THE EFFECTS OF SOUS VIDE HEATING, AGING TIME, AND STEAK LOCATION WITHIN THE MUSCLE ON TENDERNESS AND SENSORY CHARACTERISTICS OF THE *SERRATUS VENTRALIS* (DENVER STEAK)

by

JAMESON ANNA SCOTT

(Under the Direction of T. Dean Pringle)

ABSTRACT

The *serratus ventralis* has shown favorable palatability traits for steak fabrication, but a consistent tenderness pattern has not been found. Therefore, our study objective was to evaluate sous vide heating, aging time and steak location on tenderness and sensory characteristics of the *serratus ventralis*. Sous vide heating (**SV**) prior to final cooking showed no increase in tenderness and decreased juiciness and beef flavor compared to Denver steaks cooked on an electric grill (**CON**), and did not eliminate tenderness difference within the muscle with posterior steaks being more tender than anterior steaks. Proximate composition showed a 4.6% increase in fat for posterior portions compared to anterior portions. All color attributes were affected by SV where SV steaks were less red and more yellow in color compared to control steaks. Further research needs to be done to optimize time-temperature combinations for SV and to better understand composition differences within the *serratus ventralis*.

INDEX WORDS: Sous vide, Serratus ventralis, Color, Tenderness, Sensory Characteristics

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DEDICATION

This work is dedicated to the MeatDawgs. Thank all of you for giving me a purpose during my time here at the University of Georgia. Though it may seem absurd, I truly looked forward to the 6 a.m. practices, the 12-hour days in the plant, and the long drives to contests. I have enjoyed getting to know all of you and consider each of you not only friends but family. Watching vastly different personalities and backgrounds can come together to accomplish a common goal is an experience I will always cherish. Each one of you has taught me so much about life, friendship, and leadership, for which I will be forever grateful. I only hope each of you has learned half as much from me as I have learned from all of you. It truly has been an honor to be your coach for the past two years and I can’t wait to see all of the incredible things each of you will accomplish. Once a #MeatDawg, always a #MeatDawg!

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CHAPTER 1

INTRODUCTION

Whole muscle meat products have been at the center of the dinner plate for years and will continue to be a focal point in the future. In a 2020 review of "Today's Beef Consumer" by the National Cattlemen's Beef Association (**NCBA**) consumers' willingness to pay per pound of steak is above the average price per pound, and according to The Consumer Beef Tracker by the NCBA, 54% of consumers consider beef to be an excellent protein source (NCBA, Today's Beef Consumer, 2022). Traditionally, the middle meats from the rib and loin have served as the main steak products offered to consumers because of their desirable tenderness, juiciness, and flavor (Lepper-Blilie et al., 2014); however, with the increased demand for steaks, the beef industry has sought out steak-like products from underutilized muscles in the chuck and round. In the chuck, the *serratus ventralis*, or Denver steak, was found to be the juiciest steak (Carmack, 1995) and to be "Certified Tender" by the USDA (ASTM, 2011), but Grimes and Calkins (2008) found tenderness varied sporadically throughout the muscles due to heavy sheets of connective tissue and changing fiber direction. With greater connective tissue content, low temperature-long time cooking with moist heat would be the most ideal cooking method for collagen solubilization. Sous vide, a French term meaning "under vacuum", can be used as a low temperature-long time cooking method that could improve tenderness consistency in the *serratus ventralis* through solubilizing connective tissue. Sous vide cooking involves placing the food product in a heat-stable package, sealing it under a vacuum, and then immersing it into a hot water bath at precisely controlled temperature and time conditions (Baldwin, 2012). Sous vide heating may offer a tenderness intervention without the microbial concern needle tenderization carries, due to reductions in aerobic bacterial growth from the low temperature-long term cooking conditions (Baldwin, 2012).

CHAPTER 2

REVIEW OF LITERATURE

Serratus ventralis

The beef chuck has traditionally been marketed as lower-value roasts and ground beef products, but several studies have examined muscles within the chuck for palatability traits using objective tenderness measurements and trained sensory panels (Ramsbottom et al., 1945; Johnson et al., 1988). The *serratus ventralis*, a large fan-shaped chuck muscle, has muscle fibers running parallel to the muscle's long axis with thick sheets of connective tissue typically included when fabricating lesser-valued roasts accounting for approximately 7% of the chuck, and when removed individually, retailers market the *serratus ventralis* as a moderately priced steak known as the Denver steak (NCBA, 2000).

Carmack (1995) found the *serratus ventralis* ranked as the juiciest muscle when fabricated at the thickest portion with Paterson and Parrish (1986) having similar findings in juiciness as well as ranking second for flavor when compared to nine muscles from the chuck. Johnson et al. (1988) reported the *serratus ventralis* had a similar tenderness profile to the *longissimus dorsi*; however, researchers have found it does not have a consistent tenderness pattern within the muscle (Searls et al., 2005; Grimes and Calkins 2008). Searls et al. (2005) reported the middle five Denver steaks cut from the ventral side to be more tender than the steaks cut more dorsal. Grimes and Calkins (2008) found Denver steaks from USDA Choice carcasses cut from the posterior half required less force to shear than steaks cut anterior. Searls et al. (2005) speculated variations in tenderness within the muscle could be due attributed to its limited role in locomotion. The muscle's main function is to protract and retract the shoulder and flexes the neck when acting unilaterally (Von Seggern et al., 2005); however, no literature was found regarding what portions are responsible for this action. Additionally, the connective tissue is dispersed sporadically throughout the muscle, playing a role in the inability to map a consistent tenderness pattern. Contrarily, Bratcher et al. (2005) found no significant location effect on Warner-Bratzler Shear force (**WBSF**) values throughout the muscle. During a sensory evaluation, Denver steaks were moderately tender when moist-heat cooked but were moderately tough when dry-heat cooked (NCBA, 2000). This indicates cooking style can affect the tenderness in the muscle.

Meat tenderness

Beef palatability can be attributed to three main traits: tenderness, juiciness, and flavor (Smith and Carpenter, 1974) with tenderness historically being the most important consumer acceptability factor (Dikeman, 1987; Miller et al., 2001). Meat tenderness can be affected by collagen content, postmortem proteolysis, and muscle contractile state (Hopkins and Geesink, 2009). These factors are affected by differences in muscle characteristics, production traits, processing postmortem, and cookery methods (Lawrie et al., 2017).

Intramuscular fat, or marbling, associated with USDA quality grades has been shown to positively influence palatability traits as marbling degrees increase (McPeake, 2001; Emerson et al., 2013; Corbin et al., 2015). Smith and Carpenter (1974) detailed theories on the mechanisms behind marbling and its effect on tenderness. The bite theory suggests within a given bite-size portion of cooked meat, marbling reduces the overall mass per unit of volume, lowering the bulk density by replacing protein with lipid, and because fat requires less force to shear than coagulated proteins, tenderness is improved. The strain theory suggests as intramuscular fat is developed a portion is deposited inside the perimysium and endomysium walls decreasing connective tissue thickness and strength, and resulting in improved tenderness. The lubrication theory suggests intramuscular fats do not conduct heat as freely as protein during cooking and lubricate muscle fibers resulting in a more tender, juicer product. The insurance theory suggests as marbling degrees increase the room for error during cooking increases, ensuring a palatable product despite overcooking. In addition, O'Quinn et al. (2012) reported fat content contributed the most to flavor liking with flavor being the most highly correlated palatability trait to overall liking. In the *serratus ventralis*, Nyquist et al. (2018) reported an 12% variation in fat percentage from differing quality grades as USDA Prime had the highest (18%) and USDA Select had the lowest (6%). This author also reported USDA Prime Denver steaks required less force to shear than Choice and Select steaks which did not differ, and consumer sensory panelist reported Prime Denver steaks ranked higher for juiciness, tenderness, flavor liking, and overall liking than Choice and Select steaks which did not differ except for juiciness and flavor liking. Additionally, this author reported the *serratus ventralis* had the highest percent fat regardless of quality grade compared to muscles from the round chuck as well as the *longissimus lumborum*, suggesting the *serratus ventralis* has a greater amount of marbling comparatively. Hunt et al. (2014) reported USDA Select steaks from the *serratus ventralis* had a greater WBSF value than those from Top Choice steaks. This author also reported more desirable tenderness ratings by consumers for Top Choice Denver steaks compared to Select steaks and the *serratus ventralis* was ranked highest for juiciness regardless of quality grade compared to the *gluteus medius*, *longissimus lumborum*, and *semimembranosus*. The author contributed increased juiciness ratings to the *serratus ventralis* having the highest pH comparatively.

