muscle tissue. Younger animals, such as veal calves, exhibit significantly lighter muscle color due to low myoglobin levels. In contrast, as animals mature, their muscle tissue accumulates myoglobin, deepening the redness (Arthaud et al., 1977). This increase is associated with the prolonged need for oxygen storage in the muscles of older animals. For example, the muscle color of beef from mature cows is substantially darker compared to that of veal. The developmental increase in myoglobin content reflects both changes in muscle metabolism and activity levels over the animal's lifespan (Cho et al., 2015).

Water Holding Capacity

Water-holding capacity (WHC) significantly influences the visual appeal of meat by affecting light reflection and refraction. Meat with high WHC retains intracellular and

extracellular water, leading to a tighter microstructure and darker in color (Ramanathan et al., 2020). Conversely, meat with low WHC appears pale and exudative due to the scattering of light caused by loose, water-drained muscle fibers. Poor WHC is often associated with meat quality defects such as PSE (pale, soft, exudative) meat, which can result from pre-slaughter stress (Huff-Lonergan and Lonergan, 2005). The relationship between WHC and redness highlights the importance of both pre-slaughter handling and postmortem processing in maintaining meat quality.

Dark Cutter

The defect known as dark cutter results from prolonged stress before slaughter, leading to depleted glycogen reserves in muscle tissue. After exsanguination, the body shifts to use the glycogen stored in the muscle to produce ATP through glycolysis. As a byproduct of glycolysis, lactate and a hydrogen ion are produced and the buildup of these in the muscle results in the pH drop (England et al., 2013). In dark cutters, postmortem glycolysis is compromised due to the decreased glycogen reserves, causing insufficient lactate production and a higher ultimate pH (>6.0). The elevated pH reduces light scattering, giving the meat a darker appearance. This defect is particularly common in cattle subjected to chronic stress, such as long transport or adverse environmental conditions. Beyond color, dark cutters also suffer from reduced shelf life and altered flavor profiles due to higher pH (Wulf et al., 2002). Strategies to mitigate dark cutting include stress management and optimized pre-slaughter handling practices.

PSE

The defect known for pale, soft, and exudative (PSE) is predominantly observed in pork and results from acute stress immediately prior to slaughter. Stress triggers a rapid postmortem pH decline (below 5.4) while the carcass is still warm, leading to protein denaturation and

impaired WHC. The resulting meat exhibits a pale color, soft texture, and exudative surface. The phenomenon is linked to the genetic predisposition of certain breeds, such as the Halothane gene in pigs, and poor pre-slaughter handling (Barbut et al., 2008). Preventing PSE requires minimizing acute stress through careful handling, appropriate genetic selection, and rapid chilling of carcasses postmortem (Barbut et al., 2008).

Factors Influencing Meat Discoloration

Meat discoloration is largely responsible for meat waste in the meat industry. According to Ramanathan et al. (2022) which detailed the impacts of meat waste, on average, 2.55% of fresh beef in retail is wasted and discarded due to discoloration, which equates to approximately 194.7 million kilograms. Because of the economic and environmental impact of meat waste, it is crucial for the meat industry to minimize discoloration and maximize shelf life as much as possible. There are many factors influencing the discoloration of meat including the type of packaging used to store the meat product, type of lighting used in the retail case, microbial load, and metmyoglobin reducing activity (MRA).

Packaging Type

Packaging plays a large role in the rate of meat discoloration. In retail, most steaks and roasts are presented in a foam tray with a soaker pad, and are overwrapped with polyvinyl chloride (PVC) film (Nassau et al., 2012). This packaging type is oxygen permeable, allowing for bright cherry-red beef which consumers prefer and have a higher probability to purchase (Lybarger et al., 2023). However, due to the oxygen rich environment, there is ample opportunity for protein and lipid oxidation which can result in discoloration and off flavor formation (Alderton et al., 2003). When the heme iron in myoglobin oxidizes and becomes ferric (Fe^{+3})

meat will turn brown quickly and consumers will be less willing to purchase these products (Lybarger et al., 2023).

One alternative packaging method is vacuum packaging which will keep the iron in a reduced or ferrous (Fe^{2+}) state for an extended period of time and delay oxidation. Since there is little to no access to oxygen to bind to myoglobin, meat will stay in deoxymyoglobin for a longer period of time, extending the shelf life of the product. When utilizing vacuum packaging, meat will not turn brown as rapidly as with oxygen rich packaging types. While vacuum packaging could extend the shelf life of meat, Lynch et al. (1985) found that consumers were more willing to purchase traditionally overwrapped beef which displayed predominantly oxymyoglobin, as compared to vacuum packaged beef which displayed predominantly deoxymyoglobin.

Another packaging option is modified atmosphere packaging (MAP) which is a rigid packaging type where various gases such as nitrogen, oxygen, carbon dioxide, etc. have been flushed into the packaging. It is not oxygen permeable and myoglobin only has access to the gas mixture that is present in the packaging. A study conducted by Hearn et al. (2021) utilized raw chicken patties in three packaging types: PVC overwrap, High Oxygen MAP (HiOx-MAP), and Carbon Monoxide MAP (CO-MAP). The patties were displayed for four days in simulated retail display. The results showed that after four days of storage, CO-MAP and HiOx-MAP had higher a^* values than traditional PVC overwrap. Additionally, when evaluated by their trained panel, PVC had the highest discoloration score, HiOx-MAP had a lower discoloration score than PVC, and CO-MAP had the lowest discoloration score after four days of storage (Hearn et al., 2021).

Another study conducted by Rogers et al. (2014) evaluated ground beef patties in five different packaging types including: Hi-Ox MAP, Lo-Ox MAP, CO-MAP, vacuum packaging, and traditional overwrap. These treatments were displayed for 20 days in simulated retail

display. Trained panelists found that CO-MAP had the best trained panel lean color score and discoloration score for the duration of the study. Additionally, after day 6, vacuum had the second most desirable trained panel lean color and discoloration score. Furthermore, after day 5, CO-MAP was the reddest treatment. Moreover, when evaluated by a consumer panel, CO-MAP was the most likely to be purchased, with vacuum being next after day 5.

While CO-MAP is extremely beneficial to maintaining a desirable lean color, Grebitus et al. (2013) found that consumers' willingness to purchase decreased when they were provided information on the use of MAP and CO for those samples indicating that consumers likely do not prefer to purchase products packed with carbon monoxide.

Light Source

Another factor influencing discoloration of meat is the type of lighting the meat is under. Light emitting diode or LED lights can emit light at very specific wavelengths, resulting in the avoidance of damaging ultraviolet light. However, less than 1% of display cases utilize LED lighting as fluorescent lighting is the most common at retail (Cooper et al., 2016). In a study conducted by Steele et al. (2016) the impact of LED and fluorescent lighting on shelf life of various muscles was evaluated. They found that pork loin chops under LED had higher L^* and b^* than fluorescent. Additionally, beef *semimembranosus* under LED had higher a^* and b^* than under fluorescent (Steele et al., 2016).

Lipid Oxidation

Lipid oxidation occurs in three steps: initiation, propagation, and termination (Faustman et al., 2010). Aldehydes can be formed from lipid oxidation and can bind to myoglobin, which decreases color stability. Lipid oxidation is very commonly measured with the thiobarbituric acid reactive substances (TBARS) assay. TBARS measures the concentration of malondialdehyde

(MDA) in samples as a measure of oxidation. While lipid oxidation is not a direct indicator of meat discoloration, numerous studies show a correlation between lipid oxidation and meat discoloration (Zakrys et al., 2008; Faustman et al., 2010; Rogers et al., 2014). The susceptibility of meat to lipid oxidation is largely determined by its fatty acid composition and intrinsic antioxidant capacity. Meat rich in polyunsaturated fatty acids (PUFAs) is particularly prone to lipid oxidation, which in turn accelerates myoglobin oxidation and meat discoloration (Faustman et al., 2010). External factors such as exposure to light, high temperatures, and oxygen further exacerbate these oxidative processes, highlighting the importance of optimized packaging and storage conditions. Zakrys et al. (2008) demonstrated that modified atmosphere packaging with reduced oxygen concentrations can effectively limit lipid oxidation and preserve the desirable red color of meat, whereas packaging methods with high oxygen exposure increase lipid oxidation, and in turn discoloration and off flavor formation.

Color Stability

Color stability can be influenced by numerous factors including myoglobin and lipid oxidation. Meat is able to change its color based on its environment and metmyoglobin can even be reduced back to deoxymyoglobin (King et al., 2023). Metmyoglobin reducing activity (MRA) is the ability to reduce metmyoglobin and is important to maintain a desirable bright cherry-red color and prolong the storage time of meat (Ramanathan and Mancini, 2018). However, it requires reducing equivalents such as NADH, which are typically a limited product in meat, so any NADH that is produced postmortem will likely positively impacts the color stability (Mancini and Ramanathan, 2020). As meat ages, the ability to reduce metmyoglobin decreases due to the depletion of reducing agents (Peckham et al., 2019). Hagler et al. (1979) reported that a metmyoglobin reductase in beef heart required ferrocyanide and NADH to function. Some

muscles are more color stable and others are more color labile. Additionally, as time postmortem increases, MRA decreases. A study conducted by Wang et al. (2021) evaluated the *longissimus lumborum* ranging from 0, 7, 14, 21 days age time in a vacuum bag and 0, 3, and 6 days of storage in aerobic packaging. They found that as both age time and storage time increased, the MRA and color stability increased as well as decreased a^* values.

Mitochondria

Mitochondria also play a vital role in meat color development and stability (Ramanathan and Mancini, 2018). Postmortem, mitochondria continue to metabolize oxygen (Richards et al., 2022). Utilization of oxygen postmortem helps to keep muscle in the deoxymyoglobin state by limiting oxygen that is available to myoglobin (Richards et al., 2022). Muscles that are more oxidative and have higher mitochondria concentrations are more color stable because of the oxygen utilization by mitochondria, whereas muscles that are more glycolytic are less color stable. Richards et al. (2022) stated that mitochondria activity is impacted by pH, time, temperature, and ingredients added to the meat product. At a higher pH, mitochondrial activity is increased, giving meat a darker color due to the lack of oxygen (Ramanathan and Mancini, 2018). This is partially responsible for dark cutters. At a lower pH, the opposite is true, and mitochondrial activity is reduced (Ramanathan and Mancini, 2018). Additionally, mitochondrial activity decreased as time postmortem increased, and temperature decreased (Richards et al., 2022)

Microbiological Impact

Spoilage microorganisms can also play a role in discoloration of meat. A study conducted by Smith et al. (2024), beef *longissimus lumborum* (LL) and *psoas major* (PM) muscles were evaluated to explore how color stability may be impacted by microflora. They found that after

day two of display, PM had more surface discoloration than LL according to trained panelists. Additionally, after the first day of display, PM had a large decrease of MRA, and was lower than LL for all days of display, likely explaining the discoloration differences found. (Smith et al., 2024) The ability for myoglobin to be reduced from the ferric state back to the ferrous state through MRA is one of the main ways that meat can maintain a bright cherry-red color. Wang et al. (2021) found that MRA decreased as aging increased, however, once steaks reached 21-day age, MRA started to increase.

