EFFECTS OF WATER CONFIGURATION (FORM) IN BEEF LOINS ON COLOR, TENDERNESS, AND ELECTRICAL CONDUCTIVITY

by

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LIST OF ABBREVIATIONS

Abbreviation	Description
EC	Electrical Conductivity
DMb	Deoxymyoglobin
OMb	Oxymyoglobin
COMb	Carboxymyoglobin
MMb	Metmyoglobin
MAP	Modified Atmosphere Packaging
VP	Vacuum Packaging
AMSA	American Meat Science Association
ATP	Adenine Triphosphate
NADH	Nicotinamide Adenine Dinucleotide
USDA	United States Department of Agriculture
μS	Microsiemens

ABSTRACT

In this thesis, beef strip loins were used to study about the effects of apparent water configurations (free, immobilized, and bound) on color, electrical conductivity, and tenderness. These variables contribute to consumer sensory attributes that effect quality factors in beef consumption. Color variables (n = 36) tested involved chroma, hue, L*, a*, and b* to determine correlation across fresh strip loins. The Pearson correlation data demonstrated a correlation at ($P < 0.0001$) between chroma, hue, L*, a*, and b* across all loins. Further analysis displayed similar conclusions to contain a significant difference. Beef jerky (n = 72), cooked, and fresh strip loins (n = 36) were evaluated for data analysis using electrical conductivity measurements (ECM). Beef jerky determinations displayed high electrical conductivity (EC) with (SEM = 5.05), and ECM was inconclusive based on ingredients listed (food additives). Cooked strip loins, across strip loins, resulted in low ECM ($P = 0.37$) indicated no significant difference. Fresh strip loins were compared among strip loins and indicated a trend ($P < 0.078$). Both fresh and cooked strip loins were compared, and ECM showed a three-fold increase across loin types ($P < 0.0001$). Tenderness (n = 216) was different ($P < 0.0001$) across strip loins. All data were collected on one source of beef strip loins that came from different animals. Data analyses were conducted through SAS software using Pearson correlations and ANOVA to determine correlation and comparison across strip loins. Results of these experiments show that there are correlations between EC and color of fresh beef loins, and between EC and tenderness of cooked beef loins.

I. INTRODUCTION

Background

According to the United States Department of Agriculture - Economic Research Service (USDA-ERS, 2015), overall meat consumption is estimated to reach 220.5 pounds per capita in 2020. Despite the beef's calculated per capita consumption (57.3 lb) in 2019, this outcome initiated a competitive market. Beef products, even at a low consumption rate, have produced at a lesser value without jeopardizing beef quality. Research in the beef industry has made several improvements based on customer satisfaction and willingness to purchase beef products. Prior research has thoroughly investigated the primary features used to determine purchase ability, i.e., sight and taste. Visual representation of beef color has profoundly influenced a consumer's purchasing decision (Mancini & Hunt, 2005). With any indication of discoloration, consumers are prone to reject meat products. Researchers have extensively researched that beef color desirability is a bright cherry red. This color has led researchers to produce significant improvements to packaging practices to satisfy customer and retailer standards. Tenderness is another quality factor that varies based on type, quality, and cooking sensory of meat. Tenderness is also a sensory characteristic that influences a consumer's satisfaction of beef products and the willingness to grant a higher premium for a tender beef product (Nair et al., 2019). Additionally, juiciness is an additional sensory attribute that influences consumer's decisions on beef purchases. The absence of juiciness may indicate no flavor and therefore may pinpoint a subordinate beef product and an unfavorable product (Toldra, 2003). Juiciness in a beef product is subjected to electrical conductivity and water properties in meat. Consumers value these three vital properties to determine the

value of beef products in totality. Researchers are tasked to evaluate any dissatisfactory characteristics in beef, for instance, discoloration, toughness, and shrink loss in beef after cooking based on consumer demand for high-quality beef. Overall satisfaction of beef products requires researchers to grasp muscle composition and adequately improve sensory factors that influence beef product sales.

Purpose of this Study

The primary purpose of this study was to empirically improve quality assessment evaluations of beef by color score values, tenderness measurements, and electrical conductivity to estimate water forms. Specifically, this study examined one source of beef loins, one source of commercial beef jerky, and four water sources using EC determinations. The differences in water forms of fresh beef loins were compared to water sources in beef jerky. A total of three variables were used: color, tenderness, and electrical conductivity. These variables were used to provide improved appraisal methods for grading beef and to enhance quality assessment evaluations.

Limitations of this Study

The limitations of this study consisted of the research relying on a third party supplier to deliver beef loins to initiate the data collection. Beef loins were distributed ad libitum based on supplier's availibility. Subsequently, the meat processing lab capacity impacted how frequently the electrical conductivity samples were completed based on the limited availability of equipment. Lastly, the Varian spectrophotometer machine required further data parameter adjustments to measure and correlate color evaluations accurately.

Implications of this Study

This study provided an improved understanding of beef quality characteristics of color, tenderness, and electrical conductivity through instrumentation to quantify values by specified techniques. All attributes listed are exceedingly crucial for consumer acceptability of beef products. The use of methods within this study can provide the beef industry benefits to enhance their beef products to an exceptional level, thus providing high-quality products for consumers.

Research Questions

1. What effect does water configuration in beef loins have on color?
2. What effect does water configuration in beef loins have on tenderness?
3. What effect does water configuration in beef loins have on electrical conductivity?
4. What is the overall relationship of water configuration on color, tenderness, and electrical conductivity of beef loins?
5. What improvements of color, tenderness, and electrical conductivity can be made to predict estimates in water configurations in beef loins?

Theoretical Framework

The overall objective of this thesis was to improve quality assessment procedures of beef loins through correlations of electrical conductivity with color, and electrical conductivity with tenderness. In conjuction, a beef jerky sample contributed to the study to estimate water forms as well.Therefore, this approach ensured quality assessment procedure applications followed: collection of color determinations using the Varian UV-Vis Spectrophotometer in order to develop an in-depth strategy to measure and interpret color values. The next technique was the determination effects of electrical conductivity by

estimating free, immobilized, and bound water, using an in-house device in our laboratory. Subsequently, tenderness effects in beef loins were determined by shear force value calculation using the Warner-Bratzler Shear Force device. Lastly, electrical conductivity measurement for beef jerky was calculated for water form prediction. All, data values were collected on each quality assessment procedure and evaluated using the SAS software through statistical analysis of variance (ANOVA) and Pearson correlation coefficients. Data summaries were calculated for electrical conductivity, color, and tenderness.

II. LITERATURE REVIEW

Water configurations in meat are related to its ability to bond with charged species (Huff-Lonergan & Lonergan, 2005; Toldra, 2003). The chemical properties of water allow for proteins and other charged molecules to bind interchangeably. An important characteristic of water in postmortem muscle is its ability to preserve its reflexive form known as water holding capacity (WHC) (Aberle et al., 2001; Cheng & Sun, 2008; Devine et al., 2014; Huff-Lonergan & Lonergan, 2005; Hughes et al., 2014; Offer & Trinick, 1983; Toldra, 2003; Warner, 2017). WHC remains one of the principal reasons consumers identify dissatisfactory meat products . It is referred to as deficient or excessive water in the meat. Consumer purchasability drives the meat industry, so any substandard meats equate to significant economic loss (USDA-ERS, 2015). Stabilization of water in meat involves knowledge in muscle structure and structural components during pre and post mortem phases. Water composition understanding is required to comprehend and reduce WHC abnormalities that jeopardize profitability.

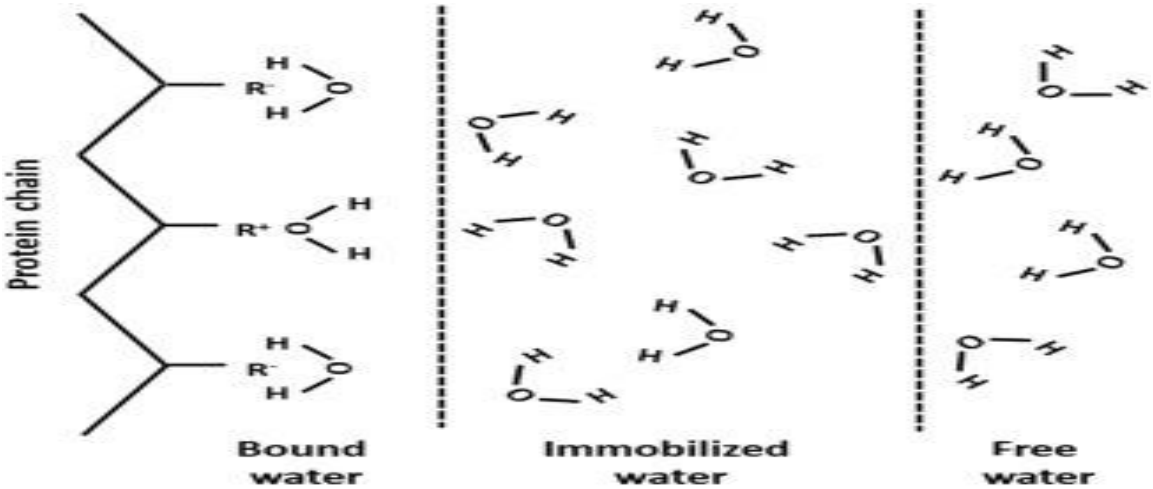

Figure 1. Three water configurations in muscle tissue. Adapted from *Principles of Meat Science* by Aberle et al., 2001, Dubuque, IA: Kendal/ Hunt Pub Co. Copyright 2001.

Color

Color in meat is complementary to the pigmentation of a meat surface in conjunction with reflection, detection, and an analysis to interpret color perception of the surface (AMSA, 2012). A visual representation of color is determined once light shines off a surface, is reflected, and processed for interpretation of hue (Aberle et al., 2001; AMSA, 2012). Hue is the final color description produced from reflection off the surface of meat. Meat is an intricate medium composed of water, protein, and fat, and these properties with color. Certain principles of color in beef such as hue, chroma, and lightness measured by instrumentation provide meats' color description, saturation perception, and luminous. These components are critical to identifying color in meat and help consumers place a color value on hue. Other factors that help identify color in meat are myoglobin, pre-harvest conditions, nutritional significances, package, and storage. All of these factors are explicitly identified and explained throughout the other sections below.

Myoglobin

Meat composition is reliant on three components: protein, fat, and bone, which are found into the structure of muscle tissue along with several biochemical properties. Proteins are macromolecules composed of amino acids, which are an indicative component of meat color. Two essential proteins related to meat pigmentation are myoglobin and hemoglobin. Myoglobin is a sarcoplasmic globular protein compromising 80-90% of the total pigment in muscle tissue (Aberle et al., 2001). The composition of myoglobin further includes a non-oxygen binding protein and a heme ring proportional to iron's oxidation that predominantly reflects meat color. Hemoglobin originates in red blood cells (RBC) and is the primary pigment of blood and is identified in muscle tissue

(Mancini & Kerth, 2013). In RBC's, hemoglobin permits oxygen transport whereas myoglobin functions to store oxygen in an animal's anatomy. Additional pigments, such as cytochrome, is present in muscle composition as well. Due to cytochrome's minimal contribution related to meat color, it is deemed infeasible to muscle tissue. Overall, myoglobin and iron oxidation states (Fe^{2+} or Fe^{3+}) predominantly control the four forms of chemical differentiation (AMSA, 2012). These are represented as deoxymyoglobin (DMb), oxymyoglobin (OMb), carboxymyoglobin (COMb), and metmyoglobin (MMb). These forms contain different distinctions associated with oxygen, iron, and stability for color maintenance. Deoxymyoglobin corresponds to a purple-red color identified interiorly in beef pinpointed in vacuum packaging (Mancini et al., 2018). Vacuum packaging coincides with a ferrous state (Fe^{2+}), generating a reduced oxygenated condition consequence of the purple-red color. Second, oxymyoglobin is the development of connecting diatomic oxygen to iron's ferrous oxidation state (Fe^{2+}) that reflects a bright red color. Oxymyoglobin remains the ideal oxidation state commercial stores display for optimal color in beef (Trinderup et al., 2015). Third, carboxymyoglobin binds to myoglobin accompanied by carbon monoxide that produces a solid bright cherry red pigmentation deficient of oxygen (Sakowska et al., 2016). The presence of oxygen permits OMb to dominate myoglobin's condensed structure. Lastly, metmyoglobin (MMb) is expressed through a transformation of Fe^{2+} to Fe^{3+} oxidation state. Through this oxidation transformation, a brown color arises by a mild to severe meat discoloration process (Quevedo et al., 2013). Meat discoloration constitutes a chemical process oxidation-reduction interconversion about myoglobin and hemoglobin. Having minimal color stability, MMb is avoided in beef due to its low desirable quality (Cooper et al.,

2017). Each of the four chemical forms of myoglobin places heavy emphasis on color, quality, and oxidation states. Prior investigations have proposed that myoglobin oxygenation is influenced by time, pH, temperature, and mitochondrial activity affects color stability (Mitacek et al., 2019). However, myoglobin's influence in color has dominated research in recent years but, little research has been conducted to show myoglobin's exact biochemical properties.

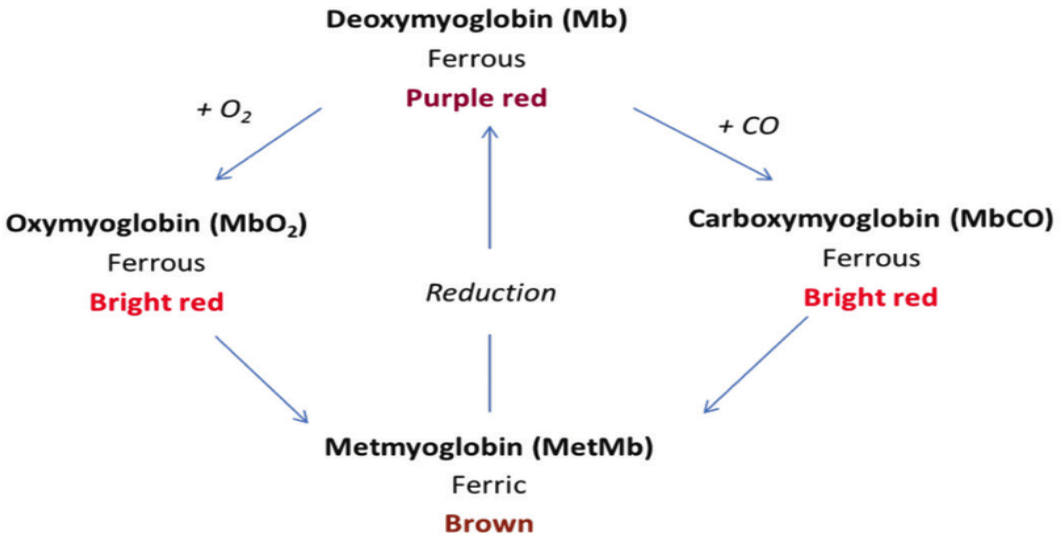

Figure 2. Myoglobin reduction-oxidation properties. Adapted from Renerre, 1990 and Ramanathan, Mancini, Konda (2009).

Pre-harvest conditions

Daily meat production transpires through small businesses or large commercial operations. Overall, today's livestock industry possesses a better grasp of production principles than in prior years. For instance, the total U.S beef consumption endured a decline from 27.9 billion/lb. in 2002 to 24.8 billion/lb., but in 2015, the overall beef price obtained a three-fold increase since 2002 (USDA-ERS, 2015). Several possible pre-

harvest biological factors contributed toward this decline, such as genetics and the environment. The initial challenge for producers is genetics produces a grade to reflect high-quality beef products if properly addressed. An influential factor in meat quality is marbling. Marbling is characterized as the intramuscular fat within a muscle tissue that is highly sought after in the United States. Respectively, several bovine breeds exhibit greater marbling qualities than others, but aforesaid high or low demand relies on consumers. Lastly, genetics can reflect meat color through the expression of proteins and denotation of a breed's tendency to display the desired meat color. The environment is an additional factor that is capable of exhibiting the desired quality/color of meat reliant on an animal's stress level. In stressful environments, beef cattle deplete glycogen stores, and converts stored energy into lactic acid (Cooper et al., 2017). Lactic acid, a weak organic acid, employs lactate to generate deoxygenated glycolysis in the liver. Production of lactic acid reduces cattle exercise, diminishing their full potential to convert feed as a consistent energy source. The utilization of lactic acid for an extended period results in a dark, firm, and dry meat, which ultimately leads to a reduced color classification reflecting an inferior beef product (Olaoye, 2011). These considerations are linked to research insufficiencies and drawbacks in meat production and require a critical assessment to preserve meat quality.

Nutritional significances

Nutrition is a critical factor that initiates by consumption of forage or feed to extract out nutrients necessary for biological activity. A different allocation of forage diets subsists of grass that precipitates lighter muscle and yellow intramuscular adipose tissue. Meat pigmentation and intramuscular fat are the main contributors to meat structure that

occupies a higher percentage of water, protein, and fat. Chemical properties, furthermore, express color pigments, and fat oxidation and pH discloses the concentration of a meat product (Fu et al. 2015). The pH is related to hydrogen concentration and is mildly related to stable meat products, but prior research indicates myoglobin as the fundamental source. Red color expression is reinforced by myoglobin; previous research confirms increased myoglobin content and the higher saturation of red. A consumer's focus on color is dependent via a precise tint of red presumed the indicator of freshness and palatability (Tapp III et al. 2011). Color properties additionally are located in iron content, glycogen, pH, and vitamin E. Specifically, vitamin E is fat-soluble and stored in the liver but is further fortified in cattle's diet. This vitamin is utilized to prevent meat discoloration through a reduced lipid oxidation process. This process requires the stabilization of meat color once vitamin E is flushed from the bloodstream by ATP.