Differences in tenderness associated with animal age and muscle location result mostly from differences in connective tissue. Collagen, a white fibrous connective tissue, is the most abundant protein in connective tissue. The relationship between tenderness and connective tissue content is known as “background toughness” (Aberle., et al, 2012), meaning higher connective tissue content typically means less tender meat. Literature has shown that as animal age increases, collagen solubility decreases due to more heat-stable crosslinks (Lawrie, 2017). These heat-stable cross-links remain largely intact after cooking, but this doesn’t always explain tenderness differences within a muscle. Muscles that are used for locomotion, primarily in the chuck and round, contain greater connective tissue content (Hunt, 2021). Grimes and Calkins (2008) contributed variable tenderness within the *serratus ventralis* to the thick sheets of connective tissue surrounding the muscle, but this is removed during steak fabrication. Because the muscle is used to protract and retract the shoulder, differences in connective tissue concentrations within the muscle may lead to mapping a tenderness pattern across the muscle; however, this has not been documented to date. During cooking, meat toughness increases in two separate phases with the first increase occurring between 40°C and 50°C and the second increase between 60°C and 80°C with a decrease in meat toughness between 50°C and 60°C (Christensen et al., 2000). According to Davey and Gilbert (1974) the first increase in toughness is due to myofibrillar protein denaturing and the second increase by connective tissue degradation; however, Christensen et al. (2000) offered a differing interpretation whereas the second increase in toughness was due to hardening of myofibrillar proteins. Myofibrillar proteins respond differently to heat application as myosin denatures at approximately 55°C and actin denatures between 70°C and 80°C (Cheng and Parrish, 1979). Collagen will begin to shrink and solubilize at 50°C with longer cooking times between 50°C and 60°C resulting in connective tissue solubilization without hardening myofibrillar proteins (Aberle et al., 2012). Sous vide cookery could reduce tenderness variation within the *serratus ventralis* by solubilizing more connective tissues using low temperature-long time cooking.

Muscle contractile state can affect tenderness through muscle ultrastructure. Sarcomeres are the smallest contractile unit of skeletal muscle (Aberle et al., 2012), and multiple sarcomeres, in series comprise the myofibers. Myofibers are further organized to form myofiber bundles (fasciculi) and multiple fasciculi form a muscle. During muscle contraction and relaxation, the myofibrillar proteins actin and myosin create a cross-bridge formation, called actomyosin, which hydrolyzes adenosine triphosphate (**ATP**) into adenosine diphosphate (**ADP**) and P*i*. The energy released during ATP splitting causes myosin to pull the actin filament to the Z-disk and closer to the center of the sarcomere (M-line), resulting in a power stroke and the sarcomere shortens in length. Following the power stroke, ADP and P*i* are released and ATP levels are restored causing the actin filament to disassociate from the cross-bridge formation, ultimately resulting in relaxation. In postmortem muscle, ATP is not able to be synthesized aerobically making relaxation impossible resulting in rigor mortis, or muscle stiffening. When rigor mortis is completed, sarcomeres are shortened and actomyosin remains bound, resulting in muscle shortening and tougher meat; however, postmortem aging has been shown to positively influence tenderness through proteolytic changes during rigor resolution (Aberle et al., 2012)

Storing meat under refrigeration for extended time periods results in postmortem aging and has long been recognized to improve beef tenderness (Smith et al., 1978; Calkins and Seidman, 1988). Postmortem aging occurs through the calpain system in which proteolytic enzymes, calpains, degrade cytoskeleton proteins with calpastatin serving as an inhibitory regulator of enzymatic activity. These enzymes weaken structural proteins by rupturing the Z-disk resulting in protein fragmentation and the degradation of desmin, titin, and nebulin (Aberle et al., 2012). Smith et al. (1978) reported *serratus ventralis* shear force values decreased when aged 21 d. Gruber et al. (2006) reported a decrease in Warner-Bratzler shear forces (**WBSF**) values in *serratus ventralis* muscles from USDA Select and Top Choice carcasses aged 21 d compared to 14 d, but no improvement past 21 d. These studies suggest postmortem aging can positively affect tenderness in the *serratus ventralis*.

Postmortem strategies, such as mechanical tenderization, can further improve beef tenderness (Pringle et al., 1998; Scanga et al., 1999) through physical disruption of the muscle structure. Needle tenderizers use blades to pierce through muscle fibers and connective tissue and maceration uses small needles attached to rollers to alter muscle structure; however, these methods risk pathogenic bacteria being translocated into the muscle interior (Thippareddi et al., 2000; Luchansky et al., 2008). Vacuum tumbling disrupts muscle structure using paddles inside a rotating bin, under a vacuum. This can be done after needle enhancement injection to ensure even solution distribution throughout the muscle. Solutions, or brines, contain salt, phosphate, flavorings, and/or tenderizing ingredients (Aberle et al., 2012). Tenderizing ingredients can include plant-based enzymes, such as papain from papaya, or organic compounds to help degrade myofibrillar proteins and connective tissue. Molina et al. (2005) showed palatability traits increased in the *serratus ventralis* when needle enhanced with water, salt, and sodium tripolyphosphate versus marinated and vacuum-tumbled treatments. Grimes and Calkins (2008) reported a decrease in WBSF values for needle enhanced, vacuum-tumbled Denver steaks compared to control steaks.

Cooking methods

Cooking is defined by Merriam-Webster (2023) as “the act of preparing food for eating especially by heating”. Heating systems for meat are categorized as either dry-heat or moist-heat and play a major role in cooking outcomes. Dry-heat cooking methods, such as grilling and roasting, use hot, dry air at high temperatures to cook food to a desired degree of doneness. This method is best for cuts known to be lower in connective tissue because the shorter cook times associated with dry-heat cookery are generally inadequate for connective tissue degradation. Moist-heat cooking methods, like braising and sous vide, use liquid or humidity to cook meat at low temperatures over long time periods. This method is ideal for cuts with higher connective tissue content because low temperature-long time cooking allows for hydrolysis of collagen (Aberle et al., 2012). One approach to utilizing both heating systems is through sous vide cookery, to improve tenderness, followed by dry-heat cookery to aid in flavor and color development (Vierck et al., 2021).

Sous vide (**SV**), the French term for “under vacuum”, is a cooking method in which vacuum-packaged food is immersed in a water bath under controlled temperature and time (Schellekens, 1996). Sous vide cooking has rapidly gained popularity amongst consumers and restaurants for its ability to control endpoint temperature, help prevent overcooking, and have high reproducibility (Baldwin, 2012). Vacuum packaging allows for efficient heat exchange from the water to the meat while also increasing shelf-life by reducing aerobic bacterial growth (Church and Parsons, 2000; Baldwin, 2012). Sous vide cooking was found to increase tenderness in tough meat cuts (Baldwin, 2012); however, different temperature and time combinations can lead to differences in palatability traits when using sous vide cookery.

It is generally accepted that when meat is cooked to greater degrees of doneness tenderness decreases due to physical changes including increased protein shrinkage, denaturation, and decreased water holding capacity (Aberle et al., 2012) with sous vide cooking having similar effects. Bryan et al. (2019) reported decreased WBSF values in boneless pork loins sous vide cooked at 63°C compared to 71°C and Mortensen et al. (2011), using a trained sensory panel, found tenderness decreased when final temperatures increased from 56°C to 60°C on beef eye of round slices. This may be due to a decrease in meat toughness from 50°C to 60°C reported by Christensen et al. (2000) caused by decreased perimysial connective tissue strength due to partial denaturation and collagen fiber shrinkage. Tenderness differences present in meat cooked at different temperatures could be attributed to sarcomeres shortening as endpoint temperature increases (Ismail et al., 2019). Contrarily, Christensen et al. (2011) reported decreased shear force values at 58°C compared to 53°C in the *longissimus dorsi* and *semitendinosus* from pigs and sows. This can be explained by collagen shrinking and solubilization occurring at approximately 60°C (Aberle et al., 2012) resulting in increased tenderness. Additionally, research shows long-period cooking (>12 h) has decreased shear force values compared to shorter-period cooking (< 6 h), allowing for more collagen solubilization in tougher cuts (Mortensen et al., 2011; Ismail et al., 2019). Juiciness in sous vide cooked beef, pork, and chicken was found to decrease with longer cooking times (> 6 h) and higher temperatures, whereas cook loss only increased with higher temperatures (Christensen et al., 2012). Similarly, Roldán et al. (2013) reported an increase in percent cook loss as both temperature and time increased, but only greater cooking temperatures caused decreased percent moisture in lamb loins. A balance for tenderness and juiciness in low temperature-long time sous vide cooking will need to be found to maximize palatability traits and consumer satisfaction.

Flavor in meat products is primarily produced through two pathways: the Maillard reaction and thermal lipid degradation (Mottram, 1998). The Maillard reaction is the non-enzymatic browning that initially occurs between carbonyl groups, such as reducing sugars, reacting with amino acids when high temperatures (> 140°C) are applied. This reaction produces a variety of heterocyclic compounds responsible for savory, roast, and boiled flavors, which are highly dependent on temperature and heat application. A subsequent reaction from the Maillard reaction aiding in flavor development is the Strecker degradation. During this reaction, amino acids are degraded by dicarbonyl compounds produced in the previous reaction, forming an aldehyde (Lawrie et al., 2017). Volatile compounds produced through thermal lipid degradation give meat species-specific flavors and aromas. Unsaturated fatty acids, primarily in chicken and pork, undergo autoxidation quicker than saturated fatty acids found in beef and lamb (Mottram, 1998; van Boekel, 2006). Sous vide cooking does not utilize extremely high temperatures (< 140°C) causing Maillard reactions to be reduced, ultimately decreasing flavor development and brown surface color associated with cooked meat. Flavor limitations are why it is a common approach to apply high temperatures to meat surfaces as the final cookery step, following sous vide preparation.

