THE CORRELATION BETWEEN COLOR AND ELECTRICAL CONDUCTIVITY IN BEEF

by

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DEDICATION

I would like to dedicate this work to my father, Vasant C. Ramkumar. Dad, the amount of love and gratitude I have for you could easily be longer than any thesis or future dissertation I may write. My lifetime alone would not be able describe the magnitude of appreciation in which I have for you. I want to thank you for being the rock to our family and being my constant source of inspiration to succeed not only in school, but in life. I don't know who I would be or where I would be going without you. Knowing I have you, the unknown future ahead reassures me that life will be much more exciting than scary. Thank you for always sharing your words of wisdom, dad jokes that only you could come up with, taking the time from your busy schedule to prioritize me when I need it most, and upholding our daddy daughter movie date tradition. I also want to thank you for sharing your love for learning, teaching and academics (even when I don't ask or resist) as it is the reason my sisters and I will always be reminded "There is always a lesson to learn if you are willing to learn it" and most importantly, "The only thing in life a person cannot take away from you is your education". I love you dad. You will always be the number one man in my life and I want you to know that no matter where in the world I am, you are ALWAYS with me. I hope to continue to make you and mom proud and that my future children will admire my future husband and me as much as they will you!

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LIST OF ABBREVIATIONS

Abbreviation	Description
DFD	Dark Firm Dry
DMb	Deoxymyoglobin
MMb	Metmyoglobin
OMb	Oxymyoglobin
COMb	Carboxymyoglobin
MAP	Modified Atmosphere Packaging
EC	Electrical Conductivity
WHC	Water Holding Capacity
EP	Electrical Permittivity
DF	Dilution Factor

I. INTRODUCTION

Background

According to the U.S. Department of Agriculture Economic Research, the United States consumed 25.668 billion pounds of beef in 2016. Competition against other meat products currently on the market encourages the beef industry to continuously improve methods to satisfy consumer product demands at the lowest economic cost without compromising quality and uphold increasing demand at the highest yield possible and provide satisfactory products to consumers (USDA, 2016). Appearance of color is the principal feature of meat that influences the consumers' purchasing decision. More specifically, the visible display of a bright cherry red color in beef give the false perception of what is a true, "fresh, and wholesome" meat product. Advancements in technology have provided reliable methods in quality determinations and steak value. (Aberle, Forrest, Gerrard, & Mills, 2012; Grebitus, Jensen, Roosen, & Sebranek, 2013; Hunt et al., 2012; Liu et al., 2003; Quevedo et al., 2013; Suman & Joseph, 2013a; Tapp, Yancey, & Apple, 2011; Trinderup, Dahl, Jensen, Carstensen, & Conradsen, 2015).

Consumer purchasing studies reveal how customers are willing to pay two-three times more for higher quality beef products. This is vital for the beef market implement methods that utilize improvement of overall production of high quality product at lowest economic cost possible (Lyford et al., 2010). Just as beauty is in the eye of the beholder, meat must please the eye as well as the palate of the consumer. For researchers, this includes knowledge on what influences quality traits associated with color and textural

characteristics, aroma, tenderness, juiciness, flavor and water content of beef.

Purpose of This Study

The purpose of this study is to evaluate and describe the several factors affecting quality of beef steaks. More specifically, this study will determine the color evaluations in selected cuts of beef from four various sources using the Varian Cary 50 spectrophotometer machine and to analyze the electrical conductivity measurements of each sample and source. Furthermore, this study will examine the overall color scores and electrical conductivity measures from the four sources to determine if a relationship between measures exist, and if so, if it can be used as a predictive determining factor for quality in beef steaks.

Limitations of This Study

The meat processing laboratory used for this entire study had an impact on the number of samples that could be processed at one time due to limited availability of instruments typically used in electrical conductivity measures. In addition, the ample amount of data calculations from color analysis reports collected using the Varian spectrophotometer machine requires additional examination on data parameters best fit for formulating a properly conducted correlation analysis of color and electrical conductivity values.

Implications of This Study

This study aims to provide a better understanding of beef quality attributes through the use of instrumental techniques to collect color and electrical conductivity data relative to color. Both of which are important in consumer satisfaction which drives the demand for meat products. Color and water binding capabilities in beef muscle is

associated with several factors including the biophysiological characteristics of myoglobin content, oxidation, nutritional and genetic traits associated with beef steak quality.

Research Objective Questions

- Is the correlation between the color and electrical conductivity measurements significant and can this be used to predict quality of beef cuts?

    1. Do color evaluations using the Varian spectrophotometer machine provide reliable quality grading relative to consumer purchasing?

    2. What is the degree of variance among color measurement scores of selected cuts?

    3. Can electrical conductivity measurements be used to predict and separate quality grades of beef cuts?

II. LITERATURE REVIEW

Meat quality is dependent on a multitude of factors which holds effect on the color, water and oxygen binding properties, and overall value of retail product (Aberle et al., 2012; R. Mancini, 2013; R. A. Mancini & Hunt, 2005; W. Zhang, Xiao, & Ahn, 2013a). The meat industry defines beef color as a bright "cherry red" and can be influenced by several factors based on environmental conditions and the animals' physiology or genetic make-up. The ability for a postmortem (rigor) muscle to retain water is defined as water holding capacity (WHC). Influence of WHC can impact physical properties of meat muscle and therefore can affect the color life potential. (Aberle et al., 2012; Ahn & Nam, 2004; Huff-Lonergan, 2005; Hughes, Oiseth, Purslow, & Warner, 2014; Li, Hviid, & Lundström, 2011; R. A. Mancini & Hunt, 2005; Puolanne & Halonen, 2010; Schrecker & Gostomski, 2005; Suman, Hunt, Nair, & Rentfrow, 2014; Suman, Nair, Joseph, & Hunt, 2016; Yang, Lanari, Brewster, & Tume, 2002; W. Zhang, Xiao, & Ahn, 2013b). This relationship will be explained in detail later in this chapter.

Meat Color

Color changes in meat muscle is due to the many factors relative to nutritional components in diet and feed formulation. Maintaining energy and metabolism levels, the myoglobin chemistry, pigment redox stability, pre/postmortem conditions, processing methods, packaging techniques, distribution, storage, display, and the biochemical components of muscle composition. All are factors of which can contribute to variation of red intensity as well. Essentially, color can be manipulated through harvesting techniques and internal and external environment conditions of the animal (Aberle et al., 2012; J. C. Brooks et al., 2008; Fu, Liu, Zhou, & Zhang, 2017; Grebitus et al., 2013;

Hunt et al., 2012; R. A. Mancini & Hunt, 2005; Suman et al., 2014; Suman & Joseph, 2013a; W. Zhang, Xiao, Samaraweera, Lee, & Ahn, 2010).

Pigment and Perception

Meat color is defined by the pigments which absorb certain wavelengths of light & reflect others. These pigments are known as Hue, Chroma and Value. Hue is the wavelength of light radiation usually displayed by colors yellow, green, blue, or red. Chroma is the intensity of fundamental color also known as the purity or saturation the color displays. The Value is the overall light reflectance of color (Aberle et al., 2012; Hunt et al., 2012). As previously mentioned, the meat industry defines beef color as a bright "cherry red" and multiple factors contribute to the variations of intensity and overall color life (Hunt et al., 2012; R. Mancini, 2013; Rogers et al., 2014).

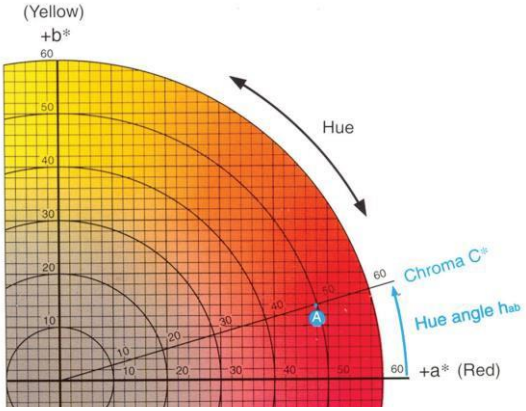


Figure 1: Hue angle and Chroma or Saturation index (Within part of a chromaticity diagram) from Konica Minolta Sensing Americas.

Color is principally a beam of light composed of irregularly distributed energy emitted at different wavelengths. Major influences of color perception can vary due to illumination, material display and packaging. These are found to alter the display of light qualities and sensations and provide the desired quality traits perceived by customers. Translucency of foods is usually referred to when describing the physiochemical properties of muscles and defined using an opaque-to-transparent scale. The perception of product appearance is vital in maintaining successful meat production sales and demand. The human eye sees the translucency of steaks and therefore important to understand

when beef products are on display (Aberle et al., 2012; Hunt et al., 2012; R. A. Mancini & Hunt, 2005; Suman et al., 2014).

The human eye is only capable of a portion of the color spectrum. This makes true color evaluations objective and the reason retailers must purposely alter their display of meat products to appear more red. This can be done through different types of lighting, packaging and deliberate adjustments in the product placement once it reaches the shelf (Aberle et al., 2012; R. Mancini, 2013; Rogers et al., 2014). The figure below displays the range of visible color spectrum to the human eye.

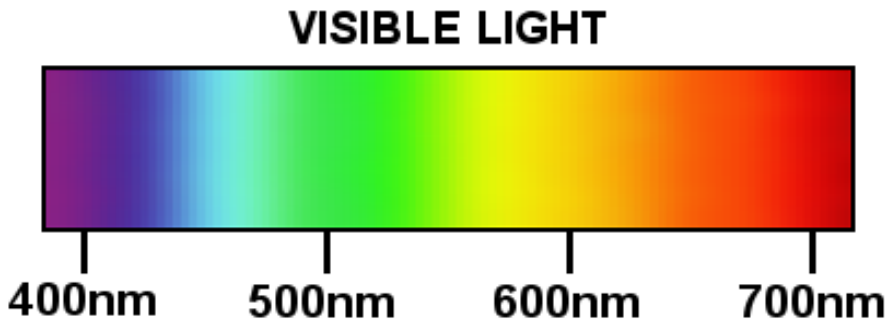


Figure 2: Visible Color Spectrum

The retina is the organelle that senses light and rods detect the lightness and darkness of the stimuli present. Cones detect light spectra for blue, green, and red color. The trichromatic function of the eye is the ability in detection of blue, green, and red spectra. After the eye detects the lighting stimuli, it is transmitted from the optic nerve to the brain where it is processed into a visual perception and object identification. The complexity of interaction between the eye and brain is what forms color perception. The capability of the eye to detect color is simply capturing wavelength of light reflected from an object. This is referred to as what humans are "seeing" and how the eye will relay the sensory input to the brain to interpret important to perception of red color in beef

steaks.Beef consumers use color or discoloration as an indicator of being fresh shapes the economic benefits and deficits faced by the beef industry. Surface discolorations in beef retail display directly corresponded with a vast economic loss for the industry. Understanding color perception in retail of beef is an essential way to reduce chances of dissatisfied customers and economic loss. (Hunt et al., 2012; Suman et al., 2014)

Myoglobin Oxidation

Other pigments and important meat quality color attributes influencing the beef color are hemoglobin, the pigment of blood and myoglobin, the pigment of muscle. Meat muscle is made up of many fibers which contain red blood cells and define the shade of red it will display (Aberle et al., 2012). Myoglobin is the richly pigmented, principal protein located in the sarcoplasm of muscle fibers that give muscle meat color. Because myoglobin is richly pigmented, the more present within cells, the redder, or dark the meat will be on pre-oxygen exposure levels (Aberle et al., 2012; Hunt et al., 2012; Suman & Joseph, 2013a).

Myoglobin color can display a brown, purple, red, or purplish-pink color depending on the chemical reactive state of the muscle. The myoglobin color can also be influenced by the environment, packaging, handling and storage conditions of the beef muscle and the color can be classified by their chemical state known as: Deoxymyoglobin, oxymyoglobin, metmyoglobin and in certain circumstances carboxymyoglobin. (Aberle et al., 2012; Hunt et al., 2012; R. A. Mancini & Hunt, 2005).