Nutritional factors are substantial for the regulation of meat color due to several vitamin, protein, sugar, and metabolic processes that emerge from pre-harvest conditions and post-harvest conditions (Gagaoua et al. 2018). A nutritional regimen is required for cattle maintenance to ensure high-quality meat; without the necessary measures, the beef industry would not prevail.

Package and storage

Perishable food products require a high demand for consistency to preserve color and shelf life. Meat products are no different; preservation of meat is critical for the appeal of the consumer. Since the demand for beef is dependent on consumer satisfaction, the application for new cost-effective quality assurance factors is imperative. Newly developed measures should not compromise beef product integrity but promote freshness,

wholesomeness, and client satisfaction. A consumer's false notion of beef discoloration has provoked an economic loss of 15% in the retail industry (Mancini & Hunt, 2005). At purchase, a beef product color ought to resemble a bright cherry red. However, the duration of beef color is dependent on the oxidation process, environment, and replication rate of spoiling bacteria. Maintenance of the desired beef color involves several factors, for instance, proper packaging techniques, cutting conditions, temperature, storage, and the series of color cycles in a beef. Proper packaging techniques are essential to eliminate the risk of contamination with other food products, spoilage, and oxidation changes in beef products (Suman et al., 2014). Inadequate packaging and deterioration of a beef product is the main factor for economic loss for the meat industry. A standard packaging technique observed in the beef industry is modified atmosphere packaging (MAP). Modified atmosphere packaging is a packaging technique used to extend the shelf life of fresh edible products categorized into two common forms of vacuum and traditional packaging. Vacuum packaging (VP) delays beef discoloration by limiting oxidative properties; in essence, the removal of oxygen (Vitale et al., 2014). The removal of oxygen promotes an anaerobic environment that produces a purple color in meat. In VP, oxygen-deficient environments are needed to reduce the replication of bacteria and conjointly a mixture of carbon monoxide at 0.4% (Nair et al., 2018). Despite its popularity for the industry, consumers disapprove of VP. Prior researchers understand this predicament and minor contributions have occurred but no overall solution for the ideal beef color. Traditional packaging creates a visual appeal for consumers while the meat is on display. Still, the extended display time reveals the instability of color and results in a limited shelf life (Suman et al., 2016). The management of oxidation

fluctuations is crucial to avoid such catastrophes in packaging beef products. In addition to oxidation, cutting conditions prior and after the distribution is critical to reduce cross-contamination, ensure sanitation of all utensils/tools and personal hygiene of all personnel. Without these regulations, contaminants linger in the packaged meat environment until the product is uncovered. Temperature is another determinant having the ability to preserve meat products and reduce enzymatic oxygen usage. Although preservation of meat products is necessary, temperature regulation is cost-effective, requiring daily upkeep of equipment and a controlled record of recurrent meat products in a freezer and cooler. Meat products typically undergo a 14-day wet aging process before display. During the wet aging process, meat color adheres to a consistent color (purple), then once removed from refrigeration, the meat product commences an OMb state. Lastly, the number of times meat goes through color cycles is vital primarily for postmortem aging. Color cycles reflect on myoglobin chemical states, any constant reversal of OMb, COMb, DMb, and MMb contributes to poor meat quality and deterioration of protein pigmentation (AMSA, 2012). Package and storage of meat are costly and problematic to ensure quality factors fulfill consumer's needs. Additional research in meat packaging is necessary to develop high-quality beef products to avoid discoloration.

Water

Water is an inorganic, isoelectronic liquid molecule established at a level of 75% in skeletal muscle tissue. Other muscle constituents are proteins, lipids, carbohydrates, minerals, vitamins, and other nitrogenous non-protein extractives (Offer & Trinick, 1983). These additional components located in muscle tissue compromise a limited

percentage, but concerning water configurations, all are accounted. The majority of the water content of the muscle supports in myofibrils, which are composed of thick and thin filaments (Byrne et al., 2000). The water forms are known as bound, immobilized, and free and each is unique based on composition, location, and functionality in muscle tissue. Bound water is supported adjacent to proteins or other hydrophobic components with limited movement (Huff-Lonergan & Lonergan, 2005). This water form contributes to a modest percentage of total water in muscle with limited changes post rigor mortis. Immobilized water, conjointly referred to as entrapped water may bind to muscle tissue but is not restricted solely to a non-aqueous component. This water configuration is affected dramatically when muscle tissue converts to meat. Producers undertake cautious measures to avert purging when a conversion occurs (Toldra, 2003). Free water contains weak covalent bonds that independently flow throughout muscle tissue readily without adhering to constituents. In pre-rigor meat, muscle-bound water conditions are capable of change to transform free to immobilized water (Warner, 2017). All three water forms acquire different effects in muscle and are limited to the tremendous ability of interaction among proteins. Regardless of the interaction, these water forms mirror the overall meat product; the absence of water in muscle tissue is ineffectual.

Characteristics of water in muscle

Water is an aqueous solution indicative of a cluster formed by Hydrogen (H^+) bonded molecules containing a partial positive and negative position known as a dipole movement. Characteristically a dipole is a water molecule with an affinity toward ions, proteins, and other charged molecules. Water is fundamental for the functionality of all major organs and provides lubrication for cell movement. Movement in muscle also

requires major elements such as calcium, magnesium, and phosphorus to regulate muscular locomotion. Muscle contraction and relaxation oversee water retention once the muscle transforms into the meat. Water holding capacity is defined as the meat's ability to retain water despite external pressure (Cheng & Sun, 2008). Water bound meat can occur through capillary action, limiting the microstructure of muscle tissue. Capillary bound water is only capable of extracting water through force, the addition of ions, or protein denaturation. The strength needed is 200 > 2000 psi to expel water from muscle tissue, which results in stretched meat with large pores (Warner, 2017). Another method for water extraction is the addition of ions accomplished with salts or phosphates, which permanently dismantles muscle tissue and protein arrangement is distorted. With muscle tissue in disarray from the inclusion of ions, water flows effortlessly. Lastly, protein denaturation identification through cooking of meat in high temperatures uncoils proteins until shrinkage occurs. Consumer preference relies on meat products being juicy, with water extracted through the forms; as mentioned earlier, this can decrease the overall palatability of a meat product. Consumer grades have indicated that juiciness supports 10% of the variation in the acceptance of meat products (Devine et al., 2014). The driving force for muscle is water, and without the juiciness of a meat product consumers are likely to disregard meat products. Research in the preservation of water forms is crucial for meat palatability to have the appropriate water content free from the destruction of meat products.

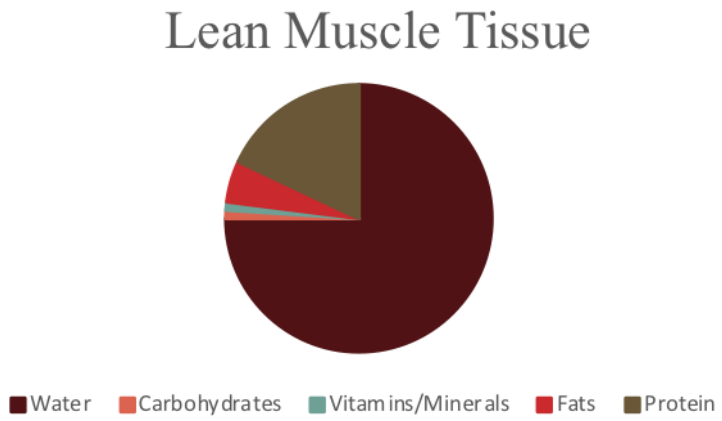

Figure 3. Composition of lean muscle tissue. Inspired by Olaoye, O.A. (2011). Meat: An overview of its composition, biochemical changes and associated microbial agents. *International Food Research Journal.*

Electrical conductivity in beef

The dielectric property of meat is categorized by electrically charged proteins, pH fluctuations, present ions, and the molecular structure, which is arranged by cellular membranes (Damez & Clerjon, 2013). These electrical properties are composed of electromagnetic waves that refer to the intra and extra-cellular segments of muscle tissue. The cellular parts of muscle tissue signal a transmitted frequency and sequentially produce an electrical current defined as electrical conductivity. Electrical conductivity, by definition, is a specialized assessment that involves cell membranes located interior to whole muscle tissue (Byrne et al., 2000). A high electrical conductivity (EC) value infers an increase in water mixture in the muscle. Water is a contributing factor that influences electrical conductivity considerably. An EC value is expressed by units siemens (S), mho (℧), or microsiemens (μS). Prior EC literature uses the above units frequently to describe electrical currents in meat. A specific type of EC is the electrical impedance that is expressed by Ohm's Law unit ohm (Ω) and is an electrical current that flows through a

circuit corresponding to a voltage without resistance (Põldvere et al., 2016). Electrical impedance in meat is related to an electrical property of a meat product that flows based on an interchanging current at a definitive frequency (Byrne et al., 2000). Both EC and electrical impedance hold a distinct relationship in which one tests resistivity and the other tests electrical currents enclosed by a sample. Factors ampere (A) and voltage (V) reflect units of EC to mirror amplitude and includes electric potential difference to represent impedance. The amount of water and muscle tissue components in meat are potentially determined through EC but are dependent on the stability of cellular membranes (Lepetit et al., 2002). In cellular membranes, charged ions located in water molecules can produce an electrical current inducing a high EC value. A short electrical current in various locations in muscle tissue affects the water configurations differently. Bound water is typically not accounted for in EC measurements because of restricted movement. The calculation of immobilized water estimated based on ion affinity produces an electrical charge. Free water is profoundly affected by EC because of its charged fluidity toward cell membranes attracting a high electrical current. The ability defines the characterization of different water forms by EC for ionic bonding, charges, and location (Zhao et al., 2017). Water extraction can inversely compromise the effect of EC, which suggests lower EC values found in a cooked meat product by forcefully extracting water by a method known as dry aging.

Tenderness

Tenderness is a quality factor related to consumer acceptability and the ease of mastication. Beef tenderness is indicative of the muscle fibers' location and muscle structure to test how easily the mastication process occurs. Marbling is intramuscular fat

that aids in meat tenderness, which allows lipids to tenderize the meat. Development to improve tenderness in meat products involves further practices to be performed in the U.S, such as postmortem aging, which involves principal biochemical means (Nair et al., 2019). Post mortem aging is the usage of cellular and biological mechanisms that incorporate proteases that undergo proteolysis (Lonergan et al., 2010). Proteolysis is a process using specialized enzymes that modify the integrity and interactions of proteins. Specific muscles in beef are considerably tender in comparison with others. The levels of tenderness are distinguished through a series of analyses utilized to indicate differences. Muscles such as the longissimus dorsi (LD), psoas major (PM) and semitendinosus (ST) are categorized based tenderness (Aroeira et al., 2016). Variations of tenderness are contingent on genetics, environment, and nutrition of an animal ante-mortem. During antemortem, muscles interact with myocytes to facilitate movement and soundness. However, prior studies substantiate the belief that supplementary quality assessment traits in tenderness are necessary to support an increased purchase of beef products.

Constituents of beef muscle

The skeletal muscle tissue consists of three sections epimysium (outer), perimysium (middle), and endomysium (inner) portion of the muscle. Each section contributes to the antemortem muscle structure indicative of locomotion, which ideally determines tenderness. The endomysium is composed of five segments which influence the overall tenderness of the beef. These parts include the sarcolemma, sarcoplasm, sarcomere, myofibril, and myofilaments. The sarcolemma is a transparent membrane that envelops the muscle fiber to protect the innermost muscle fibers. Protection of the innermost muscle fibers also includes the intra and extracellular compartments within the cell. The

sarcoplasm relates to the skeletal muscle cytoplasm that contains stored glycogen, myoglobin, and proteins that bond with oxygen (Fu et al., 2015). Myoglobin, glycogen, and proteins attribute to beef color . A sarcomere is a striated muscle that contains variable lengths of disks, bands, and lines located in the sarcolemma that initiate voluntary movement. This unique structure promotes coordinated muscle contractions supporting a functional unit. Myofibrils are elongated rods aligning to the intact muscle fiber surrounded by an intracellular colloidal substance known as water. Water that surrounds the myofibrils aid the sliding mechanism associated with contraction and relaxation. Lastly, the myofilaments acquire a striated appearance positioned with overlap regions of thin and thick filaments. Myofilament section contains two different proteins, myosin located in thick filaments and actin in thin filaments. Myosin and actin are contractile proteins associated with muscle overlap and cellular movements. Other proteins that coincide with muscle movement are tropomyosin and troponin, which are less abundant in the overall muscle structure. In specific, actin is a globular linked protein (G-protein) that forms monomers, which affect F-actin another protein to a coil (Aberle et al., 2001). Myosin, an elongated shaped protein, contains a head, tail, and body which includes C proteins on each subsection of the molecule. When muscle contraction occurs, the head portion of myosin attaches to the G-actin protein of the actin filament (Gagaoua et al., 2018). Interaction of both molecules allows either contraction, relaxation, or movement in muscle tissue. Although locomotion is required for an animal's survival, it leads to disadvantages for pre-harvest aging and dark cutting meat (Nair et al., 2018). The classification of proteins is coincided by location, which devotes to its solubility. Skeletal muscle tissue's movements rely on action potentials generated through a nerve response.

Acetylcholine is released likewise with calcium (Ca^{2+}), and sodium (Na^{2+}) initiate depolarization. Receptors bind Ca^{2+} ions at a triad junction that regulates the flow of Ca^{2+}through channels provided the animal's state. Tropomyosin, and troponin are regulatory proteins that activate the go or stop phase (Guignot et al., 1993). The regulatory proteins depend on the amount of Ca^{2+} ions located in the sarcoplasm. The energy supplied by adenine triphosphate (ATP) in the muscle is needed to complete the circuit. ATP connected to an enzyme activates hydrolysis, which commences a nerve response to slide and adjust sarcomere filaments (Aberle et al., 2001). Relaxation requires a selection of ions that trigger a response to switch off muscle contraction. Repolarization occurs in the sarcolemma, which is connected to T-tubules. T- tubles activate a regulatory Ca^{2+} channel pump reducing the number of calcium ions in the sarcoplasm. Magnesium (Mg^{2+}) is also involved in reducing the muscle energy load to contract the muscle to restore sarcomeres to rest (Aberle et al., 2001). The relaxation and contraction of a muscle is an essential part of animal physiology and rigidity of muscle. In summary, locomotion is reliant on premortem muscle structure, the presence of ions, proteins, water, and other major molecules. Researchers must contribute additional means to provide tender meat cuts in animal physiology.

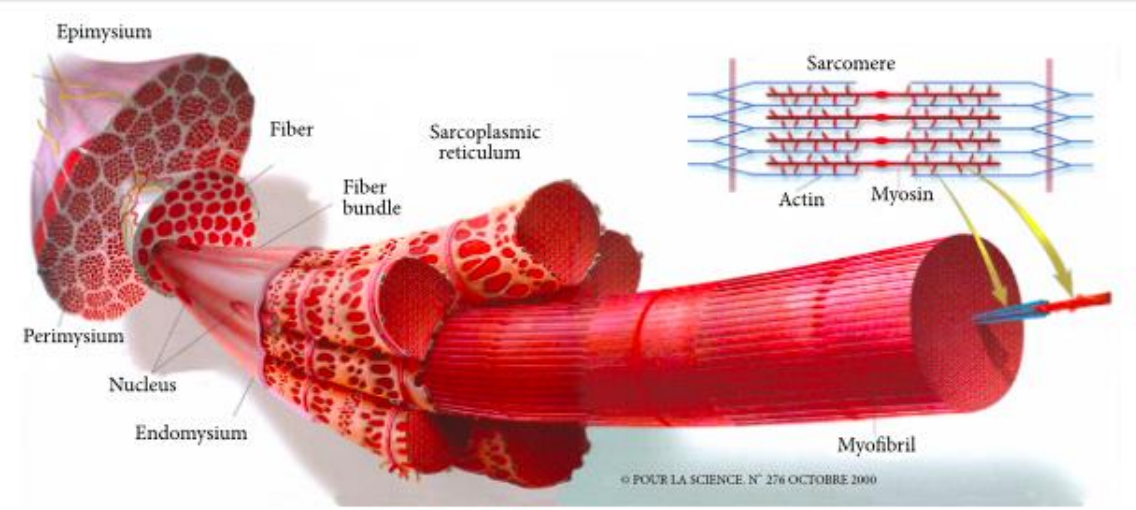

Figure 4. Structural components of muscle tissue. Adapted from Listrat, A. et al., (2016). How muscle structure and composition influence meat and flesh quality. *The Scientific World Journal.*

Determination of pH in beef

Ante-mortem pH in beef cattle is approximately 7.2 to 7.4 once the animal is harvested pH drops to 5.4 to 5.6. Tenderness is directly proportional to a pH range of 6 to 7 and as the pH drops meat is less tender over time, allowing for the introduction of post-mortem rigor mortis (Hughes et al., 2014). The release of calcium in muscle causes muscle contraction, depleting glycogen stores then interlocks permanent protein contraction (Listrat et al., 2016). The pH in rigor mortis naturally drops the oxidation-reduction potential at the cellular level resulting in a non-functional biological system. Oxygen concentration ceases in muscle tissue, and the rise of lactic acid commences. Lactate is a product of lactic acid that is generated in muscle fibers creating H^+ imbalance. Blockage of energy production adenosine triphosphate (ATP) to (NADH) nicotinamide adenine dinucleotide resorts to anaerobic energy production. Muscle acidity undertakes a loss of water-binding capabilities. Free water withdraws from muscle having no protein

attachment, then a limited portion of immobilized water. Muscle viability ceases, and muscle is converted to meat. The management of pH in meat is essential not only post-mortem but also antemortem. Lactic acid accumulation can occur en route to an abattoir due to stress leading to dark cutters. Dark cutters are the result of an animal undergoing long-term stress before harvest as lactic acid and glycogen play a significant role in stressful circumstances. The beef industry is acquainted with dark cutters and refrains from pre-stressful factors before harvest. Muscle swelling is another issue that occurs during the muscle to meat conversion. The pH dramatically decreases to 3, but the reversal of pH to 5 is achievable through time and proper storage (Lozano et al., 2016). The factors attributing to an animal's complex biological system requires a decrease in protein binding to water, protein denaturation, and lowering of pH. Previous studies have promoted knowledge of a bovine's anatomy but, the concept of continually achieving higher quality products is an extent that urges supplemental evaluation.

