RETAIL SHELF-LIFE CHARACTERISTICS OF DRY-AGED BEEF

A Senior Scholars Thesis

by

CARSON JOSEPH ULBRICH

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2010

Major: Animal Science

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Approved by:

Research Advisors:	Jeffrey W. Savell
	Davey B. Griffin
Associate Dean for Undergraduate Research:	Robert C. Webb

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ABSTRACT

Retail Shelf-Life Characteristics of Dry-Aged Beef. (April 2010)

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Department of Animal Science

USDA Choice and USDA Select beef top sirloin butts (n = 60) and Choice and Select beef bone-in strip loins (n = 60) were aged for 21 d, 28 d, and 35 d and then fabricated into steaks (n = 360). Steaks were placed on tables in a cooler under constant lighting to simulate a mock retail case for five days, and a trained panel visually evaluated the lean color, fat color, and off-odor. Microbial samples were taken from each wholesale cut, as well as, subsequent steaks and were analyzed for aerobic plate counts, lactic acid bacteria, and yeast and mold counts. Surface discoloration ($P = 0.007$) and fat discoloration ($P < 0.0001$) of steaks increased as aging period and retail steak shelf-life day increased. Also, off-odor development increased ($P < 0.0001$) as aging period increased. Steaks most susceptible to undesirable visual retail characteristics included dry-aged steaks and steaks left in retail display for long periods of time (top sirloin and top loin steaks, cut from 21 d aged subprimals, approaching days 4 and 5 of retail display; top sirloin and top loin steaks, cut from 28 d aged subprimals, approaching day 3, 4, and 5 of retail case display; and top sirloin and top loin steaks, cut from 35 d aged

subprimals approaching day 2, 3, 4, and 5 of retail display.) As for off-odor attributes, steaks cut from 35 d aged subprimals exhibited over double the amount of extreme and moderate off-odors than did steaks cut from 21 d and 28 d aged subprimals. Therefore, the preferred protocol for minimizing unappealing sensory attributes of aged steaks should be a short aging period, followed by a short retail case duration. By shortening the aging period, the producer can retain some of the product yield; however, shortening the aging period may negatively affect the flavor development and enhancement of the brown, roasted flavors associated with dry-aged beef.

DEDICATION

I dedicate this paper to my parents, Bryce and Edna Ulbrich, for supporting me in all of my endeavors. Without their support I would not have been able to achieve many things, such as this scientific paper.

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There are many people who helped me throughout this project. First off, I would like to thank Drs. Jeffrey W. Savell, Davey B. Griffin, and Kerri B. Harris for giving me the opportunity to research this topic and for their assistance along the way. I would also like to thank Ashley Haneklaus for offering many hours of her time to help and guide me through all of the tough situations I encountered. Ashley played a huge role in making sure I always had help when I needed it and that all aspects of my project were in line. Without Ashley's help I would not have been able to complete this research. Additionally, I would like to thank John Arnold for working late into the night hours helping me build lighting units as well as for helping with data interpretation and table building. Furthermore, I would like to thank my panelists for participating in this study which included three weekends of work. I would also like to thank Lisa Lucia and her team of micro graduate students who preformed my micro analyses, along with the help of Jacob Lemmons and Brittany Laster. Moreover, I would like to thank Scott Langley and Will Wiederhold for assisting me in cutting and packaging the steaks for this project. Last, but not least, I would like to thank Ray Riley for allowing me to take off of work whenever I needed so that I could work on my project.

NOMENCLATURE

AMSA	American Meat Science Association
APC	Aerobic plate count
Cx	Carcass
LAB	Lactic acid bacteria
PVC	Polyvinyl chloride
TSB	Top sirloin butt
YM	Yeast and mold

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CHAPTER I

INTRODUCTION

Aging of meat is a process common to the meat industry that has proven to increase overall palatability through increased tenderness and flavor development. Two common methods of aging beef are dry-aging, and the more standard method, wet-aging. Both aging methods achieve increased tenderness, but develop quite different flavor profiles (Campbell, Hunt, Levis & Chambers, 2001; Warren & Kastner, 1992). This difference in flavor profiles largely influences consumer preferences for dry-aged beef versus wet-aged beef.

Dry-aged beef

Dry-aging of beef is achieved by exposing meat to the ambient gaseous environment (air) in a storage cooler. Exposure to air causes the meat to have a different flavor as well as to increase weight loss through moisture evaporation. However, the exposure to oxygen and endogenous bacteria in the atmosphere may create potential problems associated with the shelf-life of the product.

Dry aging as a method to enhance the tenderness and taste of beef has been used extensively by the foodservice industry for many years. Wet aging, the predominant method of aging today, entails product being aged in a vacuum package. Vacuum

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This thesis follows the style of *Meat Science*.

packaged, or wet-aged beef, shows evidence of decreased shrinkage, and as a result, higher yields when compared to dry-aged beef (Laster et al., 2008; Smith et al., 2008). Furthermore, wet-aging permits the development and intensification of different flavors not observed in dry-aged beef. Warren and Kastner (1992) found that wet-aged beef developed a more intense sour flavor, as well as more intense bloody, serumy, and metallic flavors than did dry-aged beef. On the other hand, it was found that dry-aged beef developed a more beefy flavor, and a more brown, roasted flavor than the wet-aged counterpart (Warren & Kastner, 1992). Oreskovich et al. (1988) identified differences in microbial growth, specific to each aging treatment, as the possible cause in the development of flavors unique to each aging method.

Due to the loss in saleable yield caused by extensive trimming of the dried exterior surfaces, dry-aged beef is typically marketed at higher prices than wet-aged beef, and thus, is common among gourmet steakhouses, as well as upscale butcher shops. Recently, the retail industry has expressed interest in the wet-aged method of aging beef. Laster et al. (2008) and Smith et al. (2008) investigated the impact of dry-aging on sensory panel ratings and retail cut yields. However, these studies did not investigate shelf-life as it pertained to display life of steaks obtained from dry-aged wholesale cuts.

Shelf-life

The previous work of Campbell et al. (2001) found that dry-aged beef samples had higher aerobic plate counts (APC) when compared to control samples. However, Campbell et al. (2001) reported no significant changes in APC levels throughout the duration of the 21-day dry-aging process. Lack of continued microbial growth was attributed to meat surface dehydration and consistent storage temperatures low enough (2 °C) to prevent microbial growth. However, no data were collected on dry-aged product after 21 days of aging in the Campbell et al. (2001) experiment. Research efforts of Pierson et al. (1970) found that when vacuum packaged and non-vacuum packaged beef was aged for 15 days, off flavors developed due to lactic acid bacteria. Moreover, Oreskovich et al. (1988) found that aerobically stored beef possessed higher bacterial counts than did vacuum packaged beef, thereby agreeing with the findings of Campbell et al. (2001).

Allowing meat to exceed its shelf-life will cause products to be less appealing to the consumer, and if purchased, may result in an undesirable eating experience due to lost quality. Therefore, knowing the shelf-life of dry- and wet-aged beef is crucial to minimizing monetary losses on unsellable product, and/or the loss of repeat customers due to poor eating experiences. The retail shelf-life characteristics of dry-aged beef are extremely valuable to the foodservice industry in terms of sales, and overall customer satisfaction with the product.

Summary

The goal of this research is to determine the shelf-life of dry- versus wet-aged beef from different wholesale cut origins, allowing retail and foodservice institutions to improve their management decisions. Today, wet-aging is still considered the standard method of aging. However, Laster et al. (2008) and Smith et al. (2008) reported growing interest in dry-aged beef cuts among US retailers. Previous work has been done on dry-aged beef; however, most if it consists of palatability and yield studies. In contrast, little is known about the shelf-life of dry-aged beef, which is why this study is significant to today's industry. The objective of this study was to establish the shelf-life characteristics of dry-aged beef from different wholesale cut origins through microbial testing, odor scores, and surface discoloration scores

CHAPTER II

MATERIALS AND METHODS

Selection and aging of product

USDA Choice (n=15) and USDA Select (n=15) beef carcasses, either USDA Yield Grade 2 or 3 were selected at a large commercial beef harvesting plant located in Texas. The paired, bone-in strip loins (n=60, IMPS 175), and paired, boneless top sirloin butts (n=60, IMPS 184) from each carcass were vacuum packaged, assigned an identification tag, boxed at the plant, and then delivered by refrigerated truck to the Rosenthal Meat Science and Technology Center at Texas A&M University.