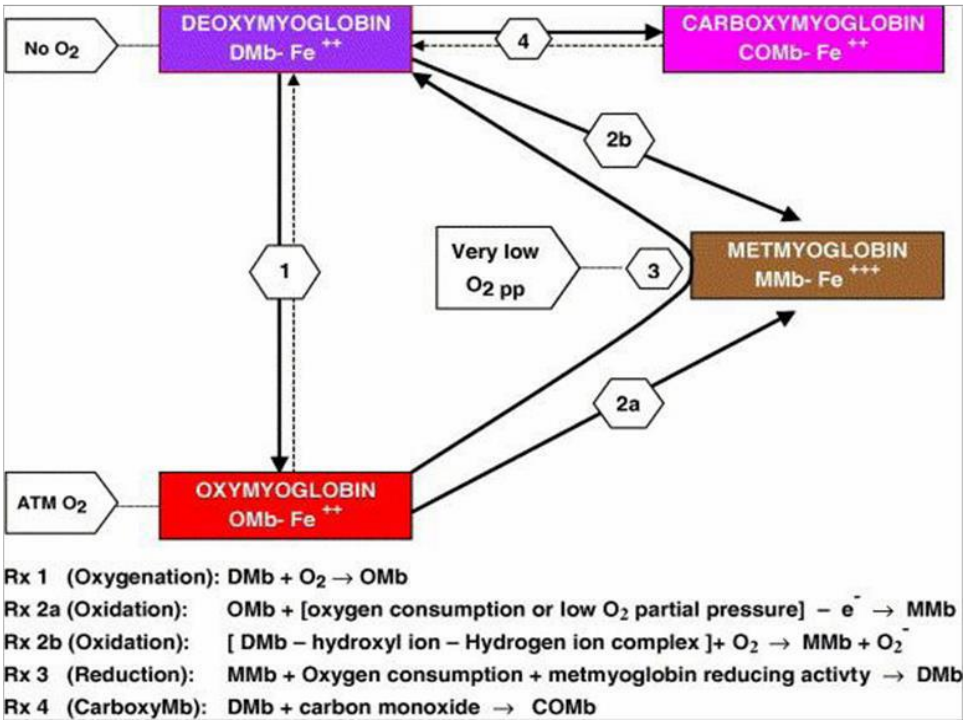


Figure 3: Oxidation Reaction and Muscle Color from AMSA

Understanding of factors of which change beef muscle color will help increase economic yields obtained through the color life potential capabilities of a muscle. Although other heme proteins like hemoglobin and cytochrome C play a role in color, myoglobin content priority in color quality. it contains that greatly impact and define beef meat color (Aberle et al., 2012; R. A. Mancini & Hunt, 2005).

Because myoglobin is richly pigmented, the more there is in the cells, the more red (or dark) the meat will be on pre-oxygen exposure levels. The impact on color in meat is important for helping production companies. Understanding factors that influence consumer purchasing decisions will allow companies to supply higher quality products with longer shelf lives and result in economic increase benefits. These improvements to the industry can be obtained through the measures of color life potential capabilities in a muscle. Myoglobin is a water-soluble protein containing eight alpha helices that are

linked by short non-helical sections. Histidine has been recognized as a major component in myoglobin because it plays a key role in the structure and functioning because it contains a heme ring with a centrally located iron atom with the ability to form six bonds. Four of the six bonds are with pyrrole nitrogen. The fifth bond coordinate is with proximal Histidine-93 and a distal Histidine-64 is proven to influence the color dynamics of the muscle through the ability to affect space relations within the hydrophobic pocket. The final bonding site within myoglobin influencing color is to reversibly binding ligands. Myoglobin's relationship with oxygen also help give color the pigment that the muscle will retain and consumers will see (Aberle, Forrest, Gerrard, & Mills, 2012; COMA, 2008; Fu, Liu, Zhou, & Zhang, 2017; Hunter et al., 1997; Limbo, Torri, Sinelli, Franzetti, & Casiraghi, 2010; R.A. Mancini & Hunt, 2005; W. Zhang, Xiao, & Ahn, 2013b)

Iron Oxidation

Oxygen combined with myoglobin is what gives the color pigments of beef the different degrees in shades of red displayed. Oxygen's ability of binding to this protein myoglobin is due to the ability to rapidly transport and easily store high affinity amounts of oxygen within the muscle (W. Zhang et al., 2013b). Along with oxygen, the different states of mineral element Iron (Fe) in the blood have influence on how bright of a red color the muscle reach. Two states of iron are required when observing the correlation of how fast and how red the muscle becomes with time: Ferric Iron and Ferrous Iron (R. A. Mancini & Hunt, 2005; Pereira & Vicente, 2013). Oxidized iron, also known as the ferric state, is when Iron cannot combine with molecular oxygen or any other molecule. Reduced state of iron, the ferrous state, is when iron readily combines with water or

oxygen. Oxidation of meat is the reduced reaction result of both ferrous myoglobin products to ferric iron. Before this can occur, the muscle first undergoes its first reaction when exposed to oxygen called oxygenation (Aberle et al., 2012; Hunt et al., 2012; Suman & Joseph, 2013a).

Iron in a pure, unoxidized state has three electrons that can be easily removed. When iron undergoes oxidation, it loses the three electrons that are easy to remove. After it has undergone oxidation, iron has lost three electrons and the oxidized form of iron is left. The different binding states of oxygen and iron can influence how quickly and how red (or brown) the meat muscle will get. Because of this, the most important factors scientists consider in meat appearance are oxygen consumption and the metmyoglobin reduction process the muscle endures (C. Brooks, 2007; R. A. Mancini & Hunt, 2005;Suman & Joseph, 2013b; Yang, Lanari, Brewster, & Tume, 2002).

The oxidation-reduction process occurs after the oxidation reaction. This includes the utilization of oxygen, hydrogen, and water to influence the color states of the meat muscle. The reduction of metmyoglobin is crucial to meat color life and greatly depends on muscle's oxygen scavenging enzymes, reducing enzyme systems and the NADH pool, which is limited in postmortem muscle. Unfortunately, both enzyme activity and the NADH pool continue to deplete as time of postmortem progresses (R. A. Mancini & Hunt, 2005; C. Brooks, 2007, Hunt et al., 2012). The result of this is reaction process is that oxymyoglobin is not able to be converted directly to deoxymyoglobin, but first goes through the ferric redox state at low-oxygen partial pressures (Hunt et al., 2012).

The endogenous removal of oxygen to achieve low-oxygen partial pressures occurs via oxygen consumption, which is likely the result in oxidation of oxy- to

metmyoglobin. Deoxymyoglobin formation depends on the muscle's reducing capacity and further reduction in oxygen tension capabilities (AMSA 2012). Different methods of packaging also are known to reduce the ability of oxygen atmospheres and therefore, further oxygen consumption coupled with the reduction of ferric to ferrous iron mentioned earlier, cannot be completed therefore displaying a darker color(AMSA 2012; Zhang, Xiao, & Ahn, 2013).

When the blood has not yet been exposed to atmospheric oxygen, it is referred to deoxymyoglobin. No ligand at the sixth binding site is open for binding and iron is its ferrous state. The muscle holds a purple-red/pink color during this stage. When oxygenation occurs, the myoglobin is exposed to oxygen in the air and begins to develop the bright red color. Iron's valence does not change; however, the sixth binding site begins combine Histidine and oxygen. This binding changes myoglobin's structure and stability (Aberle, Forrest, Gerrard, & Mills, 2012; Hunt et al., 2012). The increase of oxygen's exposure to the muscle makes oxymyoglobin begin to go deeper beneath the surface of the meat. The rate at which the muscle becomes oxygenated depends on the thickness of the myoglobin layer. The second reaction, oxidation, begins the discoloration effects in the beef muscle.

Discoloration is dependent on the amount of surface area covered by metmyoglobin, the oxidized blood. This occurs because as metmyoglobin slowly moves to the surface it thickens. The brown color meat turns at this stage are the results of most of the muscle having been exposed to oxygen and there are no more deoxygenated binding sites (Aberle et al., 2012; R. A. Mancini & Hunt, 2005; W. Zhang, Xiao, & Ahn, 2013b). After long storage time periods, this brown color is also likely to occur.

Temperatures at higher levels are also known to be a catalyst in obtaining the brown display of color on and in meat. The effects of these high temperatures are the result of myoglobin losing its ability to bind to oxygen and iron atom in the center of its molecular structure loses an electron . Some other body influences can play a role into the decrease quality in color of the beef muscle (Aberle et al., 2012; Hunt et al., 2012; Rogers et al., 2014).

Physiological Influences

In pre-harvest conditions, beef muscle can be altered to a darker color due to stress put on the animal. The physiological damage as a result to these conditions are usually caused by behavior responses, poor housing environments, stunning, handling, transportation, temperature, bruising and injury, unbalanced diets, any other stressors the animal endures. The catalyst of consequences that result from any of these encounters can include spoilage, bacterial growth, an increase in decomposition and discoloration, and a decrease in quality, shelf life and ultimately leading to a dissatisfied customer leading to an economic deficit (Aberle et al., 2012; Rogers et al., 2014; Suman, Hunt, Nair, & Rentfrow, 2014).

If an animal is stressed, the glycogen, known to give the animal energy, is used up and the lactic acid level that develops in meat after slaughter is reduced. The lactic acid cycle reverts to the metabolic pathway in which lactate produced by anaerobic glycolysis in the muscles moves to the liver and is converted to glucose, which then returns to the muscles and is metabolized back to lactate. This is process is important in producing ATP, an energy source, during muscle activity. The cycle functions more efficiently when muscle activity has ceased. This allows the oxygen debt to be repaid such that the

Krebs cycle and electron transport chain can produce energy at peak efficiency. Lower quality in meat results in displaying a dark, firm, & dry muscle (DFD). This is less acceptable to the consumer and has a higher pH-value that decreases shelf life (Aberle et al., 2012; Chriki et al., 2013; R. A. Mancini & Hunt, 2005).

Spoilage is also a result of a lactic acid indicator of stressors, injury or diseases present before slaughter. It is also an indicator of ideal pH level usually measured after 24 hours after slaughter. Proper lactic acid cycling will retard the growth of bacteria that may have been contaminated during slaughter and dressing periods. This bacteria is what causes spoilage of meat during storage. The meat begins to develop off-smells, color changes, rancidity, and slime. Major economic loss for production processing, consumers, consumer safety and loss of man-hours can be a negative result of spoilage (C. Brooks, 2007; J. C. Brooks et al., 2008; Hoyle et al., 2009).

In regard to bruising and injury, bruising can be defined as damaged blood vessels, which escape the blood and surrounding muscle tissue. This injury can occur by sticks, stones, other animals (ex: horns), and falling. These injury causes can occur during the handling, transport, penning, and stunning periods by humans. Not only does the bruising hurt the animal, it can lead to bacterial infections, both superficial and severe, making the meat useless to processing, manufacturing, and most importantly, consumer purchasing processes because the meat is going to decompose and spoil faster in these bruised areas (Hoyle et al., 2009; Suman & Joseph, 2013b).

Everything biological that has color derives from Amino Acids & Minerals. Amino acids are the building blocks of protein and enzymes that give specific functions in and of the animal's body. Cattle muscle has a fiber composition which encourage the

metabolic reactions. Proper oxygen utilization allows the proper water binding properties impacting color intensity (Bekhit et al., 2003). The effects on diet composition is also attributed to the water content and muscle color because glycogen storage can be easilyaltered. In addition, the chilling rate, or antioxidant accumulation are fundamental intrinsic color traits, pH levels, oxygen consumption, and metmyoglobin reducing activity of the muscle (Suman, Hunt, Nair, & Rentfrow, 2014).

To prevent the negative effects of glycogen loss, a proper diet and methods to reduce stress prior to slaughter is necessary. When an animal is stressed, prior experiences, slaughter conditions, and genetic background all influence the way an animal evaluates the situation before deciding on action (when muscle contraction or stiffness occurs) (Tornberg, 2005). This decision on action is the behavioral and physiological responses in the animal based on muscle metabolism (nutrition and diet) that impact ability of water and blood to flow freely between the cells and effect the meat color in the final product intended for retail. If an animal is stressed, the darker red color is prevalent over the bright red desired (Quevedo et al., 2013).

Nutritional Influences

Different types of diets are known to influence the muscle color also. These changes in muscle lightness and yellowness were due to changes by dietary effects on pre-harvest glycogen and marbling levels. Forage based diets are reported to have restricted amounts in pH levels which promote oxidative metabolism, rather than anaerobic muscle metabolism and glycogen storage. Restricted diets are shown to have less glycogen, higher muscle pH, and darker muscle color. The feeding effects on color are mostly attributed to the relationship between lipid and pigment oxidation (Giusto,

Pasquaré, Salvador, & Ilincheta de Boschero, 2010; Hunt et al., 2012; Ke, Huang, Decker, & Hultin, 2009; Tornberg, 2005).