III. METHODS

Experimental design for electrical conductivity of water

All water samples were evaluated based on ionic strength (electrical conductivity) to determine a baseline (blank) for samples that included beef jerky and beef loins. Each water type was tested in this experiment (section) using electrical conductivity (EC) values to evaluate, which showed the least variability. The different types of water sources used included tap water, purified water, deionized water, and saline (0.9 % NaCl). Each water type has unique properties that relate to the various water forms. The electrical conductivity of water sources consisted of (n = 4 water source x 20 replications = 80 outcomes). Each water type evaluation incorporated specific transference of water into a 50 mL beaker then separately into a silicon vessel. The silicon vessel is part of the EC experimental design diagram (Figure 5 and 15) in which two copper electrodes were connected simultaneously to the multimeter. A measurement of EC lasted 60 seconds with an application rate of 2 readings per second. Upon completion of each reading, the exposed vessel was rinsed through the utilization of deionized water to reduce contamination in further readings. The water type analysis was used to aid in testing ionic strength in beef jerky and beef strip loins to identify the possible water types.

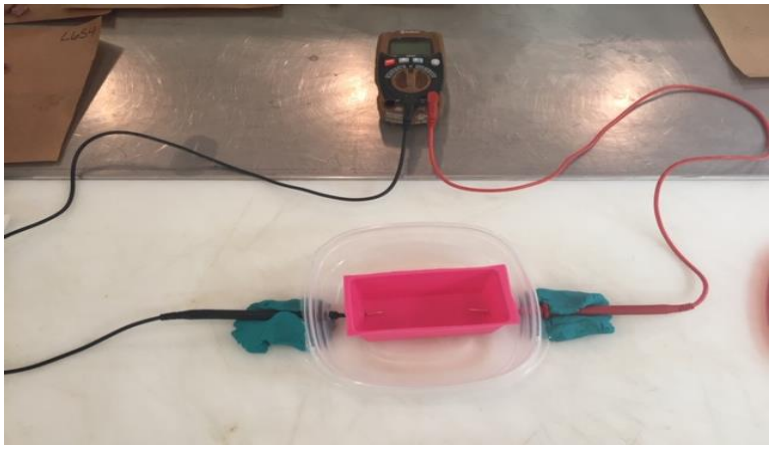

Figure 5. Water arrangement procedures for EC

Experimental design for electrical conductivity of beef jerky

After the EC experiment was completed on water sources, the water chosen to analyze EC in further analysis of deionized water based on its low variability; see the statistical analysis for further details (Table 3). The beef jerky was acquired from a well-known source Jack Link's "The Original"®, representing a specific form of water configuration. Based on the ingredients list, food additives are another consideration added to beef products, likewise listed in (Figure 6). This design began with the removal of beef jerky from 11 bags, each weighing 16 ounces. The electrical conductivity of beef jerky compromised of 50 g samples of beef jerky and was evaluated for EC measurement (n =72 beef jerky samples x 1 replication = 72 total observations). Each beef jerky strip was cut into square pieces approximately 1 centimeter in diameter as seen in (Figure 7). Upon completion, a total of 72 medium-sized square pieces of brown butcher paper was cut and labeled with a permanent marker from 1-72. Each square piece of butcher paper started at number 1, 50 g of beef jerky was weighed and put onto the paper and set aside. This procedure was repeated 72 times to provide uniformity. After each sample was weighed,

it was placed 50 mL of deionized water and put into a Ninja BL456 blender and emulsified. Once emulsified, the meat slurry was transferred into the silicon vessel. The placement of the two copper electrodes was on the right and left sides to align for accurate EC measurement. An EC measurement continued for 60 seconds with the applied rate of 2 readings per second. Voltage and current flow were monitored through a multimeter (16040T True RMS Multimeter, Southwire Tools & Equipment). Between the sample readings, all materials and equipment exposed were cleaned and bleached after every trial run. The trial runs consisted of 72 replications of EC measurements of commercial beef jerky to test ionic strength. The beef jerky analysis was necessary for testing ionic strength in beef jerky to evaluate the ionic strength of bound water.

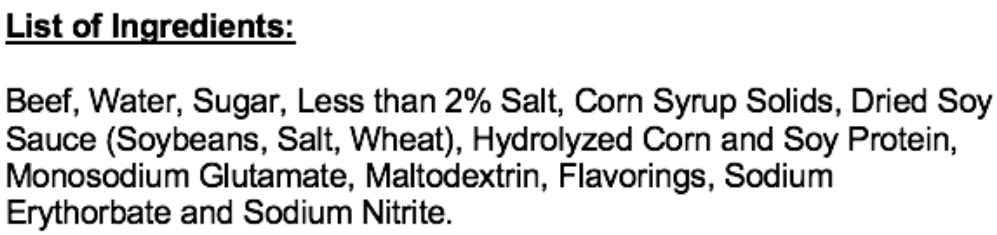

Figure 6. Jack Link's "The Original" ® list of ingredients

Figure 7. A beef jerky sample for EC measurement

Experimental design for color in fresh steaks

Beef loin samples developed for color measurements were procured from one source of six full, fresh strip loins of the same USDA grade. To ensure uniformity on color evaluations, the American Meat Science Association (AMSA) Color Measurement Guidelines provided a standard on each parameter for color values. The source used was of prime quality grade brand named HeartBrand Beef known for the Akaushi breed of cattle procured from a local retail rancher. Beef loins from HeartBrand Beef arrived with a call from the supplier. The beef loins arrived at Texas State University-San Marcos's meat laboratory as fresh whole loins. Each loin was cut into six steaks per loin, one-inch thick. All steaks were prepared with the same procedures for color evaluation. Before color measurements were taken, each steak was placed on brown butcher paper and a plastic wrap over each steak. The plastic wrap ensured a reduced oxygen exposure on the surface and provided a standardized procedure for calibration. During this time, each of the steaks remained on a sterilized meat processing table for 30 minutes to adjust for

room temperature, per literature, which is “bloom time” (AMSA, 2012); seen in (Figure 9). Once bloom time was complete, the color collection of data commenced, and continued until all measurements were concluded. Steaks were measured using the Varian Cary 50 Series Spectrophotometer following several parameters per AMSA to ensure standardization. All steaks were set to Illuminant A (this illuminant detects red wavelengths efficiently), observer angle of 10° (capturing a substantial sample portion), a wavelength of 830 to 360 nm with a scan range of 1 nm (that reflects a definite myoglobin percentage present on the meat surface) and an aperture size of 1.5 mm in diameter (adjusted per sample size). In conjunction, the spectrophotometer has an extended device known as the Harrington Barrelino device that is connected to the spectrophotometer to assist light scattering projection essential for data collection. Reflectant score parameters were measured to 0%-100% established by the reflectance standard. Specific locations on the steak were tested and measured with a one inch diameter cookie cutter that reflected the accuracy for the measurement of values for electrical conductivity and tenderness. The reported color scores in this study used Commission Internationale de l’Eclairage (CIE) L*a*b* that determined the values for lightness, redness, and yellowness color of the steak. Calibration for each group reflected on a 0%-100% reflectance score and was completed through a white tile calibration piece originated with a spectrophotometer. Calibration standard for each steak was set with the white tile placed on a flat surface with a clear plastic wrap; then, the Barrelino device was placed on top to demonstrate a baseline value for the scanned steaks. Prior to the collection of data, calibration was initially performed. This technique ensured proper adjustments to verify steaks were appropriately measured in the time frame allotted.

Several other parameters were needed to standardize the score such as “Y Mode” equivalent to the %R (reflectance), “Av Time (s) of 0.0125 (time used to calculate a data value) conjoined to a dual-beam mode and Delta LAB tolerance of 5.00 “E” (related to a change in time). The spectrophotometer was selected for Delta LAB tolerance E, which referred to a change in time, not indicative of this study. Several corrections accompanied was chosen based on thickness and refractive index in the settings section; this study consisted of Thickness [Known %T] and Thickness [unknown % T] set at 1.00. Color reports analyzed to specifically focus on Autoconvert ASCII (csv) with log a conversion tool for data importation. Each steak was scanned at 2 locations with 3 scans per location. Each of the values for the area was averaged to attain a mean color value for each location and a final average per loin. All values were statistically analyzed by using (n =6 loins x 6 steaks x 2 locations/steak = 72 total observations); see (Table 1) for more information. Furthermore, steaks color values were captured seen in (Figure 8), beef loins were weighed individually using a food-grade scale, and the room temperature was determined through a mercury glass thermometer encased in wood to provide uniformity. All steaks were placed into gallon-sized Ziploc bags labeled corresponding to the loin and steak number using a permanent marker, placed into a white plastic bin, and stored into the walk-in cooler at 34°F (1°C) overnight. Color measurements were taken to provide an improved appraisal of overall true color value in beef loins in addition to visual appraisal.

Figure 8. Image of color appraisal technique

Figure 9. Procedure for color analysis

Experimental design for electrical conductivity of fresh steaks

After being stored overnight, all steaks were removed from the walk-in cooler that was stored overnight and placed onto butcher paper labeled with the corresponding loin and steak number. All steaks were allowed to rest for one hour before EC experimentation. After rest, a 50 g sample of each raw beef steak was extracted using a fillet knife and weighed using a food-grade scale see (Figure 10). The raw beef loin 50 g samples were placed in pint-size Ziploc bags labeled with a permanent marker according to the loin and

sample number. The electrical conductivity of raw beef loin experiment involved (n=6 loins x 6 steaks/loin x 1 replication/steak = 36 total observations). All samples placed in the Ziploc bag were subsequently individually emulsified. Emulsification of each 50g raw beef loin sample was conjoined with 50 mL of deionized water then placed into a silicon vessel seen in (Figure 15). The meat slurry was placed into the silicon vessel, and two electrodes were placed on the sides aligned for an EC reading. An EC measurement appeared after 60 seconds through the applied rate of 2 readings per second. Voltage and current flow were monitored through a multimeter (16040T True RMS Multimeter, Southwire Tools & Equipment). Between the sample readings, all materials and equipment exposed were cleaned and bleached after every trial run. At the end of the experiment, all equipment was cleaned thoroughly before initiating any other EC experiments. The same loins used for color measurements were used for electrical conductivity analysis. The fresh electrical conductivity analysis was needed for testing ionic strength in raw samples to identify the ionic strength of possible water forms found in fresh beef loins.

Figure 10. A raw beef sample for EC measurement

Experimental design for tenderness in cooked loins

Beef loin samples used in this experiment were cooked for the evaluation of tenderness. Steaks placed in the walk-in cooler were taken out and left to rest approximately one hour. Steaks went through EC raw evaluation, and then the beef loins were weighed and placed onto a meat metal tray by date by loin and steak number. Once allocated, beef loins were placed into a multi-purpose smoker (UltraSource Grand Prize™ 3) with an internal temperature set at 165 °F (74°C). Beef loins were cooked for approximately three hours. Subsequently, steaks were allowed to rest for 30 minutes before storage. Afterward, steaks were weighed using a food-grade scale and placed into gallon-sized Ziploc bags with their corresponding loin and steak number, arranged into a plastic white bin and stored in a walk-in cooler overnight at 34°F (1°C) overnight. The beef loins were taken out and placed onto a square cut butcher paper labeled with its loin and steak number. Steaks were allowed to rest approximately one hour before coring. After rest, steaks were cored six times using a handheld coring device and cores weighed about 50 grams. The Warner-Bratzler Shear Force (WBSF) device (Figure 11) calculated shear force values specified through (G-R Manufacturing, Tall Grass Solutions, Manhattan, KS) to provide tenderness values. Six cores/steak, weighing at 50g, provided consistency for electrical conductivity procedures (Figure 12 & 13). The tenderness portion of this experiment consisted of (n = 6 loins x 6 steaks x 6 cores/steak = 216 total observations). When shear force values were completed, the core samples were placed on brown butcher paper labeled with loin and steak number. After all the core samples were completed, EC determinations were collected. The same loins used for color measurements were cooked

for tenderness analysis. The tenderness analysis was needed for testing the strength in cooked loins to provide an improved assessment for beef quality grading.

Figure 11. Warner Braztler Shear Force machine

Figure 12. Cored beef steak loin

Figure 13. Cores from cored beef steak loin

Experimental design for electrical conductivity of cooked steaks

Beef loins procured from HeartBrand Beef for the tenderness portion of the experiment were also subsequently used in the EC portion. The ionic strength was evaluated from six core samples with a total weight of 50 g using cooked beef that was taken from each steak (n = 6 samples x 6 steaks = 36 per source) used for EC evaluation; see (Table 2) for further explanation. The core samples were labeled by loin and steak number using white/brown butcher paper and a permanent marker. Ambient temperature was also recorded to ensure temperature calibration. Cooked 50 g core samples and 50 mL of deionized water were emulsified using Ninja BL456 blender, which created a dilution factor of 2 seen in (Figure 16). Using the diagram of electrical conductivity experimental design seen in (Figure 14 and 15) the colloidal solution was dispersed into the silicon vessel. Figures 1 and 2 were part of a previous thesis completed previously by (Martinez, 2017). Once the sample was placed into the vessel, two holes placed on the sides served to hold two copper electrodes of the digital multimeter and prevent leakage (16040T True RMS Multimeter, Southwire Tools & Equipment). The preparations in the silicon vessel and the alignment with the two electrodes were completed simultaneously. An EC reading, using units (Ω), was recorded for 60 seconds with the application of the rate of 2

readings per second. After each source was read, all materials and equipment exposed to the preparations were cleaned and bleached to prevent any contamination for the next sample. The same loins used for color measurements were cooked in order to complete cooked electrical conductivity analysis .The cooked electrical conductivity analysis was used for appraisal of the ionic strength in cooked samples, to evaluate the ionic strength of possible water forms in cooked beef loins.