Once the product arrived (Day 0) at the Rosenthal Meat Science and Technology Center, it was offloaded from the truck and immediately placed in the meat cooler. Shortly after arrival, one side of each pair of bone-in strip loins (n=30), and one side of each pair of boneless top sirloin butts (n=30) were selected randomly and removed aseptically from their vacuum package so that a sample could be excised for an initial microbial analysis. Those strip loins and top sirloin butts removed from their packaging were placed on an aging rack located inside of the cooler (temperature above −2.2 °C and equal to or below 4.4 °C) in order to receive dry-aged treatment. The other side of each pair of beef subprimals was kept in its vacuum package, and then placed inside the cooler (temperature above −2.2 °C and equal to or below 4.4 °C), on the same rack and in the same fashion so for wet aging (see Figure 1).

USDA Choice		USDA Select	
Cx: 1 21 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 16 21 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 2 21 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 17 21 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 3 21 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 18 21 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 4 21 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 19 21 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 5 21 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 20 21 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 6 28 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 21 28 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 7 28 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 22 28 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 8 28 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 23 28 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 9 28 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 24 28 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 10 28 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 25 28 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 11 35 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 26 35 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 12 35 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 27 35 d	Dry: Left Strip, TSB Wet: Right Strip, TSB
Cx: 13 35 d	Dry: Left Strip, TSB Wet: Right Strip, TSB	Cx: 28 35 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 14 35 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 29 35 d	Dry: Right Strip, TSB Wet: Left Strip, TSB
Cx: 15 35 d	Dry: Right Strip, TSB Wet: Left Strip, TSB	Cx: 30 35 d	Dry: Right Strip, TSB Wet: Left Strip, TSB

Figure 1 Product Selection/Aging Diagram

The strip loins and top sirloin butts from carcasses 1-5 and 16-20 were aged 21 days. Likewise, strip loins and top sirloins from carcasses 6-10 and 21-25 were aged 28 days, and strip loins and top sirloins from carcasses 11-15 and 26-30 were aged 35 days.

Strips loins and top sirloin butts designated for dry aging were placed on wire racks after they were sampled for an initial microbial analysis. The strip loins were placed chine-side (vertebral side) down on the racks, and the top sirloin butts were placed so that the inside (exposed) lean surface was facing down, thus leaving the subcutaneous fat positioned in an upward-facing position. Strip loins and top sirloin butts designated for wet aging were placed on the wire racks in the same position as their paired, dry aged members, except they remained in a vacuum package until the last day of their specified aging treatment.

Cutting and packaging of steaks

Before steaks were cut, subprimals were faced so that wedge cut steaks and/or discolored ends were not used. All steaks were cut 2.54 cm thick using a band saw. Top loin steaks were cut anterior to posterior on a band saw affixed with a bone-in band saw blade. However, the top sirloin steaks were cut posterior to anterior on a band saw affixed with a boneless blade. The anatomical location of each cut steak was recorded (Figure 2). After cutting, the three steaks from each subprimal were packaged individually on foam trays (top sirloin steaks: 10S trays; top loin steaks: 20S trays) with purge soaker pads and with PVC overwrap.

USDA Choice		USDA Select	
Cx: 1 21 d	Dry: Right Strip, Left TSB- ***STYLE “A”*** Wet: Left Strip, Right TSB- ***STYLE “A”***	Cx: 16 21 d	Dry: Right Strip, Left TSB- ***STYLE “A”*** Wet: Left Strip, Right TSB- ***STYLE “A”***
Cx: 2 21 d	Dry: Left Strip, TSB- ***STYLE “B”*** Wet: Right Strip, TSB- ***STYLE “B”***	Cx: 17 21 d	Dry: Left Strip, TSB- ***STYLE “B”*** Wet: Right Strip, TSB- ***STYLE “B”***
Cx: 3 21 d	Dry: Left Strip, TSB- ***STYLE “C”*** Wet: Right Strip, TSB- ***STYLE “C”***	Cx: 18 21 d	Dry: Right Strip, TSB- ***STYLE “C”*** Wet: Left Strip, TSB- ***STYLE “C”***
Cx: 4 21 d	Dry: Right Strip, TSB- ***STYLE “A”*** Wet: Left Strip, TSB- ***STYLE “A”***	Cx: 19 21 d	Dry: Right Strip, TSB- ***STYLE “A”*** Wet: Left Strip, TSB- ***STYLE “A”***
Cx: 5 21 d	Dry: Right Strip, TSB- ***STYLE “B”*** Wet: Left Strip, TSB- ***STYLE “B”***	Cx: 20 21 d	Dry: Right Strip, TSB- ***STYLE “B”*** Wet: Left Strip, TSB- ***STYLE “B”***
Cx: 6 28 d	Dry: Left Strip, TSB- ***STYLE “C”*** Wet: Right Strip, TSB- ***STYLE “C”***	Cx: 21 28 d	Dry: Left Strip, TSB- ***STYLE “C”*** Wet: Right Strip, TSB- ***STYLE “C”***
Cx: 7 28 d	Dry: Left Strip, TSB- ***STYLE “A”*** Wet: Right Strip, TSB- ***STYLE “A”***	Cx: 22 28 d	Dry: Left Strip, TSB- ***STYLE “A”*** Wet: Right Strip, TSB- ***STYLE “A”***
Cx: 8 28 d	Dry: Right Strip, TSB- ***STYLE “B”*** Wet: Left Strip, TSB- ***STYLE “B”***	Cx: 23 28 d	Dry: Left Strip, TSB- ***STYLE “B”*** Wet: Right Strip, TSB- ***STYLE “B”***
Cx: 9 28 d	Dry: Right Strip, TSB- ***STYLE “C”*** Wet: Left Strip, TSB- ***STYLE “C”***	Cx: 24 28 d	Dry: Right Strip, TSB- ***STYLE “C”*** Wet: Left Strip, TSB- ***STYLE “C”***
Cx: 10 28 d	Dry: Right Strip, TSB- ***STYLE “A”*** Wet: Left Strip, TSB- ***STYLE “A”***	Cx: 25 28 d	Dry: Right Strip, TSB- ***STYLE “A”*** Wet: Left Strip, TSB- ***STYLE “A”***
Cx: 11 35 d	Dry: Left Strip, TSB- ***STYLE “B”*** Wet: Right Strip, TSB- ***STYLE “B”***	Cx: 26 35 d	Dry: Right Strip, Left TSB- ***STYLE “B”*** Wet: Left Strip, Right TSB- ***STYLE “B”***
Cx: 12 35 d	Dry: Left Strip, TSB- ***STYLE “C”*** Wet: Right Strip, TSB- ***STYLE “C”***	Cx: 27 35 d	Dry: Left Strip, TSB- ***STYLE “C”*** Wet: Right Strip, TSB- ***STYLE “C”***
Cx: 13 35 d	Dry: Left Strip, TSB- ***STYLE “A”*** Wet: Right Strip, TSB- ***STYLE “A”***	Cx: 28 35 d	Dry: Right Strip, TSB- ***STYLE “A”*** Wet: Left Strip, TSB- ***STYLE “A”***
Cx: 14 35 d	Dry: Right Strip, TSB- ***STYLE “B”*** Wet: Left Strip, TSB- ***STYLE “B”***	Cx: 29 35 d	Dry: Right Strip, TSB- ***STYLE “B”*** Wet: Left Strip, TSB- ***STYLE “B”***
Cx: 15 35 d	Dry: Right Strip, TSB- ***STYLE “C”*** Wet: Left Strip, TSB- ***STYLE “C”***	Cx: 30 35 d	Dry: Right Strip, TSB- ***STYLE “C”*** Wet: Left Strip, TSB- ***STYLE “C”***

Figure 2 Steak Cutting Style Diagram

Panel evaluation of steaks

After the steaks were packaged and labeled, they were placed on a table located inside of a cooler (temperature above −2.2 °C and equal to or below 4.4 °C). Throughout the next five days (post cutting and packaging), the steaks were illuminated by fluorescent lighting units (Utili Tech 1233, Acuity Brands Lighting, Inc., Conyers, GA; 355291 Lithonia Lighting, Acuity Brands Lighting, Inc., Conyers, GA) equipped with GE F40 Kitchen/Bath, Warm/Natural lights. The steaks were evaluated daily by a trained panel using the American Meat Science Association (AMSA) Guidelines for Meat Color Evaluation. The panelists evaluated fat and lean surface discoloration for each packaged steak daily. Panelists rated the intensity of the surface discoloration, as well as the intensity of the fat color discoloration. Lean surface discoloration ranged from 7 (100% discoloration) to 1 (0% discoloration). Fat surface discoloration ranged from 5 (severely discolored) to 1 (white; no discoloration). If the fat was discolored, the panelists used a 6-point scale (6 = yellow, 5 = yellowish green, 4 = green, 3 = greenish blue, 2 = blue, and 1 = brown) to denote the fat color. The trained panelists also scored the off-odor level of designated steaks on days 0-, 3-, and 5-post cutting. An odor intensity scale ranging from 5 (no off-odor) to 1 (extreme off-odor) was used, as well as an off-odor characterization score, which identified the odor.