Similar to the individual enzymes and amino acids which each have a specific structure, function and mutual goal to reach the proper levels to maintain the body at balanced level, major components of nutritional influences effecting color are related to the diet and body of an animal, mineral iron, and vitamin E. This is assumed if there no deficiencies of toxicities present which can over or underwork an animal's body trying to maintain homeostasis levels of functioning (Pereira & Vicente, 2013; Simopoulos, 1996; Suman et al., 2014; Tornberg, 2005; Yang et al., 2002).

The more myoglobin an animal has, the darker of a red the muscle will display in an animal. Vitamin E is a fat-soluble vitamin stored in the liver usually given through a supplement in the diet. It is known to slow oxidation and delay the lipid oxidation process and discoloration. The vitamin is flushed out by blood flow due to the tocopherold and tocotrienols associated with the ATP process. The darker red color means more blood cells are present in the animal's body thus more likely to change into the brighter red upon exposure of oxygen (Ahn et al., 1998; Bekhit et al., 2003; Pereira & Vicente, 2013; Yang et al., 2002).

Packaging and Storage

Increase in technology advancements and social influences on nutritional health perceptions and components in food demand for providing accurate and consistent products at reasonable costs. Consumer perception of quality influences demand for consumption. By understanding these quality factors and purchasing decision the meat industry can continue developing quality assurance methods through utilization of

technology advancements to satisfy consumers. This will also help encourage consistent products without compromising nutrition, flavor and consumer satisfaction driving the demand for beef (Lee, 2010).

The consumers' false association of bright red beef with freshness of beef products and using discoloration as an indicator of spoilage can be detrimental in marketing fresh beef. As previously discussed, the biological and chemical nature of beef muscle is expected to undergo natural processes like oxidation, which impact color. Even after the desired bright red color is developed, it can be easily changed. The capability for beef to retain its bright red appearance for a longer period of time in retail stores is critical to marketing (Fu et al., 2017; R. A. Mancini & Hunt, 2005; W. Zhang et al., 2013a). The amount of time it is able to maintain the bright red color is referred to as color shelf-life or case-life (C. Brooks, 2007; Rogers et al., 2014). Color changes due to the various oxidation process, growth of spoilage bacteria, and environmental conditions. Using proper packaging, lighting and handling techniques can help increase the color shelf-life of products in grocery stores (Ahn et al., 1998; C. Brooks, 2007; COMA, 2008; Fu et al., 2017; Grebitus et al., 2013; Hoyle et al., 2009; Qiao, Fletcher, Smith, & Northcutt, 2001).

Supplying consumers with beef products that are consistent in bright red color, quality and of higher value is a major goal for the beef industry. (Grebitus et al., 2013; Hunt et al., 2012; R. Mancini, 2013) Product placement and display are vital components in the decision-making process for purchasing. Therefore, it is important to understand the various packaging techniques utilized to achieve this goal and reduce premature browning (PMB) (Suman et al., 2016). Packaging is important in supplying safe, high

quality fresh products that are visibly appealing to consumers. If used correctly, packaging assists in extending shelf life and color life of products making economic loss less of a concern(C. Brooks, 2007). For safety and cost reasons, packaging material is used as a protection agent against the contamination and deterioration of products. Poorly packaged products are more susceptible to spoilage by bacteria and negative color changing components that lead to a displeasing appearance to consumers (C. Brooks, 2007; COMA, 2008; Hoyle et al., 2009; Lee, 2010).

The various functions and variety of packaging technologies available for consumer products create a challenge for beef producers because there is a wide variance among beef products and storage conditions. These include beef products that are fresh, cooked or frozen and stored by refrigeration, freezing, and intense lighting all while withstanding the handling and transportation process. With this variance present, it is imperative that packaging must be economically low in cost to produce while meeting the demand of its purpose for protection and merchandizing (C. Brooks, 2007; Maheswarappa, Mohan, & Jagadeesh, 2016; R. A. Mancini & Hunt, 2005; O'Sullivan & Kerry, 2010; Rogers et al., 2014). The most commonly used packaging types in beef production are modified atmosphere packaging which include vacuum packaging and can be referred to as traditional packaging (J. C. Brooks et al., 2008; Reicks et al., 2008).

Modified atmosphere packaging places beef in non-air environments. Beef products in modified atmosphere packaging are typically seen towards the ending parts of the overall production process. Usually this packaging technique occurs when beef products are ready for retail. More than likely, the beef products sold in grocery stores use a modified atmosphere packaging. Products are typically seen on plastic trays with

ridges, has an absorbent pad underneath the beef and is sealed with some type of clear high-barrier plastic film (McMillin, 2017). The absorbent pad helps avoid the appearance of a watery unappealing product. During the manufacturing process, a machine vacuums any residual air from the tray with the beef product and then pushes a modified atmosphere into the package immediately before sealing it with the clear film. The modified atmosphere is usually a measured ratio of purified version of gases found in air. Most importantly, the oxygen, carbon dioxide, carbon monoxide and nitrogen content (Fu et al., 2017; Grobbel, Dikeman, Hunt, & Milliken, 2008; Hunt et al., 2004; Maheswarappa et al., 2016; Rogers et al., 2014; Šuput, Danijela Z. (Faculty of Technology et al., 2013). Oxygen is of most value because as mentioned earlier, it is the key in giving beef the bright cherry red color that customers favor. Carbon monoxide is used mostly as prevention in the growth of spoilage bacteria (Grebitus et al., 2013; Jeong & Claus, 2011; Seyfert, Mancini, & Hunt, 2004; Šuput, Danijela Z. (Faculty of Technology et al., 2013).

In 2002, the FDA and USDA approved use of carbon monoxide in gas mixtures at a 0.4% level if the mixture did not contain any oxygen. This is because carbon monoxide works closely with myoglobin bonding that helps create color in a muscle. The exclusion of oxygen in these mixtures decrease oxidation effects and creates a more stabilized red muscle and results with an increased shelf life. Nitrogen has no effect on the coloration or bacterial growth of beef products in modified atmosphere packaging, but is used as a diluting property to allow other gases to be utilized in their respective ratios (C. Brooks, 2007; McMillin, 2017; USDA, 2016).

Vacuum packaged beef products usually involve a strong durable plastic bag or pouch used as protection against abrasion, moisture migration and gas permeability. The beef cuts are placed inside these bags and then put in a packaging machine that quickly removes remaining air from inside and immediately seals it into an airtight environment (AMSA 2012). Oxygen removal in vacuum packaging usually will display fresh beef with a purple-brown color. This is because the lack of oxygen leaving or entering the bag is limited due to the tightly sealed and strength of the package. However, the purple-brown color is not what average consumers desire so vacuum packaging is usually used for long term storage and bulk transportation of products (Aberle, Forrest, Hedrick, & Merkel, 1989; Ahn et al., 1998; O'Sullivan & Kerry, 2010).

The most common fresh meat packaging technique is called store wrap. This is where retailers will receive an order of vacuum packaged products in bulk from a source where they will properly portion, cut, and repackage the products allowing the display demand criteria for consumers to be met (bright cherry red color). Although this method is popular among retailers, the shift for prewrapped products has been recently trending due to the ease of processing for retailers. Prewrapped products are delivered to the retail stores already with USDA approved labels and grading and can be placed on the shelf immediately after inventory (McMillin, 2017)

The repackaged products are usually on foam trays with the absorbent pad as mentioned earlier with the clear plastic wrap allowing oxygen to come in contact with the beef and change the color from purple to red. Although store wrapped products are mostly seen on grocery store shelves, some vacuum packaging can be beneficial for retail display if the product has a fixed color. The fixed color can only be obtained as a result of

curing or cooking. However, store wrapped beef products are used more often because of how cheap the necessary material and equipment used are. This cheaper option also results in the shortest shelf life because the continued exposure to oxygen catalyzes oxidation leading to bacterial growth (McMillin, 2017; Suman, Hunt, Nair, & Rentfrow, 2014)

Instruments Used to Measure Color

Using electronic methods to assess beef quality traits are readily available and come in a wide variety of options. The efficacy and accuracy in machines that measure the reflectance and absorbance of light properties in meat products have become universally popular for the industry (Aberle et al., 2012; R. A. Mancini & Hunt, 2005). Determining which type of machine however is dependent on what traits you want to measure and for what purpose (Hunt et al., 2012). Optical based probes are effective in differentiating between fat and lean tissue structure and predicting composition therefore helping establish the value of products and price paid to the producers from processers. High resolution cameras that detect basic red, green, and blue color are popularly used today to analyze color standards and uniformity (Aberle et al., 2012).

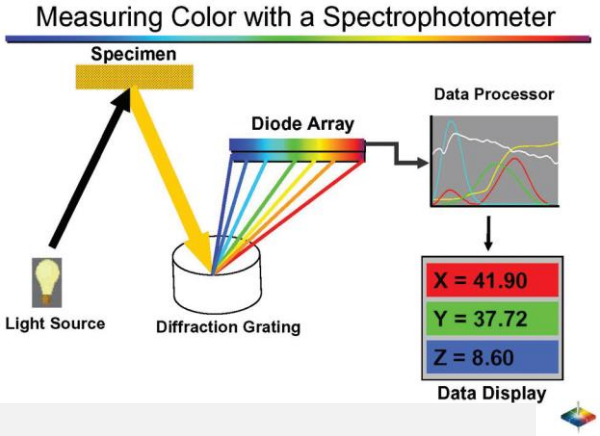


Figure 4: Measuring Color with a Spectrophotometer

Researchers have found that spectrophotometer machines are the most accurate and consistent when measuring color and therefore understandable for popularity of use in color research. When reporting color measurements, it was noted that previous

research were not consistent in what standard of measurements they were reporting. Therefore, the American Meat Science Association emphasized the importance for color researchers to report the following when conducting color studies (Aberle et al., 2012; Hunt et al., 2012).

Varian Spectrophotometer

This specific spectrophotometer brand used in this study uses a Microsoft windows based operating software which could be a possible limitation in research, however the benefits in what the company claims seem to outweigh the limitation. The Varian UV-Vis-NIR spectrophotometer has been used in research for over 50 years. The range of additional accessories that are user friendly provide accurate results necessary in the research world. It helps uniform standards in color measurement studies and provides researchers with a tool that should be used "no matter what your measurement challenge" is. It comes with a Harrick brand diffuse reflection probe that can both used to measure samples that are liquid inside or extend to the outside for solid samples. The color application "Cary 50" is a color calculation application where it performs calculations on data collected for the researcher based on preference. 50 samples an be selected at one time per calculation and the application can calculate tristimulus values, chromaticity coordinates, color coordinates for CIE L*a*b*, CIE L*u*v*, Hunter Lab and Metric. In addition, it can also calculate whiteness and yellowness with three wavelengths to choose from. Wavelengths include a 360-830nm at 1, 5 or 10 nm for data intervals. This machine also allows researchers to select thickness correction, and a Match feature which allows delta e (change over time) to be calculated. It also allows calculations to be performed after data collection is already complete allowing researchers to refer back to previous

work and use data calculations to test different studies. The ease of use and graphics it supplies make the Varian brand set an example in what they believe should be the basic standards for color researchers.

Figure 5: VARIAN UV-Vis-NIR Spectrophotometer

Electrical Properties of Beef

The electrical properties in meat tissue can be used as indicators of muscle structure and quality through its water conent. By measuring electrical conductivity (EC) and electrical permittivity (EP) in beef, researchers can provide further understanding of muscle physiology traits that affect product quality (Barbosa-Cánovas, G.V., et. al). Electrical conductivity in meats represents the tissue's capability to conduct electricity (Byrne et al., 2000) and is generally expressed in siemens (S) or microsiemens (μS) which is commonly used in meat research (Põldvere et al., 2016).

The anisotropic nature of meat make electrical properties complex and vary in electrical characteristics depending on environmental conditions (Lepetit, Salé, Favier, & Dalle, 2002; H. Zhang, 2007). Impedance on the contrary, describes "the total opposition to the flow of an alternating current at a given frequency" (Lepetit et al., 2002; H. Zhang,

2007) and is expressed in ohms (Ω). The equation seen in Figure 5 shows the relationship of ohms and Siemens. Raw meat with relatively higher EC values would be characterized by an abnormally high amount of free water and raw meat with relatively low EC indicates meats would be drier (Martinez, 2017).

$$S = \mho = \Omega^{-1} = A/V$$

Figure 6: Relationship between siemens (S),mho (℧),ohm (Ω), ampere (A) and voltage (V)

Water Forms

The basic forms of water in meat are known as bound immobilized and free because water is a polar molecule that are positively and negatively charged. Free wateris water that has been pushed out of the muscle during rigor mortis and storage. Bound water is water that tightly binds to the proteins within muscle fibers. Immobilized water is the water that is held by the steric forces and most effected by rigor mortis and correlated to color. Factors known to affect muscle water binding capacity involve production of lactic acid loss of ATP onset of rigor mortis and changes in cellular structures from proteolytic enzyme activity (Aberle et al., 2012; Martinez, 2017; Vernier et al., 2006).