Meat color

A consumer's first perception of quality and wholesomeness in both fresh and cooked meat is by visual evaluation. Pigments contribute to meat color by absorbing and reflecting different light wavelengths. The pigments in meat consist of two main proteins: hemoglobin and myoglobin. Hemoglobin carries oxygen in the bloodstream and myoglobin carries oxygen in muscle. In well-bled carcasses, myoglobin is primarily responsible for meat color and is comprised of a globular protein portion and an iron-containing heme ring. The globular protein contains a primary, secondary, and tertiary structure. The primary structure contains 153 amino acids with the order varying by species, the α-helical secondary structure offers stability to the protein, and the tertiary structure is a result of folding the primary and secondary structures together creating a globular, three-dimensional structure (Lawrie, 2017). The heme ring contains iron and its oxidative state greatly affects meat color. In whole muscles, myoglobin is not exposed to oxygen resulting in deoxymyoglobin, a purplish-red color. When muscles are exposed to oxygen, it will bind to the heme ring creating oxymyoglobin, the cherry-red color associated with raw beef. Eventually, the heme iron will oxidize, disassociate from oxygen, and bind with water resulting in metmyoglobin, the brown color associated with discoloration in fresh meat (Aberle et al., 2012; Lawrie, 2017). Cooking causes color changes in meat at temperatures as low as 43°C due to myoglobin denaturing by heat application (Davey and Gilbert, 1974). Heating results in the globular tertiary structure denaturing exposing the heme ring. The rate at which myoglobin is denatured depends on its redox state and the cooking temperature. Deoxymyoglobin, has greater stability against heat compared to oxymyoglobin or metmyoglobin, resulting in a pinkish-red cooked color; however, the exposed heme ring will eventually oxidize, and cooked meat will turn brown (Lawrie, 2017). Sous vide cooking could offer more control over the final cooked meat color (Baldwin, 2012).

Objective color measurements taken using a colorimeter are one method for evaluation of meat color. This instrument uses the Commission Internationale de l'Eclairage (**CIE**) L*a*b* for color interpretation whereas L* measures brightness, a* measures green (-) to red (+), and b* measures blue (-) to yellow (+). These measurements can be used to calculate hue angle, or color, and chroma, or color saturation [American Meat Science Association (**AMSA**), 2012].

Research has found meat cooked at lower temperatures and for shorter periods presented higher redness values (Roldan et al., 2013; Ishmail et al., 2019) and Christensen et al. (2012) reported a done cook color was developed with increasing time at 58°C in beef and pork *semitendinosus*. This could be explained by increased cook loss over longer cooking periods and the cooking loss becoming less red, suggesting more myoglobin denaturation and oxidation (Christensen et al., 2011). Sun et al. (2019) reported that partially sous vide cooked strip steaks at 55°C had a greater hue angle than raw steaks, resulting in a less red and more yellow appearance; however, two-stage sous vide cooked steaks resulted in greater a * values compared to single-stage cooked steaks. This may be related to shorter cooking periods at increased temperatures for two-stage, 3 h and 9 h, compared to single-stage coking, 6 h and 12 h. In the two-stage sous vide cook initial cooking temperature was set to 45°C or 49°C for 3 h followed by increasing temperatures to 60°C, 65°C, 70°C, or 75° for the remaining cook time allowing for myoglobin to be preserved at these lower initial temperatures. Further research will need to done regarding different time and temperature combinations and their relationship to color changes during sous vide cooking.

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CHAPTER 3

Sous Vide Heating of Intact *Serratus ventralis* as a Tenderness Intervention for Foodservice Denver steaks[1]

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[1] J. Anna Scott, John M. Gonazlez, Alexander M. Stelzleni and T. Dean Pringle. To be submitted to *Meat and Muscle Biology*

Abstract: *Serratus ventralis* (n = 40) muscles from A-Maturity, USDA Prime carcasses (n = 20) were used to assess the effects of aging time (4 and 25 d; **DOA**), preparation method [(**COK**), sous vide heating (**SV**), and control (**CON**)], and steak location (posterior and anterior; **LOC**) on composition, color, and palatability traits. Paired muscles from the first 10 carcasses were aged 4 d and from the remaining carcasses, 25 d and within paired muscles left sides were assigned to SV and right sides to CON. Muscles designated for SV were vacuum packaged, submerged in a 57.6°C water bath for 12 h, then chilled to 4°C. Muscles were separated into anterior and posterior portions and five, 2.5 cm steaks were removed for analysis. There was no DOA effect ($P = 0.75$) for percent protein, but 4 d steaks had greater fat and less moisture percent than 25 d steaks ($P < 0.04$). There was no COK effect ($P = 0.80$) for percent fat, but SV steaks had more protein and less moisture than CON steaks ($P < 0.01$). Anterior steaks had more protein and moisture, and less fat than posterior steaks ($P \leq 0.01$). All color attributes were affected ($P < 0.01$) by cookery as SV steaks had increased L*, a*, b* values. Anterior L* values increased ($P < 0.01$) compared to posterior. In 4 d steaks a* and b* values increase ($P < 0.01$) compared to 25 d steaks. There was a COK × DOA effect ($P < 0.01$) for L*, a*, and b* values and a COK × LOC effect ($P < 0.01$) for a* and b* values. There was a DOA × COK × LOC interaction ($P = 0.02$) for hue angle. Anterior SV steaks aged 25 d had the greatest hue angle, and posterior CON steaks aged 4 d had the smallest hue angle. There was a COK × DOA interaction ($P < 0.01$) for juiciness as 4 d SV steaks were the juiciest. Trained panelist rankings and WBSF showed no tenderness increase ($P > 0.57$) in SV steaks compared to CON steaks and did not negate tenderness variation within the muscle for WBSF ($P < 0.01$). A DOA effect was found for initial and sustained tenderness ($P < 0.02$) where 25 d steaks values increased compared to 4 d. A tendency ($P = 0.08$) for initial tenderness was found as posterior steaks tended to be more tender than anterior steaks. The SV steaks showed decreases in juiciness and beef flavor intensity ($P < 0.01$). This study found SV heating negatively impacted subsequent juiciness while not improving tenderness within the muscle. Day of aging positively affected WBSF and trained sensory panelist ratings by improving tenderness and steak location affected WBSF as posterior steaks were more tender than anterior steaks, and posterior steaks tended to rank higher for initial tenderness by trained panelists. Palatability differences could be caused by changes in proximate composition as SV negatively impacted moisture and posterior steaks had a 4.6% greater fat percentage than anterior steaks. Preparation method impacted all color attributes with SV preparation resulting in a less red, more yellow appearance. Further research is needed to understand composition differences within the *serratus ventralis* to possibly understand a tenderness pattern, and to optimize low-temperature long-time sous vide heating conditions to maximize palatability traits.

KEY WORDS: sous vide, serratus ventralis, tenderness, palatability traits

Introduction

Beef palatability can be attributed to three main traits: tenderness, juiciness, and flavor (Smith and Carpenter, 1974) with the literature historically identifying tenderness as the most important consumer acceptability factor (Dikeman, 1987; Miller et al., 2001). O'Quinn et al. (2018) reported overall palatability failure is 7.2 times greater when panelist rated tenderness as unacceptable. It is a widely known consumers are willing to pay premiums for beef they know to be tender (Boleman et al., 1997; Miller et al., 2001; Shackleford et al., 2001; Lyford et al., 2010). With consumers increased willingness to pay for tender steaks, research has shown undervalued beef chuck muscles might be suitable for use as steaks instead of roasts (Johnson et al., 1988; Carmack et al., 1995; Kukowski et al., 2003).

The *serratus ventralis*, a large fan-shaped chuck muscle, has muscle fibers running parallel to the muscle's long axis and thick connective tissue included when fabricated into lesser valued roasts. When removed individually, retailers market the *serratus ventralis* as a moderately priced steak known as the Denver steak [National Cattlemen's Beef Association (**NCBA)**, 2000]. Johnson et al. (1988) reported Denver steaks had similar tenderness profiles to the *longissimus dorsi* and Carmack (1995) found the *serratus ventralis* ranked as the juiciest muscle when fabricated at the thickest portion; however, Searls et al. (2005) found it did not have consistent tenderness pattern within the muscle. During sensory evaluation, Denver steaks were moderately tender when moist-heat cooked but were moderately tough when dry-heat cooked (NCBA, 2000). This indicates cooking style can affect the tenderness of lesser value cuts.

Recently, researchers utilized long time-low temperature sous vide cooking as a palatability intervention for lesser valued cuts. (Ismail et al., 2019; Naqvi et al., 2021; Bryan et al., 2021) Sous vide (**SV**), the French term for "under vacuum", is a cooking method in which vacuum-packaged food is immersed in a water bath under controlled temperature and time (Schellekens, 1996). Baldwin (2012) reported SV became popular with chefs and private households due to its precise temperature control and increased repeatability (Baldwin, 2012). Because water bath temperature and desired cooked temperature are equal, foods can be cooked and held at temperatures for extended time without overcooking (Bryan, et al., 2019). Christensen et al. (2013) reported SV caused tenderization in the *semitendinosus* through decreased protein hardening, collagen solubilization and increased water retention. Trbovich et al. (2017) reported similar tenderness values for the *semitendinosus* cooked via SV for extended periods of time compared to tender beef cuts cooked for shorter time periods. Therefore, our study objectives were to test the efficacy of SV heating as a method to ensure tenderness and improve palatability in Denver steaks and compare the effects of aging and steak location.