Light and temperature measurements also were taken using an environmental quality meter (850071, Sper Scientific Ltd., Scottsdale, AZ), a Dickson data logger (SM-325, Dickson Data, Addison, IL), and a Dickson chart recorder (KT6). The Sper Scientific light and humidity probes used in association with the environmental quality meter were models 850075 and 850074, respectively.

Microbiological sampling and analysis

On Day 0, vacuum-packaged bone-in strip loins (n=30) and boneless top sirloin butts (n=30) designated for dry-aged treatment were sampled. The wet-aged strip loins and top sirloin butts were not sampled (the sample served as the baseline for both wet- and dry-aged products). For microbial sampling, the vacuum packaged bag was opened aseptically, and three 10-cm^2 x 2 mm surface samples were excised using a sterile scalpel and forceps from the dorsal subcutaneous fat of each loin and top sirloin butt. Samples then were placed into sterile stomacher bags, packed into an insulated cooler with refrigerant packs, and transported to the Texas A&M University Food Microbiology Laboratory for analysis. On 21, 28, and 35 d of storage, microbiological sampling of each subprimal (bone-in strip loin or boneless top butt), as well as for each treatment (dry or wet) was performed as described above. The sampling was done prior to cutting steaks.

On 0, 3, and 5 d of storage, steaks were transported to the Food Microbiology Laboratory for analyses. Steaks were sampled by aseptically opening the package and using a sterile stainless steel borer, scalpel, and forceps to remove a 10-cm2 x 2 mm surface sample. The sample was placed into a sterile stomacher bag. Ninety-nine ml of sterile 0.1% peptone was added to each stomacher bag containing the sample and was then pummeled for 1 min using a Tekmar Stomacher Lab-Blander 400 (Tekmar Co., Cincinnati, OH). APCs were conducted by plating appropriate dilutions of the sample homogenate onto Petrifilm™ Aerobic Count Plates (3M Microbiology Products, St. Paul, MN), incubating at room temperature (~20 °C) for 48 h, then counting and reporting the APC per cm^2. LABs were determined by pour plating and over laying with de Man, Regosa, Sharpe agar (MRS; Difco Laboratories, Sparks, MD) the appropriate sample homogenate and incubated aerobically at 25 $\pm$ 1 °C for 72 h before reporting as LAB per cm^2. Yeast and mold counts were conducted by plating appropriate homogenate dilutions onto Petrifilm™ (3M) Yeast and Mold Count Plates and incubating at 20-25 °C for 5 d before counting and reporting per cm^2.

Statistical analyses

Significant interactions ($P < 0.05$) were analyzed using SAS PROC GLM (SAS Institute, Cary, NC). Interactions that were not significant ($P > 0.05$) were removed from the model. Analysis of variance was performed with SAS PROC GLM (SAS Institute, Cary, NC), and when significant differences occurred, least squares means were separated using the PDIFF option at $P < 0.05$. Frequency tables were created using the PROC FREQ program of SAS. Microbiological count data were transformed into logarithms before obtaining the means and performing statistical analyses. In the case of counts below the detection limit of the counting method, a number between 0 and the lowest detection limit was used in order to facilitate the data analysis (see Figures 3-5).

	Day 21 (0 d)	Day 22 (1 d)	Day 23 (2 d)	Day 24 (3 d)	Day 25 (4 d)	Day 26 (5 d)
Steak 1	Visual, odor, and micro analysis					
Steak 2	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis		
Steak 3	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis

Figure 3 Steak Analysis Table: 21 Day Cutting

	Day 28 (0 d)	Day 29 (1 d)	Day 30 (2 d)	Day 31 (3 d)	Day 32 (4 d)	Day 33 (5 d)
Steak 1	Visual, odor, and micro analysis					
Steak 2	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis		
Steak 3	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis

Figure 4 Steak Analysis Table: 28 Day Cutting

	Day 35 (0 d)	Day 36 (1 d)	Day 37 (2 d)	Day 38 (3 d)	Day 39 (4 d)	Day 40 (5 d)
Steak 1	Visual, odor, and micro analysis					
Steak 2	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis		
Steak 3	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual analysis	Visual, odor, and micro analysis

Figure 5 Steak Analysis Table: 35 Day Cutting

CHAPTER III

RESULTS

Environmental factors

The average temperature during the study ranged from 1.7 °C to 1.8 °C depending on which temperature monitoring device was used. When the temperature of the storage cooler rose above 4 °C, as indicated by the maximum values above (5.9 and 7.4 °C), the surface temperature of the product was taken and recorded. This practice is common in industry to ensure proper safe handling of food when momentary, high temperature (>4.44 °C) situations occur. Moreover, the average percent relative humidity during this project was 49.2% (Table 1).

The lighting units that illuminated the retail overwrapped steaks throughout the duration of the experiment emitted a mean lux measurement of 2449.6 with a standard deviation of 307.6 (Table 1). Furthermore, the minimum and maximum lux values were 1885 and 2977 (Table 1).

Table 1

Simple means for temperature, relative humidity, and lux measurements

Label	Mean	SD	Min	Max
Relative Humidity (%)	49.2	4.0	39.4	56.7
Chart Recorder (°C)	1.7	2.1	-2.5	5.9
Data Logger (°C)	1.8	2.0	-1.0	7.4
Lux	2449.6	307.6	1885.0	2977.0

Subprimal yield

Least squares means of subprimal yields (as defined by initial carcass final weight of the subprimal) stratified by aging treatment (wet- vs. dry-aged), aging period (21 d, 28 d, and 35 d), subprimal type (loin vs. sirloin), and USDA Quality Grade are shown in Table 2. Yields were statistically impacted by aging treatment ($P = < .0001$), aging period ($P = .0011$), and subprimal type ($P = <.0001$). However, yields were not statistically impacted by USDA Quality Grade ($P = .5166$). As predicted, wet-aged subprimals exhibited a significantly higher yield than did dry-aged subprimals. Furthermore, 21 day aged subprimal yields were considerably higher statistically than day 28 and day 35 subprimals. Also, loin yields were statistically higher than sirloin yields. Potentially, the bone-in loins provided more protection from the environment, and therefore, allowed less yield loss. There was no statistical yield difference between USDA Choice subprimals and USDA Select subprimals (Table 2).

Table 2
Least squares means of subprimal yields stratified by aging treatment, aging period, subprimal type, and USDA Quality Grade.

Main effects	Yields (%)
Aging treatment	
Wet-aged	98.87a
Dry-aged	88.12b
Aging period	
21 d	94.69a
28 d	93.06b
35 d	92.74b
Subprimal type	
Loin	94.48a
Sirloin	92.52b
USDA Quality Grade	
Choice	93.64a
Select	93.35a

Means within the same column lacking a common letter (a-b) differ ($P < 0.05$).

Least squares means of subprimal yields stratified by aging period × aging treatment are shown in Table 3. The least squares means for this interaction were statistically different ($P = .0108$). However, wet-aged product yields did not differ statistically. On the other hand, dry-aged, 21 d yields were statistically higher ($P < 0.05$) than dry-aged yields from the 28 d and 35 d aging periods. There was no statistical yield difference seen between dry-aging periods 28 and 35 indicating that after the surface of the cuts dried, weight loss rate declined dramatically.