Ions and Water Holding Capacity

The presence of ions in the water of meat give charge to the muscle. This can conclude that higher concentrations of ion content results in higher EC. At normal levels of pH, the proteins are capable of creating space between the myofibrils through resistance. However, if a muscle reaches the isoelectric point, the myofibrils become tightly packed and therefore reduces the space of mobility for water and ions to move

freely through the muscle or bind to the red blood cells. Charges in these ions are positive or negative and can be effected dependent on pH levels and the ability for water to move freely within the muscle (Aberle et al., 2012; Martinez, 2017).

Understanding the basics of water holding capacity through electrical conductivity measurements in meat muscle can validate meat quality grades in thanks to advances and availability of technology and research. Various methods of measuring water holding capacity in meat muscle for a quality testing are likely to increase emphasis on the role of water binding in the meat muscle and how it can be beneficial in determining the negative perception traits. Consumer expectation of quality can be more easily met and continue to maintain or increase the demand of beef products (Aberle et al., 2012; Li, Hviid, & Lundström, 2011; Martinez, 2017; Puolanne & Halonen, 2010).

III. METHODOLOGY

Study Design

This research study was designed to correlate quality traits of raw beef steaks from four separate sources relative to color and electrical conductivity. Statistical Analysis of Variance for both color and electrical conductivity measures were conducted. Source group 1 was analyzed and reported separately from Source groups 2-4 due to the chemical state and variance in cut at time of measurements. Samples from group 1 were frozen and thawed prior to data collection and samples from groups 2-4 were delivered as whole loins and then cut into 16 individual, 1-inch thick samples.

Sample Preparation and Color Measurements

Color evaluations were conducted based on the AMSA Meat Color Measurement Guidelines to help ensure uniformity was as close as possible throughout the study. All beef samples acquired from and selected for this study were from four different sources: Samples for group 1 was from a local retail store and varied in cuts. Samples for group 2 was from a commercial grocery store, USDA grade choice, and delivered as a whole boneless ribeye, born, Raised and Harvested in the U.S., Samples for group 3 was from a local rancher and delivered as a whole strip loin, wagyu breed, with a quality grade prime. Samples for group 4 was from a local retail rancher and delivered as a whole strip loin, akaushi, quality grade as prime. Samples from group 1 were frozen and thawed prior to data collection. Samples from groups 2-4 were delivered as raw whole loins and then cut into 16 individual, 1-inch thick samples.

Samples for group 1 were delivered in individually wrapped packages in brown butcher paper and placed in the refrigerator to thaw for 48 hours and repackaged onto white commercial styrofoam trays and seal wrapped with food grade industrial plastic film. The cuts from this sample group varied seen in figure 10 and considered to be "closed" packaging during measurements. Sample groups 2-4 were raw and whole loins upon arrival and as previously mentioned were immediately cut into 16 individual, 1-inch thick samples. Samples were placed on white commercial butcher paper with the same food grade industrial plastic film over it. The samples from these source groups are defined as "open" during color measurements because they were not sealed during color measurements (See figures 7-9 below).

Figure 7 ***Figure 8*** ***Figure 9***

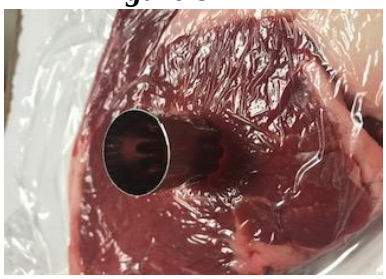


Figure 7: Aperture Port Display; Figure 8: Color Measurement Marker & Film; Figure 9: Bloom Time Conditions.

All samples were recorded for the recommended 30 minute "room adjustment" known as blooming period time for sample 1 of each group. All sample steaks was placed on the cutting table in the meat processing laboratory prior to color data collection. Once 30-minute bloom time was met for sample 1, color data collection began and continued until all measurements were completed. All samples in this study were measured using the Varian Cary 50 Series Spectrophotometer using Illuminant A with an Aperture port size of

1.5mm in diameter. The extended hand-held device was connected to the spectrophotometer instrument, brand Harrington Barrelino. Daily Chef Food Service brand of "foodservice film" distributed by Sam's West.Inc. was used to cover samples. Prior to color evaluations, the samples were covered with the translucent plastic film over it to protect the camera and used as a standard procedure for calibration. The parameters of the reflectance scores were measured to 0%-100% reflectance standard. Each location where a color measurement was taken was marked using a 1-inch diameter cookie cutter. This was done in order to insure each location was included when prepared for electrical conductivity measurements.

Color scores reported in this study use the Hunter Lab or LH score were used to determine color scores for this study. The wavelength range of nanometers scanned for all samples were 830 nm to 360 nm. Calibration for 0%-100% Reflectance scores were done using the white calibration tile that came with the machine. The plastic film used to cover each sample was used to cover the white tile to insure proper adjustment for calibration at the beginning of every measurement session, prior to collecting data for each group.

The following standardized parameters/calculations were standardized for all sources: Scan Range of 830 nm to 360 nm, with data interval of 1 nm, "Y Mode" equals %R, "Av Time (s)" of 0.0125, a Dual Beam monde, and a baseline correction (as mentioned above) were performed at the beginning of each color data collection. Illuminant A with an observer angle of 10 degrees was also set. The Delta LAB tolerance was set to 5.00 and the Delta E tab was selected. However, the delta e, changes over time, were not utilized for this specific study in analysis. On the "Corrections" tab in settings of the spectrophotometer

settings the thickness correction was not selected and the settings of a refractive index Thickness [Known %T] and Thickness [unknown%T] at 1.00. For the reporting of color analysis a focused trace and "Autoconvert ASCII (csv) with log" was selected.

Each sample was scanned repeatedly for a total of nine times at three locations and three scans per a location. Averages for each location were taken to obtain one total average color score for each sample. For example, the averages of three scans for location "A", the average of three scans for location "B", the average of three scans for location "C", and then the average from the three location scans for one total average color measure of sample. The three location averages were used for statistical analysis (N=3 x 16 steaks = 48 total observations per source group). Ambient Temperature was recorded before each sample was scanned using a basic thermometer.

Sample Preparations and Electrical Conductivity Measurement

Sample preparation for electrical conductivity were done immediately after color scans on raw samples were taken. Three 50 g samples were of raw beef were taken from each steak and included 1 area where color scans were taken in each and placed in individual Ziploc freezer quart size seal bags (N= 3 x 16 steaks = 48 total observations per a source). The design of this study was replicated from a previous graduate student, Ms. Sarah Martinez who performed EC study for a thesis on "Water Holding Capicity and Forms of Water Loss in Beef Sources". A Edlund Poseidon WSC-20 scale was used to measure weights. Once samples were sorted, they were stored overnight in the laboratory refrigerator at 32°F. When collecting EC measurements, the 50g samples were blended using a NINJA food blender with 40mg of distilled water for a dilution factor (DF) of 2.

The emulsified meat slurry solution was then placed into silicon vessels that were 3 inches wide and had a copper nail inserted into each side. The silicon vessel was then placed into a Rubbermaid brand plastic container with holes to allow the two test leads from the digital multi meter (16040T True RMS Multimeter, Southwire Tools & Equipment) to be properly aligned and in contact with the copper nails. The EC reading was recorded for two minutes with a sampling rate of two measures per second. In between each sample reading, all containers, tools and/or vessels exposed to samples were cleaned with soap, sterilized with bleach, and rinsed thoroughly prior to the next reading/sample. The design of EC tests can be seen below in Figure

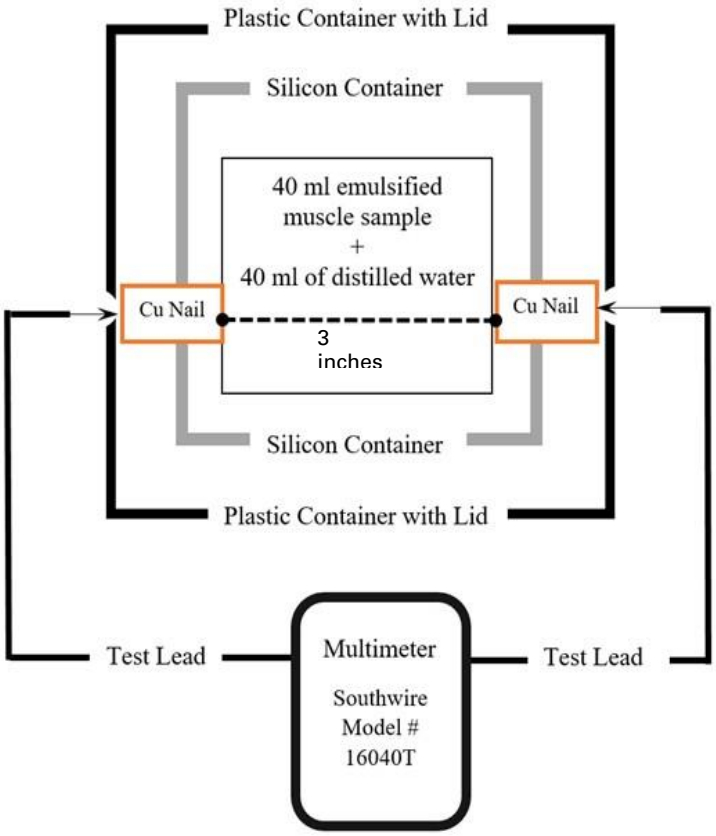


Figure 6: Electrical Conductivity Design Diagram

Statistical Analysis

Microsoft Excel 2016 data analysis tool pack was used to for in this study using the proper analysis of variance (ANOVA) across sample group 1 and then pooled ANOVA test was conducted for sample groups 3-4 were for color average replications, electrical conductivity replications and total color and EC averages. This was done to examine the degree of variance in measures of the Varian spectrophotometer machine validity and reliability and relationship to quality traits of color and water holding capacity (EC) in beef steaks.