Materials and Methods

The University of Georgia Institutional Review Board approved all procedures for human subject use in trained sensory panel evaluations (IRB 6379, February 14, 2023).

Sample Collection

Paired "A" maturity, USDA Prime beef chuck rolls (*N* = 40, Institutional Meat Purchase Specifications #116A) were collected from 20 carcasses at FPL Foods Inc. (Augusta, GA) at 3 d postmortem. Carcasses one through ten were assigned to 25 d aging and carcasses eleven through twenty were assigned to 4 d aging. Product was vacuum packaged and transported in coolers with ice packs to the University of Georgia Meat Science and Technology Center (Athens, GA) for further processing. At 4 d postmortem, chuck rolls were weighed and the *serratus ventralis* was removed, denuded, and weighed. Within paired chuck rolls the left side was designated for SV heating and the right for electric grill cookery (**CON**). After fabrication, all *serratus ventralis* muscles were vacuum packaged and aged for the designated time period at 2 ± 1°C. Following the designated aging period, the SV heating protocol was initiated on left side *serratus ventralis* muscles with CON *serratus ventralis* were cut into steaks and stored frozen (-20°C) for subsequent analyses.

Sous Vide Heating

On cook day, two large coolers were filled with 90 L of water and three immersion circulators (Imersa Pro, Vesta Precision, Seattle, WA) were placed in each cooler. Wire racks were suspended in the coolers to allow water movement around the entire serratus ventralis. Following the assigned aging period, the *serratus ventralis* designated for SV heating were vacuum sealed in cook-in bags (CN545T, Sealed Air Corporation, Charlotte, NC). Due to limited cooler space, five muscles were placed in each cooler with all 10 being from the same treatment and one muscle in each cooler having a copper-constantan thermocouple (Omega Engineering, Stamford, CT, USA) placed in the muscle's approximate geometric center to monitor temperature. The water bath temperature was set to 51.6°C and temperature was monitored by the immersion circulators and the samples were heated for 12h. Following heating, muscles were removed from the water bath and placed on wire racks to chill overnight at 2 ± 1°C. Muscles were removed from packaging, blotted dry, and weighed the following morning to calculate percent cook loss.

Steak Fabrication

Following aging or sous vide heating, muscles were separated into posterior (thick) and anterior (thin) halves and a minimum of five 2.5 cm steaks were cut dorsal to ventral, with the first steak being discarded, the second steak designated for proximate analysis, the third steak designated for Warner Bratzler Shear Force (**WBSF**), and steaks four and five designated for trained sensory panel. Following 30 minutes of bloom time, instrumental color was measured on the steaks designated for sensory evaluation and then all steaks were vacuum sealed and frozen at -20°C until further analysis.

Instrumental Color

Color measurements were collected on the SV and CON steaks designated for trained sensory panel 30 minutes following steak fabrication prior to freezing using a HunterLab MiniScan EZ (MSEZ0115; Reston, VA) with Illuminant A, 31.8 mm aperture, and 10° observer angle. Three measurements were taken from each location and averaged. Lightness (**L***), redness (**a***) and yellowness (**b***) were determined following CIE (Commission Internationals de I'Eclairage) color coordinates. Hue angle (**HA**) were calculated from a* and b* color coordinates using the following equation from the Meat Color Measurement Guidelines [American Meat Science Association (**AMSA**), 2012]: *HA = [arctangent (b*/a*)]*

Warner-Bratzler Shear Force

Frozen WBSF steaks were removed, unpackaged, frozen weights (**FW**) were recorded, samples were placed on absorbent pads, covered with polyvinyl chloride film, and thawed overnight at 2 ± 1°C. On cook day, thawed weight (**TWT**) was recorded, and copper-constantan thermocouples (Omega Engineering, Stamford, CT, USA) were placed in the steaks' approximate geometric center to record internal temperature using a thermocouple data logger (Omega HH520, Omega Engineering, Stamford, CT). Initial temperature (**IT**) was recorded, and samples were cooked on an electric grill (George Formen, Saltotn Inc., Miramar, FL) to an internal temperature of 62°C to mimic a medium degree of doneness (USDA). After cooking, cooked weight (**CWT**) was recorded and steaks were placed on absorbent pads, covered with polyvinyl chloride film, and allowed to chill overnight (2 ± 1°C). The following day, six 1.27 cm diameter cores were taken parallel to the muscle fibers from each steak. Cores were sheared by an Instron Universal Testing Machine 3365 (Instron Limited, High Wycombe, UK) with a cross-head speed of 250 mm/min and a load cell of 500 N. Measurements were averaged across 6 cores per steak and recorded as average peak force.

Proximate Composition

Steaks designated for proximate analysis were thawed 24 h, cubed and homogenized using a food processor. Homogenized samples were kept under ice packs or refrigeration until analyses could be performed with samples being processed the same day. Proximate composition was analyzed at the USDA Richard Russell Research Center (Athens, GA) in triplicate for each sample. The Association of Analytical Communities (**AOAC**) procedures (AOAC Official Method 2011.04, Protein in Raw and Processed Meats) were used to analyze protein content using the Sprint Rapid Protein Analyzer (CEM Corporation, Matthews, NC). The AOAC procedures (AOAC Official Method 985.14, Rapid Microwave Drying Method) were used to analyze moisture and crude fat content using the SMART Profat 6 (CEM Corporation, Matthews, NC).

Trained Sensory Panel

Sensory panelists training was performed according to the Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness of Measurements of Meat (AMSA, 2016). Four sensory training sessions were held 1 week prior to panel start with training references and anchors being consistent with the guidelines stated above.

Steaks were prepared as described previously for WBSF to a medium degree of doneness without chilling. Ten panel sessions were conducted by an 8-member trained panel. Steaks were processed by cutting off all fat and epimysia, cut into cubes (1.27 cm × 1.27 cm × steak thickness) using a sample sizer, and placed in warmed yogurt makers (Euro Cuisine, Inc., Los Angeles, CA, USA) until sampled (≈ 5 min). Eight samples, with two cubes per sample, were given each session with two sessions being held per day with 3 h between sessions. Panelists were given a paper ballot, water cup, expectorant cup, napkin, toothpick, and unsalted crackers were used as palate cleansers between samples. Panelists were served in individual sensory booths at Rhodes Animal and Dairy Science Center (Athens, GA). Samples were served in a dark room with positive airflow illuminated by red lighting to mask color variations among samples. Each sample was evaluated for initial tenderness, sustained tenderness, beef flavor intensity, and overall juiciness on a 1 (extremely tough, extremely bland, extremely dry) to 8 (extremely tender, extremely intense, extremely juicy) scale. Panelist also assessed for off-flavor which was rated on a 1 (none detected) to 6 (extreme off-flavor) scale. If off-flavors were detected panelist were asked to describe the flavor in one word with a pre-arranged lexicon.

Statistical Analysis

All data were analyzed as a split-split-plot design using paired chuck rolls as the experimental unit. Carcass served as the whole plot, side served as the sub-plot, and location within muscle served as the sub-sub plot. Fixed effects included aging time (**DOA**), cooking method (**COK**), muscle location (**LOC**), and the interactions. Random effects include carcass, carcass × DOA, and carcass × DOA × COK. All categorical data were analyzed using the PROC GLIMIXX procedure of SAS (Version 9.4; SAS Inst. Inc., Cary, NC). Pairwise comparisons between the least squares means of the factor levels were computed using the Kenward-Rodger option of the LSMEANS statement. Statistical significance was declared at $P \leq 0.05$.

Results

Weights and Yields

Whole chuck roll weights (Table 1) for SV and CON and the *serratus ventralis* accounts for 25.3 and 22.3% of chuck roll weight, respectively. Sous vide heating resulted in a 9.3% cook loss. In post-SV, anterior weight accounted for 41.2% and anterior steaks for 34.9% of the whole muscle weight with posterior weight accounting for 59.5% and posterior steaks for 54.2% of total muscle weight. In CON, anterior weight accounted for 43.8% and posterior steaks for 37.0% of total muscle weight as posterior weight accounted for 56.0% and posterior steaks for 50.4% of total muscle weight. Sous vide steaks had an 89.1% steak yield and CON steaks had an 87.4% steak yield.

Objective Color

L*, a*, and b* values were greater for SV steaks compared to CON steaks ($P < 0.01$; Table 2). Steaks aged 4 d had greater a* and b* values than steaked aged 25 d ($P < 0.01$). Anterior steaks had greater L* and b* values than posterior steaks ($P < 0.01$).

There were no COK × DOA × LOC interactions for L*, a*, and b* values ($P > 0.08$). There were COK × DOA interactions for L*, a*, and b* values ($P < 0.01$; Figure 1) and COK × LOC interactions for a* and b* values ($P < 0.05$; Figure 2). Sous vide heated steaks aged 4 and 25 d had greater L* and b* values than CON steaks ($P < 0.01$). At 4 d aging, SV steaks had a greater ($P < 0.01$) a* value than CON steaks, but at 25 d aging a* values did not differ across COK ($P = 0.74$). Control steaks were darker and redder at 4 vs 25 d of aging and b* values did not differ ($P = 0.22$). In the COK x DOA interactions, color parameters (L*, a*, and b*) were consistently higher in SV than CON across DOA, except for a* values after 25 d of aging which did not differ ($P = 0.74$). The interactions noted in these parameters were due primarily to the magnitude of difference noted across the aging times with the 4-d aging time having greater differences across COK than the 25-d aging time.