Table 3
Least squares means of subprimal yields stratified by aging period × aging treatment

Interaction	Yield (%)
Wet-aged	
21 d	99.12a
28 d	98.70a
35 d	98.78a
Dry-aged	
21 d	90.27b
28 d	87.42c
35 d	86.69c

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

Table 4 lists the least squares means for subprimal yields stratified by aging treatment × subprimal type. This interaction was statistically different ($P = .0109$). The yield for wet-aged loins and sirloins was not statistically different. Dry-aged loins had higher yields statistically ($P < 0.05$) than did dry-aged sirloins. Suggesting that either subprimal type and/or bone-in versus boneless subprimals affected the amount of weight lost during aging.

Table 4
Least squares means of subprimal yields stratified by aging treatment × subprimal type

Interaction	Yield (%)
Wet-aged	
Loin	99.27a
Sirloin	98.47a
Dry-aged	
Loin	89.68b
Sirloin	86.57c

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

Microbial growth

Least squares means of subprimal microbiological counts stratified by aging period and aging treatment are shown in Table 5. The APC (P = .0054), LAB (P = < .0001), and YM counts (P < .0001) were all impacted by aging period. Aerobic plate counts were not statistically different when stratified by aging treatment (P = .6202). However, aging treatment statistically impacted lactic acid bacteria (P = < .0001) and yeast and mold counts (P = < .0001). Since wet-aged subprimals were not sampled for microbiological testing on day 0, no data were available for statistical analysis, thus making the associated least squares means non-estimable for day 0 subprimals and all wet-aged subprimals. Increasing aging period from 21 d to 28 d resulted in statistical differences in APC and LAB counts, as indicated by higher values. However, YM counts between 21 d and 28 d were indifferent statistically. 35 d counts for APC and LAB were slightly lower than the respective counts taken on 28 d, however these values were not statistically different. 35 d YM counts were higher than 28 d YM counts, and were determined to be statistically different.

Table 5

Least squares means of subprimal microbiological counts stratified by aging period and aging treatment

Main effects	Aerobic Plate Count (log CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold (log CFU/cm^2)
Aging period			
0 d		-	-
21 d	4.23b	3.10c	1.50b
28 d	5.38a	4.58a	1.71b
35 d	5.12a	4.01b	2.04a
Aging treatment			
Wet-aged	-	-	-
Dry-aged	4.85	3.27	2.05

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

Least squares means of steak microbiological counts stratified by aging period, retail steak shelf-life day, USDA Quality Grade, steak type, and aging treatment are shown in table 6. Aerobic plate counts were statistically impacted by aging period ($P = < .0001$), retail steak shelf-life day ($P = < .0001$), steak type ($P = < .0001$), and aging treatment ($P = .0199$). Aerobic plate counts did not differ statistically when stratified by USDA Quality Grade ($P = .6108$). Lactic acid bacteria were statistically impacted by aging period ($P = < .0001$), retail steak shelf-life day ($P = < .0001$), steak type ($P = < .0001$), and aging treatment ($P = < .0001$). USDA Quality Grade did not statistically impact lactic acid bacteria counts ($P = .9257$). Yeast and mold counts were statistically different when stratified by aging period ($P = < .0001$), retail steak shelf-life day ($P = < .0001$), USDA Quality Grade ($P = .0351$), steak type ($P = .0037$), and aging treatment ($P = < .0001$). APC, LAB, and YM counts all increased as aging period increased from 21 d to 28 d, and finally to 35 d. As expected, microbiological counts also increased as retail steak shelf-life day increased from day 0 to day 3, and day 3 to day 5. No microbiological differences were noticed between USDA Quality Grades (Choice and Select) for APC and LAB. However, Select steaks exhibited statistically higher YM counts than did Choice steaks. Also, top loin steaks showed statistically higher counts for APC, LAB, and YM than did top sirloin steaks. APC and LAB counts were statistically higher in wet-aged steaks, whereas YM counts were statistically higher in dry-aged product.

Table 6
Least squares means of steak microbiological counts stratified by aging period, retail steak shelf-life day, USDA Quality Grade, steak type, and aging treatment

Main effects	Aerobic Plate Count (log CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold (log CFU/cm^2)
Aging period			
21 d	3.82c	3.15c	1.17b
28 d	4.50b	3.77b	1.29b
35 d	4.85a	4.02a	1.56a
Retail steak shelf-life day			
Day 0	3.99c	3.52b	1.10c
Day 3	4.31b	3.52b	1.30b
Day 5	4.87a	3.90a	1.61a
USDA Quality Grade			
Choice	4.37a	3.65a	1.23b
Select	4.41a	3.64a	1.40a
Steak type			
Top loin	4.67a	3.92a	1.42a
Sirloin	4.11b	3.37b	1.25b
Aging treatment			
Wet-aged	4.48a	4.41a	0.90b
Dry-aged	2.30b	2.89b	1.78a

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

Table 7 provides the least squares means of steak microbiological counts stratified by aging period × retail steak shelf-life day. The APC ($P = .0005$) and YM count ($P = < .0001$) differed statistically when stratified by aging period × retail steak shelf-life day.

However, LAB counts did not differ (P = .6381) when stratified by aging period × retail steak shelf-life day. APC and LAB counts increased as aging period and retail steak shelf-life day increased. However, few differences in YM growth were noticed during aging period 21 for retail shelf-life days 0, 3, and 5. On the other hand, YM counts grew proportionally through aging periods 28 and 35 and their respective retail shelf-life days (0, 3, 5).

Table 7

Least squares means of steak microbiological counts stratified by aging period × retail steak shelf-life day

Interactions	Aerobic Plate Count (log CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold log CFU/cm^2)
21 d			
Day 0	3.64d	2.93d	1.34c
Day 3	3.71d	3.04d	0.95d
Day 5	4.12c	3.49c	1.19cd
28 d			
Day 0	4.21c	3.74bc	0.97d
Day 3	4.37c	3.64bc	1.26c
Day 5	4.91b	3.93b	1.62b
35 d			
Day 0	4.11c	3.89b	0.97d
Day 3	4.86b	3.89b	1.68b
Day 5	5.60a	4.29a	2.04a

Means within the same column lacking a common letter (a-d) differ (P < 0.05).

The least squares means of steak microbiological counts stratified by aging period × aging treatment are shown in Table 8. The APC (P = 0.0006), LAB (P < 0.0001), and YM counts (P < 0.0001) were different when stratified by aging period × aging treatment. Wet-aged counts for APC and LAB differed between 21 d and 28 d. However, there was no difference noted for these counts between 28 d and 35 d. YM counts did not differ for wet-aged samples taken from aging periods 21 d, 28 d, and 35 d.

APC, LAB, and YM counts obtained from dry-aged steaks increased as aging period increased from 21 d to 28 d and from 28 d to 35 d.

Table 8
Least squares means of steak microbiological counts stratified by aging period × aging treatment

Interactions	Aerobic Plate Count (log CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold (log CFU/cm^2)
Wet-aged			
21 d	3.94c	3.82b	1.00d
28 d	4.77a	4.77a	0.81d
35 d	4.74a	4.63a	0.89d
Dry-aged			
21 d	3.70c	2.49e	1.33c
28 d	4.22b	2.77d	1.76b
35 d	4.96a	3.41c	2.34a

Means within the same column lacking a common letter (a-d) differ ($P < 0.05$).

Table 9 shows the least squares means of steak microbiological counts stratified by retail steak shelf-life day × aging treatment. The APC ($P = 0.0006$), LAB ($P < 0.0001$), and YM ($P < 0.0001$) counts were influenced by aging treatment interactions with retail shelf-life day. Wet-aged steaks exhibited higher APC counts between day 0 and day 3 of retail steak shelf-life. Also, wet-aged steaks experienced more LAB growth, statistically, between retail shelf-life days 3 and 5. However, little difference in YM counts was observed in wet-aged steaks for retail steak shelf-life days 0, 3, and 5. Dry-aged steaks exhibited no change in APC and LAB counts between days 0 and 3; however, dry-aged steak APC and LAB counts were higher between day 3 and 5. The

YM counts for dry-aged steaks were greater across days 0, 3, and 5. These YM counts increased as retail steak shelf-life day increased.