IV. RESULTS

Color Replication and Color Scores

Comparison of Means All Source Groups

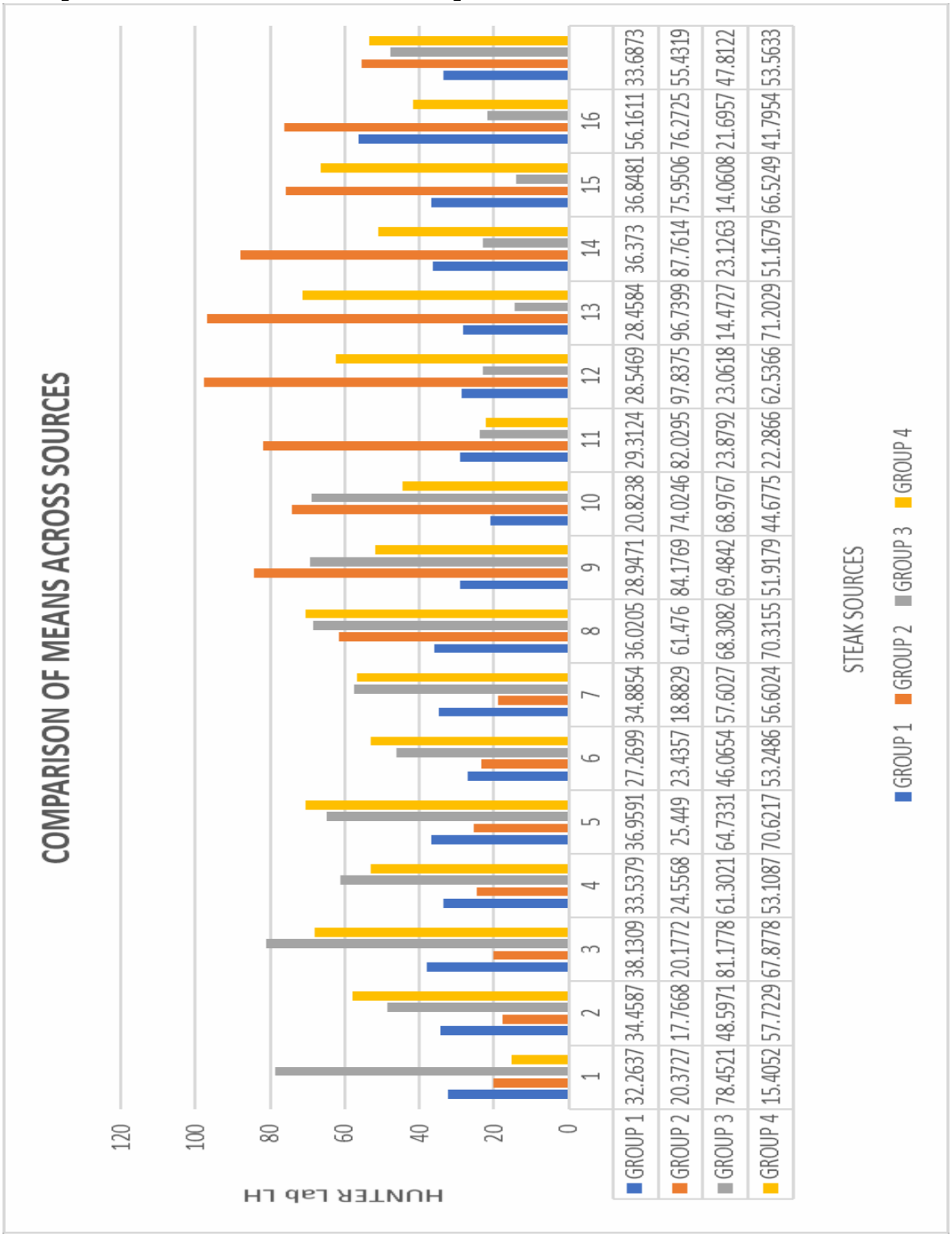


Figure 11: Color Comparison of Means Across All Source Groups

Sample Group 1

Table 1: ANOVA Variance

SAMPLE	*Count*	*Sum*	*Average*	*VARIANCE*
STEAK 1	3	96.7911	32.2637	**0.831264804**
STEAK 2	3	103.3762	34.45873333	**0.018351858**
STEAK 3	3	114.3927667	38.13092222	**0.075301089**
STEAK 4	3	100.6135667	33.53785556	**5.29493E-05**
STEAK 5	3	110.8773	36.9591	**0.256576848**
STEAK 6	3	81.80966667	27.26988889	**0.002146188**
STEAK 7	3	104.6561667	34.88538889	**0.345280787**
STEAK 8	3	108.0614	36.02046667	**0.068677293**
STEAK 9	3	86.84143333	28.94714444	**0.011091509**
STEAK 10	3	62.47126667	20.82375556	**0.099917838**
STEAK 11	3	87.93716667	29.31238889	**0.125903667**
STEAK 12	3	85.6406	28.54686667	**0.006525853**
STEAK 13	3	85.3751	28.45836667	**0.509416408**
STEAK 14	3	109.1189	36.37296667	**0.020455521**
STEAK 15	3	110.5442	36.84806667	**0.207936341**
STEAK 16	3	168.4832	56.16106667	**0.097453981**

VARIATION	*SS*	*df*	*MS*	*F*	*P-value*	***F CRIT***
BETWEEN GROUPS	2592.827156	15	172.8551437	1033.377273	1.42399E-38	**1.99198**
WITHIN GROUPS	5.352705872	32	0.167272058			
TOTAL	**2598.179861**	**47**				

Total color score means for each group are seen in the last column on the right of Figure 11. Group 1 had a noticeably lower color average in comparison to groups 3-4. This could be presumed to be a result of the frozen state and decreased myoglobin content over time as expected based on the longtime understood chemistry and structure of meat composition. Group 3 had the next lowest overall color score with a mean of 47.81. During color measurement procedures for this source were noticeably more marbled throughout each sample. This made locations more limited for the aperture port size to only cover all/only red areas.

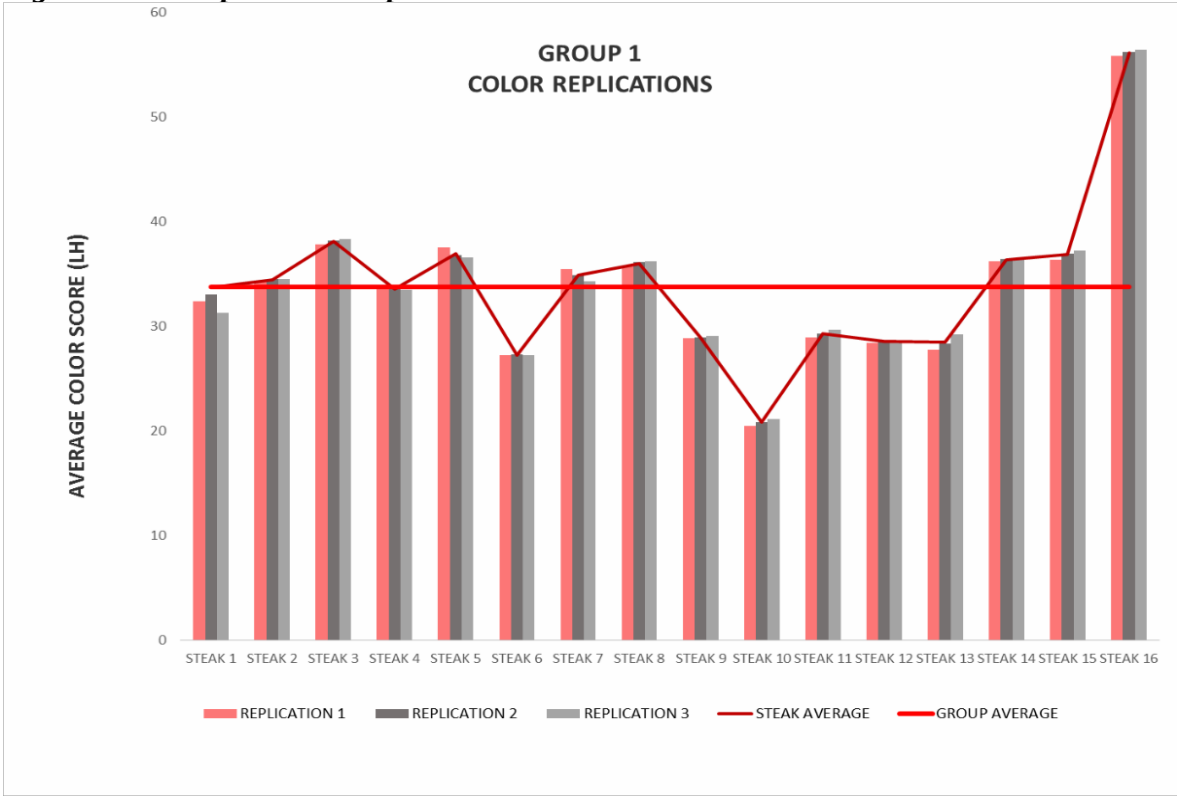
The P-value with an alpha 0.05 and 95% confidence level in ANOVA results of

group 1 shows the difference of means of this sample group is statistically non-significant. This means the variance among the source prove the Varian machine to be a reliable method for conducting color replication measurements and color score. The degree of variance can be more easily seen in Table 1.

Table 2: Source Group 1 Color Mean Replications

SAMPLE	REPLICATIONS			AVERAGE	CUT
	1	2	3		
STEAK 1	32.42076667	33.0867	31.28363333	**33.68729236**	**Top Round**
STEAK 2	34.30433333	34.55766667	34.5142	**34.45873333**	**Chuck Roast**
STEAK 3	37.82406667	38.21593333	38.35276667	**38.13092222**	**Shoulder Roast Chuck**
STEAK 4	33.5428	33.54126667	33.5295	**33.53785556**	**Filet Tenderloin**
STEAK 5	37.53156667	36.77673333	36.569	**36.9591**	**Shoulder Roast**
STEAK 6	27.23146667	27.32133333	27.25686667	**27.26988889**	**NY Strip**
STEAK 7	35.45816667	34.914	34.284	**34.88538889**	**Eye of Round**
STEAK 8	35.71813333	36.16053333	36.18273333	**36.02046667**	**Shoulder Roast Chuck**
STEAK 9	28.8562	28.9227	29.06253333	**28.94714444**	**Shoulder Roast Chuck**
STEAK 10	20.49983333	20.84003333	21.1314	**20.82375556**	**Shoulder Roast Chuck**
STEAK 11	28.94706667	29.3344	29.6557	**29.31238889**	**Top Round**
STEAK 12	28.45433333	28.58293333	28.60333333	**28.54686667**	**Top Round**
STEAK 13	27.79513333	28.3663	29.21366667	**28.45836667**	**Top Round**
STEAK 14	36.21296667	36.41753333	36.4884	**36.37296667**	**Top Round**
STEAK 15	36.34636667	36.9605	37.23733333	**36.84806667**	**NY Strip**
STEAK 16	55.8211	56.22726667	56.43483333	**56.16106667**	**Top Round**
TOTAL	---	---	---	**33.77626688**	

Figure 12: Group 1 Color Replications

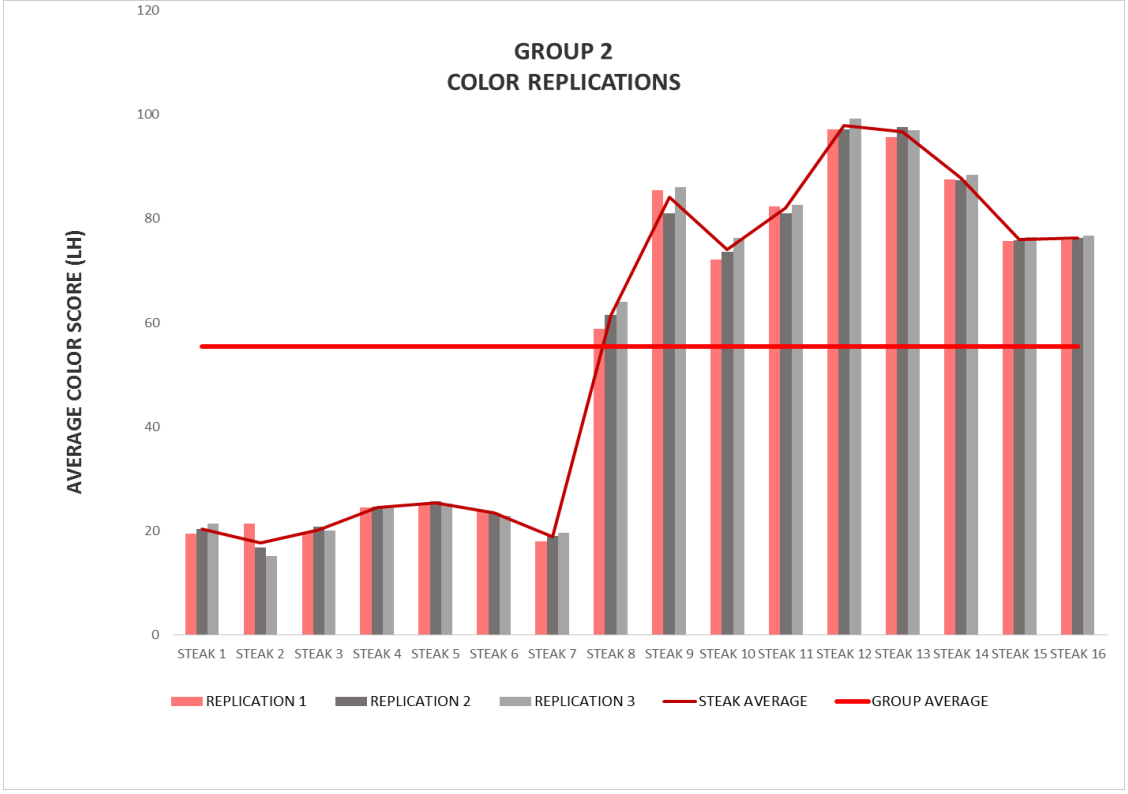


Sample Group 2

Table 3: Group 2 Color Replications Averages

SAMPLE	*REPLICATION 1*	*REPLICATION 2*	*REPLICATION 3*	*SAMPLE AVG*	*GROUP AVG*
STEAK 1	19.42993333	20.33406667	21.35423333	20.37274444	55.43189306
STEAK 2	21.33253333	16.75366667	15.21433333	17.76684444	55.43189306
STEAK 3	19.66773333	20.8202	20.04373333	20.17722222	55.43189306
STEAK 4	24.5309	24.57953333	24.55993333	24.55678889	55.43189306
STEAK 5	25.34576667	25.73323333	25.26813333	25.44904444	55.43189306
STEAK 6	23.979	23.44243333	22.88573333	23.43572222	55.43189306
STEAK 7	17.98546667	19.03863333	19.62473333	18.88294444	55.43189306
STEAK 8	58.8709	61.52816667	64.0288	61.47595556	55.43189306
STEAK 9	85.46896667	80.9991	86.06256667	84.17687778	55.43189306
STEAK 10	72.14236667	73.66793333	76.26363333	74.02464444	55.43189306
STEAK 11	82.3496	81.08986667	82.64903333	82.0295	55.43189306
STEAK 12	97.10353333	97.14833333	99.26063333	97.8375	55.43189306
STEAK 13	95.62193333	97.55993333	97.03796667	96.73994444	55.43189306
STEAK 14	87.54943333	87.33883333	88.396	87.76142222	55.43189306
STEAK 15	75.62546667	75.82353333	76.4028	75.9506	55.43189306
STEAK 16	75.813	76.29093333	76.71366667	76.27253333	55.43189306