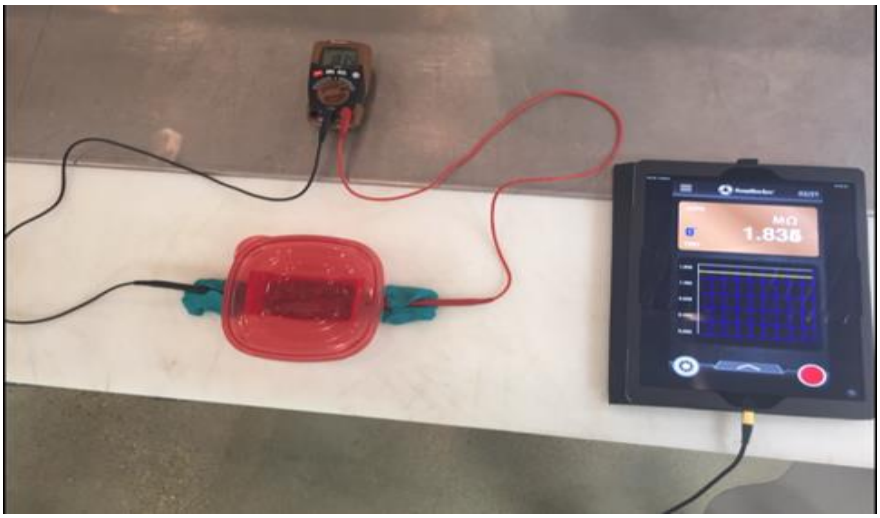

Figure 14. Electrical conductivity cooked beef loin experimentation

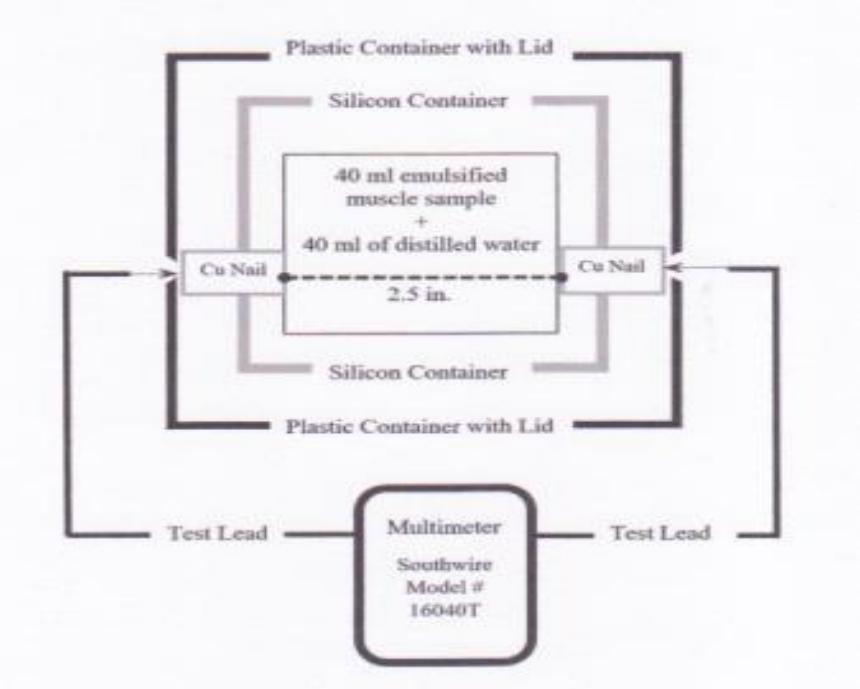

Figure 15. Electrical conductivity diagram of experimental design

$$DF = Vf / Vi = 100\ mL / 50\ mL = 2$$

Figure 16. Dilution factor equation

Statistical analysis

All data collected in this study were analyzed through SAS software and Microsoft Excel 2016 procedures. Applicable procedures for statistics included Pearson correlation coefficient to examine color variables, tenderness and electrical conductivity for water configuration predictions.The use of one way and two way ANOVA were completed to identify any differences of means. The statistical design for experiments were as follows: color variables consisted of a complete block design (blocks were steaks within a strip loin); electrical conductivity consisted of a block design (blocks were steaks within a strip loin) in both fresh and cooked loins; and electrical conductivity in beef jerky consisted of repeated measures from one source. Tenderness in cooked loins encompassed a completely randomized design.

IV. RESULTS

To further understand the results ahead, two tables are presented below to explain the experimental design used in the overall study of EC of water and beef sources involving fresh and cooked loins and commercial jerky found in (Table 1), along with (Table 2) which indicates the variables to evaluate treatments.

Table 1. Overall experimental design for EC of water and beef sources involving fresh loins, cooked loins, and commercial jerky

Experimental Design
• Three water types (n=20, each)
• Saline (n=20)
• Six full fresh strip loins (n=36)
• Six steaks cut from each strip loin and cooked as a group (n=36)
• One electrical conductivity measurement determined from each fresh and cooked steak (n=36 fresh, n=36 cooked)
• Six meat cores taken from each cooked steak for tenderness determinations (n=216)
• Color determinations taken at two locations on each fresh steak (n=72 each), for chroma, hue, L*(lightness), a*(red), b*(yellow) color factors
• One commercial jerky source (n=72)

Table 2. Treatment evaluations for EC, tenderness, color, and cooking loss

Variables to evaluate treatments[1]
• Electrical conductivity (EC)
• Warner Bratzler Shear Force (WBSF)
• Color determinations (chroma, hue, L*, a*, b*)
• Loin cooking weight loss (CL)

[1] EC in microsiemens (μS); WBSF in kg/f ; Color in chroma, hue, L* a* b* values via Varian Cary 50 spectroscopy; CL by % .

Electrical conductivity water determinations

The results presented for water are visually shown on (Table 3). The analysis used was a one-way and two way ANOVA to understand further the interaction between variables listed and to establish a baseline (blank) for EC in beef sources. Each analysis compared variables of deionized water, purified water, tap water, and saline (0.9% NaCl) and was replicated 20 times, providing a degree of freedom 19. The overall EC indicates saline exhibited significantly lower EC (Mean = 0.04, SD = 0.02, $r^2 = 0.09$,) , followed by deionized water (Mean = 0.40, SD = 0.06, $r^2 = 0.38$), tap water (Mean = 1.30, SD = 0.45, $r^2 = 0.37$) and purified water (Mean = 1.56, SD = 0.40, $r^2 = 0.31$). An analysis of variance (ANOVA) was completed for each water type with replications 1-10 indicating treatment A and 11-20 indicating treatment B. All water types indicated a significant difference except for saline. Deionized water ($P = 0.0041$), purified water ($P = 0.0099$), tap water ($P = 0.0045$), and saline ($P = 0.19$). The model for the statistical analysis was established at alpha ($P < 0.05$). The two way ANOVA showed a difference ($P < 0.0001$) among all water types, which indicates there was a high degree of variation across water sources.

Table 3. Electrical conductivity of water types and saline in microsiemens (μS)

	Variable			
Replications	Deionized water	Purified water	Tap water	Saline (0.9% NaCl)
1	0.42	1.93	1.43	0.024
2	0.43	2.32	1.91	0.013
3	0.53	1.14	1.66	0.032
4	0.42	1.92	1.49	0.016
5	0.52	1.97	1.53	0.037
6	0.41	1.57	1.44	0.014
7	0.47	1.62	1.13	0.024
8	0.39	1.46	1.59	0.038
9	0.41	2.13	1.69	0.042
10	0.39	1.78	1.79	0.076
11	0.45	1.69	0.67	0.027
12	0.35	1.59	0.66	0.061
13	0.41	1.26	0.91	0.032
14	0.32	0.94	1.47	0.038
15	0.29	1.29	0.87	0.039
16	0.38	1.33	2.09	0.024
17	0.29	1.11	0.74	0.039
18	0.40	2.01	1.25	0.087
19	0.32	0.93	0.58	0.038
20	0.39	1.29	1.11	0.043
Mean	0.40	1.56	1.30	0.04
SD[1]	0.06	0.40	0.45	0.02
CV[2]	6.22	3.89	2.90	1.95

[1] SD= Standard deviation
[2] CV= Coefficient of variation

Beef jerky electrical conductivity determinations

The results for EC determinations of commercial beef jerky (Table 4) were analyzed using one way ANOVA to evaluate EC values statistically. The results indicated (Mean = 106.87 , SD = 42.85, SEM = 5.05 and CV = 40.10). Ingredients in Jack Link's "The

Original" beef jerky comprised of food additvies that contained ions which reflected high EC values and indicated high ionic concentration.

Table 4. Electrical conductivity of commercial beef jerky in microsiemens (μS)

Replication No.	Microsiemens (μS)	Replication No.	Microsiemens (μS)
1	69.11	37	59.09
2	19.95	38	108.28
3	117.25	39	66.00
4	222.00	40	112.55
5	91.21	41	148.67
6	93.22	42	119.62
7	69.68	43	133.70
8	82.43	44	98.50
9	64.11	45	96.73
10	154.39	46	62.08
11	114.57	47	102.54
12	115.70	48	92.02
13	97.79	49	142.04
14	128.03	50	92.73
15	82.54	51	129.74
16	91.82	52	105.51
17	140.22	53	93.39
18	109.16	54	125.78
19	105.31	55	88.94
20	112.03	56	100.56
21	77.41	57	82.07
22	56.21	58	147.44
23	86.88	59	128.08
24	55.15	60	93.46
25	91.55	61	109.81
26	149.55	62	94.81
27	149.97	63	129.29
28	102.51	64	120.53
29	85.13	65	86.64
30	95.34	66	150.71
31	126.76	67	137.27
32	41.42	68	106.71
33	79.32	69	123.78
34	345.21	70	82.64
35	82.64	71	158.75
36	56.31	72	102.36
Mean	106.87		
SD[1]	42.85		
CV[2]	40.10		
SEM[3]	5.05		

[1] SD = Standard deviation
[2] CV= Coefficient variation
[3] SEM= Standard error of mean

Color attribute/component evaluations

The results for individual color variables are listed in separate tables to express their contribution to color in strip loins from one source. All color data were analyzed using one way ANOVA and Pearson correlation coefficients to dictate further how color variables correlated within each other. Table 5 shows determinations for Chroma that indicate a loin average for strip loins 1-6, a location mean = 2 means per strip loin, which includes a standard deviation and coefficient of variation for each location. The data indicates strip loins (1, 3), (1, 4), (2, 3), (6, 3), (5, 3), (3, 4) and (1, 6) are all statistically different at ($P < 0.05$) and (SEM = 6.49) with confidence limit at 95%. The difference of means between loin 1 and 3 was (5.28), loin 1 and 4 was (1.99), loin 2 and 3 was (4.16), loin 6 and 3 was (4.16), loin 5 and 3 was (3.73), and loin 3 and 4 was (3.29). Overall strip loin 2 exhibited the highest Chroma value (Mean = 44.81 ,L1 SD = 7.98, L2 SD = 4.50) and the lowest strip loin 6 (Mean = 30.05, L1 SD= 9.44, L2 SD= 11.13) .Data analysis determined there was a significant difference within the strip loins at a ($P < 0.0001$) with overall (Mean = 43.50 and r2 = 0.88), which indicates there was a saturation of variation in color across loins in this study.

Table 5. Color determinations of chroma.

	Strip loins[1]											
Steak No.	1		2		3		4		5		6	
	L1 [a]	L2 [a]	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1	59.96	56.48	41.08	38.08	33.09	37.99	34.20	39.07	47.07	41.11	31.09	28.87
2	38.79	40.38	47.71	44.08	40.29	38.45	47.37	52.56	41.47	41.47	42.57	35.33
3	30.09	37.12	39.73	40.00	43.29	35.46	47.89	49.36	37.43	37.69	40.03	42.43
4	49.80	54.95	42.54	39.98	44.43	38.97	47.58	43.12	48.80	50.80	51.82	55.77
5	38.31	40.67	61.54	48.60	40.61	45.22	47.62	40.04	41.94	39.00	57.10	56.24
6	44.47	43.98	46.18	48.13	39.99	41.79	33.28	37.00	49.20	48.35	50.46	49.22
Location Mean	43.57	45.60	46.46	43.15	40.28	39.65	42.99	43.53	44.32	43.07	45.51	44.64
Loin Avg.[2]	44.59		44.81		39.97		43.26		43.70		45.08	
SD[3]	10.39	8.15	7.98	4.50	3.95	3.40	7.17	6.17	4.75	5.28	9.44	11.13
CV[4]	0.24	0.18	0.17	0.10	0.10	0.09	0.17	0.14	0.12	0.12	0.21	0.25

[1] L= loin location within the steak

[2] Avg= average of two locations within a loin

[3] SD= standard deviation

[4] CV= coefficient of variation

[a] Each steak was sampled at two different locations (L1, L2); all values per location were averaged

Determinations for hue are indicated in (Table 6) which show a loin average for strip loins 1-6; a location means = 2 means per strip loin, which includes a standard deviation and coefficient of variation for each location. These data indicate loins (1, 6), (1, 3), (1, 5), (1, 2), and (1, 4) are all different at ($P < 0.05$) , SEM = 8.22 with confidence limit at 95%. The difference of means of loin 1 and 6 was (2.99), loin 1 and 3 was (3.61), loin 1 and 5 was (3.64), loin 1 and 2 was (3.99), and loin 1 and 4 was (4.80). Overall strip loin 1 exhibited the highest hue (Mean = 19.07, L1 SD = 6.58, L2 SD = 3.67) and the lowest strip loin 4 (Mean = 14.06, L1 SD = 5.58, L2 SD = 2.35). Data analysis determined there was a difference within the strip loins at a ($P < 0.0001$) with overall (Mean = 15.96 and $r2 = 0.67$), which indicates there was a high degree of variation in color description across loins in this study.

Table 6. Color determinations of Hue.

	Strip loins[1]											
Steak No.	1		2		3		4		5		6	
	L1 [a]	L2 [a]	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1	15.51	18.41	16.78	21.34	17.69	11.87	10.96	14.92	11.25	11.38	20.39	23.19
2	18.28	19.12	21.19	20.69	17.90	19.14	14.92	10.55	17.27	17.26	12.73	13.36
3	27.30	27.23	10.80	17.13	19.06	19.95	10.44	13.18	23.78	17.45	15.93	22.58
4	23.15	17.21	13.15	18.20	12.83	14.76	9.94	13.95	12.93	12.43	12.43	12.18
5	14.23	18.29	8.56	11.50	15.21	10.56	12.99	14.28	13.06	22.65	13.60	15.03
6	8.88	21.15	8.86	13.47	13.41	13.87	24.75	17.76	9.28	17.31	8.92	21.56
Location mean	17.89	20.24	13.22	17.06	16.01	15.03	14.00	14.11	14.59	16.41	14.00	17.98
Loin avg[2]	19.07		15.14		15.52		14.06		15.50		16.00	
STD[3]	6.58	3.67	4.96	3.91	2.58	3.81	5.58	2.35	5.21	4.07	3.86	4.99
CV[4]	0.37	0.18	0.37	0.23	0.16	0.25	0.39	0.17	0.36	0.25	0.28	0.28

[1] L= loin location within the steak
[2] Avg = average of two locations within a loin
[3] STD = standard deviation
[4] CV= coefficient of variation
[a] Each steak was sampled at two different locations (L1, L2); all values per location were averaged

Determination for L* value is indicated in (Table 7) that shows a loin average for strip loins 1-6, a location mean = 2 means per strip loin, which includes a standard deviation and coefficient of variation for each location. These data indicate loins (2, 3), (1, 3) , (6, 3), (5, 3) and (4, 3) are all different at ($P < 0.05$) , SEM = 7.50 with confidence limit at 95%. The difference of means of loin 2 and 3 (4.70), loin 1 and 3 (4.18), loin 6 and 3 (3.93), loin 5 and 3 (3.57), and loin 4 and 3 (3.41). Overall strip loin 6 exhibited the highest L* (Mean = 43.40, L1 SD = 9.67 , L2 SD = 11.21) and the lowest strip loin 3 (Mean = 38.47, L1 SD = 3.95, L2 SD = 3.83). Data analysis showed there was a difference within the strip loins at a ($P < 0.0001$) with overall (Mean = 41.75 and r2 = 0.87) , which indicates there was a high degree of variation in lightness across loins in this study.

Table 7. Color determinations of L* value.

	Strip loins[1]											
Steak No.	1		2		3		4		5		6	
	L1 [a]	L2 [a]	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1	57.80	53.59	39.33	35.47	31.52	37.17	33.57	37.75	46.17	40.29	29.14	26.53
2	36.82	38.16	44.49	41.24	38.34	36.32	45.77	51.67	39.59	39.59	41.51	34.30
3	33.85	33.01	39.04	38.23	40.91	33.32	47.10	48.06	34.26	35.94	38.49	39.12
4	45.79	52.46	41.42	37.97	43.32	37.67	46.87	41.85	47.57	49.61	50.60	54.50
5	37.09	38.61	60.85	47.62	39.18	44.45	45.70	38.80	40.86	35.99	55.50	54.31
6	43.93	40.74	45.63	46.81	38.88	40.56	30.21	35.23	48.56	46.15	49.85	45.78
Location Mean	42.55	42.76	45.13	41.22	38.69	38.25	41.54	42.23	42.84	41.26	44.18	42.42
Loin Avg.[2]	42.66		43.26		38.47		41.89		42.05		43.30	
SD[3]	8.76	8.35	8.15	4.99	3.95	3.83	7.57	6.39	5.56	5.54	9.67	11.21
CV[4]	0.21	0.20	0.18	0.12	0.10	0.10	0.18	0.15	0.13	0.13	0.22	0.26

[1] L= loin location within the steak
[2] Avg= average of two locations within a loin
[3] SD= standard deviation
[4] CV= coefficient of variation
[a] Each steak was sampled at two different locations (L1, L2); all values per location were averaged

Determination for a* value is shown in (Table 8) that states a loin average for strip loins 1-6, a location mean = 2 means per strip loin, which includes a standard deviation and coefficient of variation for each location. The data indicates loins (1, 6), (1, 5) , (1, 2), (1, 3) and (1, 4) are all different at ($P < 0.05$) , SEM = 3.57 with confidence limit at 95%. The difference of means of loin 1 and 6 (2.82), loin 1 and 5 (3.17), loin 1 and 2 (3.18), loin 1 and 3 (3.99), and loin 1 and 4 (4.14). Overall strip loin 1 exhibited the highest L* (Mean = 14.15, L1 SD = 4.56, L2 SD = 2.57) and the lowest strip loin 3 (Mean = 38.47, L1 SD = 3.95 , L2 SD = 3.83). Data analysis showed there was a difference within the strip loins at a ($P < 0.0001$) with overall (Mean = 11.70 and $r2 = 0.67$), which indicates there was a high degree of variation in redness across loins in this study.