Table 9
Least squares means of steak microbiological counts stratified by retail steak shelf-life day × aging treatment

Interactions	Aerobic Plate Count log (CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold (log CFU/cm^2)
Wet-aged			
Day 0	4.13c	4.26b	0.92d
Day 3	4.55b	4.32b	0.84d
Day 5	4.78ab	4.64a	0.94d
Dry-aged			
Day 0	3.85d	2.78d	1.28c
Day 3	4.07cd	2.73d	1.76b
Day 5	4.97a	3.16c	2.29a

Means within the same column lacking a common letter (a-d) differ ($P < 0.05$).

Table 10 exhibits the least squares means of steak microbiological counts stratified by USDA Quality Grade × steak type. This interaction was statistically different when used to determine the least squares means for APC counts ($P = 0.0179$). However, least square means for this interaction involving LAB ($P = 0.1172$) and YM ($P = 0.0596$) were not different. USDA Choice top sirloin steaks had lower APC counts when compared to USDA Select top sirloin steaks. No other differences were noted involving the interactions between steak type and USDA Quality Grade, except that USDA Choice top loin steaks had less YM counts than did USDA Select top loin steaks.

Table 10

Least squares means of steak microbiological counts stratified by USDA Quality Grade × steak type

Interactions	Aerobic Plate Count (log CFU/cm^2)	Lactic Acid Bacteria (log CFU/cm^2)	Yeast and Mold (log CFU/cm^2)
Top sirloinSteak			
Choice	4.00c	3.32b	1.24b
Select	4.23b	3.43b	1.26b
Top loin Steak			
Choice	4.74a	3.99a	1.31b
Select	4.59a	3.86a	1.54a

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

Least squares means of microbiological counts stratified by aging period × steak type × aging treatment are shown in Table 11. Of these, the least squares means for APC (P = .0002) and YM (P = .0496) counts were statistically different, unlike those for LAB (P = .89061). In general, all counts increased as aging period increased. All APC counts for wet-aged top loin steaks, given any aging period, were higher than the APC count for the respective dry-aged top loin steak. Dry-aged top sirloin steaks, from aging periods 28 and 35, had higher APC counts than did wet-aged top sirloin steaks sampled during the same aging periods. The LAB counts were much higher in wet-aged steaks than in the dry-aged steaks regardless of aging period. However, most LAB growth in the wet-aged steaks took place between aging period 21 and 28, whereas the most dry-aged LAB growth (seen in the top loin steaks) was observed between aging periods 28 and 35. The LAB counts for dry-aged top sirloin steaks increased proportionally to length of aging period. The YM counts in wet-aged steaks were for the most part were not different. However, the dry-aged steaks exhibited higher YM counts, which increased as aging period increased. Dry-aged top loin steaks experienced the most YM growth between aging periods 28 and 35, whereas YM counts for dry-aged top sirloin steaks increased more linearly.

Table 11

Least squares means of steak microbiological counts stratified by aging period × steak type × aging treatment

Interactions	Wet-aging						Dry-aging					
	Top loin steak			Top sirloin steak			Top loin steak			Top sirloin steak		
	21 d	28 d	35 d	21 d	28 d	35 d	21 d	28 d	35 d	21 d	28 d	35 d
APC (log CFU/cm^2)	4.41de	5.37a	5.32a	3.48g	4.17ef	4.17ef	3.97f	3.82fg	5.12ab	3.43g	4.63cd	4.80bc
LAB (log CFU/cm^2)	4.23b	5.00a	4.94a	3.40cd	4.54b	4.32b	2.82ef	2.86ef	3.67c	2.16g	2.68f	3.15de
Yeast and Mold (log CFU/cm^2)	1.04d	0.90de	0.85de	0.96de	0.72e	0.93de	1.58c	1.76c	2.42a	1.08d	1.77c	2.05b

Means within the same row lacking a common letter (a-g) differ (P < 0.0

Least squares means of visual sensory attributes for 21 d aging period, retail steak shelf-life day 0, 1, and 2 stratified by sensory evaluation day, aging treatment, steak type, and USDA Quality Grade are shown in Table 12. Fat color least squares means for steak type (P = 0.0988) and USDA Quality Grade (P = 0.0649) did not differ statistically. On retail steak shelf-life day 2, panelists noted a significant change in surface discoloration (P < 0.0001) and fat color (P = 0.0001). "Steak has good color" significantly (P < 0.0001) decreased as retail steak shelf-life day increased from day 0 to 1 and from 1 to 2. Wet-aged steak scores were better (P < 0.0001) than dry-aged steaks when analyzed for surfaced discoloration, fat color, and steak has good color. Top loin steaks exhibited significantly less surface discoloration (P < 0.0001) and a higher "steak has good color" score than did top sirloin steaks (P < 0.0001). No statistical differences (P = 0.0988) in fat color between top sirloin and top loin steaks were recorded by panelists. USDA Choice steaks received a lower (P < 0.0001) surface discoloration score from panelists, and a higher "steak has good color score" (P < 0.0001) than did Select steaks. There were no differences (P = 0.0649) for fat color found between Choice and Select steaks.

Table 12

Least squares means of visual sensory attributes for 21 d aging period, retail steak shelf-life day 0, 1, and 2 stratified by sensory evaluation day, aging treatment, steak type, and USDA Quality Grade

Main effects	Surface Discoloration[A]	Fat Color[B]	Steak Has Good Color[C]
Aging treatment			
Wet-aged	1.46b	1.79b	5.94a
Dry-aged	1.85a	2.29a	5.17b
Steak type			
Top loin	1.56b	2.09a	5.68a
Sirloin	1.75a	1.99a	5.43b
USDA Quality Grade			
Choice	1.58b	1.99a	5.78a
Select	1.74a	2.09a	5.33b

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).

[A] 7 = Total discoloration; 1 = no discoloration.

[B] 5 = Yellow; 4 = moderately yellow; 3 = slightly yellow; 2 = creamy white; 1 = white.

[C] 7 = Very strongly agree; 1 = very strongly disagree.

Table 13 shows least squares means of visual sensory attributes for 21 d aging period, retail steak shelf-life days 3, 4, and 5 through 35 d aging period, retail steak shelf-life day 5 stratified by retail steak shelf-life day × aging period. As expected, surface discoloration scores ($P = 0.0077$) and fat discoloration scores ($P < 0.0001$) increased as retail steak shelf-life day and aging period increased. Also, as expected “steak has good color” scores decreased as aging period and retail steak shelf-life day increased. However, the differences for “steak has good color” score were not significant ($P = 0.4365$). Regardless of statistical significance, it is easy to see that the decline in “steak has good color” score was linear to length of aging period and retail steak shelf-life day.

Table 13

Least squares means of visual sensory attributes for retail steaks stratified by retail steak shelf-life day × aging period

Main effects	Surface Discoloration[A]	Fat Discoloration Scale 2[B]	Steak Has Good Color[C]
Retail steak shelf-life day			
21 d			
Day 0	1.54i	-	5.85a
Day 1	1.55i	-	5.63b
Day 2	1.87h	-	5.19c
Day 3	2.17g	2.40i	4.59e
Day 4	2.85e	2.85g	4.00g
Day 5	3.44c	3.46cd	3.30j
28 d			
Day 0	1.59i	2.22j	5.22c
Day 1	1.86h	2.40i	4.97d
Day 2	2.18g	2.67h	4.54ef
Day 3	2.38f	3.02ef	3.99g
Day 4	3.12d	3.31d	3.43ij
Day 5	4.05b	3.59bc	2.83k
35 d			
Day 0	2.30fg	2.56h	4.69e
Day 1	2.40f	2.94fg	4.37f
Day 2	2.96de	3.03ef	3.80gh
Day 3	3.15d	3.13e	3.60hi
Day 4	4.04b	3.74b	2.67i
Day 5	5.03a	3.95a	2.11j

Means within the same column lacking a common letter (a-k) differ ($P < 0.05$).
[A] 7 = Total discoloration; 1 = no discoloration.
[B] 5 = Severly discolored; 4 = moderately discolored; 3 = slightly discolored; 2 = creamy white; 1 = white.
[C] 7 = Very strongly agree; 1 = very strongly disagree.