Impact of Meat Color on Consumer Purchasing Decisions

Consumer preferences for meat are multifaceted, influenced by numerous factors including price, cut, quality grade, color, seasonality, and packaging (Harr et al., 2022). Among these, color is consistently identified as a critical determinant of consumer purchase behavior, particularly in beef (Olson et al., 2019; Farmer et al., 2022; Harr et al., 2022). Color serves as an immediate visual indicator of freshness and quality, which influences both consumer perception and purchasing decisions. Understanding the impact of color and discoloration on consumer preferences is essential for the meat industry to develop strategies that enhance product appeal and reduce waste.

Meat discoloration is influenced by packaging type, color stability, microbial load, and lighting conditions. These factors interplay to affect consumer perceptions of freshness and quality. For instance, modified atmosphere packaging (MAP) can enhance the color stability of meat, maintaining the bright red appearance that consumers associate with freshness. However, improper storage or display lighting can accelerate the oxidation of myoglobin to metmyoglobin, leading to a brown discoloration that deters consumers (Faustman et al., 2010).

Numerous studies have been conducted to define thresholds for consumer acceptance of discolored meat. However, many earlier studies have design limitations that restrict their applicability. For example, Hood and Riordan (1973) conducted one of the earliest in-store trials to evaluate consumer preferences for beef steaks with varying degrees of discoloration. They used a spectrophotometer to collect instrumental color data and displayed steaks with discoloration levels ranging from 5% to 33%. Their findings indicated significant consumer discrimination against discolored steaks, particularly when discolored meat was displayed alongside bright red meat. While this study provided foundational insights, it did not encompass the full spectrum of discoloration, limiting its applicability to real-world scenarios.

Holman et al. (2017) attempted to address some of these limitations by using images and an online survey to determine consumer purchase thresholds for discolored steaks. Photographed steaks were accompanied by instrumental color data, and participants were provided with explicit instructions to standardize screen settings. Their study found that the a^* value was the most reliable predictor of consumer acceptance. However, the inability to verify whether participants adhered to the prescribed screen settings introduced potential variance and the opportunity for skewed data.

Carpenter et al. (2001) investigated the impact of consumer preferences for beef color and packaging on eating satisfaction. Their study examined various beef packaging methods including: MAP, vacuum packaging, and PVC and their influence on purchase intent and taste perception. Consumers were asked to visually evaluate beef samples with different colors (red, purple, and brown) and packaging types before taste evaluation of samples. The findings revealed that consumers consistently rated bright cherry-red beef and PVC packaging as the most appealing, correlating strongly with purchase intent. However, these visual preferences did not

translate to differences in eating satisfaction, as taste evaluations of the identical samples showed no significant variation. This disconnect highlights that while visual cues like color and packaging influence purchasing decisions, they do not affect sensory satisfaction such as tenderness, juiciness, or flavor. The study shows the importance of educating consumers on the limited relationship between appearance and eating quality to reduce reliance on superficial attributes during purchasing decisions.

The spillover effect is where non-discolored steaks are perceived more positively when displayed near discolored steaks (Feuz et al. 2020). This adds another layer of complexity to understanding consumer behavior. Lybarger et al. (2023) conducted a two-phase study at Kansas State University to evaluate consumer purchase thresholds for ground beef. Phase 1 displayed ground beef packages with nine different display dates, representing a wide range of discoloration levels. Phase 2 used ground beef packages from the same display date, minimizing discoloration differences. The study found that consumers preferred ground beef with higher a^* values, lower calculated metmyoglobin percentages, and lower trained panel discoloration scores. By incorporating the spillover effect into their analysis, Lybarger et al. (2023) provided a more nuanced understanding of consumer preferences. From this study, it is apparent that consumer decisions are not made in isolation but are heavily influenced by the visual context provided by adjacent products.

Despite the insights provided by these studies, significant gaps remain in understanding consumer purchase thresholds for discoloration, particularly in beef steaks. Most studies have focused on ground beef or utilized controlled experimental designs that may not fully replicate retail conditions.

Economic and Environmental Impact of Meat Discoloration

Meat discoloration has significant environmental and economic implications, primarily due to its contribution to food waste. A study conducted by Ramanathan et al. (2022) found that approximately 2.55% of meat at the retail level is discarded due to discoloration, which is the equivalent of approximately 780,000 animals. Additionally, wasted meat also results in other wasted resources. The same study also found that discarded beef resulted in 968.84 million mega joules of energy wasted, 2,395.11 billion liters of water wasted, and 40.76 million tons of CO₂ equivalent wasted (Ramanathan et al., 2022). In a society where that cares very deeply about the environment as well as feeding the growing population, it is important to find ways to decrease waste. Decreasing meat waste by just 1%, would save 23.95 billion liters of water, 96.88 billion mega joules of energy, and 0.40 million tons of CO₂ equivalent (Ramanathan et al., 2022).

Globally, meat is among the most resource-intensive foods to produce, requiring substantial inputs of water, feed, and energy. When discolored meat is rejected by consumers and discarded, these resources are effectively wasted, exacerbating environmental challenges such as water scarcity, greenhouse gas emissions, and land degradation (Gustavsson et al., 2011). The environmental burden of producing meat that is not consumed underscores the importance of reducing waste at all stages of the supply chain.

Economically, meat discoloration also imposes considerable costs on retailers and producers. Retailers often experience reduced profit margins due to markdowns on discolored meat that remains unsold. Additionally, the disposal of unsold meat involves logistical and waste management costs. For producers, discoloration can lead to decreased demand and reduced prices for their products, ultimately affecting their profitability. Ramanathan et al. (2022) found that \$3.73 billion is lost annually due to discoloration alone as shown in Figure 1.4.

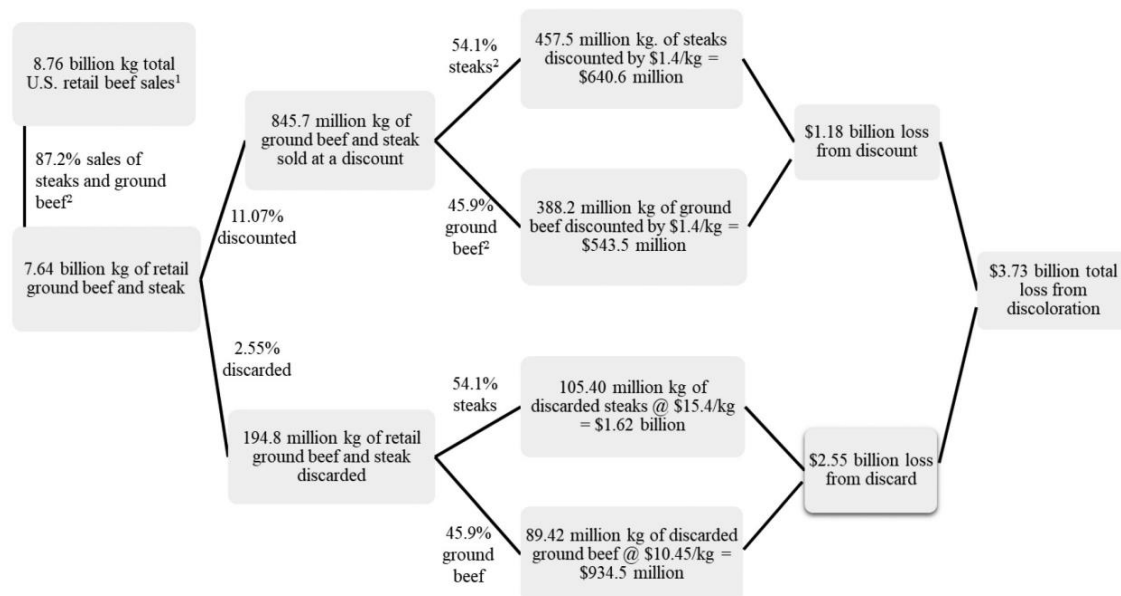


Figure 1.4 Approximate economic impact of discolored ground beef and steaks on the beef industry (Ramanathan et al., 2022)

Efforts to mitigate the environmental and economic impacts of meat discoloration include the development of advanced packaging technologies, such as vacuum skin packaging and active packaging, which can extend shelf life and improve color stability. Consumer education on the safety and edibility of slightly discolored meat may also help reduce waste and associated costs. By addressing the challenges posed by discoloration, the meat industry can contribute to more sustainable practices and improve economic efficiency.

Conclusion

Meat color is one of the factors most influencing consumer purchasing decisions. Meat color is determined largely by what ligand is present at the sixth coordination site as well as the state of the heme iron. However, there are numerous factors including: specie, animal age, muscle fiber type that impact the redness of meat. Additionally, many factors impact how quickly meat discolors. This includes packaging type, lipid oxidation in the meat, and inherent color stability of the meat. Consumers prefer non-discolored meat over brown discolored meat,

and they view discoloration as a negative and are less willing to purchase discolored products.

Discoloration results in a large amount of waste for the beef industry, not only monetary, but also energy, water, and greenhouse gas emissions. Research has been conducted to attempt to quantify how discoloration impacts consumer purchasing, however more research needs to be done to have a deeper understanding of consumer purchase.

Chapter 2 - Determination of Consumer Purchase Thresholds for Discoloration of Beef Steaks

Introduction

Meat color is one of the most important purchasing motivators for beef consumers (Olson et al., 2019; Farmer et al., 2022; Harr et al., 2022). Annually, 2.2 billion pounds of beef are discarded due to discoloration at retail (Ramanathan et al., 2022). Discoloration alone accounts for about \$3.73 billion in economic loss yearly in addition to other wasted resources such as water and energy. Previous studies have tried to establish a consumer purchase threshold for discoloration of steaks. However, much of the previous work has been conducted with an online survey, which does not ensure uniform evaluation by consumers or represent an actual in-store experience (Holman et al., 2016; Holman et al., 2017). Other work with this objective was completed over 50 years ago and did not account for the full range of discoloration (Hood and Riordan, 1973). Understanding consumer purchase thresholds for steak discoloration can help optimize retail practices, reduce waste, and improve economic outcomes for the beef industry

A study conducted at Kansas State University worked to determine consumer purchase thresholds for discoloration of ground beef in retail display and established highly predictive models for consumer purchasing likelihood based on numerous objective factors including redness and discoloration (Lybarger et al., 2023). However, ground beef discolors in an “all at once” manner (Lybarger et al., 2023), whereas steaks develop brown spots which expand during discoloration. Thus, the predictive models established by Lybarger et al. (2023) are likely not adequate predictors for steaks. It was therefore the objective of this study to evaluate and determine similar purchasing tendencies and develop predictive models for consumer purchase

likelihood based on objective measures of steak redness and discoloration to identify thresholds for consumer purchase of beef strip loin steaks.