Posterior SV steaks had greater (*P* < 0.02) a* values than posterior CON steaks while anterior SV and CON steaks did not differ (*P* = 0.11) in a* values. Anterior SV steaks had greater a* values than posterior CON steaks (*P* = 0.02) and CON steaks a* values did not differ by LOC (*P* = 0.39). Posterior and anterior SV steaks b* values did not differ (*P* = 0.67) and had greater b* values than posterior and anterior CON steaks (*P* < 0.01). Anterior CON steaks had greater (*P* < 0.01) b* values than posteriors CON steaks. Again, color parameters within the COK x LOC interactions were consistently higher for SV versus CON, except for a* values in the anterior portion which did not differ by COK (*P* = 0.12).

There was a COK × DOA × LOC interaction for HA (*P* = 0.02; Figure 3). There were no 2-way interactions for HA (*P* > 0.20). Anterior SV steaks aged 25 d had the greatest HA value (*P* < 0.01), but posterior SV steaks aged 4 and 25 d, and anterior SV steaks aged 4 d HA values did not differ (*P* >0.06). Posterior CON steaks aged 25 d and anterior CON steaks aged 4 and 25 d HA values did not differ (*P* > 0.07). Posterior CON steaks aged 4 d had the least HA (*P* < 0.03). Sous vide steaks had greater HA than CON steaks (*P* < 0.01). Steaks aged 25 d had greater HA than steaks aged 4 d (*P* < 0.01). Anterior steaks had a greater HA than posteriors steaks (*P* < 0.01).

Warner-Bratzler Shear Force

There were no COK × DOA × LOC, COK × LOC or DOA × LOC interactions for thaw loss (*P* > 0.11; Table 3), but there were COK × DOA interactions for thaw loss (*P* = 0.02), whereas 25-d aged CON steaks had less thaw loss than all other treatments (*P* < 0.01), which did not differ from each other (*P* > 0.05). Sous vide steaks had greater (*P* = 0.02) thaw loss than CON steaks. Steaks aged 4 d had greater (*P* < 0.01) thaw loss than steaks aged 25 d. Anterior steaks had greater (*P* < 0.01) thaw loss than posterior steaks.

There were no interactions for cook loss ($P > 0.15$; Table 3). There were no treatment effects for COK or LOC ($P > 0.23$), but there was a DOA effect for cook loss ($P < 0.04$).). Steaks aged 25 d had greater cook loss than steaks aged 4 d ($P < 0.04$).

There were no interactions for WBSF ($P > 0.07$; Table 3). There were no COK or DOA effects for WBSF ($P > 0.13$). Posterior cut steaks had smaller ($P < 0.01$) WBSF values than anterior steaks.

Proximate Composition

There were no interactions for protein, fat, and moisture percent ($P > 0.15$, Table 3). There was no DOA effect ($P = 0.75$) for percent protein, but 4-d aged steaks had greater fat and less moisture percent than 25-d aged steaks ($P < 0.04$). There was no COK effect ($P = 0.80$) for percent fat, but SV steaks had more protein and less moisture than CON steaks ($P < 0.01$). Anterior steaks had more protein and moisture, and less fat than posterior steaks ($P \leq 0.01$).

Trained Sensory Panel

There were no 3-way interactions for all attributes or 2-way interactions for initial tenderness, sustained tenderness, or beef flavor intensity ($P > 0.07$; Table 4). There were DOA × COK interactions for juiciness and off-flavor ($P < 0.01$; Figure 4). The 4-d aged SV steaks had the least juiciness ($P < 0.02$) compared to 25-d SV steaks and 4- and 25-d aged CON steaks which did not differ ($P > 0.11$). The 25-d aged SV steaks had the greatest off flavor ($P < 0.04$) compared to 4-d aged SV steaks and 4- and 25-d aged CON steaks which did not differ ($P > 0.15$). There were DOA effects for initial and sustained tenderness ($P < 0.02$) as 25-d aged steaks had increased values for both measurements, but there were no DOA effects for juiciness, beef flavor, or off-flavor ($P > 0.06$). There were COK effects for juiciness and beef flavor ($P < 0.01$) as CON steaks had increased values for both measurements, but there were no COK effects for initial tenderness, sustained tenderness, or off-flavor (*P* > 0.42). There was a tendency (*P* = 0.08) for initial tenderness values in posterior steaks to be higher than in anterior steaks, but there were no LOC effects for sustained tenderness, juiciness, beef flavor, or off-flavor (*P* > 0.11).

Discussion

Palatability Traits

Postmortem processes, such as aging and cookery methods, can greatly affect beef palatability traits leading to differences in consumer acceptance. Postmortem aging involves storing meat under refrigeration for extended periods and has been well-documented to improve beef tenderness (Smith et al., 1978; Calkins and Seidman, 1988). In the current study, trained sensory panelists reported a 9.3% and 7.9% increase in initial and sustained tenderness values respectively for 25-d aged Denver steaks compared to 4-d aged steaks; however, there was no aging effect on WBSF values. Initial tenderness mimics WBSF as it is the force needed to initially bite through the piece of meat, whereas sustained tenderness represents overall tenderness during mastication. In previous literature, WBSF values for the *serratus ventralis* from USDA Choice and Select carcasses decreased as aging time increased up to 21 d (Smith et al., 1978; Gruber et al., 2006). It is unclear why trained panelists reported differences in tenderness based on days of aging but no differences were found in WBSF; however, the muscle aging response may be different based on different quality grades. Nyquist et al. (2018) reported increases in tenderness for USDA Prime Denver steaks compared to USDA Choice and Select Denver steaks, but differences in aging time were not evaluated.

Steak location from within the *serratus ventralis* has been shown to affect tenderness (Searls et al., 2005; Grimes and Calkins 2008). In the present study, trained panelists tended to report a 4.0% increase in initial tenderness for posterior steaks compared to anterior steaks, and instrumental tenderness supports this as there was an 11% decrease in WBSF values from posterior cut steaks compared to anterior steaks. Previous literature has varying reports on WBSF values within the muscle as Grimes and Calkins (2008) reported posterior portions required less shear force compared to anterior portions, but Searls et al. (2005) found no consistent tenderness pattern with intermediate and high WBSF values intermixed throughout the muscle. Contrary to both, Bratcher (2005) found no location effect on WBSF values within *serratus ventralis* muscles sourced from USDA Select and Top Choice carcasses. The reason for the variation in tenderness is not clearly known, but differences in connective tissue, changing fiber direction, and the muscle's function in protracting and retracting the shoulder are possible explanations. Variations in tenderness in the present study may be explained by proximate analysis showing a 4.6% increase in percent fat in posterior steaks compared to anterior steaks. It is known that intramuscular fat, or marbling, increases beef palatability (McPeake, 2001; Corbin et al., 2015) and Nyquist et al. (2018) reported a strong correlation between percent fat and trained panelists' scores in the *serratus ventralis* whereas Denver steaks from USDA Prime carcasses ranked higher than USDA Choice and Select. Although all muscles in this study were from USDA Prime carcasses, it's clear there are differences in percent fat within the muscle which may cause the tenderness variation of the *serratus ventralis*.

Heating prior to steak fabrication had more effect on juiciness and beef flavor than the day of aging or steak location in this study. Trained panelists reported SV heated steaks had a 9.8% and 8.3% decrease in juiciness and beef flavor intensity respectively compared to CON steaks. The decrease in juiciness could be a result of SV heating prior to steak fabrication as there was a 9.3% cook loss Additionally, proximate analysis found SV heated steaks had a 4.0% decrease in moisture content and an increased thaw loss compared to CON steaks. These compounding moisture losses may explain the decrease in juiciness for SV heated steaks. In the present study, SV heated steaks were frozen prior to dry-heat cookery, which is contrary to most literature, and may have played a role in the decline in juiciness. The decrease in beef flavor coincides with Christensen et al. (2012) findings using descriptive sensory analysis on beef *semitendinosus* cooked via SV for >6 h that was described as bland in meat flavor. It may be possible that flavor compounds were lost with the cooking losses during SV. Meat flavor is mainly developed by dry-cookery methods using high temperatures (<140°C) and this development occurs through two pathways: the Maillard reaction and lipid degradation (Mottram, 1998). Because SV does not typically utilize high temperatures limited flavor development is a concern, which is why SV preparation followed by dry-heat cookery is common (Vierck et al., 2021).

Color

Meat color and appearance are the consumer's first perception of quality in raw and cooked meat. The pigment responsible for meat color is myoglobin which has an iron-containing heme ring whose oxidative state greatly affects meat color; however, during heat application color changes can happen at temperatures as low as 43°C (Davey and Gilbert, 1974). It is known cooking meat to lower temperatures results in a redder internal color, and sous vide cooking could offer more control over meat color. Differences in objective color can be detected by trained panelists at changes of 0.95 and 0.99 units in a* and b* respectively (Mancini et al., 2022).