Figure 13: Group 2 Color Replications



Sample Group 3

Figure 14: Group 3 Color Replications

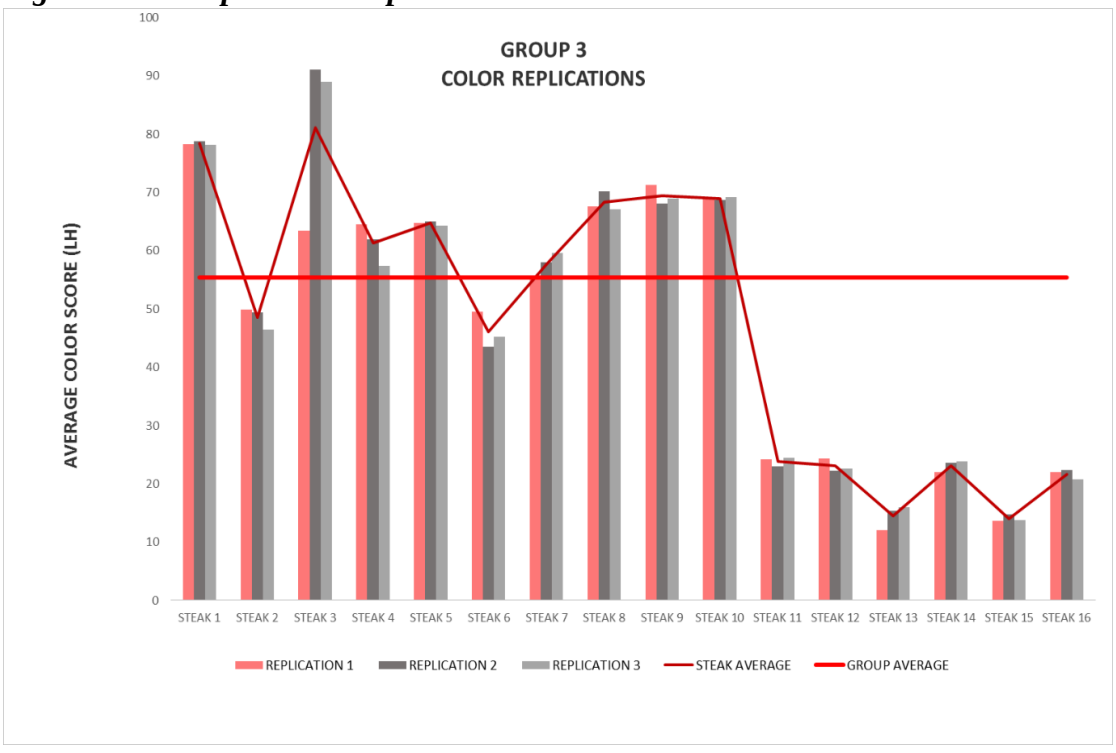


Table 4: Group 3 Color Replications

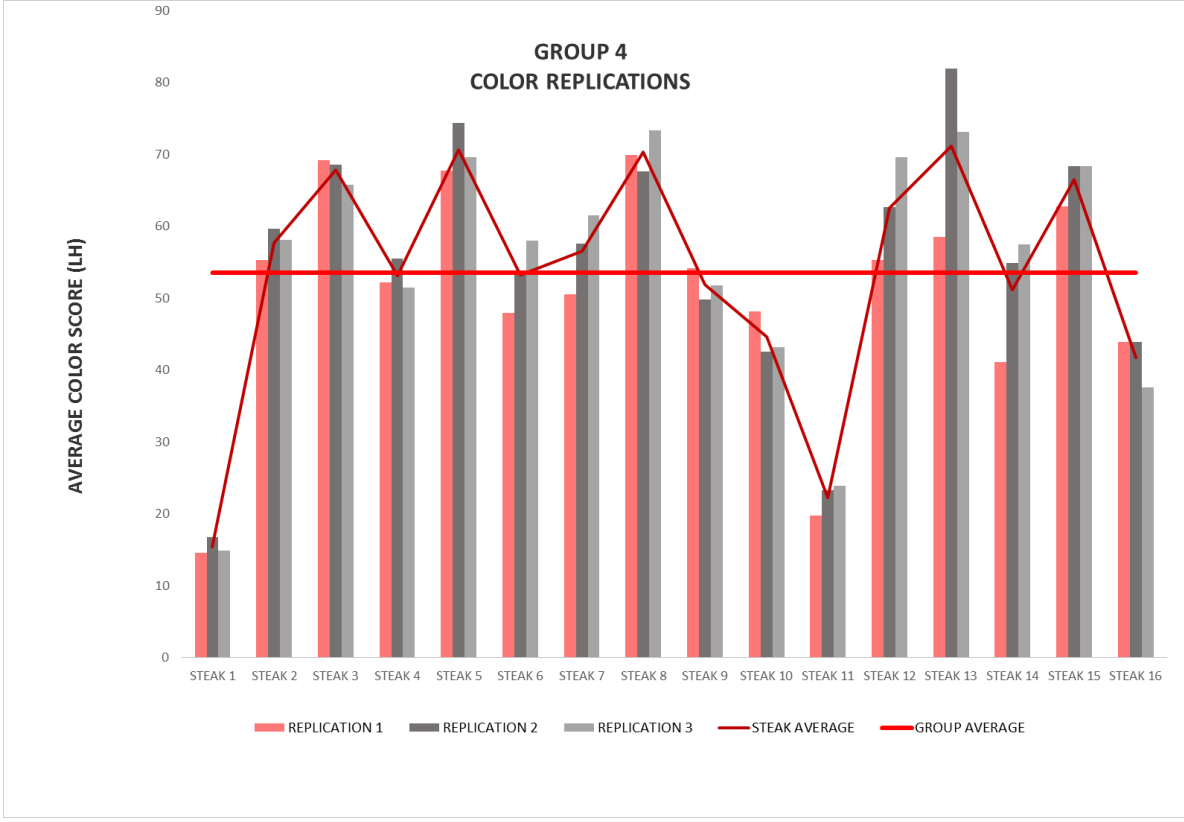
SAMPLE	REPLICATION 1	REPLICATION 2	REPLICATION 3	SAMPLE AVG	GROUP AVG
STEAK 1	78.35346333	78.76456667	78.23823333	78.45208778	47.81222944
STEAK 2	49.88573333	49.45	46.45543333	48.59705556	47.81222944
STEAK 3	63.43183333	91.072	89.0295	81.17777778	47.81222944
STEAK 4	64.50493333	61.99476667	57.40666667	61.30212222	47.81222944
STEAK 5	64.81606667	65.06553333	64.31756667	64.73305556	47.81222944
STEAK 6	49.49893333	43.5056	45.1916	46.06537778	47.81222944
STEAK 7	55.2035	58.02703333	59.57763333	57.60272222	47.81222944
STEAK 8	67.62383333	70.1678	67.13286667	68.30816667	47.81222944
STEAK 9	71.3445	68.0914	69.01663333	69.48417778	47.81222944
STEAK 10	68.97056667	68.74443333	69.21513333	68.97671111	47.81222944
STEAK 11	24.21593333	22.94368333	24.47803333	23.87921667	47.81222944
STEAK 12	24.3069	22.21396667	22.6644	23.06175556	47.81222944
STEAK 13	12.09533333	15.3123	16.01033333	14.47265556	47.81222944
STEAK 14	22.0267	23.55146667	23.80063333	23.12626667	47.81222944
STEAK 15	13.6187	14.8058	13.75793333	14.06081111	47.81222944
STEAK 16	21.9731	22.36146667	20.75256667	21.69571111	47.81222944

Sample Group 4

Table 5: Group 4 Color Replication Averages

SAMPLE	REPLICATION 1	REPLICATION 2	REPLICATION 3	SAMPLE AVG	GROUP AVG
STEAK 1	14.59433333	16.74503333	14.87636667	15.40524444	53.56328125
STEAK 2	55.3366	59.72133333	58.11083333	57.72292222	53.56328125
STEAK 3	69.1858	68.60436667	65.84316667	67.87777778	53.56328125
STEAK 4	52.23856667	55.5626	51.52486667	53.10867778	53.56328125
STEAK 5	67.80946667	74.4368	69.6187	70.62165556	53.56328125
STEAK 6	47.93343333	53.74656667	58.06593333	53.24864444	53.56328125
STEAK 7	50.58963333	57.6507	61.56676667	56.60236667	53.56328125
STEAK 8	69.92236667	67.63566667	73.38833333	70.31545556	53.56328125
STEAK 9	54.16043333	49.83423333	51.7591	51.91792222	53.56328125
STEAK 10	48.17813333	42.61673333	43.23753333	44.67746667	53.56328125
STEAK 11	19.73123333	23.25653333	23.87213333	22.28663333	53.56328125
STEAK 12	55.27593333	62.73373333	69.6	62.53655556	53.56328125
STEAK 13	58.51653333	81.95336667	73.1388	71.2029	53.56328125
STEAK 14	41.0899	54.95956667	57.45433333	51.16793333	53.56328125
STEAK 15	62.79213333	68.3656	68.41696667	66.5249	53.56328125
STEAK 16	43.9229	43.88116667	37.58226667	41.79544444	53.56328125

Figure 14: Group 4 Color Replications



The degree of variance among color measurement scores using the Hunter LH score of selected the selected cuts show little variance among replication measures. It is notable that the different samples among each group source vary which can be due to marbling, location of cut and the type of muscle. In regard to frozen samples versus the raw samples, the color measurements indicate little variance across each sample replication and overall source, however had color average score lower in comparison to raw sources. This could due to the loss of myoglobin content through time, storage, handling and/or packaging.

Electrical Conductivity Measures

Correlation between color scores and EC values are better understood through visual representation as seen in Figures below. From these graphs it can be understood that there is a relationship between color and EC. However, the mathematical method for correlation analysis is beyond the scope of this research study. Future studies should test the correlation for quality by using time, reflectance scores, myoglobin content, or other color calculation parameters given by the Varian Spectrophotometer. For comparison purposes, the color and EC ratio were created based on mean scores.