Materials and Methods

The approval for all protocols utilizing human subjects for sensory evaluation was completed by the Kansas State University (KSU) Institutional Review Board (IRB #7440.8, October 2022).

The study was conducted in two phases with Phase 1 allowing consumers to evaluate steaks ranging from 0 - 14 days of display simultaneously, while in Phase 2 consumers only evaluated steaks from a single display day, with each being relatively similar in terms of redness and discoloration. Each phase was conducted at separate periods of time about four months apart.

Sample display

Samples were acquired from a commercial beef processor as case-ready packages in mother-bags and transported to the Kansas State University Meat Laboratory under refrigeration conditions (2 - 4° C). Samples were delivered in mother-bags of six packages. Samples were kept in their mother-bags in the absence of light under refrigeration until the designated display day.

During Phase 1, five of the six packages per mother-bag were allocated randomly to one of five retail case sections. The last package in the mother-bag was allocated to pH and proximate analysis. Three mother-bags were opened every other day to allow for variation in sample discoloration. Since the steak packages contained 2 steaks each, one steak per package was covered with a piece of matte black tape so only one steak was visible. If one of the steaks had the *gluteus medius* present, that steak was covered, otherwise the steak for display was randomly selected. Pilot work had indicated that when packaged two in the same package, steaks

would discolor and very different rates. Thus, covering one steak was done to ensure sensory panelists and instrumental data was all consistently collected from the same steak. On their designated display day, samples were placed in 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). Packages were rotated within each section daily.

During Phase 2, all six packages per mother-bag were allocated to display: two packages per mother-bag in one of three retail case sections. One steak per package was covered with a piece of matte black tape, leaving only one steak visible, similar to Phase 1. In both phases of the study there was no pricing or weight information available to the consumers on a label. Packages were placed in their respective case sections on the morning of their display day, approximately 6 hours prior to sensory and objective evaluations.

Objective color measurement

Objective L^* , a^* , and b^* and spectral data were collected using a HunterLab MiniScan Spectrophotometer (Illuminant A, 10° observer, 2.54 cm aperture; HunterLab, Reston, VA). Three readings were collected from the surface of the package, being cognizant of avoiding the external fat. The readings were averaged then used to calculate chroma, hue angle, and percent metmyoglobin and oxymyoglobin according to the American Meat Science Association (AMSA) Guidelines for Meat Color Measurement (King et al., 2023).

Trained sensory panel evaluation

For both phases, panelists were trained according to the AMSA Guidelines for Meat Color Measurement (King et al., 2023). Panelists were screened for color blindness with the Farnsworth Munsell 100 Hue Color Vision Test (Munsell, Grand Rapids, MI). Trained sensory

panelists ($N = 12$ -20 for Phase 1 and $N = 14$ -23 for Phase 2) were required to attend at least three training sessions to familiarize themselves with the scales used. Panelists were shown multiple packages and provided with reference pictures of varying discoloration, redness, and fat color during the training. Redness was assessed using the references provided by Lybarger et al. (2023). On panel dates, all samples were evaluated on 100-point line scales for percent discoloration (0% - 100%) as shown in Figure 2.8, redness score - with 0 being extremely dark red and 100 being bright cherry-red, and fat color score - with 0 being brownish-white and 100 being bright white as shown in Figure 2.7. Sensory panelists completed their evaluation using an electronic ballot (Version 2417833; Qualtrics Software, Provo, UT) on tablets (Lenovo TB-8505F, Morrisville, NC).

Consumer sensory panel evaluation

For both phases, consumers were recruited from the Manhattan, Kansas community and surrounding areas and monetarily compensated for their participation. In Phase 1 consumer panelists ($N = 200$) evaluated 24 samples varying in discoloration, with 3 samples from each day of display ranging from 0 to 14 days. In Phase 2, consumer panelists ($N = 176$) evaluated 20 samples all from the same day of display, with similar amounts of discoloration. Samples were presented to consumers in a random order. For each sample, consumers were asked to designate an overall appearance score on a 100-point continuous line scale with 0 being extremely undesirable and 100 being extremely desirable. They also were asked if they would purchase the sample at retail (yes/no). If they selected yes, they would move on to the next sample, however, if they selected no, they would be shown an additional question asking if they would purchase the sample if it was discounted (yes/no). Consumers were given electronic tablets (Lenovo TB-

8505F, Morrisville, NC) to complete the surveys (Version 2417833; Qualtrics Software, Provo, UT).

Proximate and pH analysis

Thirteen steaks from phase 1 and twelve steaks from phase two were randomly selected for analysis. Samples were trimmed of external fat and individually ground using a small table-top grinder (STX International Turbo Force II, Lincoln, NE). Samples were then packed into petri dishes, ensuring there were no air bubbles were present and analyzed using the FOSS FoodScan (FOSS Analytical, Hillerød, Denmark). Proximate analysis (moisture, protein, and fat) was recorded. Five grams of each sample in duplicate were weighed into 100 ml beakers. 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, Hampton, NH) and the pH of each sample was measured with a pH meter (Mettler Toledo, Columbus, OH).

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. 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

The demographics of the consumers who participated in the study are presented in Table 2.1. The consumers who participated in the current study were split between males (53.1%, 57.4%) and females (46.9%; 42.6%). Most (70.9%; 79%) of the consumers were from a multi-person household. Additionally, consumers were split between those greater than 30 years old (30.1%; 45.5%) and those less than 30 (69.9%; 54.5%). The consumers were primarily Caucasian (83.2%; 85.2%) and educated, with over 80% in each phase having at least some college education. The majority of consumers (64.3%; 58.0%) consumed beef at least 4 times a week and purchased beef 1 to 3 times a week (41.8%; 40.3%). Overall, the demographic profile of the consumers used in the current study is similar to previous works conducted in Manhattan, KS (Farmer et al., 2022; Harr et al., 2022; Lybarger et al., 2023).

Logistic regression models

The average pH of steaks in this study was 5.63 (SD = 0.06). Proximate analysis identified the average moisture of samples as 69.21% (SD = 2.44), protein as 20.25% (SD = 1.03), and fat as 8.66% (SD = 3.14).

Table 2.2 summarizes the descriptive statistics for the dependent variables used in the study for the development of the predictive models. Overall, in both phases, a wide range of all variables were accounted for. This was required for the calculation of robust regression models for the prediction of consumer purchase intent (yes/no). In both phases of the study, fresh, bright, cherry-red colored steaks and steaks that were close to or were completely discolored were evaluated by consumers.

The developed regression equations for Phase 1 (Table 2.3) and Phase 2 (Table 2.4) indicated that most of the objective measures evaluated were predictors ($P < 0.05$) of consumer purchase intent in both full-priced and discounted scenarios. However, in Phase 1, the developed equations accounted for only a moderate amount of the variation in consumer purchase intent (R^2 values of 0.30 to 0.78) in fully-priced samples and less variation (R^2 values of 0.27 to 0.72) in the discounted samples. Still, the models were able to correctly classify more than 73% of fully-priced and more than 66% of discounted samples as would / would not purchase by consumers. In Phase 1, a^* value was among the best objective measurements evaluated with R^2 values of 0.64 and 0.56 for full-priced and discounted models, respectively (Figure 2.1). Calculated chroma was determined from spectral data and resulted in high R^2 values of 0.56 in full-priced models and 0.58 in discounted models. Also in Phase 1, trained sensory panel discoloration score was a noteworthy predictor, with R^2 values of 0.56 in the full-priced model, and 0.47 in the discounted model (Figure 2.3).

For Phase 2 of the study, the models were not as robust or predictive as the models in Phase 1. For product sold at full-price, the models accounted for only 11 – 57% of the variation in consumer purchasing intent, and the models were only able to classify 61 – 73% of the samples correctly as would / would not purchase. Phase 2 presented similar results among the objectives measurements as observed in Phase 1. Values for a^* continued to be one of the strongest measurements, with R^2 values of 0.25 and 0.28 for full-priced and discounted models, respectively (Figure 2.2). Calculated chroma models also resulted in moderate R^2 values of 0.25 and 0.28 for full-priced and discounted models, respectively. The trained sensory panel discoloration score models (Figure 2.4) had R^2 values of 0.20 in the full priced models and 0.21

in the discounted models. Overall, the Phase 2 models accounted for less variation among the variables than the Phase 1 models.

Tables 2.5 and 2.6 present the various thresholds for consumer purchase intent from the logistic regression models. Of particular note are the thresholds related to a^* value and trained sensory panel discoloration score. Figures 2.1 – 2.4 show the relationship between these variables for both the fully-priced and discounted scenarios for both Phases of the study. The trained sensory panel discoloration score was a visual measure of the amount of metmyoglobin or browning on the surface of the steaks. Both variables were among the best evaluated for both phases of the current study. In Phase 1, a^* values of 25.3, 29.9, and 34.4 were associated with a 50, 75, and 90% chance of a consumer purchasing the product. When discounted, these numbers shifted to 20.3, 25.8, and 31.3 for the same likelihoods, indicating consumers were more willing to purchase steaks that were less red when the product was discounted. For Phase 2 of the study, a^* values of 23.6 and 34.2 were associated with a 50 and 75% chance of consumer purchase, and shifted to 15.9 and 25.5 when discounted. For trained sensory panel discoloration score, in Phase 1, only 12% discoloration was associated with a 50% chance of a consumer purchasing the product. If it was discounted, consumers were more tolerant of discoloration, with 35.8% and 8.3% discoloration associated with a 50% and 75% chance of purchase. For Phase 2, fully-priced samples that had 22.7% discoloration had a 50% chance of purchase, which increased to 56.8% for discounted samples.

Pearson correlations

Table 2.7 presents the Pearson correlation coefficients among the objective measures used in the study. Many of the variables were closely associated ($P < 0.05$) in both phases of the study. a^* value, as expected, was highly associated with trained sensory panel redness scores ($r =$

0.90) and consumer overall appearance scores ($r = 0.87$) in Phase 1 of the study. In Phase 2, a^* 's relationship to trained sensory panels was shown to be just as strong ($r = 0.95$), but was much weaker ($r = 0.69$) with consumer overall acceptance scores, further highlighting the diminished relationship between redness and consumer willingness to purchase when all steaks were of the same display period in the retail case. Other measures that were closely correlated to consumer overall liking in Phase 1 included b^* ($r = 0.85$), chroma ($r = 0.88$), trained sensory panel redness score ($r = 0.89$), and both lean discoloration scores ($r = -0.76$), and fat color scores ($r = 0.83$). For Phase 2, each of these variables was also related to consumer overall appearance score, but showed much weaker ($r = 0.67, 0.69, 0.64, -0.61, 0.67$) relationships than in Phase 1.