Table 14 shows the least squares means of fat color (scales 1 and 2) stratified by aging period, aging treatment, steak type, and USDA Quality Grade. Scale 1 was used for retail steak shelf-life days 0, 1, and 2 of the 21 d aging period before it was modified (Scale 2) and used for the remainder of the study. It is important to note that there was 1119 observations recorded and analyzed using scale 1, whereas 4000 observations were recorded and analyzed using scale 2. Therefore, results from scale 1 and scale 2 should not be compared. Fat discoloration score was higher ($P < 0.0001$), when referring to fat discoloration scale 2, for steaks from 35 d aging period as opposed to 21 d and 28 d aging period. Wet-aged steaks received higher ($P < 0.0001$) fat discoloration scores (scales 1 and 2) than did dry-aged steaks. Also, according to panelists' observations when using scale 2, top sirloin steaks were ($P < 0.0001$) less discolored than were top loin steaks. No statistical differences ($P = 0.2890$) in fat discoloration were observed between USDA Quality Grades Choice and Select steaks, when the steaks were analyzed using scale 2. However, scale 1 revealed differences ($P < 0.0001$) in fat discoloration due to USDA Quality Grade differences among steaks. Again, scale 1 was only used to evaluate steaks on retail steak shelf-life days 0, 1, and 2 of the 21 d aging period. Therefore, this trend cannot be extrapolated to fit the rest of the retail steak shelf-life days or aging periods in this study, as seen by the panelists' different observations using scale 2 for the remainder of the study.

Table 14
Least squares means of fat color (scales 1 and 2) stratified by aging period, aging treatment, steak type, and USDA Quality Grade

Main effects	Fat Discoloration Scale 1[A]	Fat Discoloration Scale 2[B]
Aging period		
21	2.02	2.78b
28	-	2.70b
35	-	3.05a
Aging treatment		
Wet-aged	2.30a	3.06a
Dry-aged	1.75b	2.63b
Steak type		
Top loin	2.06a	2.91a
Sirloin	1.99a	2.77b
USDA Quality Grade		
Choice	1.97b	2.86a
Select	2.08a	2.83a

Means within the same column lacking a common letter (a-b) differ (*P* < 0.05).
[A] 5 = Yellow; 4 = moderately yellow; 3 = slightly yellow; 2 = creamy white; 1 = White.
[B] 5 = Severly discolored; 4 = moderately discolored; 3 = slightly discolored; 2 = creamy white; 1 = white.

As seen in Table 15, off-odor intensity increased (*P* < 0.0001), and somewhat linearly as aging period progressed. Also, wet-aged steaks received lower (*P* = 0.0462) off-odor scores than dry-aged steaks, thus indicating higher levels of detectable off-odors. In addition, panelists' observations of detectable off-odors were greater (*P* = 0.0020) for top sirloin steaks than top loin steaks. As retail shelf-life day increased, the detectable off-odor level for all retail steaks increased (*P* < 0.0001). A statistical difference was noticed where Select steaks had greater detectable levels of off-odors than Choice steaks.

Table 15
Least squares means of steak off-odor intensity stratified by aging period, aging treatment, steak type, retail steak shelf-life day, and USDA Quality Grade.

Main effects	Off-odor Intensity[A]
Aging period	
21	4.39a
28	4.18b
35	3.74c
Aging treatment	
Dry	4.19a
Wet	4.02b
Steak type	
Top loin	4.23a
Sirloin	3.97b
Retail shelf-life day	
0	4.74a
3	4.16b
5	3.41c
USDA Quality Grade	
Choice	4.16a
Select	4.04b

Means within the same column lacking a common letter (a-c) differ ($P < 0.05$).
[A] 5 = No off-odor; 1 = extreme off-odor.

Table 16 shows the least squares means of steak off-odor intensity stratified by aging treatment × steak type × retail shelf-life day. Off-odor increased for both aging treatments and steak types as retail steak shelf-life day increased.

Least squares means for steak off-odor intensity stratified by USDA Quality Grade × steak type × aging period are shown in Table 17. Increased aging period resulted in greater detectable off-odor for the Choice top sirloin steaks and the Select top sirloin steaks compared to the Choice top loin steaks.

Table 16

Least squares means of steak off-odor intensity stratified by aging treatment × steak type × retail steak shelf-life day.

Interactions	Wet-aging						Dry-aging					
	Top loin steak			Top sirloin steak			Top loin steak			Top sirloin steak		
	0 d	3 d	5 d	0 d	3 d	5 d	0 d	3 d	5 d	0 d	3 d	5d
Off-odor intensity^{A}	4.88a	3.88e	3.28f	4.71ab	4.19d	3.17fg	4.76ab	4.45c	4.13d	4.59bc	4.11d	3.08g

Means within the same row lacking a common letter (a-g) differ ($P < 0.05$)

^{A} 5 = No off-odor; 1 = extreme off-odor.

Table 17

Least squares means of steak off-odor intensity stratified by USDA Quality Grade × steak type × aging period.

Interactions	USDA Choice						USDA Select					
	Top loin steak			Top sirloin steak			Top loin steak			Top sirloin steak		
	21 d	28 d	35 d	21 d	28 d	35 d	21 d	28 d	35 d	21 d	28 d	35 d
Off-odor intensity^{A}	4.60a	4.34b	4.06de	4.27bc	4.12cde	3.59f	4.60ab	4.31bc	3.64f	4.25bcd	3.94e	3.68f

Means within the same row lacking a common letter (a-f) differ ($P < 0.05$)

^{A} 5 = No off-odor; 1 = extreme off-odor.

Table 18 shows the panelists' responses for surface discoloration. Severity of discoloration increased as length of aging period increased. Similarly, as expected, severity of discoloration increased as retail steak shelf-life day increased. Wet-aged steaks exhibited less surface discoloration (41.95% no discoloration; 58.05% possessed slight or worse discoloration) when compared to dry-aged steaks (12.81% no discoloration; 87.19% possessed slight or worse discoloration). Little difference in surface discoloration was noticed between top loin steaks and top sirloin steaks, as well as between Choice steaks and Select steaks.

Frequency of steak has good color panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf-life day 5 of the 35 d aging period are shown in Table 19. As aging period increased, the steak color became less appealing to panelists. As expected, steak color was less appealing as retail steak shelf-life day increased. Additionally, wet-aged steak received much higher "steak has good color" entries (66.23% slightly agree or better; 33.77% no opinion or worse) than dry-aged steaks (42.34% slightly agree or better; 57.66% no opinion or worse). Top loin steaks performed slightly better than top sirloin steaks on the steak has good color scale. No obvious differences were seen between Choice and Select steaks.

Table 18

Frequency of panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf-life day 5 of the 35 d aging period for surface discoloration

	Surface Discoloration							
	1	2	3	4	5	6	7	
	No Discoloration[A]	Slight Discoloration[B]	Small Discoloration[C]	Modest Discoloration[D]	Moderate Discoloration[E]	Extensive Discoloration[F]	Total Discoloration[G]	Total Responses
Aging period								
21	548	904	188	43	30	33	14	1760
28	540	739	251	85	52	57	36	1760
35	314	509	274	177	119	115	92	1600
Total	1402	2152	713	305	201	205	142	5120
Retail steak shelf-life day								
0	617	637	100	35	30	17	4	1440
1	326	478	97	28	15	14	2	960
2	191	447	133	58	22	23	6	880
3	176	375	171	69	44	36	9	880
4	64	126	115	55	36	47	37	480
5	28	89	97	60	54	68	84	480
Total	1402	2152	713	305	201	205	142	5120
Treatment								
Wet-Aged	1074	830	263	148	87	89	69	2560
Dry-Aged	328	1322	450	157	114	116	73	2560
Total	1402	2152	713	305	201	205	142	5120
Subprimal								
Strip	825	1025	363	140	88	78	41	2560
Sirloin	577	1127	350	165	113	127	101	2560
Total	1402	2152	713	305	201	205	142	5120
Grade								
Select	681	1050	375	159	92	110	93	2560
Choice	721	1102	338	146	109	95	49	2560
Total	1402	2152	713	305	201	205	142	5120

[A] No discoloration = (0%)
[B] Slight discoloration = (1-19%)
[C] Small discoloration = (20-39%)
[D] Modest discoloration = (40-59%)
[E] Moderate discoloration = (60-79%)
[F] Extensive discoloration = (80-99%)
[G] Total discoloration = (100%)

Table 19

Frequency of steak has good color panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf-life day 5 of the 35 d aging period