Sample Group 1

Figure 16: Group 1 Electrical Conductivity & Color Averages

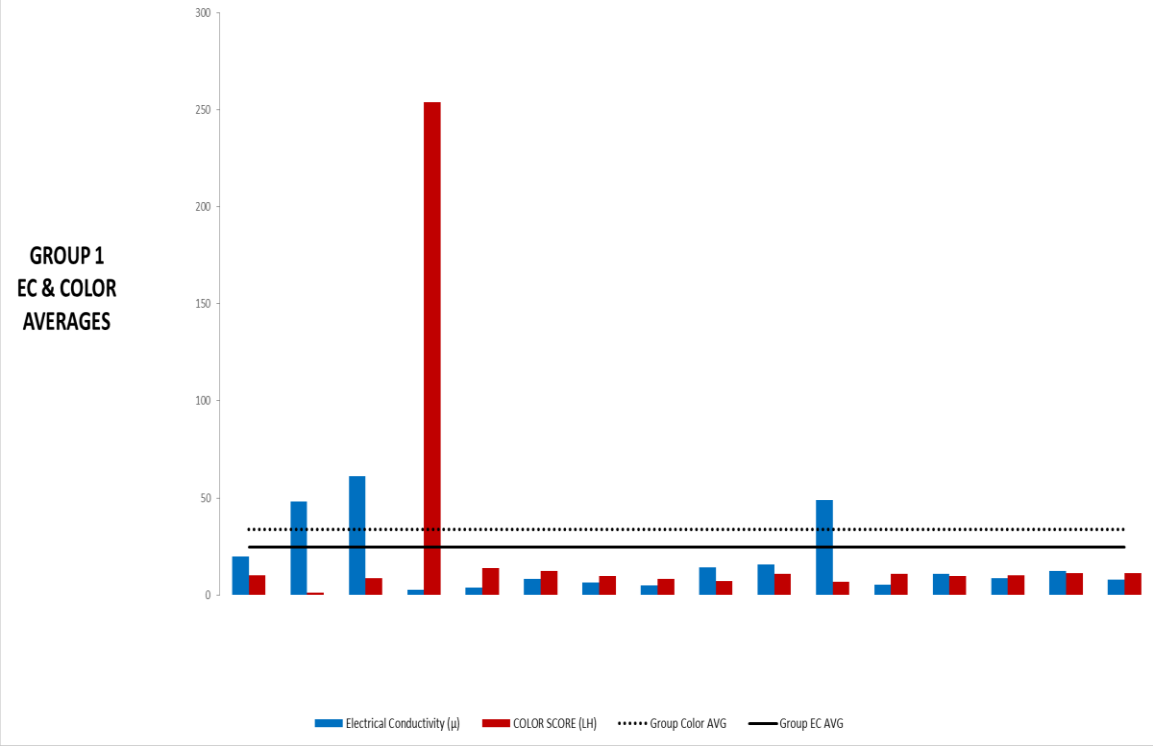


Table 6: Group 1 EC & Color

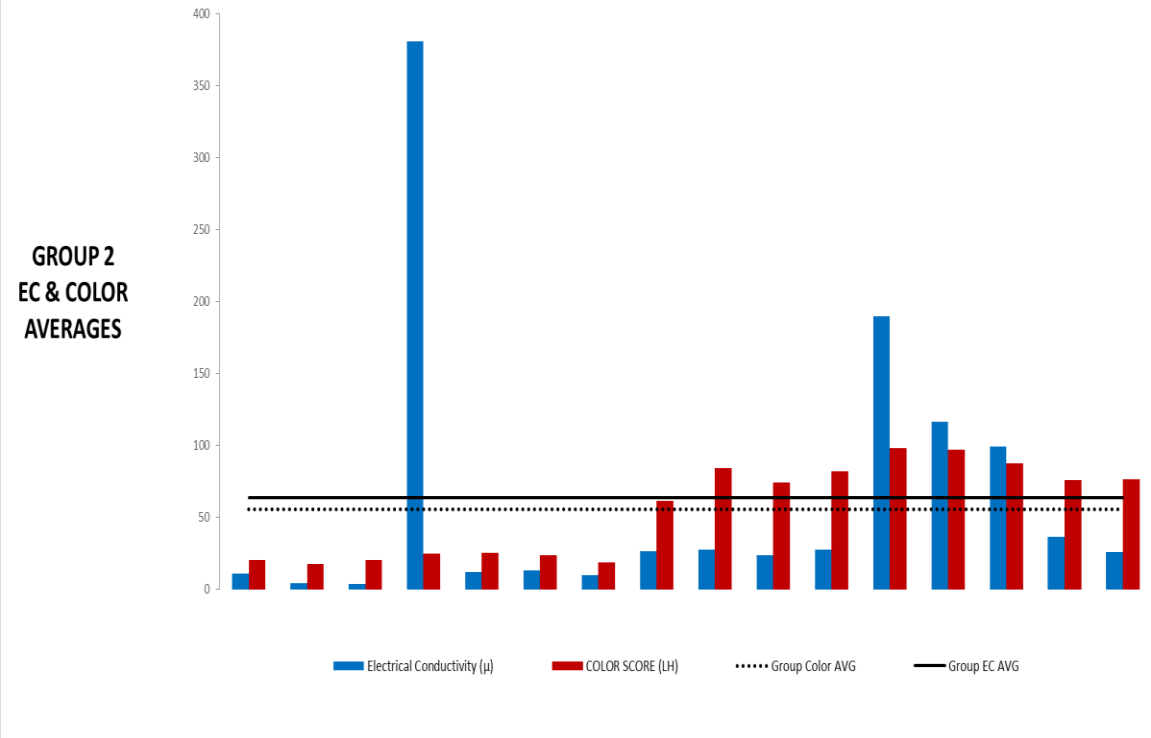
SAMPLE	EC AVG	TOTAL EC AVG	COLOR AVG	EC: COLOR RATIO
STEAK 1	10.20129812	24.80426815	33.68729236	10:34
STEAK 2	1.223564944	24.80426815	34.45873333	1:35
STEAK 3	8.733779725	24.80426815	38.13092222	9:38
STEAK 4	253.8998186	24.80426815	33.53785556	253:34
STEAK 5	13.89743473	24.80426815	36.9591	14:37
STEAK 6	12.49450053	24.80426815	27.26988889	12:27
STEAK 7	9.776359266	24.80426815	34.88538889	10:35
STEAK 8	8.408627892	24.80426815	36.02046667	8:6
STEAK 9	7.086667855	24.80426815	28.94714444	7:29
STEAK 10	10.76263824	24.80426815	20.82375556	10:20
STEAK 11	7.017298528	24.80426815	29.31238889	7:29
STEAK 12	11.02531681	24.80426815	28.54686667	11:29
STEAK 13	9.9285009	24.80426815	28.45836667	10:28
STEAK 14	10.02166362	24.80426815	36.37296667	10:36
STEAK 15	11.25096319	24.80426815	36.84806667	11:37
STEAK 16	11.13985747	24.80426815	56.16106667	11:56

Sample Group 2

Table 7: Group 2 EC & Color

SAMPLE	EC AVG	TOTAL EC AVG GROUP	COLOR AVG	EC: COLOR RATIO
STEAK 1	4.193381562	63.52944822	33.68729236	4:34
STEAK 2	3.861731644	63.52944822	34.45873333	4:34
STEAK 3	380.8950517	63.52944822	38.13092222	381:38
STEAK 4	11.92892081	63.52944822	33.53785556	12:34
STEAK 5	12.8575744	63.52944822	36.9591	13:37
STEAK 6	9.886462457	63.52944822	27.26988889	10:27
STEAK 7	26.22269011	63.52944822	34.88538889	26:35
STEAK 8	27.58041662	63.52944822	36.02046667	28:36
STEAK 9	23.83338098	63.52944822	28.94714444	24:29
STEAK 10	27.67059643	63.52944822	20.82375556	28:21
STEAK 11	189.876333	63.52944822	29.31238889	190:29
STEAK 12	116.5772195	63.52944822	28.54686667	117:29
STEAK 13	98.92744043	63.52944822	28.45836667	99:28
STEAK 14	36.61489706	63.52944822	36.37296667	37:36
STEAK 15	25.73929114	63.52944822	36.84806667	26:37
STEAK 16	19.80578358	63.52944822	56.16106667	20:56

Figure 17: Group 2 Electrical Conductivity & Color Averages

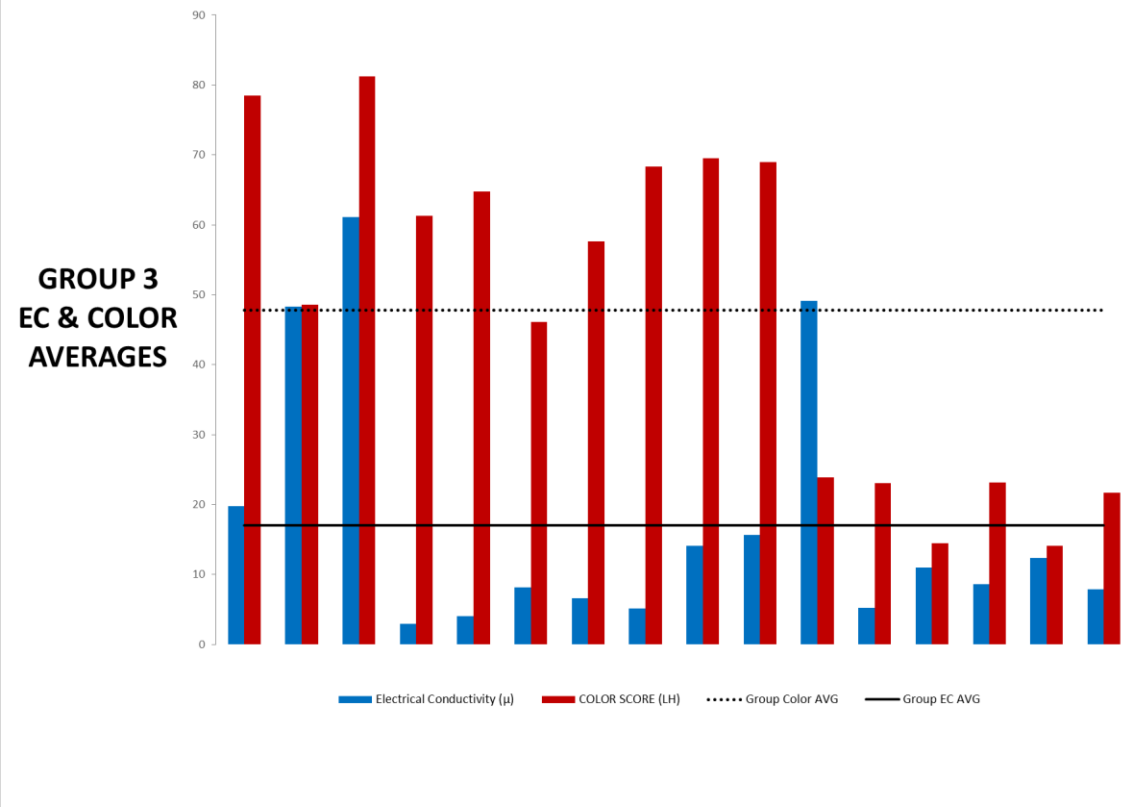


Sample Group 3

Table 8: Group 3 EC & Color

SAMPLE	EC AVG	TOTAL EC AVG	COLOR AVG	EC: COLOR RATIO
STEAK 1	48.33676314	17.04510506	48.33676314	48:48
STEAK 2	61.08345284	17.04510506	61.08345284	61:
STEAK 3	2.913428947	17.04510506	2.913428947	9:38
STEAK 4	4.021315062	17.04510506	4.021315062	253:34
STEAK 5	8.150711362	17.04510506	8.150711362	14:37
STEAK 6	6.591663106	17.04510506	6.591663106	12:27
STEAK 7	5.094804788	17.04510506	5.094804788	10:35
STEAK 8	14.13190544	17.04510506	14.13190544	8: 6
STEAK 9	15.66510022	17.04510506	15.66510022	7:29
STEAK 10	49.084458	17.04510506	49.084458	10:20
STEAK 11	5.23663505	17.04510506	5.23663505	7:29
STEAK 12	11.00195402	17.04510506	11.00195402	11:29
STEAK 13	8.587208006	17.04510506	8.587208006	10:28
STEAK 14	12.34059273	17.04510506	12.34059273	10:36
STEAK 15	7.893862446	17.04510506	7.893862446	11:37
STEAK 16	12.58782575	17.04510506	12.58782575	11:56