Linear regression equations

Table 2.8 presents linear regression equations for predicting consumer overall appearance rating scores using the various objective measures, and Figures 2.5 and 2.6 show the regressions for using a^* value and trained sensory panel discoloration score for predicting consumer overall rating. All of the objective measures were able to predict consumer overall rating ($P < 0.05$) and explained 32 – 80% of the variation in the consumer scores for Phase 1 and 22 – 48% of the variation in Phase 2. Linear regression equations predicting consumer overall appearance ratings with objective measures also resulted in significant ($P < 0.01$) models, with R^2 values of 0.32 to 0.80 in Phase 1 (Table 2.8) and R^2 values of 0.22 to 0.28 in Phase 2 . 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 2.5) and trained sensory panel discoloration score (Figure 2.6) in their prediction of consumer willingness to purchase. The linear regression equations for a^* resulted in robust R^2 values of 0.76 and 0.48 for Phases 1 and

2, respectively. The linear regression equation generated in Phase 1 accounted for 76% of the variation within the data points collected. Moreover, Figure 2.8 demonstrates that as a^* (sample redness) increases there is a linear increase in consumer overall appearance ratings. The linear regression equations for trained panel discoloration score produced R^2 values of 0.59 and 0.37 for Phases 1 and 2, respectively (Figure 2.6). The linear regression equation generated in Phase 1 accounted for 59% of the variation within the data. Figure 2.6 demonstrates that as the trained sensory panel discoloration score increases (percent discoloration), there is an equivalent decrease in consumer overall appearance ratings.

Discussion

In both the current study and the Lybarger et al. (2023) study, a^* was one of the best predictors for consumer purchase intent. For steaks, consumers required higher a^* values for the same level of purchase likelihood compared to ground beef. For example, fully-priced steaks required a 25.3 and 29.9 a^* value for a 50 and 75% likelihood of purchase, whereas for ground beef, only a 21.6 and 24.9 were needed for the same level of purchase likelihood (Lybarger et al., 2023). The same was observed in discounted samples, with an a^* of 31.3 associated with a 90% likelihood of purchase in the steak study, but only an a^* value of 25.0 was needed for a 90% chance of purchase in ground beef. As for discoloration, in the Lybarger et al. (2023) ground beef study, consumers had a 50% chance of purchasing samples with close to 38% discoloration. However, in the current study, only 12% discoloration in steaks reduced the consumer purchase intent to 50%. When comparing the ground beef results to the current study's results for steaks, it is obvious that consumers were more tolerant of discoloration and poor color characteristics in the ground beef than they were in the steak samples.

One of the largest contrasts between the results for the steaks and the similar ground beef study by Lybarger et al. (2023) was in the predictive power of the logistic regression models. Lybarger's models were very robust and highly effective at identifying points at which ground beef failed to meet consumer expectations for purchase. The results of the current study did not produce results that were as clear. Undoubtedly this is a result of the differences in the products evaluated in each study. As discussed previously, ground beef and steaks discolor throughout retail display in very different manners, with ground beef uniformly discoloring and steaks forming discolored spots which eventually expand to the whole cut surface. It is clear that this difference in discoloration has a significant impact on how consumers assess these products. But, an even larger likely reason for the difference is related to the price-point of the meat products. Ground beef is the most inexpensive beef product available for consumers, whereas steaks are often viewed as a premium product and are sold at a price-point which is reflective of such. Thus, consumers' willingness to purchase steaks that had even minor "problems" was less than with ground beef. Consumers viewed the higher price and premium nature of steaks to require the products to more fully and completely meet their expectations as opposed to be willing to overlook some of the same deficiencies within the cheaper ground beef products. This highlights the need for ensuring that steaks sold at retail are maintained in an ideal condition, with essentially no discoloration for consumers to purchase, as only small amounts of discoloration and poor redness (darkened) will prevent consumers from purchasing the product, even if sold at discounted prices.

When compared to the ground beef study conducted by Lybarger et al. (2023), the models in the current work were not as predictive. In their study, when samples representing a range of discoloration were evaluated by consumers, models for fully-priced samples accounted

for greater than 77% of the variation in consumer willingness to purchase, with the some of the best models, such as the one using a^* value as a predictor, accounting for over 80% (Lybarger et al., 2023). Additionally, their models almost all classified greater than 90% of samples correctly related to consumer would / would not purchase and had higher C-statistic values, indicative of models with better fit for the binomial outcomes. Similar to the current work, Lybarger's models for their discounted models were less robust and predictive than their full-priced models, but still accounted for more than 77% of the variation in consumer purchase intent compared to the 40 – 60% of the variation accounted for by the same variables in the current work.

Additionally, the Lybarger study also had models that were less predicative when all samples in the case were of the same day of retail display. Their models accounted for about half as much variation in their Phase 2 vs Phase 1, but still accounted for about 40% of the variation in consumer purchase intent. In the current work, these models accounted for a much lower percentage (< 25% for most variables). Moreover, these models had a very low predictive power for both full-priced and discounted samples as evidenced by the low amount of variation accounted for by the models (R^2), the relatively low percentage of correctly classified samples, and the low C-statistic values. Both studies did highlight the same theme – when consumers evaluate samples that are more similar than different, they inherently use different criteria and become more selective than when there is abundant variation. Thus, the predictors that are the most predictive in Phase 1 – redness and discoloration – become less when the variation is minimal, thus weakening the predictive strength of each. This is noteworthy as when consumers purchase meat from the meat case at retail, it is almost always in a scenario where there is only minimal variation, as much of the displayed meat would have been in the case for a similar display period. Taken together, this indicates that predicting consumer purchase of retail meat

products in a representative retail setting is likely more variable and more difficult to predict than when consumers are presented with a range of variation in color and discoloration traits simultaneously.

Moreover, the current results also demonstrate the challenges with attempting to quantify consumer willingness to purchase steaks at retail. All of the samples used in the current study were from the same production lot, of the same quality grade (upper 2/3 Choice), and packaged identically from the same commercial supplier. Despite these attempts to standardize all samples, slight differences in marbling amount, external trim level, loineye size, packaging variation, etc. that were not quantified in the study design may have had an impact on consumer willingness to purchase samples. This is clearly shown in samples with 0% discoloration, of which in Phase 1 of the study only had a 70% chance of being purchased at full-price and in Phase 2 of the study had only a 64% chance of being purchased. These probabilities were increased to only 81% for Phase 1 and 80% for Phase 2 if products were discounted. This means that there were samples that when displayed fresh, at 0 days of retail display that consumers simply identified that they would not purchase. It is unclear as to what the reasons were for these responses, as it was not captured clearly in any of the objective measures evaluated, but is likely related to the aforementioned package-to-package variance. This further indicates consumers unwillingness to purchase steaks at retail that have any perceived “defect,” regardless of what is related to. Additionally, these preferences and aversions likely are highly specific to each consumer, making them further difficult to identify and quantify, and as a result, weakened the predictive power of the calculated regression equations in the current study. Furthermore, these preferences are likely increased when viewing numerous samples simultaneously in a retail display case, allowing consumers to identify and show preference to only the samples that are

“most ideal” to them, while discriminating against those which are less ideal. Thus, many of the packages consumers identified as lower on the liking scale or as “would not purchase” may have been viewed and rated differently had consumers had fewer samples in the case to compare to and show preference towards.

It is challenging to directly compare the results of the current work with other previously published reports that have attempted to assess consumer willingness to purchase beef steaks based on color and discoloration due to numerous methodological differences. However, a^* value has repeatedly been shown to be one of the best predictors of consumer purchase intent (Carpenter et al., 2001; Holman et al., 2017; Najar-Villarreal et al., 2021). One such study identified a lower threshold a^* value of 20.99 needed for acceptance of *longissimus dorsi* steaks (Najar-Villarreal et al., 2021). When compared to the current study, this identified threshold would have been well below the a^* value needed for a 50% likelihood of purchase in both phases, and thus would likely be much too low for a reasonable indicator of consumer purchase intent. However, these authors used trained sensory panel scores for assessment of acceptance, which differs significantly from the consumer model used in our study.

Similar limitations within other published works provide a lack of a clear and direct comparison to the results from the current study for retail beef steaks. Holman et al., (2016) required consumers to evaluate 10 images of beef *longissimus lumborum* steaks using an online survey to determine consumer purchase thresholds and beef color acceptability. Photographed steaks were accompanied by instrumental color data, and participants were provided with explicit instructions to standardize screen settings. They found that b^* was more predictive of consumer acceptability of beef color. than a^* , which is contradictory to the current study. However, in a follow up study Holman et al. (2017) increased the number of steaks to be

evaluated and included 80 images and found that a^* value was a more reliable predictor of consumer acceptance, which contradicts their previous study. This contradiction is likely due to an increase in sample number and resulted in more accurate and powerful results. However, in both studies (Holman et al., 2016; Holman et al., 2017) illuminant D⁶⁵ was used, which does not allow for direct comparison to the current study which used illuminant A as advised by the AMSA Guidelines for Meat Color Measurement (King et. al., 2023). Additionally, the inability to verify whether participants adhered to the prescribed screen settings introduced potential for variance and the skewed data.

An older study conducted by Hood and Riordan (1973) was one of the earliest in-store trials to evaluate consumer preferences for beef steaks with varying degrees of discoloration. Steaks from the *semimembranosus*, *semitendinosus*, *biceps femoris*, and *vastus lateralis* were displayed in PVC overwrap packaging were subjected to room temperature until desired discoloration and then refrigerated until retail display. They collected instrumental color data and displayed steaks with discoloration levels ranging from 5% to 33%. Their findings indicated significant consumer discrimination against discolored steaks, particularly when discolored meat was displayed alongside bright red meat, which aligns with the findings in the current study. While Hood and Riordan (1973) provided foundational insights into consumer preferences, it did not encompass the full spectrum of discoloration, like the current work which included discoloration from 0% to 100%. Furthermore, Hood and Riordan (1973) was conducted over 50 years ago, limiting its applicability to real-world scenarios as consumer preferences and expectations may have changed over time.