	Steak Has Good Color							
	1	2	3	4	5	6	7	
	Very Strongly Disagree	Strongly Disagree	Slightly Disagree	No Opinion	Slightly Agree	Strongly Agree	Very Strongly Agree	Total
Aging period								
21 d	31	64	167	256	504	460	277	1759
28 d	89	186	304	249	402	256	271	1757
35 d	166	264	337	226	221	228	158	1600
Total	286	514	808	731	1127	944	706	5116
Retail steak shelf-life day								
Day 0	14	57	206	152	266	333	411	1439
Day 1	10	53	134	115	242	240	165	959
Day 2	22	80	117	146	251	190	73	879
Day 3	35	113	153	190	239	115	35	880
Day 4	77	91	99	78	75	45	14	479
Day 5	128	120	99	50	54	21	8	480
Total	286	514	808	731	1127	944	706	5116
Treatment								
Wet-Aged	131	188	239	306	553	545	596	2558
Dry-Aged	155	326	569	425	574	399	110	2558
Total	286	514	808	731	1127	944	706	5116
Subprimal								
Strip	122	224	424	371	523	511	385	2560
Sirloin	164	290	384	360	604	433	321	2556
Total	286	514	808	731	1127	944	706	5116
Grade								
Select	172	262	421	368	540	427	367	2557
Choice	114	252	387	363	587	517	339	2559
Total	286	514	808	731	1127	944	706	5116

Table 20 shows the frequency of panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf-life day 5 of the 35 d aging period for off odor. The majority (66.18%) of off-odor responses for aging period 21 d steaks were no off-odor. The 28 d aging period majority was nearly split between no off-odor (41.67%) and slight off-odor (41.46%). However, the top three responses for the 35 d aging period steaks were no off-odor (30.61%), slight off-odor (32.43%), and small off-odor (22.22%). This indicates that as aging period increase, more off-odors were detectable. This same trend was seen in the length of retail steak shelf-life days. Dry-aged steaks performed slightly better than wet-aged steaks in the off-odor analysis. Dry-aged steaks received no off-odor scores 50.71% of the time, slight off-odor scores 29.26% of the time, and small off-odor scores 11.2% of the time. In comparison, wet-aged steaks received no off-odor scores 42.39% of the time, slight off-odor scores 29.45% of the time, and small off-odor scores 18.82% of the time. Top loin steaks received fewer scores for off-odor than did top sirloin steaks. Top loin steaks received extreme off-odor scores 1.71% of the time, moderate off-odor scores 5.00% of the time, and small off-odors 12.57% of the time, whereas sirloins received extreme off-odor scores 2.14% of the time, moderate off-odor scores 9.29% of the time, and small off-odors 17.43% of the time. Additionally, 52.43% of top loin steaks were scored as having no off-odor, whereas 40.71% of top sirloin steaks scored as not having an off-odor. Choice steaks performed slightly better than Select steaks as evidenced by less detection of off-odors.

Table 20
Frequency of panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf-life day 5 of the 35 d aging period for off odor

	Off-odor					
	1	2	3	4	5	
	Extreme Off-odor	Moderate Off-odor	Small Off-odor	Slight Off-odor	No Off-odor	Total Responses
Aging period						
21 d	6	28	59	69	317	479
28 d	6	22	53	199	200	480
35 d	15	50	98	143	135	441
Total	27	100	210	411	652	1400
Retail steak shelf-life day						
Day 0	1	2	21	76	381	481
Day 3	2	21	58	163	195	439
Day 5	24	77	131	172	76	480
Total	27	100	210	411	652	1400
Treatment						
Wet-Aged	13	52	131	205	295	696
Dry-Aged	14	48	79	206	357	704
Total	27	100	210	411	652	1400
Subprimal						
Strip	12	35	88	198	367	700
Sirloin	15	65	122	213	285	700
Total	27	100	210	411	652	1400
Grade						
Select	17	56	113	201	319	706
Choice	10	44	97	210	333	694
Total	27	100	210	411	652	1400

Table 21 shows the frequency of panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf life day 5 of the 35 d aging period for off odor characterization. The percentages following this statement were calculated using only the off-odor characteristic scores, thus excluding N/A entries meaning no off-odor was detected. When off-odors were detected the top three off-odor characteristics for the 21 d aging period were sweet (32.10%), putrid (27.16%), and sour (25.31%). Again, when off-odors were detected the top three off-odor characteristics for the 28 d aging period were sweet (39.15%), sour (29.54%), and putrid (21.35%). Finally, when off-odors were detected the top three off-odor characteristics for the 35 d aging period were sweet (34.10%), putrid (30.49%), and sour (21.97%). The top three most common off-odor characteristics for retail steak shelf-life days 0 and 3 were: sweet, sour, and putrid. The top three most common off-odor characteristics for retail steak shelf-life day 5 were: putrid, sweet, and sour. The most common off-odor characteristics for dry-aged steaks were putrid (32.29%), sweet (29.71%), and sour (21.71%), whereas the most common off-odor characteristics for wet-aged steaks were sweet (40.70%), sour (28.89), and putrid (21.11%). Top three off-odor characteristics for top sirloin steaks were sweet (34.30%), putrid (31.64%), and sour (22.71%). The top three off-odor characteristics for top loin steaks were sweet (37.13%), sour (29.04%), and putrid (19.76%). Choice steaks exhibited sweet (37.02%), sour (24.86%), and putrid (24.59%) characteristics of the top three most common off-odors. In contrast, 34.20% of Select steaks that exhibited some characteristic of off-odor were sweet smelling, 27.98% were putrid smelling, and 26.17% were sour smelling.

Table 21

Frequency of panel responses for retail steak shelf-life day 0 of the 21 d aging period through retail steak shelf life day 5 of the 35 d aging period for off odor characterization

	Off-odor Characterization							
	0	1	2	3	4	5	6	
	N/A	Other	Arid	Sweet	Sour	Acid	Putrid	Total Responses
Aging period								
21 d	160	2	16	52	41	7	44	322
28 d	0	0	19	110	83	9	60	281
35 d	0	4	17	104	67	20	93	305
Total	160	6	52	266	191	36	197	908
Retail steak shelf-life day								
Day 0	160	0	7	49	22	8	14	260
Day 3	0	2	9	99	88	11	34	243
Day 5	0	4	36	118	81	17	149	405
Total	160	6	52	266	191	36	197	908
Treatment								
Wet-Aged	78	3	20	162	115	14	84	476
Dry-Aged	82	3	32	104	76	22	113	432
Total	160	6	52	266	191	36	197	908
Subprimal								
Strip	79	3	30	124	97	14	66	413
Sirloin	81	3	22	142	94	22	131	495
Total	160	6	52	266	191	36	197	908
Grade								
Select	85	2	25	132	101	18	108	471
Choice	75	4	27	134	90	18	89	437
Total	160	6	52	266	191	36	197	908

Table 22 shows the frequency of panel responses for retail shelf-life days 0, 1, and 2 of the 21 d aging period for fat color. The majority of wet- and dry-aged steaks had creamy white fat color characteristics. Wet-aged steaks possessed white fat color characteristics as their second most frequent fat color, whereas dry-aged steaks possessed slightly yellow fat color as their second most frequent fat color. The most common fat color for steak type and USDA Quality Grade was creamy white. Second most common fat color for top loin steaks was slightly yellow, whereas the second most common fat color for sirloins was white. In addition, the second most common fat color for Select steaks was slightly yellow, whereas the second most common fat color for Choice steaks was white.

Table 23 shows the frequency of panel responses for retail shelf-life days 3 and 5 of the 21 d aging period to retail shelf-life day 5 of the 35 d aging period for fat discoloration. On average, around 40% of steaks from aging periods 21 d, 28 d, and 35 d exhibited slight fat discoloration. Moderate fat discolorations were seen in 7.97% of 21 d steaks, 12.21% of 28 d steaks, and 24.94% of 35 d steaks. Thus, fat discoloration increased as aging period increased. Also, one can easily see that fat discoloration increased proportional to retail steak shelf-life day. Wet-aged steaks exhibited fat with less discoloration than did fat belonging to dry-aged steaks. Top sirloin steaks had less fat discoloration than did top loin steaks. Also, Select steaks had less fat discoloration than did Choice steaks.

Table 22

Frequency of panel responses for retail shelf-life days 0, 1, and 2 of the 21 d aging period for fat color.