Increased L* and b* values showed SV heated steaks were paler colored than CON steaks coinciding with the dull-brown color of cooked beef. Sous vide heated steaks had a 1.9 unit increase in a* compared to CON steaks, resulting in a redder internal color immediately following the bloom time. Research has found meat cooked using sous vide at lower temperatures and for shorter periods presented higher redness values (Roldan et al., 2013; Ishmail et al., 2019). Different time and temperature combinations using two-stage sous vide cooking may offer a redder product. Ishmail et al. (2019) reported cooking at 45 and 49°C for 3 h followed by increasing temperatures above 60°C had increased a* values compared to single-stage SV. The 25-d aging period showed a 3.5 unit decrease in a* values compared to 4 d aging, resulting in less red color. This could be due to decreases in mitochondrial activity as aging time increases; however, Mancini et al. (2022) reported longer aging times resulted in increases in initial color intensity but decreases in color stability. The difference in L* values from anterior and posterior ends may be a result of thickness. Anterior portions are thinner than the posterior portion which could lead to more heat penetration resulting in more oxidation of myoglobin, but further research will need to be done.

The interaction between cookery, location, and aging time showed that SV heated, anterior steaks aged 25 d had the greatest hue angle meaning that these steaks were less red compared to other treatment combinations. In contrast, posterior CON steaks aged 4 days had the smallest hue angle indicating that they were the reddest of the treatment combinations. Sun et al. (2019) reported SV prepared strip steaks had a greater hue angle compared to raw steaks, resulting in a less red, more yellow appearance; the same effect was found in this study. The location effect may be caused by differences in thickness and myoglobin concentration within the muscle, but further research is needed.

Conclusion

Palatability traits are affected by differing cookery methods with tenderness being a driving factor toward consumer acceptability. This study found sous vide heating negatively impacted juiciness and off-flavor intensity while not improving tenderness variation within the *serratus ventralis*. Day of aging positively affected WBSF and trained sensory panelist ratings by improving tenderness and steak location affected WBSF as posterior steaks were more tender than anterior steaks, and posterior steaks tended to rank higher for initial tenderness by trained panelists. Differences in palatability traits could be caused by changes in proximate composition as SV negatively impacted moisture and posterior steaks had a 4.6% increase in fat percentage. From a color standpoint, SV heating greatly impacted all color attributes resulting in a less red, more yellow appearance. Further research is needed to understand composition differences within the *serratus ventralis* to possibly map a pattern of tenderness, and to optimize low-temperature long-time combinations via sous vide heating to maximize palatability traits and to better understand color development during sous vide heating.

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Table 1. *Serratus ventralis* weights from raw and following sous vide heating.

	SV[1]		CON	SEM[2]
	Pre	Post		
Chuck roll, kg	8.74	———	9.03	0.20
Whole muscle weight, g	2,214.44	2,008.15	2,031.55	77.84
Fabricated weights, g				
Anterior whole, g	——	827.44	890.30	49.38
Anterior steaks, g	_____	700.75	751.15	47.55
Posterior whole, g	_____	1,194.84	1,138.65	41.76
Posterior steaks, g	_____	1,088.35	1,023.75	43.84

[1] Sous vide (SV) whole muscle weights were recorded before (Pre) and after (Post) preparation.

[2] Standard error (largest) of the mean.

Table 2. Main effects of aging, cookery and steak location on instrumental color of Denver steaks

	Aging time, d		Cookery		Steak location			*P* - Values		
	4	25	SV[1]	CON[2]	Anterior	Posterior	SEM[3]	Cookery	Aging	Location
L*	49.70	48.54	53.08	45.16	49.74	48.50	1.28	<0.01	0.20	<0.01
a*	26.74	26.24	25.97	24.00	24.74	25.23	0.92	<0.01	<0.01	0.23
b*	19.05	16.81	20.11	15.75	18.14	17.72	0.67	<0.01	<0.01	0.14
Hue angle	35.22	35.90	37.86	33.26	36.21	34.91	0.49	<0.01	<0.01	<0.01

1 Sous vide (SV) prepared whole muscle at 51.6°C for 12 h prior to steak fabrication.
2 Control (CON) were raw Denver steaks.
3 Standard error (largest) of the least square means.

Table 3. Effects of aging, cookery method, and steak location on Denver steak proximate composition and instrumental tenderness

	Aging, d		Cookery[1]		Steak location			*P*- Value			
	4	25	SV	CON	Anterior	Posterior	SEM[4]	Aging × Cookery	Cookery × Location	Aging × Location	Cookery × Aging × Location
Protein, %	20.07	20.18	20.74^{a}	19.50^{b}	20.56^{a}	19.69^{b}	0.51	0.75	<0.01	<0.01	0.33
Fat, %	18.79^{a}	14.43^{b}	16.39	16.83	14.31^{a}	18.91^{b}	3.56	0.04	0.80	0.01	0.28
Moisture, %	62.78^{a}	65.40^{b}	62.89^{a}	65.28^{b}	65.09^{a}	63.08^{b}	1.08	<0.01	<0.01	<0.01	0.99
Thaw loss, %[3]	9.56^{a}	7.05^{b}	8.87^{a}	7.74^{b}	9.20^{a}	7.41^{b}	0.53	0.02	0.50	0.98	0.12
Cook loss, %[2]	13.04^{a}	15.09^{b}	13.90	14.24	14.51	13.62	1.62	0.15	0.97	0.27	0.57
WBSF, kg	2.55	2.31	2.45	2.40	2.57^{a}	2.28^{b}	0.21	0.27	0.13	0.80	0.07

[1] Format is the same as in Table 2.
[2] Cook loss = [(thaw weight- cooked weight) / thaw weight] × 100
[3] Thaw loss = [(frozen weight- thaw weight) / frozen weight] × 100
[4] Standard error (largest) of the least square means.
[a,b] Least squares means in the same main effect without common superscript differ ($P < 0.05$).

Table 4. Effects of aging, cookery method, and steak location on grilled Denver steak trained panelist rating[1]

	Aging, d		Cookery[2]		Steak location			*P*- Value			
	4	25	SV	CON	Anterior	Posterior	SEM[4]	Aging × Cookery	Cookery × Location	Aging × Location	Cookery × Aging × Location
Initial tenderness	5.65^{a}	6.23^{b}	5.90	5.98	5.82	6.06	0.20	0.79	0.61	0.71	0.84
Sustained tenderness	5.30^{a}	5.76^{b}	5.50	5.56	5.44	5.62	0.23	0.51	0.64	0.75	0.83
Juiciness	5.13	5.31	4.95^{a}	5.49^{b}	5.19	5.25	0.28	<0.01	0.51	0.91	0.88
Beef flavor intensity	4.71	4.76	4.53^{a}	4.94^{b}	4.73	4.73	0.18	0.07	0.37	0.27	0.44
Off-flavor intensity	1.06	1.15	1.12	1.09	1.13	1.08	0.07	<0.01	0.07	0.14	0.08

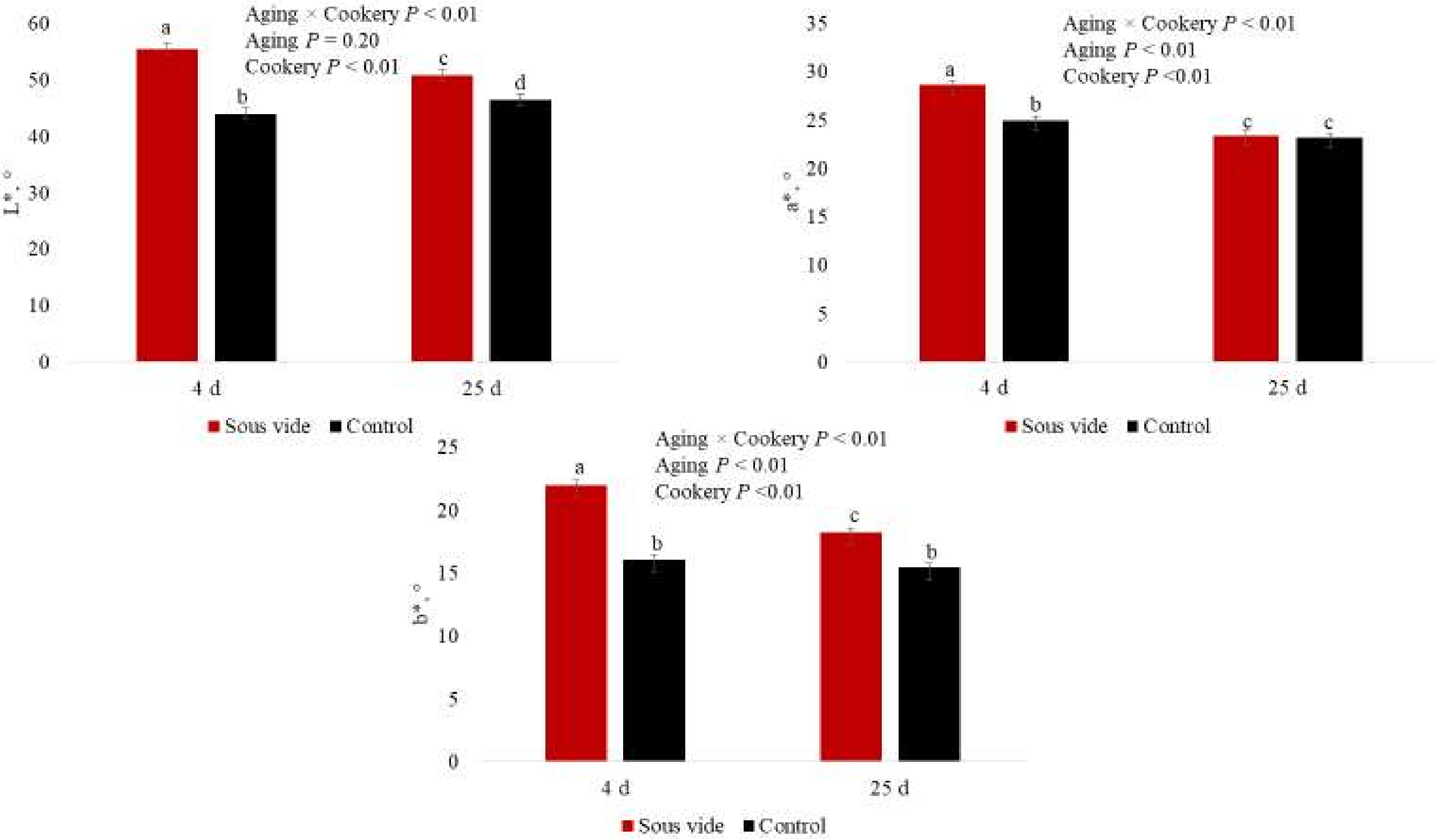
[1] Sensory scores: 1 = extremely tough/bland/dry; 5 = slightly tender/intense/juicy; 8 = extremely tender/intense/juicy; 1 = no off-flavor detected; 6 = extreme off-flavor detected.