Conclusion

Overall, objective color measures are predictive of consumer purchasing likelihood of fresh beef steaks. a^* was one of the most predictive measures, accounting for 64% of the variation in consumer purchase intent when steaks are sold at full price. With only 12% discoloration, consumer likelihood to purchase was reduced to only 50%, with discounts only marginally improving the chances. Consumers expected steaks to be almost completely free of discoloration to be willing to purchase, and any perceived defect would likely result in a decrease in likelihood to purchase. When evaluating steaks for consumer purchase, numerous factors likely impact the consumer purchase intent including but not limited to redness, discoloration, and fat color, which were evaluated in this study, as well as other not measured factors such as marbling amount and packaging defects. This variability differs from ground beef, which is typically a more uniform product, resulting in less robust models when evaluating steak. During phase 2, when all steaks evaluated by consumers were similar in appearance, consumers were more selective than in phase 1 when steaks had a wide range of variation. These findings offer valuable insights into the impact of discoloration on consumer purchase decisions using objective measurements and can help retailers reduce waste, improve sales, and better meet consumer expectations.

Figure 2.1 Probability of a consumer purchasing a beef strip loin steak based on a^* value and pricing - Phase 1

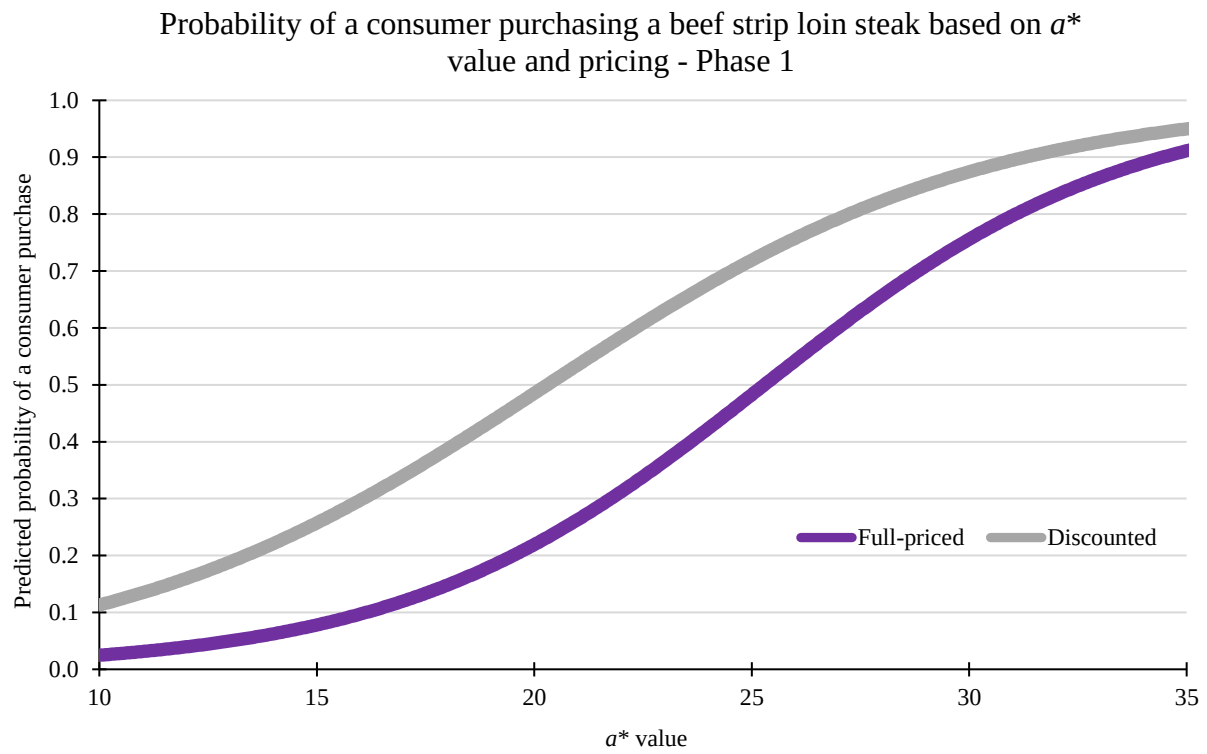


Figure 2.2 Probability of a consumer purchasing a beef strip loin steak based on a^* value and pricing - Phase 2

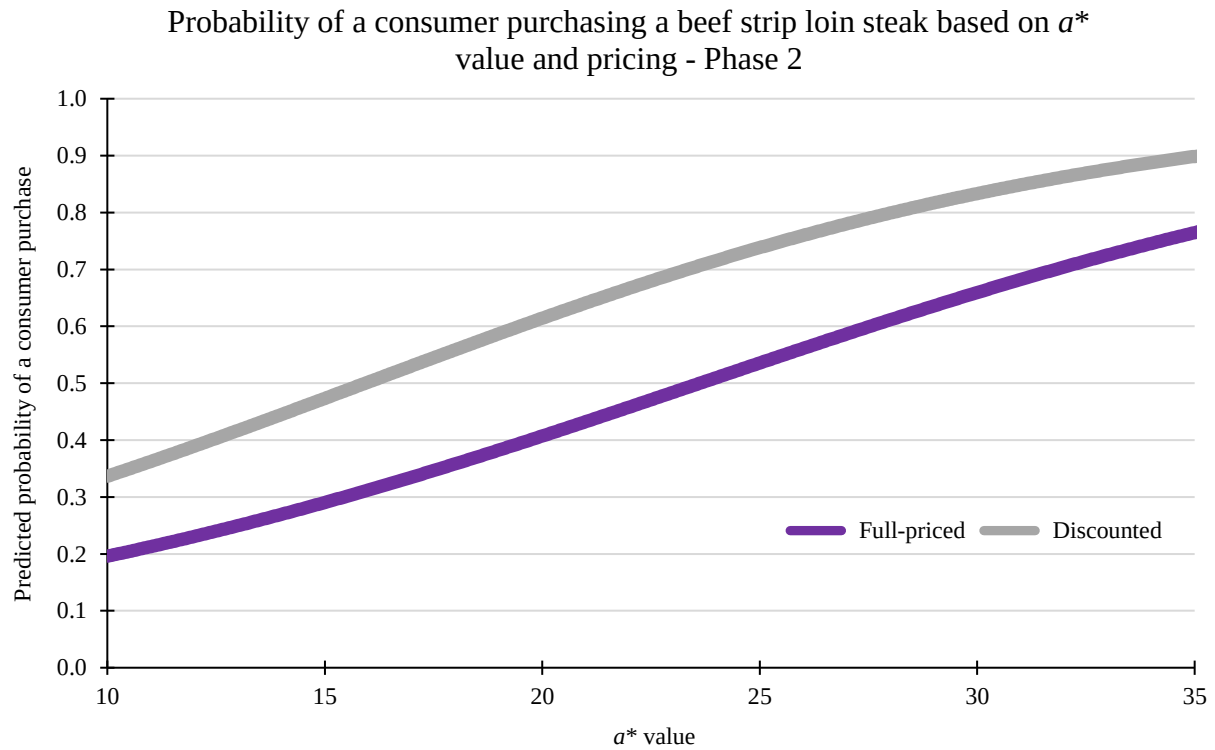


Figure 2.3 Probability of a consumer purchasing a beef strip loin steak based on trained sensory panel discoloration score and pricing - Phase 1

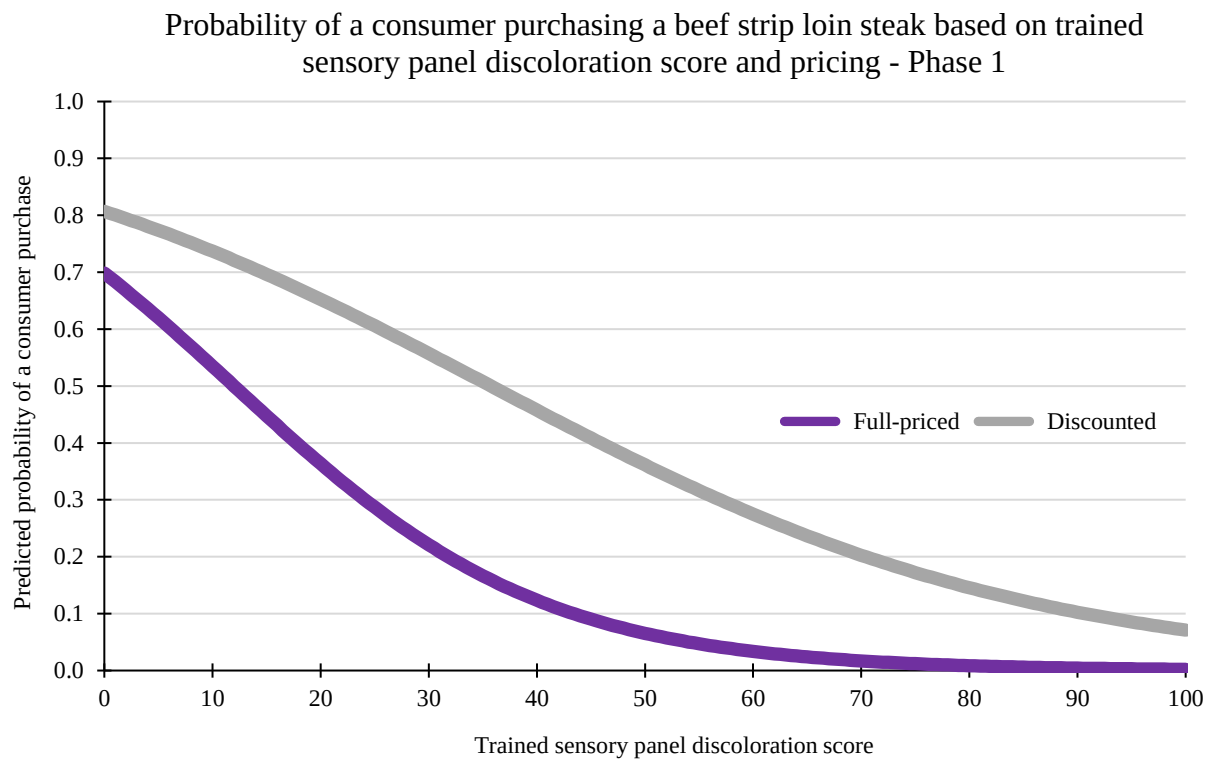


Figure 2.4 Probability of a consumer purchasing a beef strip loin steak based on trained sensory panel discoloration score and pricing - Phase 2