	Fat Discoloration[A]					
	1	2	3	4	5	
	White	Creamy White	Slightly Yellow	Moderately Yellow	Yellow	Total Responses
Treatment						
Wet-aged	224	270	65	0	0	559
Dry-aged	84	235	232	9	0	560
Total	308	505	297	9	0	1119
Steak type						
Top loin	152	247	155	6	0	559
Sirloin	156	258	142	3	0	560
Total	308	505	297	9	0	1119
USDA Quality Grade						
Select	129	263	162	6	0	559
Choice	179	242	135	3	0	560
Total	308	505	297	9	0	1119

Table 23

Frequency of panel responses for retail shelf-life days 3 and 5 of the 21 d aging period to retail shelf-life day 5 of the 35 d aging period for fat discoloration.

	Fat Discoloration[B]					
	1	2	3	4	5	
	White	Creamy White	Slightly Discolored	Moderately Discolored	Severely Discolored	Total Respons es
Aging period						
21 d	24	242	275	51	48	640
28 d	215	500	735	215	95	1760
35 d	102	340	647	399	112	1600
Total	341	1082	1657	665	255	4000
Retail steak shelf-life day						
0	148	375	359	69	9	960
1	84	157	295	94	10	640
2	45	136	253	124	2	560
3	48	261	389	166	16	880
4	12	108	171	102	87	480
5	4	45	190	110	131	480
Total	341	1082	1657	665	255	4000
Treatment						
Wet-aged	266	757	614	247	116	2000
Dry-aged	75	325	1043	418	139	2000
Total	341	1082	1657	665	255	4000
Subprimal						
Strip	161	481	857	360	141	2000
Sirloin	180	601	800	305	114	2000
Total	341	1082	1657	665	255	4000
Grade						
Select	202	553	794	320	131	2000
Choice	139	529	863	345	124	2000
Total	341	1082	1657	665	255	4000

Table 24 shows the frequency of panel responses for retail shelf-life days 3 and 5 of the 21 d aging period to retail shelf-life day 5 of the 35 d aging period for fat color. The most common fat colors for 21 d aging period steaks were greenish blue (32.44%), yellow (23.86%), and yellowish green (21.18%). The most common fat colors for 28 d aging period steaks were yellowish green (25.88%), greenish blue (21.87%), and brown (19.29%). The most common fat colors for 35 d aging period steaks were yellowish green (36.53%), yellow (20.81%), and brown (16.58%). Yellowish green was the most common fat discoloration characteristic noted throughout the retail steak shelf-life days. Yellowish green also was the most common fat discoloration characteristic for dry- and wet-aged steaks. However, the second most common fat discoloration characteristic for dry-aged steaks was greenish blue, and the second most common fat discoloration characteristic for wet-aged steaks was yellow. The most common fat discoloration characteristic for top sirloin and top loin steaks was yellowish green. Yellowish green was also the most common fat discoloration characteristic found in both Choice and Select steaks.

Table 24
Frequency of panel responses for retail shelf-life days 3 and 5 of the 21 d aging period to retail shelf-life day 5 of the 35 d aging period for fat color.

	Fat Color						
	1	2	3	4	5	6	
	Brown	Blue	Greenish Blue	Green	Yellowish Green	Yellow	Total Responses
Aging period							
21 d	15	7	121	62	79	89	373
28 d	202	64	229	95	271	186	1047
35 d	192	21	169	112	423	241	1158
Total	409	92	519	269	773	516	2578
Retail steak shelf-life day							
Day 0	50	22	93	46	161	65	437
Day 1	36	31	103	58	114	56	398
Day 2	49	22	73	20	124	93	381
Day 3	80	6	155	30	172	129	572
Day 4	93	1	61	38	86	81	360
Day 5	101	10	34	77	116	92	430
Total	409	92	519	269	773	516	2578
Treatment							
Wet-aged	179	23	160	76	292	250	980
Dry-aged	230	69	359	193	481	266	1598
Total	409	92	519	269	773	516	2578
Subprimal							
Strip	150	70	278	145	423	291	1357
Sirloin	259	22	241	124	350	225	1221
Total	409	92	519	269	773	516	2578
Grade							
Select	209	46	267	129	364	231	1246
Choice	200	46	252	140	409	285	1332
Total	409	92	519	269	773	516	2578

CHAPTER IV

SUMMARY AND CONCLUSIONS

Subprimal yield differences in this study were significantly different. As expected dry-aged subprimals had lower yields compared to wet-aged subprimals due to moisture loss during the aging period. This yield difference was also noted in the Laster et al. (2008) and Smith et al. (2008) studies. Also, as aging period increased, so did the opportunity for purge loss and evaporation. Therefore, longer periods of aging negatively affected the yield of both dry- and wet-aged subprimals. However, dry-aged subprimal yield, unlike wet-aged subprimal yield, was drastically affected by the length of aging period. Few differences were observed between wet-aged loins and wet-aged sirloins. However a significant difference was seen between dry-aged loins and dry-aged sirloins. Perhaps what caused this difference was that the ventral side of the loins was partially shielded (by lumbar vertebrae and transverse processes) from the cooler atmosphere, thus reducing opportunity for moisture loss, whereas the sirloins were boneless thereby leaving all surfaces directly exposed to the atmosphere of the cooler. Microbial counts (APC, LAB, and YM) increased, in both subprimals and steaks, as length of aging period and/or length of retail steak shelf-life day increased. These findings were similar to those of the Campbell et al. (2001) study. Quality Grade alone, as expected, did not affect microbial counts for APC and LAB. However, YM counts were higher in Select steaks when compared to Choice steaks. Wet-aged steaks compared to dry-aged steaks had higher APC and LAB counts and lower YM counts. The YM counts taken from wet-aged steaks did not change significantly over the length of the different aging periods. Overall, dry-aged steaks received worse panel ratings for surface discoloration, fat color discoloration, and steak has good color. Top loin steaks, as well as Choice steaks received higher panel ratings for surface discoloration and "steak has good color". Surface discoloration, fat discoloration, and "steak has good color" received lower scores as aging period and retail steak shelf-life day increased. Off-odors were more detectable as aging period and retail steak shelf-life day increased, as well as in wet-aged steaks, top sirloin steaks, and Select steaks. The most common off-odors by aging period were: 21 d sweet (32.10%), putrid (27.16%), and sour (25.31%); 28 d sweet (39.15%), sour (29.54%), and putrid (21.35%); 35 d sweet (34.10%), putrid (30.49%), and sour (21.97%). The most common off-odor found in dry-aged steaks was putrid (32.29%), whereas the most common off-odor found in wet-aged steaks was sweet (34.30%). The most common fat colors observed in steaks from the 21 d aging period were: greenish blue (32.4%), yellow (23.86%), and yellowish green (21.18%). Most common fat colors for steaks from the 28 d aging period were: yellowish green (25.88%), greenish blue (21.87%), and brown (19.29%). Additionally, the most common fat colors for steaks from the 35 d aging period were: yellowish green (36.53%), yellow (20.81%), and brown (16.58%). Yellowish green was the most common fat color discoloration seen across all steaks. Given the results of this experiment, steaks most susceptible to undesirable visual retail characteristics included dry-aged steaks and steaks left in a retail case for long periods of time (top sirloin and top loin steaks, cut from 21 d aged subprimals, approaching days 4 and 5 of retail case display; top sirloin and top loin steaks, cut from 28 d aged subprimals, approaching day 3, 4, and 5 of retail case display; and top sirloin and top loin steaks, cut from 35 d aged subprimals approaching day 2, 3, 4, and 5 of retail case display.) As for off-odor attributes, steaks cut from 35 d aged subprimals exhibited over double the amount of extreme and moderate off-odors than did steaks cut from 21 d and 28 d aged subprimals. Therefore, the preferred protocol for minimizing unappealing sensory attributes of aged steaks should be a short aging period, followed by a short retail case duration. Also, by shortening the aging period, the producer can retain some of the product yield. However, shortening the aging period may negatively affect the flavor development and enhancement of the brown, roasted flavors associated with dry-aged beef that were reported in the Warren & Kastner (1992) study. It would be beneficial to understand the aging process in terms of the brown, roasted flavor development. Then dry-aged beef producers could achieve optimal flavor enhancement, while minimizing yield loss, and unsellable product due to unappealing sensory attributes.

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