Table 8. Color determinations of a* value

	Strip loins[1]											
Steak No.	1		2		3		4		5		6	
	L1 [a]	L2 [a]	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1	15.91	17.84	11.85	13.86	11.20	10.05	10.01	6.49	11.28	9.18	14.35	10.84
2	12.17	11.44	17.24	15.57	7.81	12.38	10.06	12.19	8.11	12.30	11.37	9.36
3	14.10	16.98	7.40	11.78	12.61	14.10	9.62	8.67	12.30	15.09	8.13	10.97
4	19.58	16.20	9.68	12.33	12.10	9.87	11.24	8.21	11.29	10.91	16.13	11.69
5	9.41	12.77	9.15	9.68	9.92	10.65	10.40	13.38	10.92	9.47	13.42	14.59
6	6.86	16.59	7.11	11.20	8.28	9.28	9.88	13.92	15.02	7.93	7.82	18.08
Location Mean	13.00	15.30	10.40	12.39	10.32	11.06	10.20	10.47	11.49	10.81	11.87	12.59
Loin Avg.[2]	14.15		11.40		10.69		10.34		11.15		12.23	
SD[3]	4.56	2.57	3.76	2.07	1.99	1.83	0.56	3.08	2.23	2.58	3.39	3.20
CV[4]	0.35	0.17	0.36	0.17	0.19	0.17	0.06	0.29	0.19	0.24	0.29	0.25

[1] L= loin location within the steak
[2] Avg= average of two locations within a loin
[3] SD= standard deviation
[4] CV= coefficient of variation
[a] Each steak was sampled at two different locations (L1, L2); all values per location were averaged

Determination for b* value is shown in (Table 9) that states a loin average for strip loins 1-6, a location mean = 2 means per strip loin, which includes a standard deviation and coefficient of variation for each location. The data indicates loins (1, 2), (1, 6) , (1, 5), (1, 4) and (1, 3) are all different at ($P < 0.05$) , (SEM = 2.42) with confidence limit at 95%. The difference of means of loin 1 and 2 (3.52), loin 1 and 6 (4.08), loin 1 and 5 (4.10), loin 1 and 4 (5.01), and loin 1 and 3 (5.42). Overall strip loin 1 exhibited the highest L* (Mean = 12.01, L1 SD = 4.91, L2 SD = 1.84) and the lowest strip loin 3 (Mean = 8.38, L1 SD = 3.19, L2 SD = 31.85). Data analysis showed there was a difference within the strip loins at a ($P < 0.0001$) with overall (Mean = 8.34 and r2 = 0.77), which indicates there was a high degree of variation in yellowness across loins in this study.

Table 9. Color determinations of b* value

	Strip loins[1]											
Steak No.	1		2		3		4		5		6	
	L1 [a]	L2 [a]	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
1	14.72	13.64	9.55	10.06	5.45	4.09	3.89	5.66	5.18	5.12	7.38	8.20
2	11.36	11.44	13.09	11.92	7.33	8.49	8.18	6.49	8.21	8.21	5.83	3.87
3	14.10	7.28	4.82	8.61	9.86	8.13	5.08	7.34	11.02	8.75	6.91	11.18
4	12.99	9.07	7.16	9.29	6.22	5.94	6.43	7.83	7.87	7.40	6.90	8.39
5	17.65	4.59	7.11	6.67	6.14	7.55	7.96	7.65	7.17	11.13	9.87	10.79
6	13.69	13.58	4.63	7.64	5.45	7.16	9.14	8.41	4.68	10.19	4.27	14.64
Location Mean	11.62	12.40	7.73	9.03	6.74	6.89	6.78	7.23	7.36	8.47	6.86	9.51
Loin Avg.[2]	12.01		8.38		6.82		7.00		7.92		8.19	
SD[3]	4.91	1.84	3.19	1.85	1.68	1.63	2.01	0.99	2.30	2.12	1.85	3.62
CV[4]	0.42	0.15	0.41	0.21	0.25	0.24	0.30	0.14	0.31	0.25	0.27	0.38

[1] L= loin location within the steak
[2] Avg= average of two locations within a loin
[3] SD= standard deviation
[4] CV= coefficient of variation
[a] Each steak was sampled at two different locations (L1, L2); all values per location were averaged

A summary of the color results obtained from the evaluation of beef strip loins for color values is presented in (Table 10), to display significance among color variables. The individual tables presented in Tables 5 to 9 show color determinations between loins for individual color variables. These variables analyzed overall show a significance among strip loins at ($P < 0.0001$) , which indicates there was a high degree of variation in color across loins in this study. Across strip loins, loin 3 had the lowest mean among all color variables. As indicated in the chart with superscripts a, b, c, d, e, or f loins were different for color variables. This table shows all loins were respectively different which indicates animal genetics and/or nutritional management were factors.

Table 10. Evaluation of beef strip loins (treatments) for color values[1]

Variables	n[2]	Mean	SD[3]	CV[4]	P-value
L*	1[ab]	42.65	7.96	0.19	< 0.0001†
	2[ab]	43.17	6.72	0.16	
	3[c]	38.47	3.67	0.10	
	4[b]	41.88	6.52	0.16	
	5[ab]	42.05	5.26	0.13	
	6[a]	43.30	9.81	0.23	
a*	1[a]	14.58	3.74	0.26	< 0.0001†
	2[bc]	11.41	3.02	0.26	
	3[c]	10.45	1.86	0.18	
	4[c]	10.59	2.11	0.20	
	5[bc]	11.41	2.50	0.22	
	6[b]	11.97	3.19	0.23	
b*	1[a]	12.01	3.53	0.29	< 0.0001†
	2[b]	8.49	2.71	0.32	
	3[f]	6.59	1.66	0.25	
	4[e]	7.00	1.55	0.22	
	5[d]	7.92	2.17	0.27	
	6[c]	8.19	3.09	0.38	
hue	1[a]	39.08	3.06	0.08	< 0.0001†
	2[b]	36.24	2.15	0.06	
	3[b]	31.54	2.84	0.09	
	4[b]	33.75	3.29	0.10	
	5[b]	34.40	2.72	0.08	
	6[b]	33.60	3.97	0.12	
chroma	1[a]	18.92	5.06	0.27	< 0.0001†
	2[a]	14.23	4.02	0.28	
	3[c]	12.49	2.42	0.19	
	4[b]	12.60	2.53	0.20	
	5[b]	13.90	3.25	0.24	
	6[a]	14.53	4.34	0.30	

[1] P level ($P < 0.05$) established for analysis
[2] N: six strip loins per color value
[3] SD: standard deviation
[4] CV: coefficient of variation
† Variables are different across all loins ($P < 0.0001$)
[abcdef] Loins with different super scripts are significantly different within each color variable

Further analysis was completed using Pearson correlation coefficient to determine whether a linear correlation between the color variables were present within strip loins. These data displayed in (Table 11) exhibited that L* value showed no correlation and significance with a* ($P = 0.74$) and b* ($P = 0.26$). L* showed a strong negative relationship with hue (-0.524) .The L* relationship with chroma was a strong positive relationship ($P < 0.0001$). The a* relationship with b* and hue both indicated a strong positive relationships and showed a significant difference with b* (0.94) and hue (0.82). The correlation value for a* with chroma indicated no correlation and a significant difference ($P = 0.02$). Next, b* value with hue and chroma both showed a significant difference , hue ($P < 0.0001$) and chroma , ($P = 0.00032$). The correlation was a strong positive relationship with hue but chroma showed no correlation. Lastly, hue and chroma correlation indicated a strong negative relationship and a significant difference ($P < 0.001$) , which indicates there was a high degree of variation in color variables across loins in this study. This table overall indicates (hue, chroma) and (L*, hue) had strong negative relationships. Hue had higher correlation with the other variables and two were negatively and two were positively correlated within strip loins.

Table 11. Pearson Correlation Coefficients for chroma, hue, L*, a*, b* color variables [1]

	L*	a*	b*	hue	chroma
L*	1.000	0.022	0.077	-0.524†	0.991†
a*	0.022	1.000	0.946†	0.824†	0.151
b*	0.077	0.946†	1.000	0.745†	0.199†
hue	-0.524†	0.824†	0.745†	1.000	-0.409†
chroma	0.991†	0.151	0.199†	-0.409†	1.000

[1] Correlation is significant at ($P < 0.05$)
† Correlation is significant at ($P < 0.001$)

A evaluation of color was demonstrated in (Figure 17) which showed the color comparison of means across fresh strip loins with color variable chroma, hue, L*, a*, and b*. The figure held similar color values across means for chroma, hue, L*, a*, and b*. Still, when compared to different color values, there was a variation among all loins, especially chroma, hue, and L* value. The overall values are seen in (Table 10) and (Figure 17) can be used simultaneously to differentiate means either in the tabular or figure illustration method. The correlation indicates there was a high degree of variation in color variables across loins in this study.

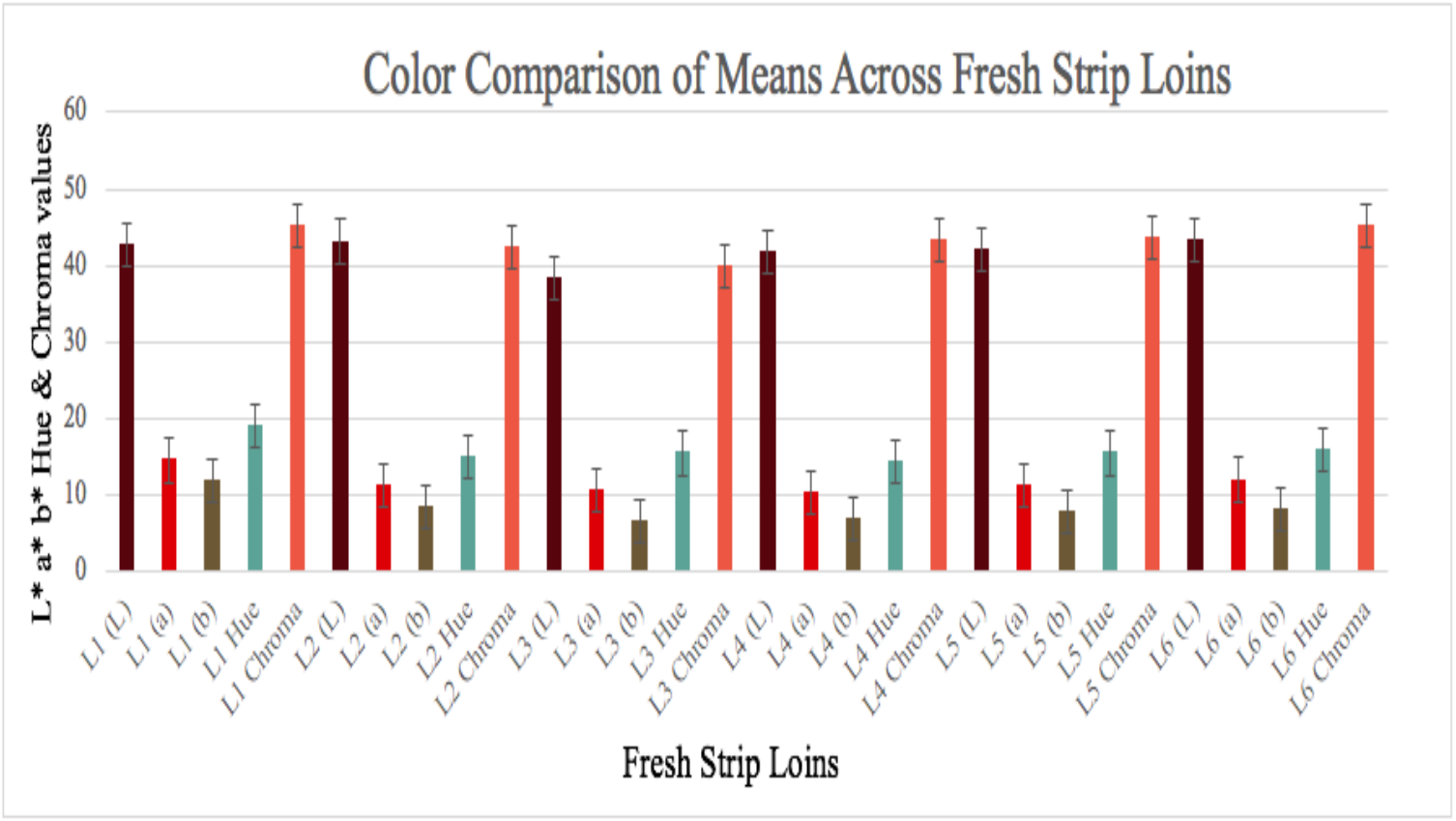

Figure 17. Color comparison of means across fresh strip loins

Analysis of electrical conductivity in fresh and cooked strip loins

Individual results for EC in fresh loins are found in (Table 12) and showed no difference at the ($P > 0.05$). Strip loin 2 showed a high EC (Mean = 42.52, SD = 27.23), CV = 0.64) but, strip loin 1 indicated a low EC (Mean = 14.37, SD = 13.03, CV = 0.90). The significance among all fresh steaks was ($P = 0.078$), with other overall factors estimated, such as ($r2 = 0.27$ and SEM = 322.35). No significant difference was found for fresh strip loins which suggested similar EC values. Similar ionic concentration was located in strip loins 1 to 6. This table indicates there was a low degree of variation in fresh electrical conductivity across loins in this study.

Table 12. Electrical conductivity of fresh steaks in microsiemens (μS)

	Strip loins					
Steak No.	1	2	3	4	5	6
1	0.55	45.59	66.26	32.95	0.18	15.06
2	9.96	18.24	36.82	46.89	17.89	25.81
3	32.68	63.58	5.83	0.59	26.63	30.91
4	24.48	0.66	19.96	12.96	7.09	32.81
5	0.65	59.76	41.64	7.95	17.23	38.28
6	17.89	67.31	38.65	36.02	27.26	5.33
Mean	14.37	42.52	34.86	22.89	16.05	24.70
SD[1]	13.03	27.23	20.57	18.27	10.72	12.31
CV[2]	0.90	0.64	0.59	0.80	0.67	0.50

[1] SD = Standard deviation
[2] CV= Coefficient of variation

Individual results for EC in cooked loins is found in (Table 13) and showed no significant difference at the ($P < 0.05$). Strip loin 2 showed a high EC (Mean =16.47, SD = 13.59, CV = 0.83) but, strip loin 5 indicated a low EC (Mean = 5.17, SD = 8.39, CV = 1.62).

The significance among all cooked steaks was (P = 0.37) with other overall factors estimated such as (r2 = 0.16 and SEM = 87.64). With no significant difference for cooked strip loins within the same source suggests similar EC values. Similar ionic concentration was located in strip loins 1 to 6. Cooking % loss was consistent between strip loins. Strip loin 6 retained the highest CL (32%) and strip loin 5 with the lowest CL (25%). On average, there were no significant differences in CL % between loins based on mean percent values. This table indicates there was a low degree of variation in cooked electrical conductivity and cooking loss percent across loins in this study.

Table 13. Electrical conductivity of cooked steaks in microsiemens (μS)

	Strip loins					
Steak No.	1	2	3	4	5	6
1	6.02	6.01	9.15	0.67	1.61	35.81
2	5.22	7.77	11.41	6.51	1.91	0.25
3	11.14	5.44	1.53	17.59	0.26	0.25
4	7.33	14.98	8.92	7.22	2.03	9.49
5	9.81	24.79	6.64	17.56	3.00	0.37
6	7.15	39.82	0.87	14.85	22.22	1.79
Mean	7.78	16.47	6.42	10.73	5.17	7.99
SD[1]	2.27	13.59	4.32	6.96	8.39	14.09
CV[2]	0.29	0.83	0.67	0.65	1.62	1.76
CL (%)[3]	28	26	30	29	25	32

[1] SD = Standard deviation
[2] CV= Coefficient of variation
[3] CL (%) = Cooking loss (%)

The data analyzed from fresh and cooked strip loins are presented in (Figure 18), which indicates a significant difference at (P < 0.05). The EC for fresh loins is indicated by maroon bars and cooked loins by gold bars. The EC for fresh loins (Mean = 25.90) was

higher than cooked loins (Mean = 9.11), indicative of a three-fold difference in EC value. In the model for statistical analysis ($r^2 = 0.43$ and CV = 14.31) with the overall ($P < 0.001$), which presented a significant difference between fresh and cooked strip loins. This indicates there was a high degree of variation in both fresh and cooked electrical conductivity across loins in this study.