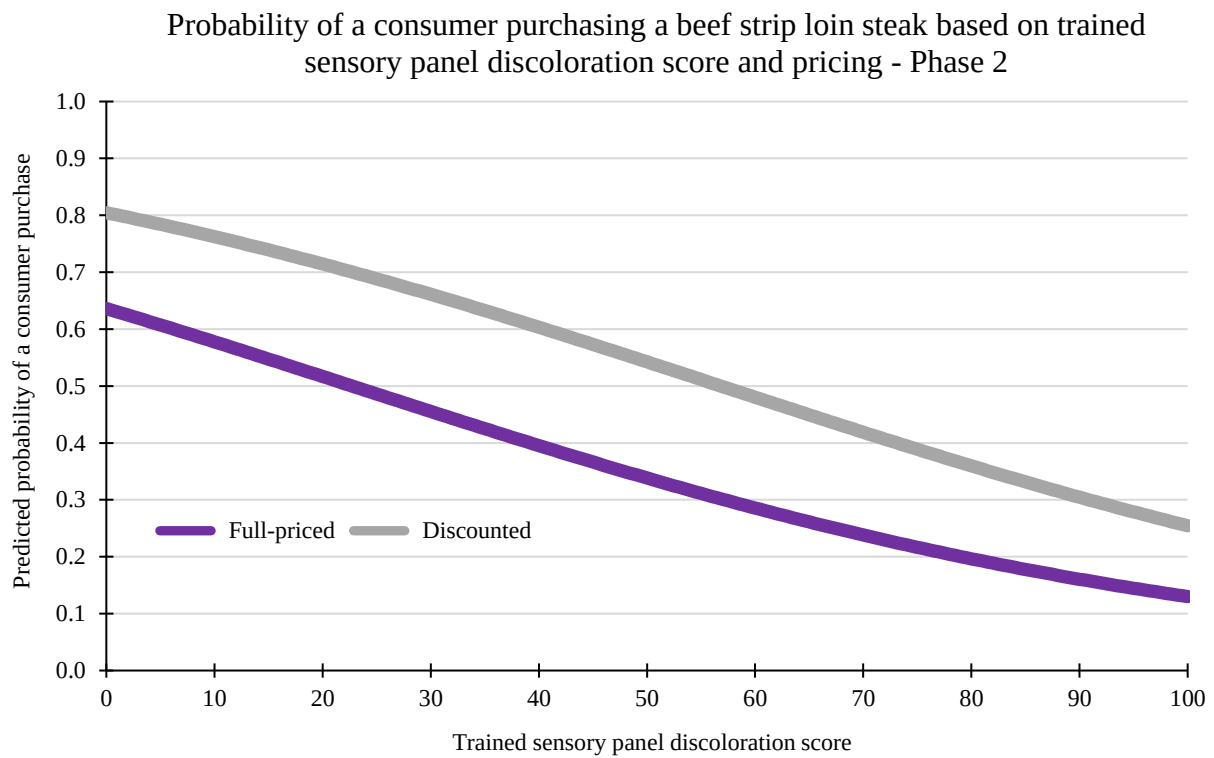


Figure 2.5 Linear regressions for predicting consumer overall appearance rating based on a^* value

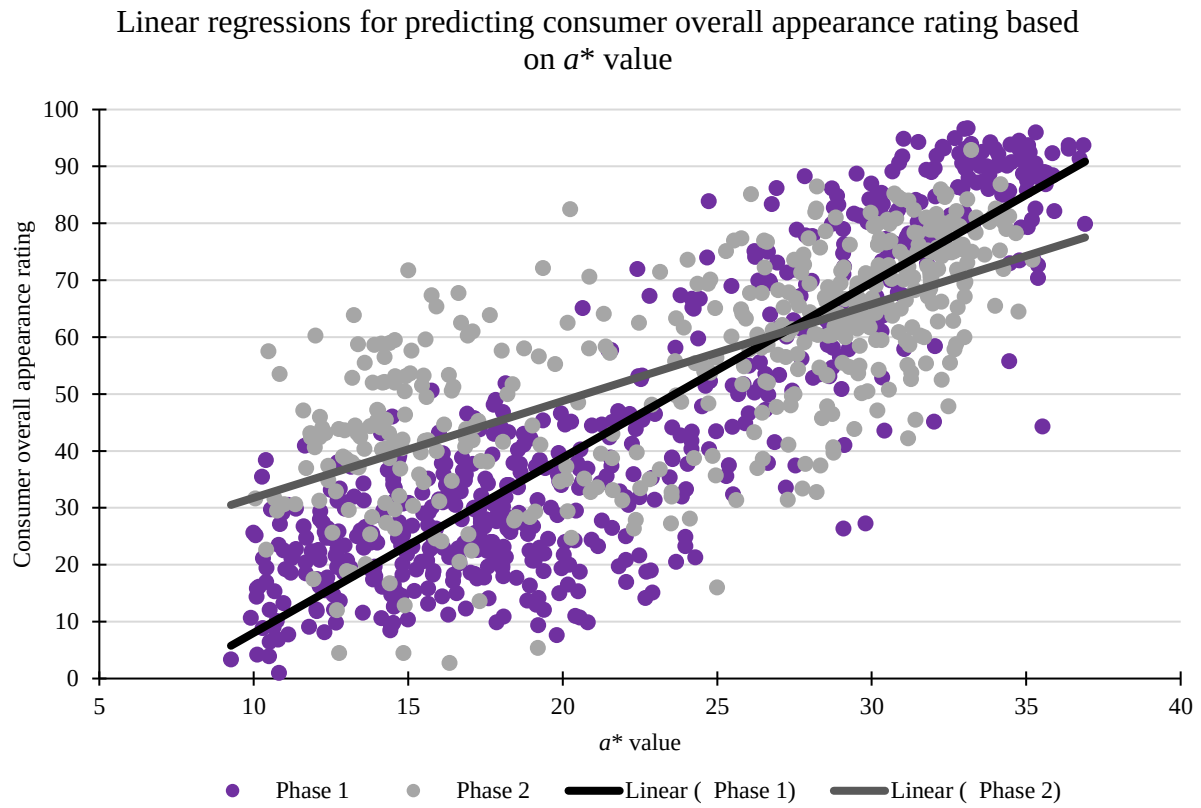


Figure 2.6 Linear regressions for predicting consumer overall appearance rating based on trained sensory panel discoloration score

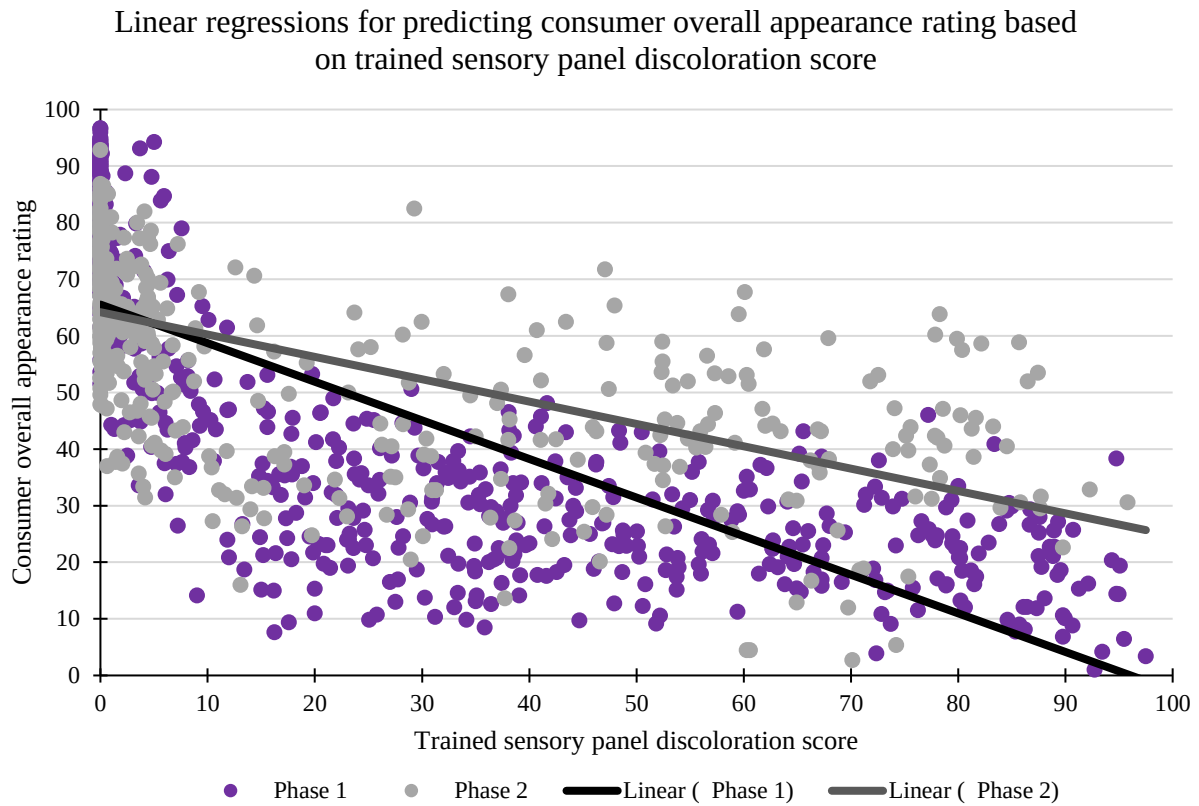


Figure 2.7 Visual guide provided to trained sensory panelists for fat color score evaluation

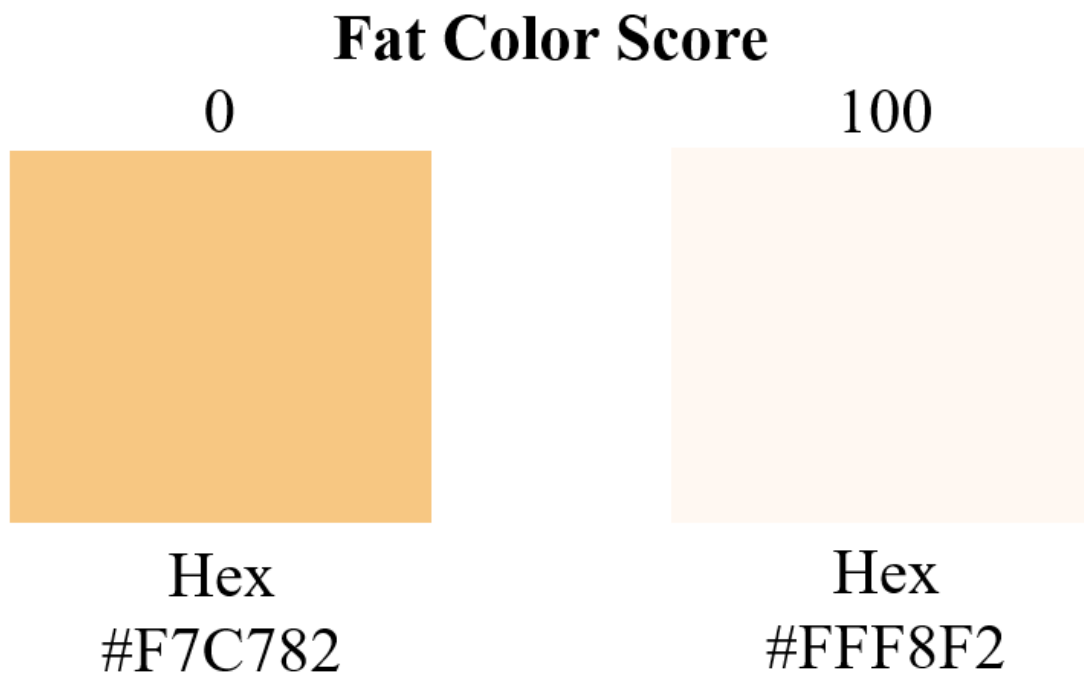


Figure 2.8 Visual guide provided to trained sensory panelists for percent discoloration evaluation