[2] Format same as in Table 2.

[4] Standard error (largest) of the least square means.

[a,b] Least squares means in the same main effect without common superscript differ ($P < 0.05$).

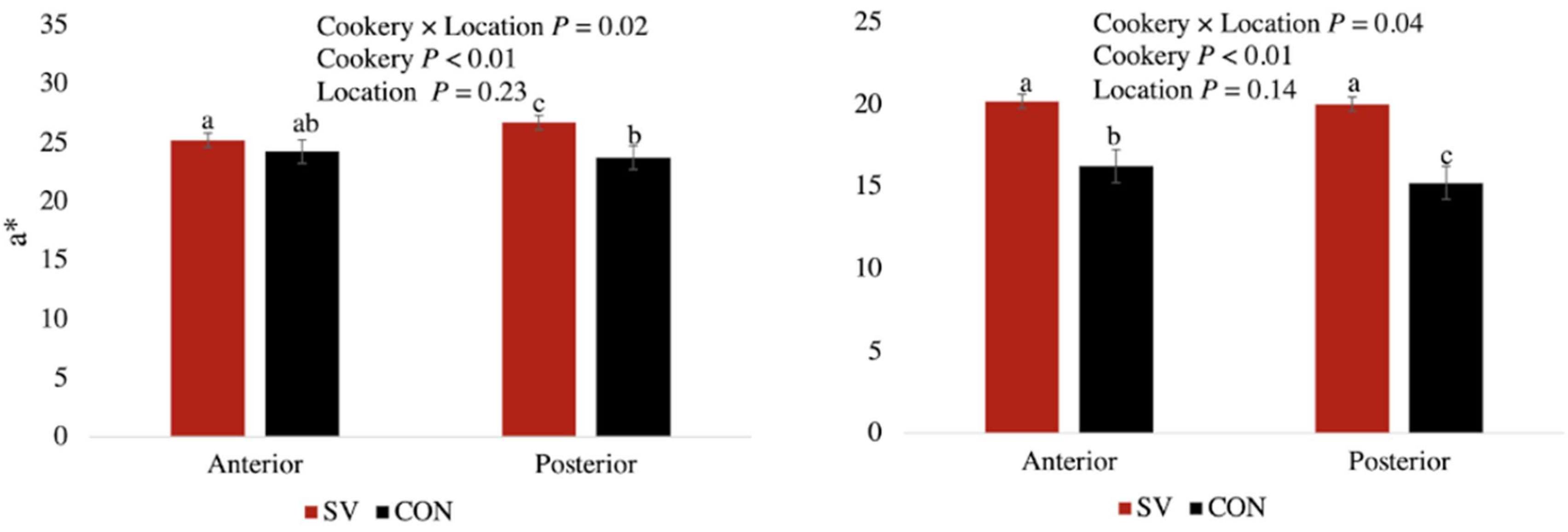
Figure 1. Effects of cookery and aging on internal instrumental color for raw and sous vide heated Denver steak



Serratus ventralis muscle were sous vide heated at 51.6°C for 12 h.

^{a,b,c,d} Treatments with different superscripts differ ($P < 0.05$)

Figure 2. Effects of cookery and location on instrumental color for raw and sous vide heated Denver steaks

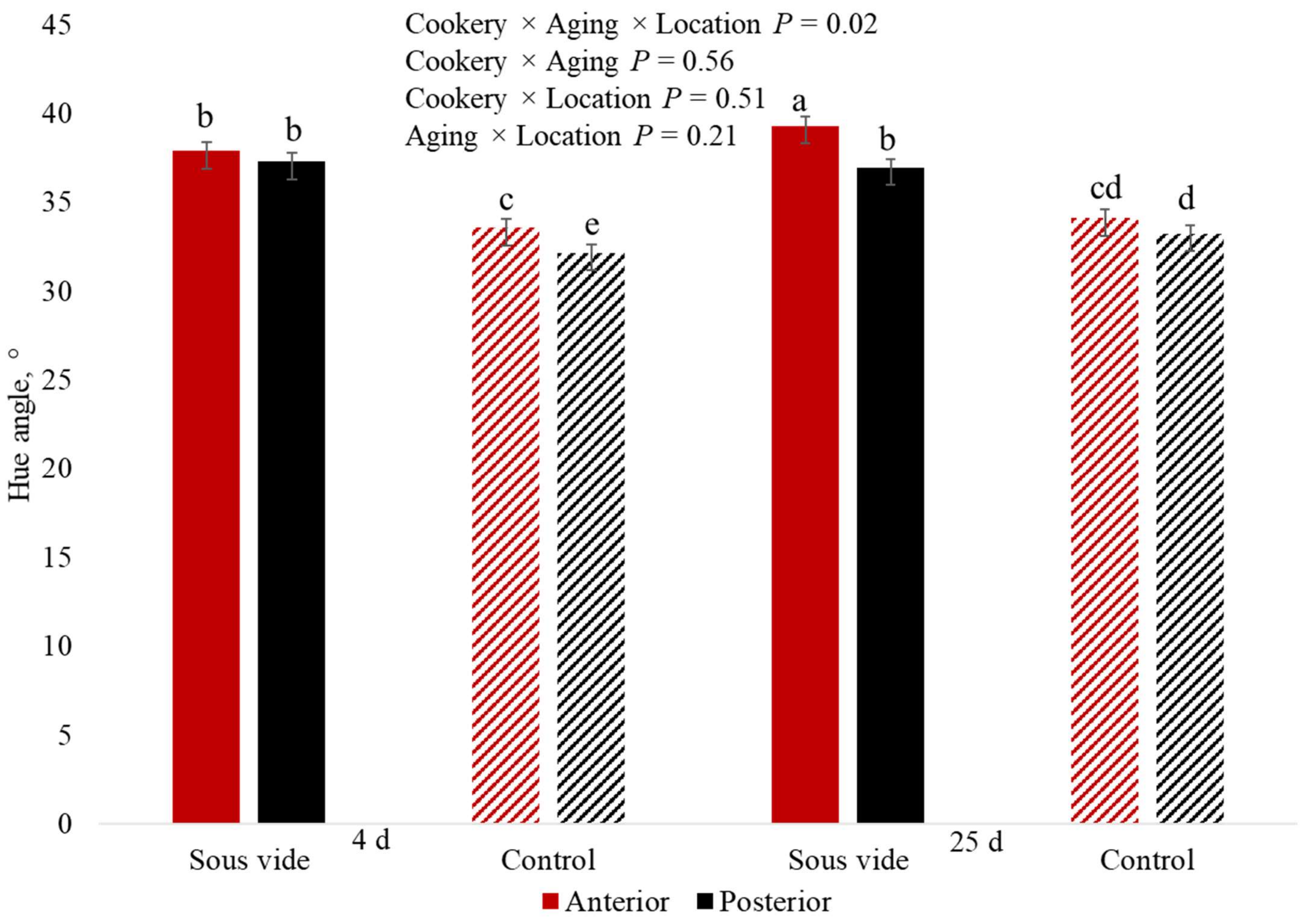


Serratus ventralis muscle were sous vide heated at 51.6°C for 12 h.

^{a,b} Treatments with different superscripts differ ($P < 0.05$).