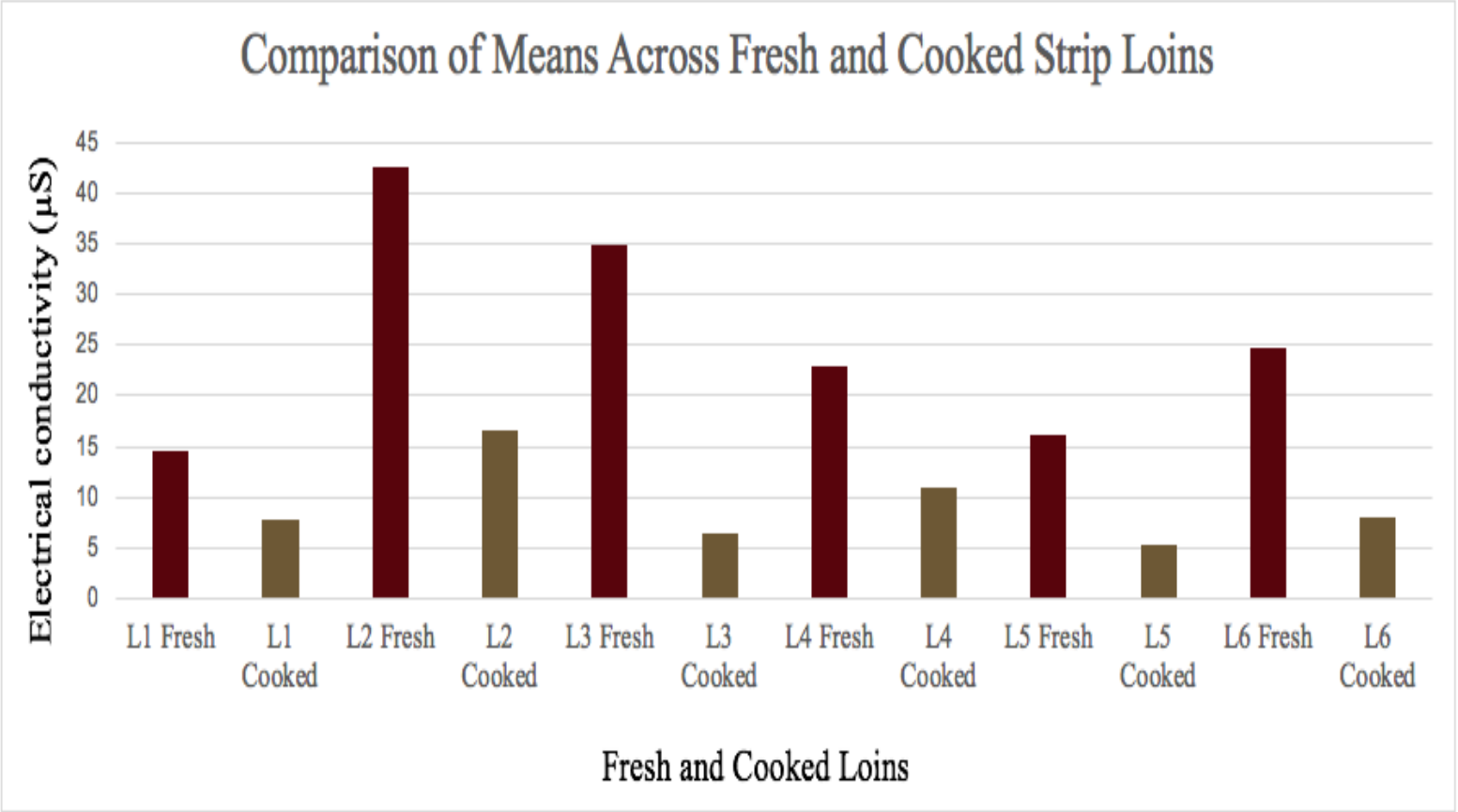

Figure 18. Electrical conductivity comparison across cooked and fresh strip loins

Tenderness evaluation for cooked strip loins

The results for tenderness are indicated by Warner Bratzler Shear Force (WBSF) values found in (Table 14) which are individually identified as strip loins 1-6, which were cooked. The overall results indicated a difference between strip loins ($P < 0.05$) with other factors estimated ($r2 = 0.46$ and $CV= 23.29$). These data indicate cooked strip loins (4, 1), (4, 2), (5, 2), (3, 2), (6, 2), (1, 2) and (2, 4) are all different at ($P < 0.05$) , (SEM = 0.11) with confidence limit at 95%. Difference of means of loin 4 and 1 (0.24), loin 4 and 2 (0.48), loin 5 and 2 (0.42), loin 3 and 2 (0.36), loin 6 and 2 (0.26), loin 1 and 2 (0.24) and loin 2 and 4 (-0.48) Overall strip loin 4 exhibited the highest mean core values (Mean = 9.49) and high core value (2.26 kg/f) , strip loin 2 had the lowest mean core values (Mean = 6.64) and a low core value (0.86 kg/f) . Data analysis determined there is a significant difference within the strip loins at a ($P < 0.0001$) but, no significant difference between steaks ($P = 0.27$), indicating there was a high degree of variation in tenderness across loins in this study.

Table.14 Warner Braztler Shear Force values of cooked loin steaks in (kg/f)[1]

	Strip loin no.1					
Steak No.[a]	1	2	3	4	5	6
1	1.23	1.28	1.41	2.04	1.76	1.47
2	1.06	0.98	1.36	1.29	1.42	0.95
3	1.42	0.99	1.43	1.69	1.99	0.71
4	1.29	1.17	1.94	1.20	1.77	0.80
5	1.35	1.13	1.23	1.49	1.84	1.17
6	1.28	0.69	1.57	1.67	1.41	0.93
Mean	1.27	1.04	1.49	1.56	1.70	1.00
SD[2]	0.12	0.21	0.25	0.31	0.23	0.28
CV[3]	0.10	0.20	0.17	0.20	0.14	0.27

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

Table.14 Continued

	Strip loin no. 2[1]					
Steak No.[a]	1	2	3	4	5	6
1	0.76	1.09	0.80	0.85	1.36	1.02
2	1.33	1.23	1.44	0.86	0.83	0.70
3	1.11	1.08	0.61	0.96	1.76	1.93
4	0.70	1.36	0.66	1.01	1.36	1.74
5	1.64	1.24	0.78	0.89	1.21	1.27
6	1.57	0.94	0.86	0.85	0.77	1.19
Mean	1.19	1.16	0.86	0.90	1.22	1.31
SD[2]	0.40	0.15	0.30	0.07	0.37	0.46
CV[3]	0.34	0.13	0.35	0.07	0.30	0.35

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

Table.14 Continued

	Strip loin no.3[1]					
Steak No.[a]	1	2	3	4	5	6
1	1.36	1.03	1.50	2.39	2.01	1.95
2	1.27	1.57	1.59	1.53	1.24	1.80
3	1.54	1.46	1.56	1.79	1.26	0.99
4	1.32	1.59	1.36	1.30	1.48	0.76
5	1.96	1.62	1.70	1.63	1.53	1.17
6	1.39	1.35	1.24	1.09	1.27	1.25
Mean	1.47	1.44	1.49	1.62	1.47	1.32
SD[2]	0.26	0.22	0.17	0.45	0.29	0.46
CV[3]	0.17	0.15	0.11	0.28	0.20	0.35

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

Table.14 Continued

	Strip loin no.4[1]					
Steak No.[a]	1	2	3	4	5	6
1	1.00	2.54	1.68	1.38	1.28	1.91
2	0.98	2.17	1.69	1.40	1.61	2.66
3	0.71	2.83	1.56	1.23	1.34	1.70
4	0.53	2.17	1.69	1.60	1.41	1.72
5	1.23	1.76	1.95	1.22	1.83	0.83
6	1.23	2.09	0.99	1.73	1.28	1.97
Mean	0.95	2.26	1.59	1.43	1.46	1.80
SD[2]	0.28	0.38	0.32	0.20	0.22	0.59
CV[3]	0.30	0.17	0.20	0.14	0.15	0.33

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

Table 14. Continued

Strip loins no.5[1]						
Steak No.[a]	1	2	3	4	5	6
1	1.32	1.43	1.63	1.67	1.55	1.27
2	1.59	1.49	1.88	1.41	1.18	1.96
3	1.48	1.76	1.62	1.33	0.93	1.10
4	1.75	1.57	2.06	0.95	1.71	1.80
5	1.44	1.84	1.55	1.20	1.03	1.72
6	2.06	1.39	1.67	1.07	1.72	1.65
Mean	1.61	1.58	1.74	1.27	1.35	1.58
SD[2]	0.27	0.18	0.19	0.26	0.35	0.33
CV[3]	0.17	0.12	0.11	0.20	0.26	0.21

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

Table 14. Continued

Strip loin no.6[1]						
Steak No.[a]	1	2	3	4	5	6
1	1.00	0.85	1.01	2.50	1.14	0.80
2	1.73	1.27	2.20	1.23	0.97	0.90
3	0.93	1.11	1.49	1.63	0.90	1.44
4	1.08	1.62	1.81	1.83	1.00	2.18
5	1.39	1.64	0.55	1.22	1.36	1.16
6	1.15	1.17	1.88	1.44	1.80	1.29
Mean	1.21	1.28	1.49	1.64	1.20	1.30
SD[2]	0.30	0.31	0.61	0.48	0.34	0.49
CV[3]	0.25	0.24	0.41	0.29	0.28	0.38

[1] (kg/f) = kilograms per force
[2] SD = Standard deviation
[3] CV= Coefficient of variation
[a] Six core determinations per steak

A complete visual representation of tenderness between cooked strip loins 1-6 is presented in (Figure 19). Strip loin 4 showed a high mean WBSF value of (Mean = 1.59 kg/f) and strip loin 2 had a low mean WBSF value of (Mean = 1.1 kg/f). Other factors considered for analysis were overall (Mean = 1.39, F = 9.74, df = 5). All analyses were set to alpha ($P < 0.05$), which showed a significant difference between strip loins at ($P < 0.001$), indicating there was a high degree of variation in tenderness across loins in this study.

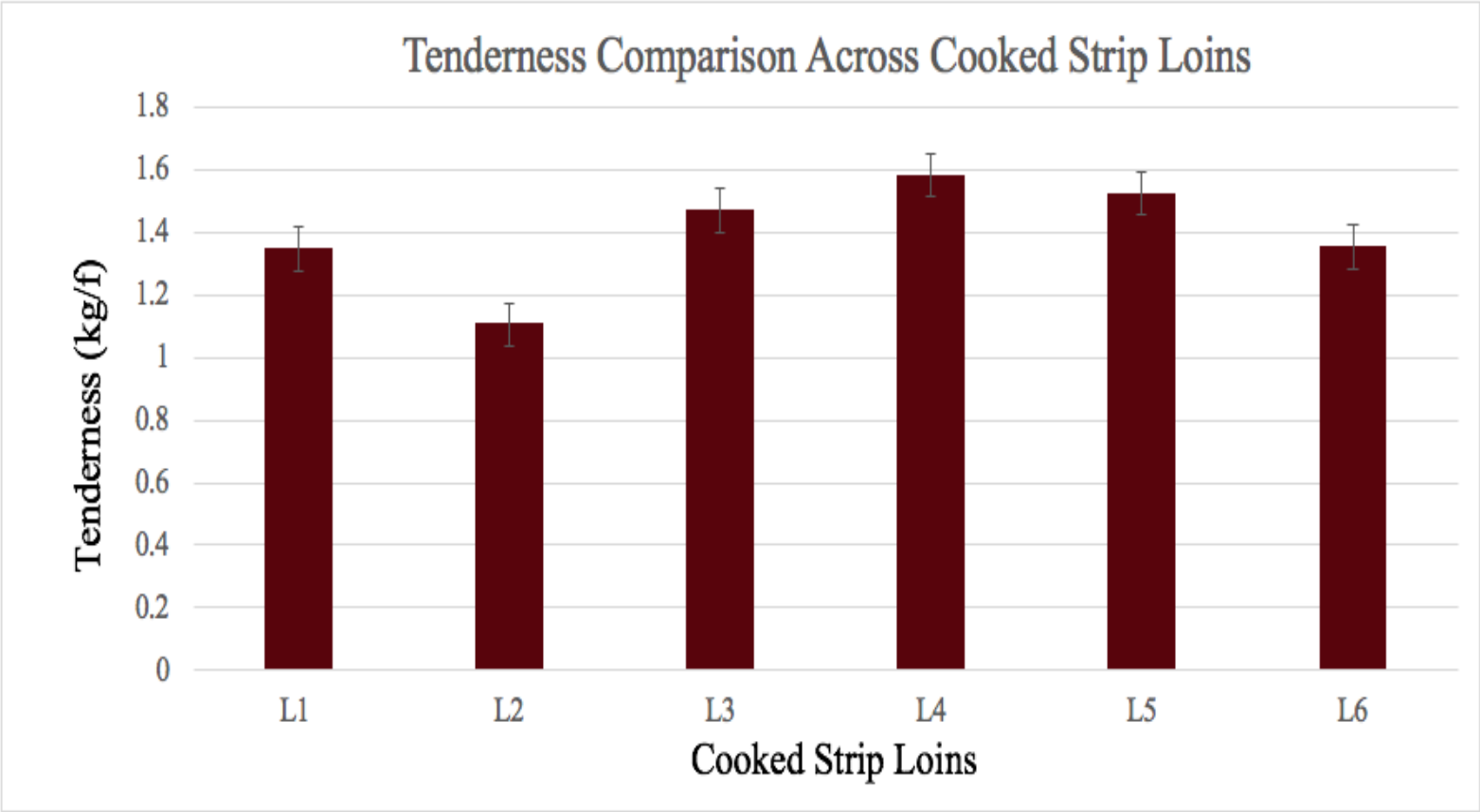

Figure 19. Tenderness comparison across cooked strip loins

A summary evaluation table for cooked and fresh beef loins for EC, tenderness, and hue is presented in (Table 15). EC of fresh loins showed ($P = 0.07$) and cooked loins was ($P = 0.36$). Individually evaluated, there is no significant difference, but together, there was a significant difference, as mentioned above. Tenderness for cooked strip loins indicated a significant P-value ($P < 0.0001$). Evaluation for fresh strip loins in tenderness was not preformed/analyzed. Hue also showed at a high significance ($P < 0.0001$) in fresh strip loins, and evaluation for cooked strip loins were not preformed/analyzed. Strip loin 2 showed a high mean value for fresh (Mean = 16.47) and cooked (Mean = 42.52) strip loins. Low values for fresh was located in strip loin 5 (Mean = 5.17) and cooked strip loin 1 (Mean = 14.37). High tenderness value was found in strip loin 4 (Mean = 1.58) and low strip loin 2 (Mean = 1.10). Hue color value was highest in strip loin 1 (Mean = 39.08) and lowest in strip loin 3 (Mean = 31.55). This indicated there was a high degree of variation in color, tenderness, and electrical conducitivity across loins in this study

Table 15. Summary evaluation of beef loins (treatments) for electrical conductivity (μS), tenderness (kg/f), and color (hue)[1]

Electrical Conductivity				Tenderness				Color			
Beef loins (treatment)	n[2]	μS[3]	P-value	Beef loins (treatment)	n[2]	kg/f[4]	P-value	Beef loins (treatment)	n[2]	hue[5]	P-value
Fresh loins	1	14.37	0.0779	Tenderness	1	-		hue	1	39.08	< 0.0001
	2	42.52			2	-			2	36.24	
	3	34.86			3	-			3	31.55	
	4	22.89			4	-			4	33.75	
	5	16.05			5	-			5	34.40	
	6	24.70			6	-			6	33.60	
Mean		25.90				-				34.77	
SD[6]		10.93				-				2.59	
CV[7]		0.42				-				0.30	
Cooked loins	1	7.78	0.3654	Tenderness	1	1.34	< 0.0001	hue	1	-	
	2	16.47			2	1.10			2	-	
	3	6.42			3	1.47			3	-	
	4	10.73			4	1.58			4	-	
	5	5.17			5	1.52			5	-	
	6	7.99			6	1.35			6	-	
Mean		9.09				1.40				-	
SD		4.09				0.17				-	
CV		0.45				0.12				-	

[1] P level (P < 0.05)
[2] N: 6 strip loins, and 6 steaks per loin for all variables measured
[3] μS: microsiemens average
[4] kg/f: kilograms/force average
[5] hue: average
[6] SD: standard deviation
[7] CV: coefficient of variation
- not applicable for analysis

Relationship of fresh electrical conductivity to color

The data displayed in (Figure 20) is from fresh strip loins correlated with EC to color. The fresh EC is indicated by a line and the color variables are indicated by columns. This illustration indicates loin 2 peaked at a higher EC value (42.52) than other loins. At the peak, the EC declined to a low for loin 5 (16.05) then increased at loin 6 (24.70). Loins 1 & 5 contained the lowest EC values at (14.37) and (16.05). All analysis was completed at ($P < 0.05$), and showed a negative relationship among these variables (Figure 20). The data displayed in (Table 16) shows the relationship with color and fresh EC values. This relationship suggests that values L*, a*, b*, hue and chroma values have a negative correlation with fresh loin EC. The L* value was not different ($P = 0.98$), a* value was ($P = 0.05$), b* not different ($P = 0.10$), hue not different ($P = 0.46$) and chroma not different ($P = 0.84$) ; the analysis was completed at ($P < 0.05$). As the color variables increase the electrical conductivity decreases in fresh beef loins. Fresh electrical conductivity may indicate the color depiction in beef loins.