0% Discoloration



25% Discoloration



50% Discoloration



75% Discoloration



100% Discoloration

Table 2.1 Demographic characteristics of consumers who participated in consumer visual sensory panels

Characteristic	Response	Phase 1 (N = 200)	Phase 2 (N = 176)
		Percentage of consumers	
Gender	Male	53.1	57.4
	Female	46.9	42.6
Household size	1 person	29.1	21.0
	2 people	27.0	26.7
	3 people	11.7	13.1
	4 people	16.3	13.1
	5 people	9.7	17.1
	6 people	2.6	5.7
	Greater than 6 people	3.6	3.4
Marital status	Married	24.9	43.7
	Single	75.1	56.3
Age	Under 20	12.2	15.9
	20-29	57.7	29.6
	30-39	10.2	20.5
	40-49	6.1	15.3
	50-59	4.6	8.0
	Over 60	9.2	10.8
Ethnic origin	African American	2.0	2.3
	Asian	8.7	3.4
	Caucasian/white	83.2	85.2
	Hispanic	4.1	5.1
	Mixed race	1.5	3.4
	Native-American	0.5	0.6
	Other	0.0	0.0
Household income level	Under \$25,000	36.4	16.5
	\$25,000-\$34,999	9.2	6.3
	\$35,000-\$49,999	5.6	6.3
	\$50,000-\$74,999	10.8	17.6
	\$75,000-\$99,999	12.3	14.2
	\$100,000-\$149,999	9.7	18.8
	\$150,000-\$199,999	6.7	10.2
	Greater than \$199,999	9.2	10.2
Education level	Non-high school graduate	0.5	0.0
	High school graduate	19.4	23.3
	Some college/technical school	41.8	28.4
	College graduate	22.5	25.0
	Post-college graduate	15.8	23.3
Weekly beef consumption	0 times	0.5	0.0
	1 to 3 times	35.2	41.5
	4 to 6 times	34.7	32.4
	7 to 9 times	13.8	15.9
	10 or more times	15.8	9.7
Monthly beef purchase	0 times	13.8	9.7
	1 to 3 times	41.8	40.3
	4 to 6 times	26.5	27.8
	7 to 9 times	5.6	7.4
	10 or more times	12.2	14.8

Table 2.2 Summary statistics for independent variables evaluated in the study for beef strip

Measurement	Phase 1				Phase 2			
	Mean	Minimum	Maximum	SD ¹	Mean	Minimum	Maximum	SD ¹
<i>L</i> *	42.5	33.3	52.9	3.6	45.0	34.9	52.2	3.3
<i>a</i> *	22.0	9.3	36.9	7.7	24.3	10.1	35.2	7.3
<i>b</i> *	19.1	11.1	28.6	4.1	19.8	11.8	27.1	3.6
Metmyoglobin ²	36.6	17.8	69.0	13.3	32.7	18.1	66.5	12.5
Oxymyoglobin ²	50.0	15.8	75.0	17.4	58.3	15.4	74.2	15.3
Chroma ²	29.3	15.1	61.3	8.2	31.4	15.5	44.5	7.7
Hue angle ²	42.2	30.4	46.7	6.1	40.3	29.7	56.9	5.2
Trained sensory panel redness score ³	54.8	0.3	100.0	31.9	62.3	10.3	93.7	24.1
Trained sensory panel discoloration score ⁴	29.9	0.0	97.5	29.8	20.7	0.0	95.8	27.7
Trained sensory panel fat color score ⁵	52.6	4.3	100.0	28.8	55.5	10.9	93.9	23.6
Consumer appearance score ⁶	45.1	1.0	96.7	26.7	56.0	17.9	92.9	17.9

steaks

¹Standard deviation²Calculated utilizing the equations presented in the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023)³Sensory scores: 0 = extremely dark red, 100 = bright cherry red⁴Sensory scores: 0 = no visible discoloration, 100 = complete discoloration⁵Sensory scores: 0 = brownish-white, 100 = bright white⁶Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.3 Logistic regression equations for predicting consumer sensory panel purchase intent of beef strip steaks for Phase 1

Measurement	Intercept	Slope	Adjusted R^2	P – value	C – statistic ¹	% Correct ²
Product sold at full price						
L^*	-12.97	0.29	0.30	< 0.01	0.75	73.2
a^*	-6.07	0.24	0.64	< 0.01	0.87	83.5
b^*	-8.69	0.41	0.60	< 0.01	0.85	82.6
Metmyoglobin ³	3.70	-0.13	0.51	< 0.01	0.85	79.4
Oxymyoglobin ³	-5.63	0.09	0.56	< 0.01	0.86	81.9
Chroma ³	-7.11	0.21	0.64	< 0.01	0.87	83.6
Hue angle ³	8.27	-0.22	0.33	< 0.01	0.79	75.1
Trained sensory panel redness score ⁴	-4.08	0.06	0.64	< 0.01	0.88	82.9
Trained sensory panel discoloration score ⁵	0.84	-0.07	0.56	< 0.01	0.88	82.3
Trained sensory panel fat color score ⁶	-4.10	0.06	0.61	< 0.01	0.86	82.4
Consumer appearance score ⁷	-4.62	0.08	0.78	< 0.01	0.91	86.2
Product sold at discounted price						
L^*	-10.49	0.25	0.27	< 0.01	0.72	66.4
a^*	-4.06	0.20	0.56	< 0.01	0.82	75.0
b^*	-6.60	0.36	0.53	< 0.01	0.81	74.8
Metmyoglobin ³	3.36	-0.09	0.41	< 0.01	0.80	70.8
Oxymyoglobin ³	-3.45	0.07	0.49	< 0.01	0.81	74.6
Chroma ³	-5.27	0.19	0.58	< 0.01	0.82	76.0
Hue angle ³	6.39	-0.15	0.27	< 0.01	0.74	69.7
Trained sensory panel redness score ⁴	-2.34	0.05	0.59	< 0.01	0.84	76.2
Trained sensory panel discoloration score ⁵	1.43	-0.04	0.47	< 0.01	0.83	73.0
Trained sensory panel fat color score ⁶	-2.15	0.05	0.48	< 0.01	0.80	72.1
Consumer appearance score ⁷	-3.03	0.08	0.72	< 0.01	0.87	78.4

¹Measure of goodness of fit for binary outcomes in a logistic regression model, ranging from 0 – 1

²Percentage of correctly classified events and nonevents by the model

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

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

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

⁶Sensory scores: 0 = brownish-white, 100 = bright white

⁷Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.4 Logistic regression equations for predicting consumer sensory panel purchase intent of beef strip steaks for Phase 2 of this study

Measurement	Intercept	Slope	Adjusted R^2	P – value	C – statistic ¹	% Correct ²
Product sold at full price						
L^*	-6.56	0.15	0.11	< 0.01	0.65	61.2
a^*	-2.45	0.10	0.25	< 0.01	0.71	66.9
b^*	-3.97	0.20	0.23	< 0.01	0.70	66.8
Metmyoglobin ³	1.96	-0.06	0.23	< 0.01	0.71	65.0
Oxymyoglobin ³	-2.47	0.04	0.20	< 0.01	0.70	64.9
Chroma ³	-3.00	0.10	0.25	< 0.01	0.70	67.1
Hue angle ³	5.13	-0.13	0.18	< 0.01	0.68	63.4
Trained sensory panel redness score ⁴	-1.70	0.03	0.21	< 0.01	0.70	65.5
Trained sensory panel discoloration score ⁵	0.56	-0.02	0.20	< 0.01	0.71	64.8
Trained sensory panel fat score ⁶	-1.60	0.03	0.22	< 0.01	0.69	66.6
Consumer appearance score ⁷	-4.36	0.08	0.57	< 0.01	0.81	73.1
Product sold at discounted price						
L^*	-6.09	0.15	0.11	< 0.01	0.66	68.1
a^*	-1.82	0.11	0.28	< 0.01	0.73	70.2
b^*	-3.68	0.23	0.27	< 0.01	0.72	70.5
Metmyoglobin ³	2.90	-0.06	0.24	< 0.01	0.73	70.5
Oxymyoglobin ³	-1.70	0.04	0.21	< 0.01	0.71	69.4
Chroma ³	-2.49	0.11	0.28	< 0.01	0.73	70.7
Hue angle ³	5.99	-0.13	0.19	< 0.01	0.70	70.2
Trained sensory panel redness score ⁴	-1.01	0.03	0.23	< 0.01	0.72	68.8
Trained sensory panel discoloration score ⁵	1.42	-0.03	0.21	< 0.01	0.74	70.6
Trained sensory panel fat color score ⁶	-1.03	0.04	0.26	< 0.01	0.72	68.3
Consumer appearance score ⁷	-3.46	0.08	0.58	< 0.01	0.83	78.3

¹Measure of goodness of fit for binary outcomes in a logistic regression model, ranging from 0 – 1

²Percentage of correctly classified events and nonevents by the model

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

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

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

⁶Sensory scores: 0 = brownish-white, 100 = bright white

⁷Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.5 50, 75, 90, and 95% likeliness thresholds for various objective quality measures for consumer purchase intent of beef strip steaks for Phase 1

Measurement	50%	75%	90%	95%
Product sold at full price				
L^*	44.7	48.5	52.3	-
a^*	25.3	29.9	34.4	-
b^*	21.2	23.9	26.6	28.4
Metmyoglobin ¹	28.5	20.0	-	-
Oxymyoglobin ¹	62.6	74.8	-	-
Chroma ¹	33.9	39.1	44.3	47.9
Hue angle ¹	37.6	32.6	-	-
Trained sensory panel redness score ²	68.0	86.3	-	-
Trained sensory panel discoloration score ³	12.0	-	-	-
Trained sensory panel fat color score ⁴	68.4	86.7	-	-
Consumer appearance score ⁵	57.8	71.5	85.2	94.6
Product sold at discounted price				
L^*	42.0	46.4	50.8	-
a^*	20.3	25.8	31.3	35.0
b^*	18.3	21.4	24.4	26.5
Metmyoglobin ¹	37.4	25.1	-	-
Oxymyoglobin ¹	49.3	65.0	-	-
Chroma ¹	27.4	33.5	39.3	43.2
Hue angle ¹	42.6	35.3	-	-
Trained sensory panel redness score ²	46.8	68.8	90.8	-
Trained sensory panel discoloration score ³	35.8	8.3	-	-
Trained sensory panel fat color score ⁴	43.0	65.0	87.0	-
Consumer appearance score ⁵	37.9	51.6	65.4	74.7