Sous vide (SV); Control (CON)

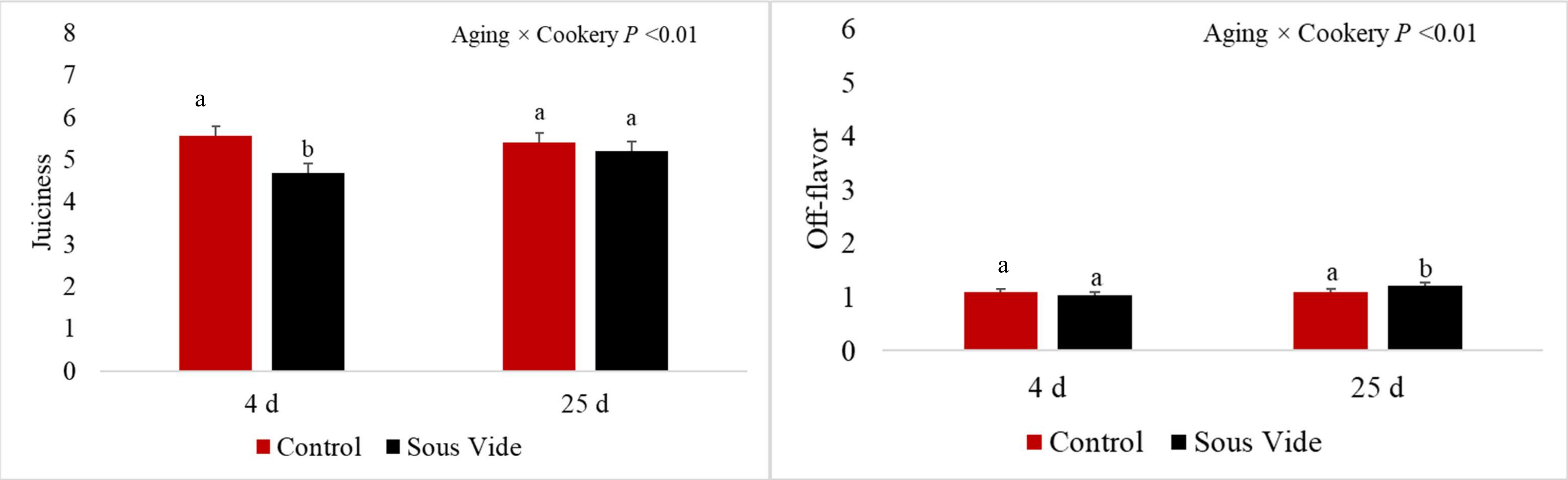
Figure 3. Effects of aging, cookery, and steak location on hue angle for raw and sous vide heated Denver steaks



Serratus ventralis muscle were sous vide heated at 51.6°C for 12 h.

^{a,b,c} Treatments with different superscripts differ ($P < 0.05$)

Figure 4. Effects of aging and cookery on juiciness and off-flavor trained panelist ratings from grilled Denver steaks



Serratus ventralis muscle were sous vide heated at 51.6°C for 12 h.

^{a,b,c} Treatments with different superscripts differ ($P < 0.05$)

APPENDICES

Denver Steak Study

Sensory Card UGA- MSTC 2023

Dr. T. D. Pringle

Panelist Initials: ______________________ Date: ____________ Time: AM / PM

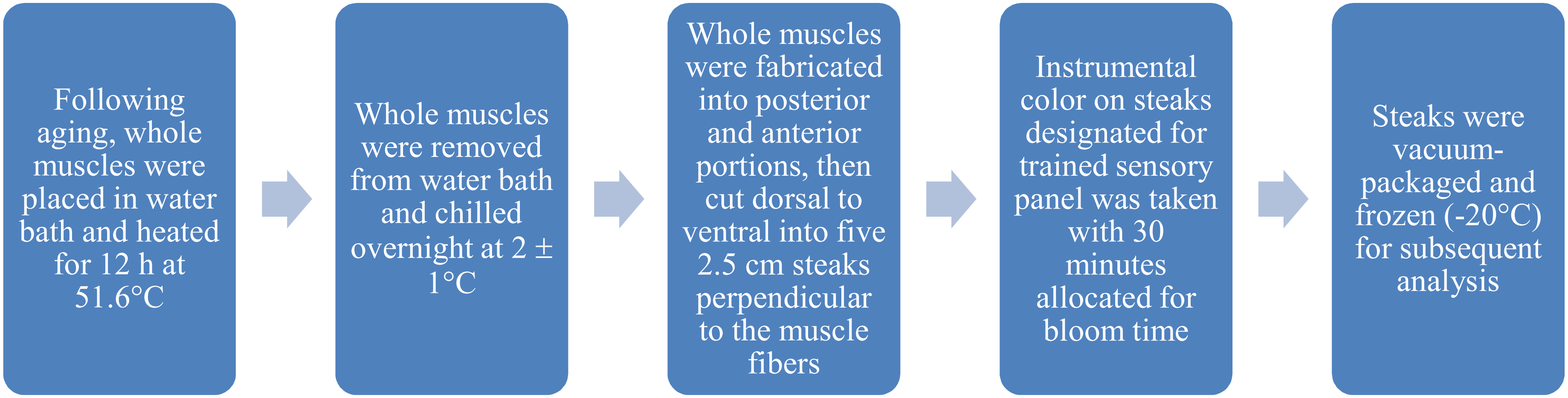
Initial Tenderness 8- Extremely tender 7- Very tender 6- Moderately tender 5- Slightly tender 4- Slightly tough 3- Moderately tough 2- Very tough 1- Extremely tough First 10 chews (Muscle fiber, tooth penetration, muscle separation)	**Sustained Tenderness** 8- Extremely tender 7- Very tender 6- Moderately tender 5- Slightly tender 4- Slightly tough 3- Moderately tough 2- Very tough 1- Extremely tough (Muscle fiber, tooth penetration, muscle separation)	**Overall Juiciness** 8- Extremely juicy 7- Very juicy 6- Moderately juicy 5- Slightly juicy 4- Slightly dry 3- Moderately dry 2- Very dry 1- Extremely dry
Beef Flavor Intensity 8- Extremely intense 7- Very intense 6- Moderately intense 5- Slightly intense 4- Slightly bland 3- Moderately bland 2- Very bland 1- Extremely bland	**Off- Flavor** --------------- --------------- 6- Extreme off-flavor 5- Strong off-flavor 4- Moderate off-flavor 3- Slight off-flavor 2- Threshold off-flavor 1- None detected	**Off- Flavor Lexicon** Metallic Vinegar Acidic Salty Grassy Livery Soapy Fishy

ID	**Initial Tenderness**	**Sustained Tenderness**	**Juiciness**	**Beef Flavor Intensity**	**Off-Flavor**	**Descriptor**
1						
2						
3						
4						
5						
6						
7						
8						

Please wait 20 second between samples

Flow Chart for Fabrication

Sous vide Preparation



Following aging, whole muscles were placed in water bath and heated for 12 h at 51.6°C

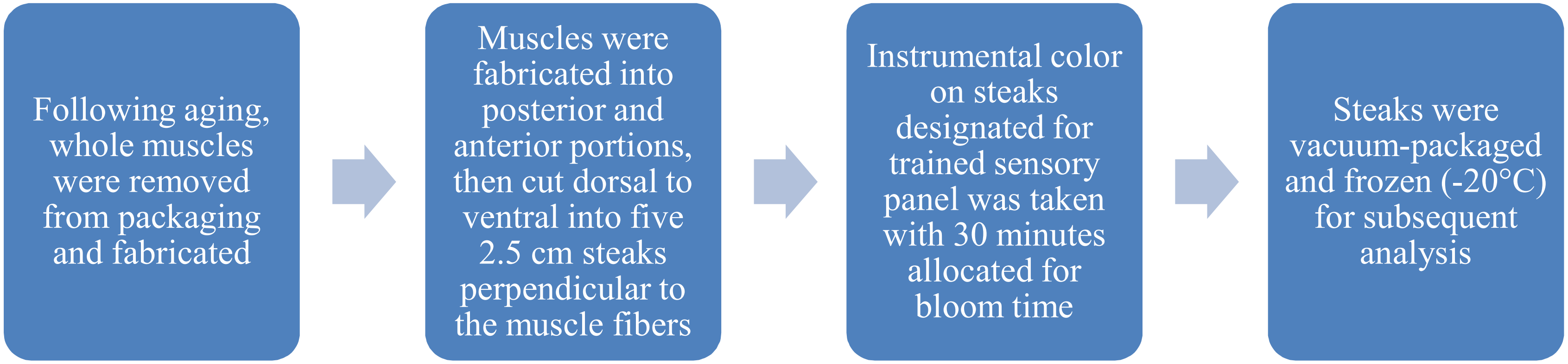
Whole muscles were removed from water bath and chilled overnight at 2 ± 1°C

Whole muscles were fabricated into posterior and anterior portions, then cut dorsal to ventral into five 2.5 cm steaks perpendicular to the muscle fibers

Instrumental color on steaks designated for trained sensory panel was taken with 30 minutes allocated for bloom time

Steaks were vacuum-packaged and frozen (-20°C) for subsequent analysis

Control



Following aging, whole muscles were removed from packaging and fabricated

Muscles were fabricated into posterior and anterior portions, then cut dorsal to ventral into five 2.5 cm steaks perpendicular to the muscle fibers

Instrumental color on steaks designated for trained sensory panel was taken with 30 minutes allocated for bloom time

Steaks were vacuum-packaged and frozen (-20°C) for subsequent analysis