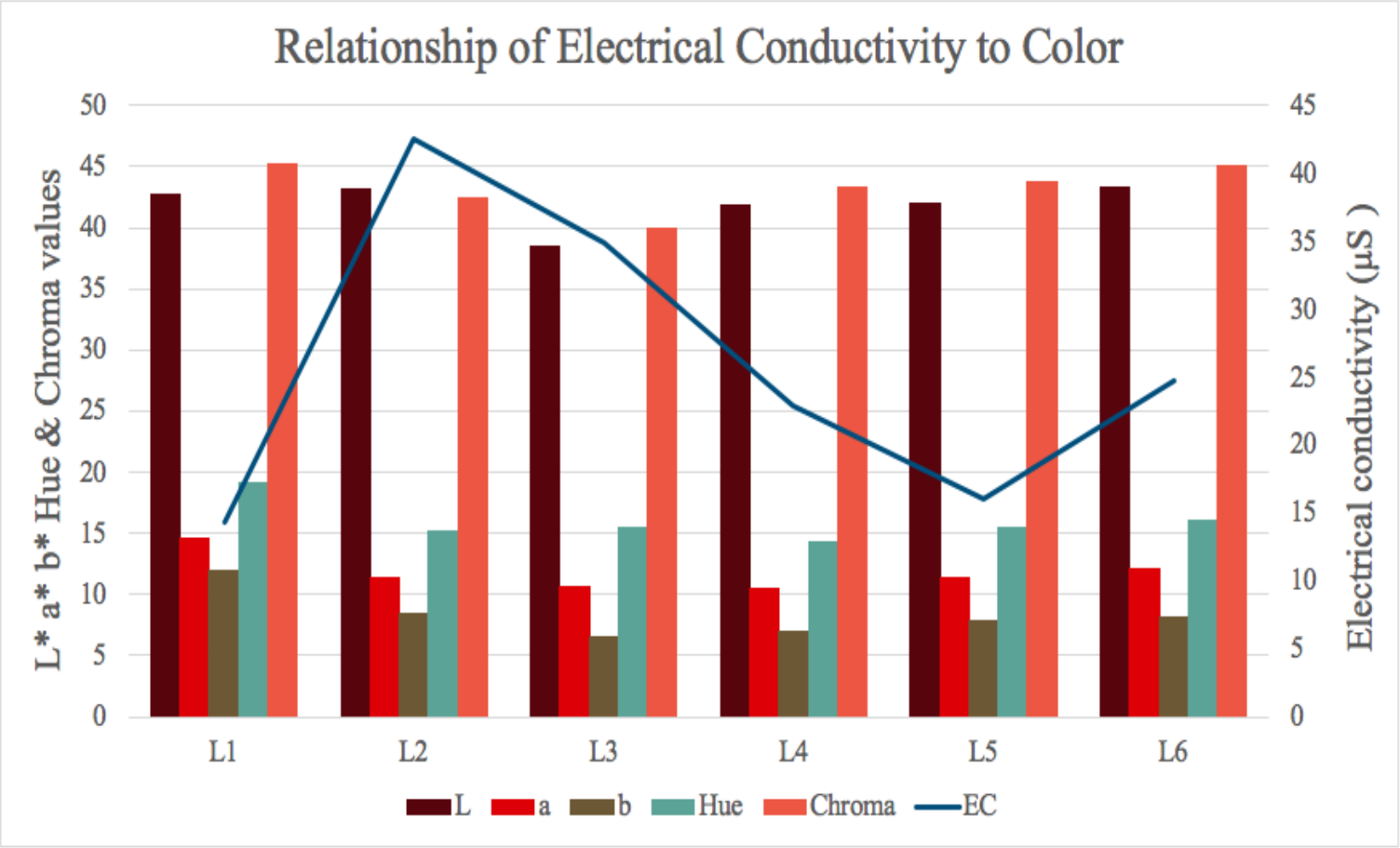

Figure 20. Relationship of electrical conductivity to color in beef loins

Table 16. Correlation of fresh electrical conductivity to color[1]

	L*	a*	b*	hue	chroma	Fresh EC
L*	1.000	0.022	0.077	-0.524†	0.991†	-0.009
a*	0.222	1.000	0.946†	0.824	0.151	-0.131[a]
b*	0.077	0.946†	1.000	0.745†	0.199†	-0.110
hue	-0.524†	0.824†	0.745†	1.000	-0.409†	-0.050
chroma	0.991†	0.151	0.199†	-0.409†	1.000	-0.013
Fresh EC	-0.009†	-0.131[a]	-0.110	-0.050	-0.013	1.000

[a] Correlation is significant at ($P < 0.05$)
† Correlation is significant at ($P < 0.0001$)
[1] Fresh loin electrical conductivity = Fresh EC

Relationship of fresh electrical conductivity to tenderness

The data displayed in (Figure 21) is from fresh strip loins correlated with electrical conductivity to color. The fresh EC is indicated by a line and tenderness is indicated by columns. This illustration indicates loin 2 peaked at a higher EC value (42.52) than other loins. A decline in EC began from loin 2 (42.52) to loin 5 (16.04) then, began an increase at loin 6 (24.70). Loins 1 and 5 contained the lowest EC values at (14.37) and (16.05). This figure showed no relationship with fresh EC and tenderness. In (Table 17), it shows a value of (-0.015) which indicates no relationship was found . Furthermore, with no correlation for fresh EC and tenderness this suggests no prediction for tenderness of beef loins can be made for raw beef EC values.

Table 17. Correlation of fresh electrical conductivity to tenderness[1]

	Tenderness	Fresh EC
Tenderness	1.000	-0.015
Fresh EC	-0.015	1.000

[1] Fresh loin electrical conductivity = Fresh EC

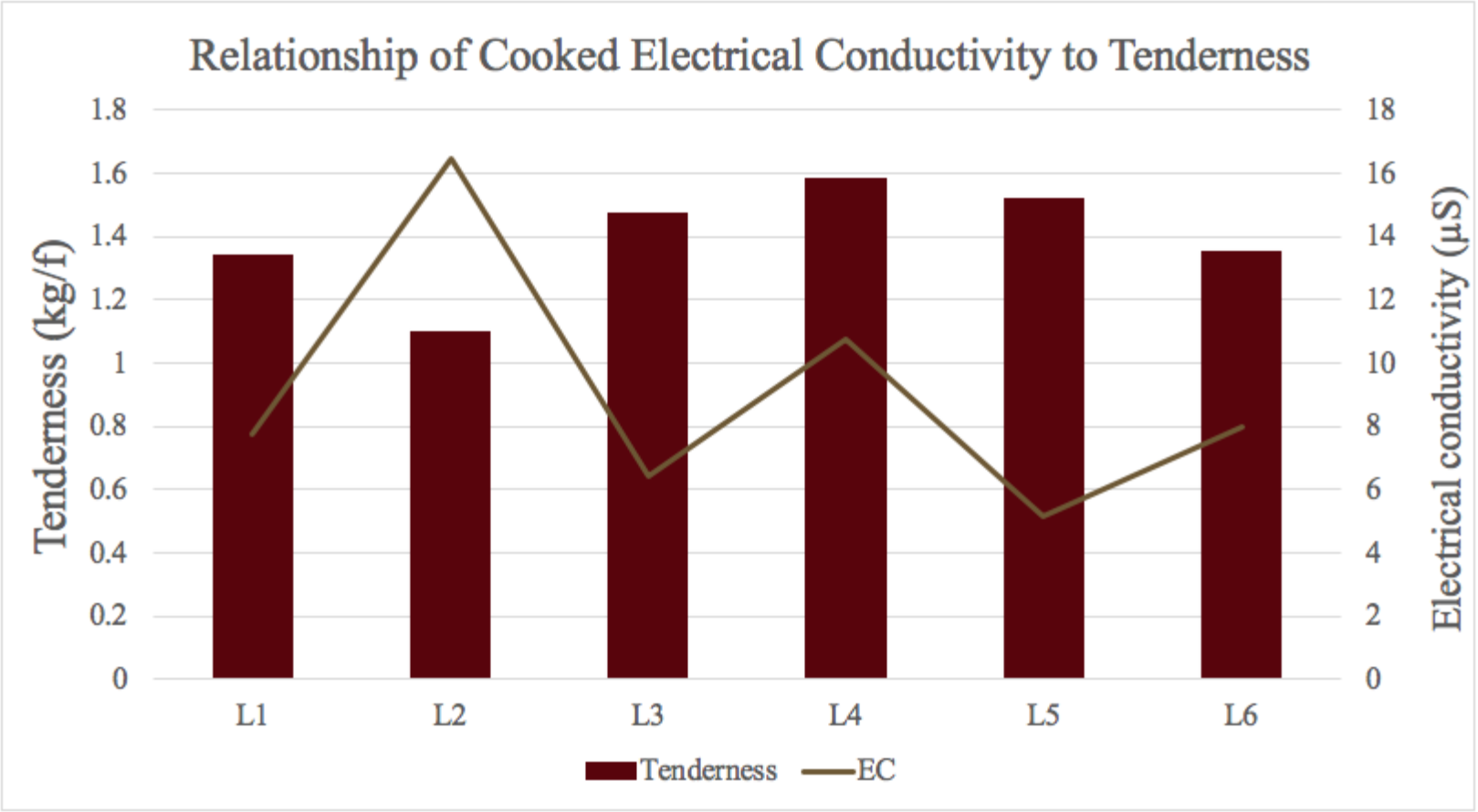

Figure 21. Relationship of electrical conductivity to tenderness in beef loins

Relationship of fresh electrical conductivity to cooked electrical conductivity

In (Figure 18) as mentioned above indicated of a three-fold difference in EC value from fresh and cooked electrical conductivity. This displayed a high degree of variation in electrical conductivity across beef loins in this study. Based on data (Table 18) there is a correlation value of (0.220) indicating a correlation ($P < 0.0001$). Based on these results there may be a way to measure fresh beef loin and cooked beef loin EC to appraise quality of both beef loin forms .

Table 18. Correlation of fresh electrical conductivity to cooked electrical conductivity[1]

	Fresh EC	Cooked EC
Fresh EC	1.000	0.220†
Cooked EC	0.220†	1.000

[1] Cooked loin electrical conductivity = Cooked EC

† Correlation is significant at ($P < 0.0001$)

Relationship of cooked electrical conductivity to tenderness

The data displayed in (Figure 22) shows the correlation of EC to tenderness. The cooked EC is indicated by a line and tenderness is indicated by columns. This illustration shows loin 2 peaked at a higher EC value (16.47) than the other loins. At the peak, the EC drops in loin 3 (6.42), then rises in loin 4 to (10.73), decreases again in loin 5 (5.17) lastly, rises in loin 6 (7.99). Loins 1 and 6 show similar EC values (7.99 and 7.78). All analyses were completed at ($P < 0.05$), and showed a negative relationship among these variables (Figure 22). The data shown in (Table 19) references the relationship with tenderness and cooked EC values. The relationship indicates that tenderness and cooked EC have a negative relationship (-0.011) with ($P = 0.86$); as the analysis was completed at ($P < 0.05$). There is low correlation for cooked EC and tenderness suggesting no prediction indicated for ionic strength to measure tenderness.

Table 19. Correlation of cooked electrical conductivity to tenderness[1]

	Tenderness	Cooked EC
Tenderness	1.000	-0.011
Cooked EC	-0.011	1.000

[1] Cooked loin electrical conductivity = Cooked EC

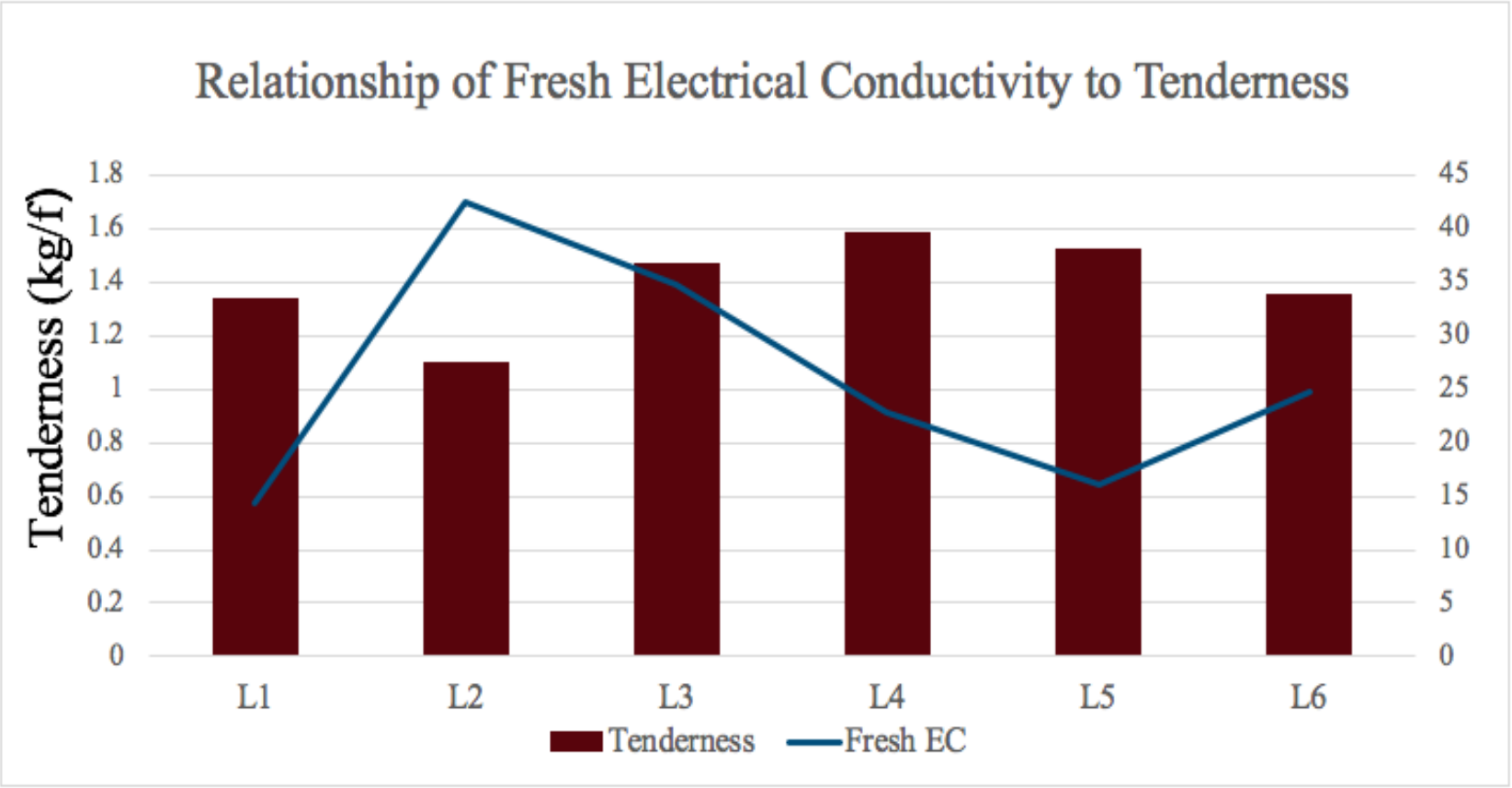

Figure 22. Relationship of fresh electrical conductivity to tenderness in beef loins

Relationship of cooked electrical conductivity to color

The data displayed in (Figure 23) shows the correlation of EC to color in cooked loins. The cooked EC is indicated by a line and color variables are indicated by columns. This illustration indicates loin 2 peaked at a higher EC value (16.47) than the other loins. At the peak, the EC drops in loin 3 (6.42), then rises in loin 4 to (10.73), decreases again in loin 5 (5.17) lastly, rises in loin 6 (7.99). Loins 1 and 6 show similar EC values (7.99 and 7.78). In (Table 20) the correlation for color and cooked electrical conductivity is displayed. Color variables a* (-0.186), b* (-.0217) and hue (-0.121) showed a slight correlation. The data indicate there may be a way to measure redness, yellowness and the color description for beef loins using cooked electrical conductivity. For color variables L* (-0.026), and chroma (-0.046) showed no correlation. This indicates there is no way to predict lightness and the saturation for beef loins using cooked electrical conductivity. To conclude, the ionic strength for cooked beef loins may aid in identifying the redness, yellowness and color description of the meat.