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

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

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

⁴Sensory scores: 0 = brownish-white, 100 = bright white

⁵Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.6 50, 75, 90, and 95% likeliness thresholds for various quality measures for consumer purchase intent of beef strip steaks for Phase 2

Measurement	50%	75%	90%	95%
Product sold at full price				
<i>L</i> *	44.6	52.0	-	-
<i>a</i> *	23.6	34.2	-	-
<i>b</i> *	19.4	24.8	-	-
Metmyoglobin ¹	33.7	-	-	-
Oxymyoglobin ¹	57.0	-	-	-
Chroma ¹	30.7	42.0	-	-
Hue angle ¹	40.7	32.0	-	-
Trained sensory panel redness score ²	60.0	-	-	-
Trained sensory panel discoloration score ³	22.7	-	-	-
Trained sensory panel fat color score ⁴	53.0	89.4	-	-
Consumer appearance score ⁵	55.5	69.5	83.5	-
Product sold at discounted price				
<i>L</i> *	39.4	46.5	-	-
<i>a</i> *	15.9	25.5	35.1	-
<i>b</i> *	15.7	20.4	25.1	-
Metmyoglobin ¹	47.9	29.8	11.6	-
Oxymyoglobin ¹	38.0	62.5	-	-
Chroma ¹	22.7	32.7	42.7	-
Hue angle ¹	47.3	38.6	29.9	-
Trained sensory panel redness score ²	32.5	67.9	-	-
Trained sensory panel discoloration score ³	56.8	12.7	-	-
Trained sensory panel fat color score ⁴	28.6	59.2	89.8	-
Consumer appearance score ⁵	42.2	55.6	69.0	78.1

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

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

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

⁴Sensory scores: 0 = brownish-white, 100 = bright white

⁵Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.7 Pearson correlation coefficients for objective color measurements, trained sensory panel color ratings, and subjective consumer ratings¹

	<i>L</i> *	<i>a</i> *	<i>b</i> *	Metmyoglobin ²	Oxymyoglobin ²	Chroma ²	Hue angle ²	Trained sensory panel redness score ³	Trained sensory panel discoloration score ⁴	Trained sensory panel fat score ⁵
Phase 1										
<i>a</i> *	0.59									
<i>b</i> *	0.68	0.90								
Metmyoglobin ²	-0.48	-0.92	-0.68							
Oxymyoglobin ²	0.64	0.85	0.89	-0.69						
Chroma ²	0.63	0.99	0.96	-0.85	0.88					
Hue angle ²	-0.25	-0.78	-0.44	0.94	-0.50	-0.67				
Trained sensory panel redness score ³	0.68	0.90	0.91	-0.75	0.88	0.92	-0.58			
Trained sensory panel discoloration score ⁴	-0.45	-0.87	-0.68	0.91	-0.74	-0.82	0.85	-0.82		
Trained sensory panel fat color score ⁵	0.61	0.77	0.86	-0.57	0.85	0.82	-0.37	0.86	-0.63	
Consumer appearance score ⁶	0.60	0.87	0.85	-0.73	0.81	0.88	-0.56	0.89	-0.76	0.83
Phase 2										
<i>a</i> *	0.69									
<i>b</i> *	0.73	0.95								
Metmyoglobin ²	-0.67	-0.97	-0.86							
Oxymyoglobin ²	0.76	0.93	0.89	-0.93						
Chroma ²	0.71	0.99	0.98	-0.95	0.93					
Hue angle ²	-0.49	-0.89	-0.70	0.95	-0.83	-0.84				
Trained sensory panel redness score ³	0.76	0.95	0.92	-0.91	0.92	0.95	-0.81			
Trained sensory panel discoloration score ⁴	-0.65	-0.91	-0.80	0.95	-0.93	-0.88	0.91	-0.88		
Trained sensory panel fat color score ⁵	0.72	0.88	0.87	-0.84	0.86	0.89	-0.72	0.89	-0.79	
Consumer appearance score ⁶	0.47	0.69	0.67	-0.65	0.61	0.69	-0.57	0.64	-0.61	0.67

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

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

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

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

⁵Sensory scores: 0 = brownish-white, 100 = bright white

⁶Sensory scores: 0 = extremely undesirable, 100 = extremely desirable

Table 2.8 Linear regression equations for predicting consumer sensory panel overall liking scores for beef strip steaks

Measurement	Intercept	Slope	Adjusted R^2	P – value
Phase 1				
L^*	-145.85	4.49	0.36	< 0.01
a^*	-21.62	3.04	0.76	< 0.01
b^*	-60.69	5.53	0.73	< 0.01
Metmyoglobin ¹	98.55	-1.46	0.53	< 0.01
Oxymyoglobin ¹	-16.32	1.23	0.64	< 0.01
Chroma ¹	-39.02	2.88	0.78	< 0.01
Hue angle ¹	148.72	-2.45	0.32	< 0.01
Trained sensory panel redness score ²	4.13	0.75	0.80	< 0.01
Trained sensory panel discoloration score ³	65.54	-0.68	0.59	< 0.01
Trained sensory panel fat color score ⁴	4.64	0.77	0.69	< 0.01
Phase 2				
L^*	-57.87	2.53	0.22	< 0.01
a^*	14.76	1.70	0.48	< 0.01
b^*	-10.84	3.38	0.45	< 0.01
Metmyoglobin ¹	86.63	-0.94	0.42	< 0.01
Oxymyoglobin ¹	14.36	0.71	0.37	< 0.01
Chroma ¹	5.44	1.61	0.48	< 0.01
Hue angle ¹	136.03	-1.99	0.33	< 0.01
Trained sensory panel redness score ²	26.33	0.48	0.41	< 0.01
Trained sensory panel discoloration score ³	64.19	-0.39	0.37	< 0.01
Trained sensory panel fat color score ⁴	27.63	0.51	0.45	< 0.01

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

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

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

⁴Sensory scores: 0 = brownish-white, 100 = bright white

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Appendix A - Sensory Panel Evaluation Forms

Consumer Sensory Panel Ballot



Panel 1 - Case A

Please tell us a little about yourself.

Panelist Initials

Gender

Male

Female

Are you color blind?

Yes

No

Age

Under 20

20 to 29 years old

30 to 39 years old

40 to 49 years old

50 to 59 years old

over 60

Ethnic Origin

African American

Asian

Caucasian/White

Latino

Native American

Other

Mixed Race

Marital Status

Single

Married

Household Size

1 person
2 People
3 People
4 People
5 People
6 People
> 6 People

Annual Household Income

< \$25,000
\$25,000 - \$34,999
\$35,000 - \$49,999
\$50,000 - \$74,999
\$75,000 - \$99,999
\$100,000 - \$149,999
\$150,000 - \$199,999
> \$199,999

Highest Level of Education Completed

Non-High School Graduate

High School Graduate

Some College / Technical School

College Graduate

Post-College Graduate

How many times a week do you consume beef?

036912151821

None

How many times a month do you purchase beef at retail?

036912151821

None

Sample Number

2194

Overall Appearance

Extremely Undesirable
0

Neither Desirable or Undesirable
50

Extremely Desirable
100

Appearance



Would you purchase the sample at retail?

Yes

No

Would you purchase the sample if it was discounted at retail?

Yes

No

Trained Sensory Panel Ballot



Trained Panel 4/22/24

Panelist Name

Date

Sample Number

Percent Discoloration

0% 50% 100%
0 50 100

Total Discoloration



Lean Color

Extremely Dark Red



0

Slightly Dark Red



50

Bright Cherry Red



100

Redness

☐ Not Applicable



Fat Color

Brownish-White



0

50

Bright White



100

Fat Color



Appendix B - Sample Photos with Corresponding Likelihood to Purchase Thresholds

a^* Value – Full Price – Phase 1



90% likelihood to purchase
 $a^* : 34.4$



75% likelihood to purchase
 $a^* : 29.9$



50% likelihood to purchase
 $a^* : 25.3$

a^* Value – Discount – Phase 1



95% likelihood to purchase
 $a^* : 35.0$



90% likelihood to purchase
 $a^* : 31.3$



75% likelihood to purchase
 $a^* : 25.8$



50% likelihood to purchase
 $a^* : 20.3$

a^* Value – Full Price – Phase 2



75% likelihood to purchase
 $a^* : 34.2$



50% likelihood to purchase
 $a^* : 23.6$

α^* value – Discount – Phase 2



90% likelihood to purchase

α^* : 35.1



75% likelihood to purchase

α^* : 25.5



50% likelihood to purchase

α^* : 15.9

Trained Panel Discoloration Score – Full Price – Phase 1



50% likelihood to purchase

Trained Panel Discoloration Score :
12.0

Trained Panel Discoloration Score – Discount – Phase 1



75% likelihood to purchase

Trained Panel Discoloration Score :
8.3



50% likelihood to purchase

Trained Panel Discoloration Score :
35.8

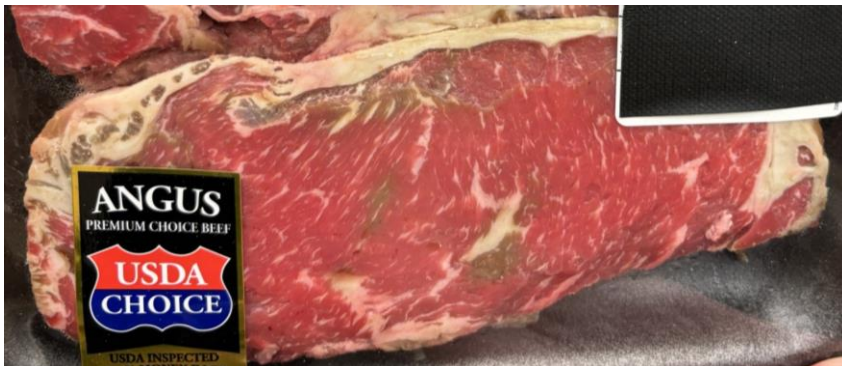
Trained Panel Discoloration Score – Full Price – Phase 2



50% likelihood to purchase

Trained Panel Discoloration Score :
22.7

Trained Panel Discoloration Score – Discount – Phase 2



75% likelihood to purchase

Trained Panel Discoloration Score :
12.7



50% likelihood to purchase

Trained Panel Discoloration Score :
56.8