Table 20. Correlation of cooked electrical conductivity to color[1]

	L*	a*	b*	Hue	Chroma	Cooked EC
L*	1.000	0.022	0.077	-0.524†	0.991†	-0.026
a*	0.222	1.000	0.946†	0.824	0.151	-0.186
b*	0.077	0.946†	1.000	0.745†	0.199†	-0.217
Hue	-0.524†	0.824†	0.745†	1.000	-0.409†	-0.121
Chroma	0.991†	0.151	0.199†	-0.409†	1.000	-0.046
Cooked EC	-0.026	-0.186	-0.217	-0.121	-0.046	1.000

† Correlation is significant at ($P < 0.0001$)

[1] Cooked loin electrical conductivity = Cooked EC; The same loins used for color measurements were cooked then tenderness analysis was completed

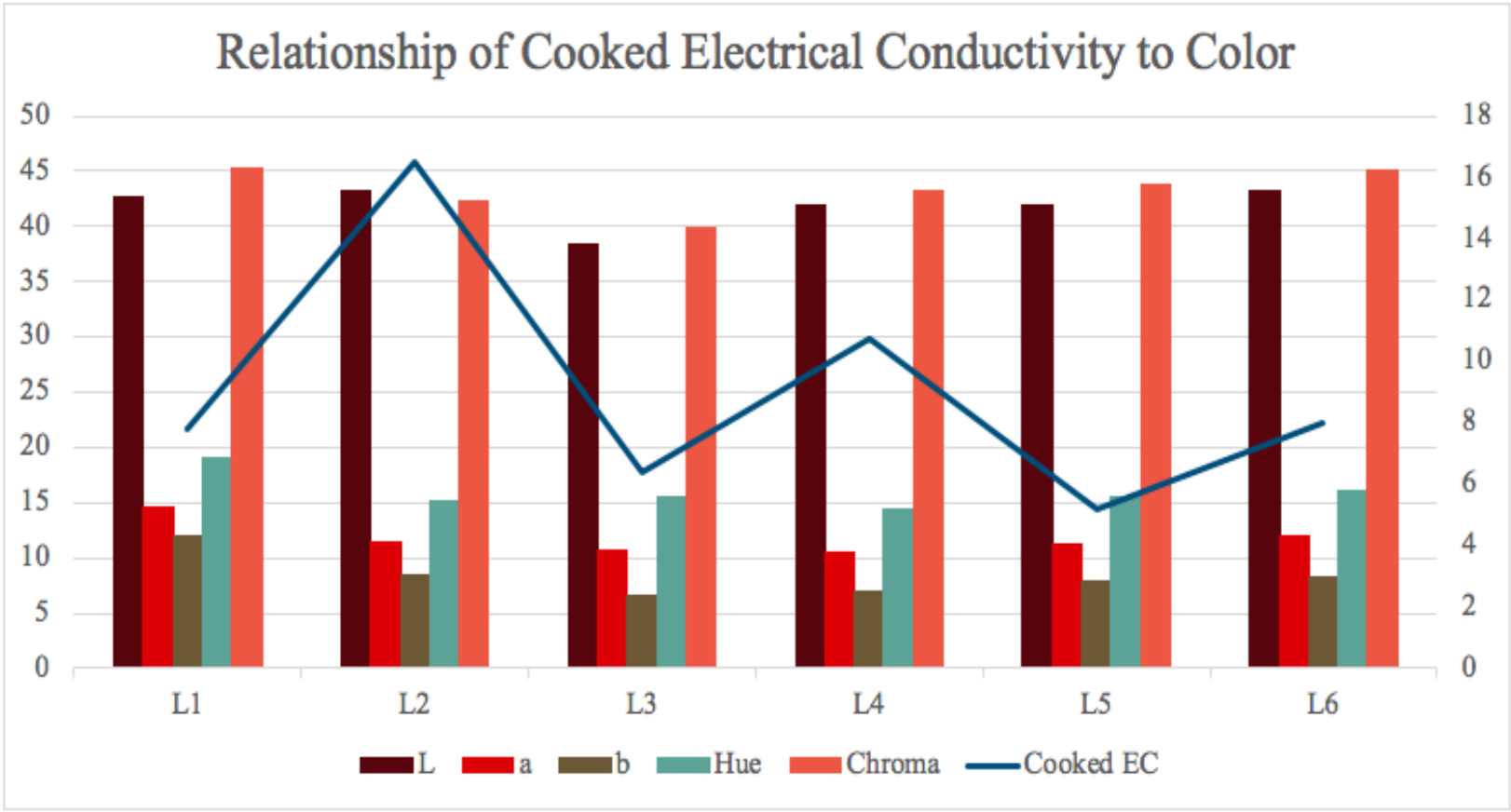

Figure 23. Relationship of cooked electrical conductivity to color in beef loins

Relationship of tenderness to color

The data displayed in (Figure 24) indicates tenderness by a line and color variables by columns. This figure indicates loin 2 had a lower higher tenderness value (1.10) than the other loins. A steady plateau was shown from loins 3 (1.47), 4 (1.58) and, 5 (1.52) to demonstrate a consistency of tenderness values across these loins. Loin 1 (1.34) initiated the downward slope of tenderness to loin 2 (1.10). The steady tenderness values was exhibited throughout the loins with color variables containing a high degree of variability. In (Table 21) no correlation was displayed for tenderness and color variables. With no correlation for tenderness and color, this suggests that color in beef loins may not be a reliable measurement to estimate tenderness.

Table 21. Correlation of tenderness to color[1]

	L*	a*	b*	Hue	Chroma	Tenderness
L*	1.000	0.022	0.077	-0.524†	0.991†	0.067
a*	0.222	1.000	0.946†	0.824	0.151	0.044
b*	0.077	0.946†	1.000	0.745†	0.199†	-0.042
Hue	-0.524†	0.824†	0.745†	1.000	-0.409†	0.024
Chroma	0.991†	0.151	0.199†	-0.409†	1.000	0.073
Tenderness	0.067	0.044	-0.042	0.024	0.073	1.000

† Correlation is significant at ($P < 0.0001$)

[1] The same loins used for color measurements were cooked then tenderness analysis was completed

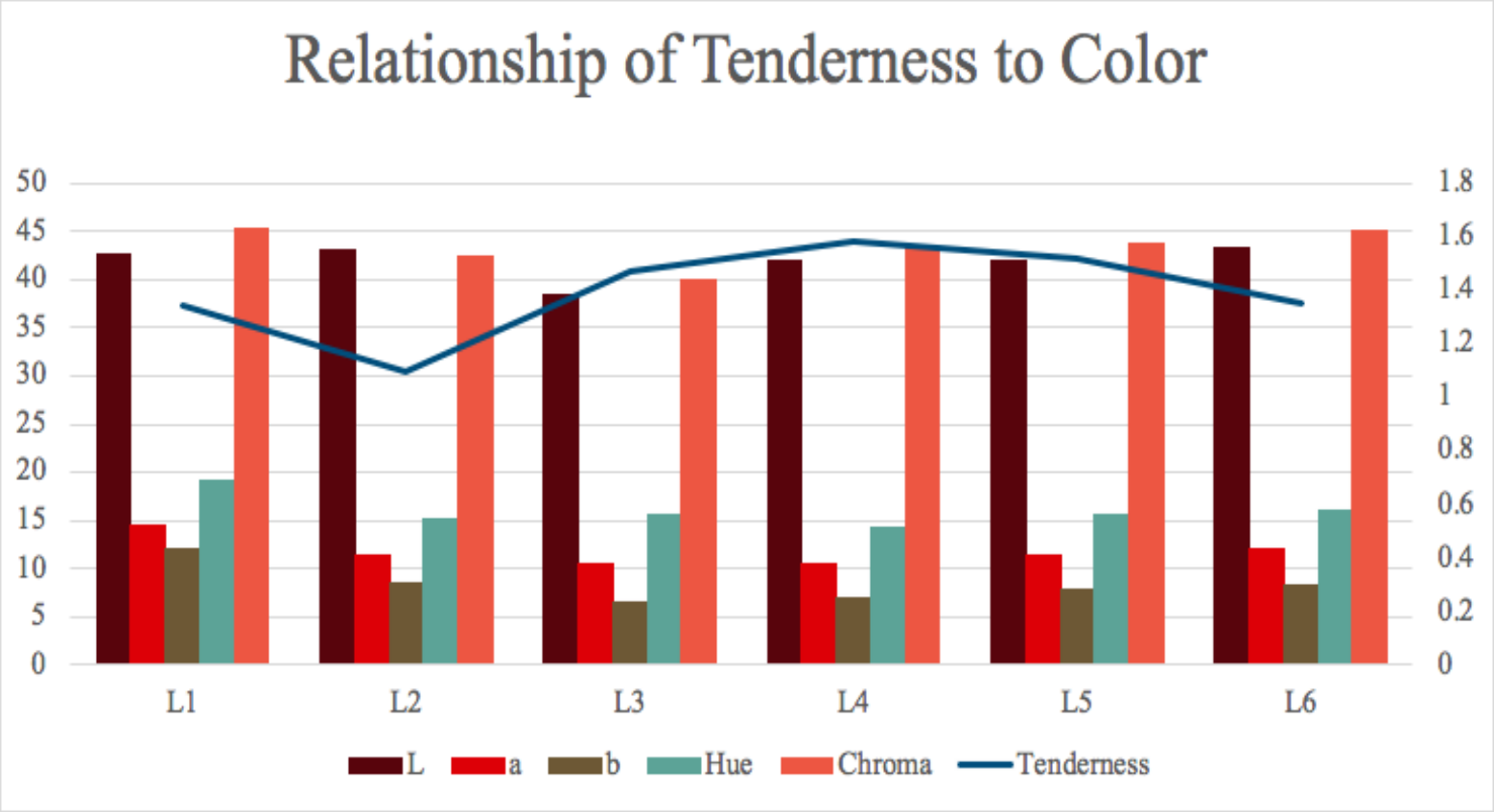

Figure 24. Relationship of tenderness to color in beef loins

Overall correlations among fresh and cooked loins on color, electrical conductivity, and tenderness

The overall correlations shown in (Table 22). The relationships of color in the summary table across beef loins suggests: a negative relationship between color variables and fresh EC, color variables and tenderness show no relationship, and color variables (a*, b* and hue) with cooked EC displayed a weak correlation. Relationship between tenderness and cooked EC suggested a negative relationship and, tenderness with fresh EC no relationship. Results demonstrated color variable (a* and b*) had a slight correlation with fresh EC with a* ($P = 0.05$) and b* ($P = 0.10$). Relationship for (a*, b* and hue) with cooked EC expressed a slight correlation with a* ($P = 0.0062$), b* ($P = 0.0013$) and hue ($P = 0.075$). All color variables correlated with tenderness showed no relationship. In color, the results pinpoint there may be an approach to use fresh EC to determine the redness and yellowness in beef loins; after the meat is cooked there may be a way to measure cooked EC to measure redness, yellowness and color description; and there may not be a means to measure color and tenderness without a relationship. In tenderness, results correlated with both fresh and cooked EC showed no correlation, indicating there may not be a route to measure how tenderness of beef loins is based on electrical conductivity. Lastly, fresh and cooked EC when correlated together showed a slight correlation ($P = 0.0011$), illustrating there may be a way to measure fresh beef loin and cooked beef loin EC to determine ionic strength in both beef states.

Table 22. Pearson Correlation Coefficients for chroma, hue, L* , a*, b*, tenderness, and electrical conductivity in fresh and cooked loins.[1]

	L*	a*	b*	hue	chroma	Tenderness	Fresh EC	Cooked EC
L*	1.000	0.022	0.077	-0.524†	0.991†	-0.067	-0.009	-0.027
a*	0.222	1.000	0.946†	0.824†	0.151	0.044	-0.131[a]	-0.186†
b*	0.077	0.946†	1.000	0.745†	0.199†	-0.042	-0.110	-0.217†
hue	-0.524†	0.824†	0.745†	1.000	-0.409†	0.025	-0.050	-0.121[b]
chroma	0.991†	0.151	0.199†	-0.409†	1.000	0.073	-0.013	-0.047
Tenderness	-0.067	0.044	-0.042	0.025	0.073	1.000	-0.015	-0.011
Fresh EC	-0.009†	-0.131[a]	-0.110	-0.050	-0.013	-0.015	1.000	0.220†
Cooked EC	-0.027	-0.186	-0.217	-0.121	-0.047	-0.011	0.220†	1.000

[a] Correlation is significant at ($P < 0.05$)
[b] Correlation is significant between ($P = 0.05$ and $P = 0.10$)
† Correlation is significant at ($P < 0.0001$)
[1] Fresh loin electrical conductivity = Fresh EC and Cooked loin electrical conductivity = Cooked EC

V. DISCUSSION

The conclusions derived within this study were based on examination of fresh and cooked strip loins using treatment comparisons. Fresh and cooked strip loin data were used to address research questions that pertain to water configuration comparison to color, tenderness, and electrical conductivity of all the evaluations in this study.

Color and water assessment

Color is a sensory characteristic consumers often resort to indicate the overall quality, freshness, safety, and flavor of a meat product (Mancini & Hunt, 2005). The water-soluble sarcoplasmic protein myoglobin is heavily influenced by meat pigmentation. Water in meat is characterized in three forms free, immobilized, and bound, which is found in the sarcoplasm where myoglobin is located. This study was designed to determine if water forms could be used to predict color in beef strip loins. Akauski beef strip loins were used for this study and are known for their high marbling characteristics. In light of this, abundant marbling can increase the lightness (L*) value despite if pigment content is increased (Kim & Lee, 2003). In (Figure 17), the overall L* values are relatively high, but, as mentioned above, that may be related to the abundance of intramuscular fat. High L* (lightness) mean value throughout loins 1-6, which predicts a light color lean, and is correlated with the meat's hue and chroma. Value a* (redness); this value was correlated with b* (yellowness) and hue. Based on the loin data, all loins for a* values were significantly different and contained steady mean values indicative of a low red lean color. The b* value was correlated with a*, hue, and chroma. Based on the data, the loins had steady mean values which reflected on a less yellow color and possibly relatively less intramuscular fat. The hue throughout all loins is described to be

interrelated to L* a* b* and saturation of beef loins. Based on the constant mean values across loins, the data mostly indicated stable color values, which included darker color lean, less red lean color, and less intramuscular fat. The intensity and distribution of intramuscular fat changed the color values measured within the strip loins. Lean tissue is known to have 80% water. In the circumstances with high marbling in meat, the percentage is reduced based on fat to lean ratio (AMSA, 2012). The overall hue was significantly different for all strip loins, which possibly indicates non-uniformity in myoglobin content. Approximately 95% of water is the determined amount of free and immobilized water (Bertram et al., 2002). The low raw EC values indicate more immobilized water than free water . The determination above is based on previous statements on water configuration percentages stated in the literature review. Myoglobin level is reflected in consumer preference for bright cherry red color though composition and is also reflected by water form in meat. The spectrophotometer gives results of color values and is of valuable assistance to the beef industry. Consistent methods for quality grading can aid consumers for true overall meat value rather than idiosyncratic visual appraisal, and provide an increase in profit margins to the industry. Further recommendations for color would be to provide a larger database of samples from multiple sources to compare color values to further narrow chroma, hue, L*, a* and b* values for consistency purposes. Color variables may provide an improved appraisal of overall true color value in fresh beef loins, in addition to visual appraisal. Color may aid in water estimates by ionic strength determinations to identify specific water forms found in beef to reduce negative aspects of water holding capacity such as dark cutting.

Electrical conductivity and water assessment

Electrical conductivity is defined as the ability of a substance to produce an electrical current (Byrne et al., 2000). Based on beef's anisotropic nature, it contains an electrical charge and interactions with ions and water. Electrical conductivity can evaluate water constituents and muscle components **(**Põldvere et al., 2016). Based on data analyzed in (Table 15) with raw and cooked EC values, raw values were significantly higher than cooked EC values, nearly a three-fold increase. This indicated more free water and/or ions were contained in fresh strip loins than cooked strip loins. Concurrently, the muscle to meat conversion allowed ions such as Calcium and Magnesium to dramatically increase corresponding to a rapid decrease in pH 5.5-5.8 (Puolanne & Kivikari, 2000). The ions in raw beef strip loins contributed to water stability to provide a reduction of electrostatic repulsion of proteins and ideally contribute to the moistening of proteins (Puolanne & Halonen, 2010; Richardson & Martinez, 2019). This statement brings forth water binding capacity properties that aids in beef quality attributes. Cooking loss percentage (CL %) demonstrated in cooked loin (Table 13) can be suitable for water concentrations /configuration determination (cooking loss values additionally enclosed fat, drippings, and probable minute quantities of meat). Strip loins 1-6 contained somewhat similar low values based on the initial raw weight subtracted from the final cooked weight. The water form most probable for these strip loins was free water loss rather than immobilized or bound water. This study may provide a feasible approach to commercialize EC measurements as a quality assessment procedure. Corresponding to commercialization, EC may assist producers to understand ionic strength and measure free water in order to reduce negative aspects of water holding capacity such as dark

cutting and dark, firm and dry meats. Lower values of CL% is reflected in high marbling beef (Kim & Lee, 2003); this is associated with Wagyu beef desirability. Further recommendations on EC would be to provide more samples from multiple sources to compare EC values to further evaluate EC values for consistency purposes. Beef jerky data are found in (Table 4), which show higher EC values and did not follow the pattern for beef strip loins. This product in this research was to resemble bound water that contains < 5% water (Bertram et al., 2002). The ingredients listed in (Figure 6) indicated other ingredients, i.e., food additives present in Jack Links "The Original" ® list of ingredients package. No further data analysis was concluded for beef jerky than (Table 4), but, overall through literature review affirms the electrical properties of meat are directly dependent on water, which furthermore indicates higher EC equates to increased particle interaction in beef (Lee et al., 2000; Richardson & Martinez, 2019). In drier meats for instance, beef jerky is often shown to contain lower EC values with less particle interaction (Lee et al., 2000; Richardson & Martinez, 2019). However, due to the food additives, the prediction upon the data suggests food additives with high ionic concentration reflected a higher EC value. Further research recommendations in beef jerky are to possibly hand manufacture this beef product precisely without food additives in order to provide a stable sample of bound water to predict EC accurately.

Tenderness assessment

Tenderness is another quality characteristic associated with consumer satisfaction (Silva et al., 2015). Overall tenderness was analyzed in (Table 15), which consisted of a low standard deviation. Also, individual strip loin and steak core values indicated low standard deviation values, which shows consistent tenderness in beef loins. Marbling in

meat has an impact on eating quality exclusively in beef (Luchak et al., 1987). Although no research has concretely stated the impact, other studies have mentioned intramuscular fat slightly related to tenderness (Kim & Lee, 2003). The tenderness in the beef strip loins analyzed, although all were significantly different, this may indicate undistributed fat within the beef strip loins and can affect tenderness quality. This study may provide insight for tenderness in prime grade beef loins. Further research recommendations in tenderness would be to perform a fatty acid analysis on beef strip loins to collect data on meat quality compatibility.

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