Figure 18: Group 3 Electrical Conductivity & Color Averages



Sample Group 4

Figure 19: Group 4 Electrical Conductivity & Color Averages

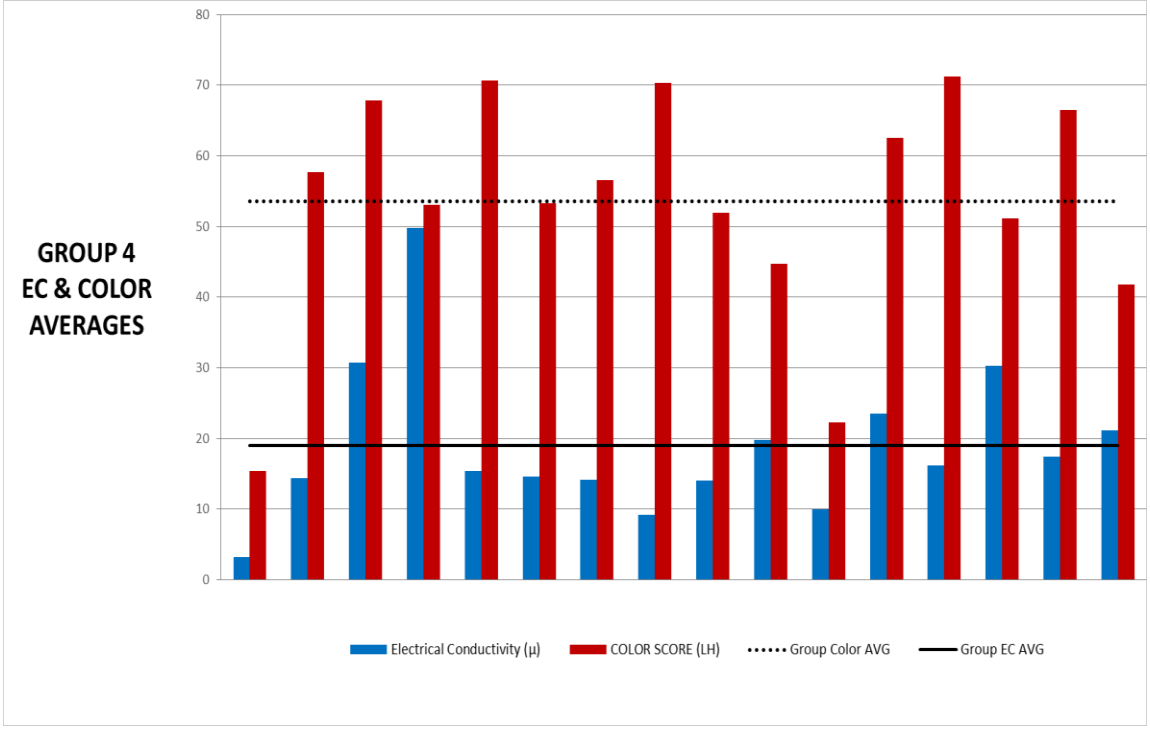


Table 9: Group 4 EC & Color

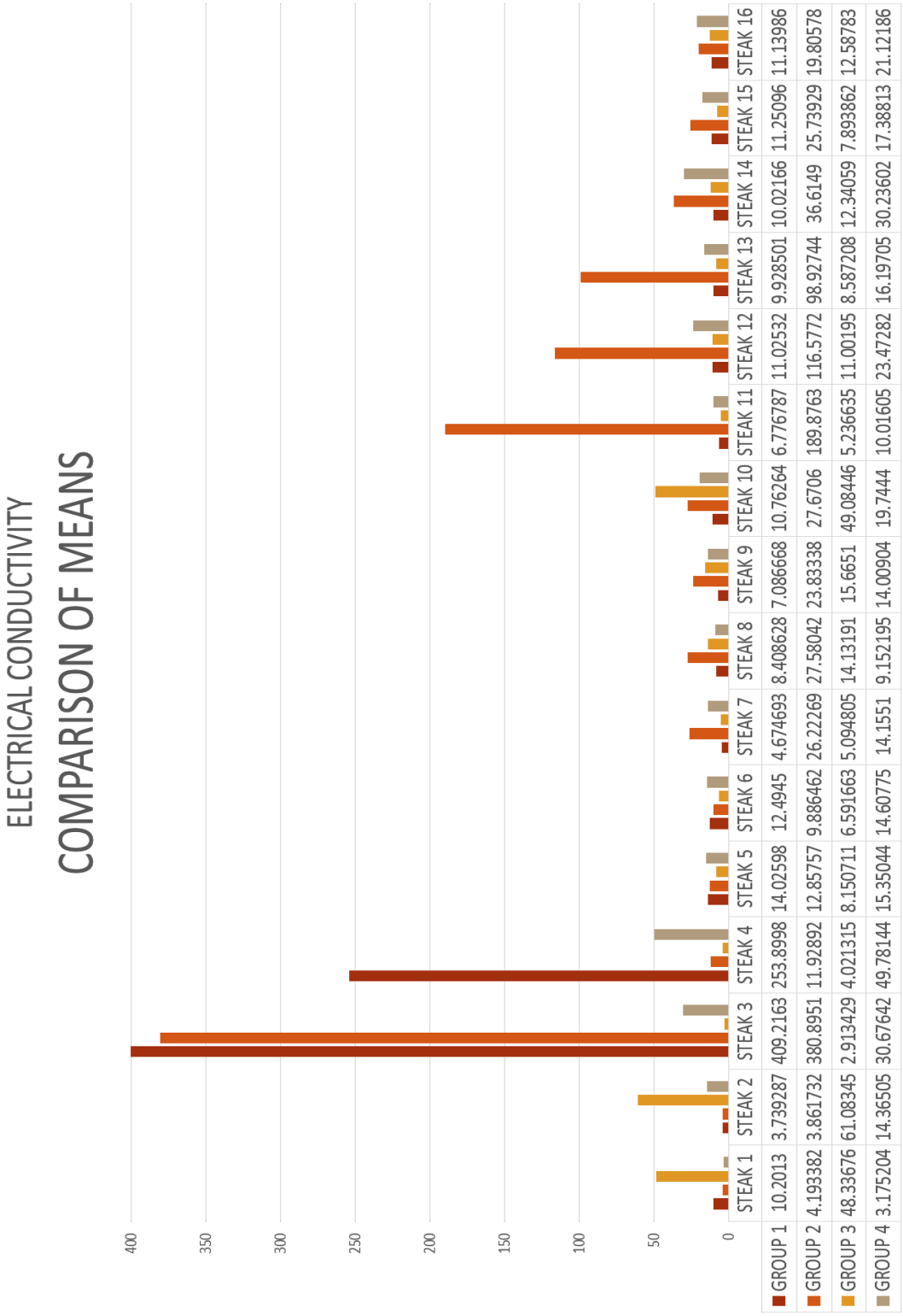
SAMPLE	EC AVG	TOTAL EC AVG	COLOR AVG	EC: COLOR RATIO
STEAK 1	3.175204158	18.96556083	15.40524444	3:15
STEAK 2	14.36505475	18.96556083	57.72292222	14:58
STEAK 3	30.67642235	18.96556083	67.87777778	31:68
STEAK 4	49.78143846	18.96556083	53.10867778	50:53
STEAK 5	15.3504365	18.96556083	70.62165556	15:71
STEAK 6	14.60774796	18.96556083	53.24864444	14:53
STEAK 7	14.15510056	18.96556083	56.60236667	14:57
STEAK 8	9.152194959	18.96556083	70.31545556	9:70
STEAK 9	14.00904247	18.96556083	51.91792222	14:52
STEAK 10	19.74439818	18.96556083	44.67746667	20:45
STEAK 11	10.01604838	18.96556083	22.28663333	10:22
STEAK 12	23.47282341	18.96556083	62.53655556	23:63
STEAK 13	16.19705499	18.96556083	71.2029	16:71
STEAK 14	30.236019	18.96556083	51.16793333	30:51
STEAK 15	17.38812514	18.96556083	66.5249	17:67
STEAK 16	21.12186203	18.96556083	41.79544444	21:42

Table 10: Color and Electrical Conductivity Values of Selected Fresh and Frozen Beef Steaks

SOURCE EVALUATION	**TREATMENTS**			
	GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
NUMBER OF SAMPLES	16	16	16	**16**
QUALITY GRADE	CHOICE	CHOICE	PRIME	**PRIME**
MEAN COLOR VALUES (LH)	33.7762	55.4319	47.8122	**53.5633**
MEAN EC VALUES (μ)	24.8043	63.5294	17.0451	**18.9656**
COLOR:EC RATIO	**34:25**	**55:64**	**48:17**	**54:19**

Comparison of Means All Source Groups

Figure 20. Electrical Conductivity Comparison of Means



	STEAK 1	STEAK 2	STEAK 3	STEAK 4	STEAK 5	STEAK 6	STEAK 7	STEAK 8	STEAK 9	STEAK 10	STEAK 11	STEAK 12	STEAK 13	STEAK 14	STEAK 15	STEAK 16
GROUP 1	10.2013	3.739287	409.2163	253.8998	14.02598	12.4945	4.674693	8.408628	7.086668	10.76264	6.776787	11.02532	9.928501	10.02166	11.25096	11.13986
GROUP 2	4.193382	3.861732	380.8951	11.92892	12.85757	9.886462	26.22269	27.58042	23.83338	27.6706	189.8763	116.5772	98.92744	36.6149	25.73929	19.80578
GROUP 3	48.33676	61.08345	2.913429	4.021315	8.150711	6.591663	5.094805	14.13191	15.6651	49.08446	5.236635	11.00195	8.587208	12.34059	7.893862	12.58783
GROUP 4	3.175204	14.36505	30.67642	49.78144	15.35044	14.60775	14.1551	9.152195	14.00904	19.7444	10.01605	23.47282	16.19705	30.23602	17.38813	21.12186

VI. SUMMARY

The ratios seen in the tables above were based on overall averages from color scores and EC values. By comparing overall means, a difference can be more closely evaluated for future studies in seeing a correlation between the two types of measuring quality in beef. When comparing the electrical conductivity and color scores, it is clear from source groups 3 and 4 that a significant correlation of color and EC exist, however the precise degree of correlation will need further evaluations. These two groups were of higher quality grades (prime) and showed significantly lower EC scores. This supports the claim that lower EC values will result in higher quality grading and less water loss of the muscle when it is cooked. These prime quality groups also scored much higher color scores in comparison to their EC values. Indicating that higher color scores have higher myoglobin and water content retention. The high marbling in source group 3 could be the reason for the second lowest color score, however it scored the lowest EC score, very close to group 4 which was also prime. The marbling may have been in the area where color was measured and changing the true value of overall red.

Quality of beef can be determined using various methods. However, consumer perception on color and association of red intensity with freshness can avoided through utilizing production advancements. Myoglobin content is what gives meat the bright red color and can be easily influences from lighting, oxygen, water and other various environmental conditions of exposure.

The use of the Varian spectrophotometer machine as a reliable source of color

measurement is proven reliable in providing consistent results in this study and could be beneficial to the beef industry. It saves time and calculates various measures that can be utilized to help understand quality of color in sources. The electrical conductivity measurements compared to the color scores are clear indication that a relation to quality is present, however will need to be further studied to find the true degree of correlation. If the ratio in future studies can be properly determined, color scores can be utilized to predict electrical conductivity scores and vice versa. It can also be a predictor for overall quality and possibly a formula utilizing the cheaper and reliable method in the beef industry.

Quality grades of beef have such variance in changes throughout the production process and utilizing electrical conductivity to predetermine color or color to predetermine EC values could overtime shift consumer perceptions of bright red and fresh. The industry can use these methods in quality grading to give consumers a true quality score instead of using subjective eye evaluations. By doing this, they can utilize the cheaper packaging techniques and profit on providing consumers with consistent desired products.

LITERATURE REVIEW

Aberle, E., Forrest, J., Gerrard, D., & Mills, E. (2012). *Principles of Meat Science* (5th ed.). Dubuque, IA: Kendall Hunt Publishing Company.

Ahn, D. U., & Nam, K. C. (2004). Effects of ascorbic acid and antioxidants on color, lipid oxidation and volatiles of irradiated ground beef. *Radiation Physics and Chemistry* (Vol. 71, pp. 149–154).

Ahn, D. U., Olson, D. G., Jo, C., Chen, X., Wu, C., & Lee, J. I. (1998). Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production, and color in raw pork patties. *Meat Science*, *49*(1), 27–39.

Bekhit, A. E. D. A., Geesink, G. H., Ilian, M. A., Morton, J. D., Sedcole, R., & Bickerstaffe, R. (2003). Particulate metmyoglobin reducing activity and its relationship with meat color. *Journal of Agricultural and Food Chemistry*, *51*(20), 6026–6035.

Brooks, C. (2007). Beef Packaging. *National Cattlemen's Beef Association*, 1–4. Retrieved from http://www.beefresearch.org/CMDocs/BeefResearch/BeefPackaging.pdf

Brooks, J. C., Alvarado, M., Stephens, T. P., Kellermeier, J. D., Tittor, a W., Miller, M. F., & Brashears, M. M. (2008). Spoilage and safety characteristics of ground beef packaged in traditional and modified atmosphere packages. *Journal of food protection*, *71*(2), 293–301.

Chriki, S., Renand, G., Picard, B., Micol, D., Journaux, L., & Hocquette, J. F. (2013). Meta-analysis of the relationships between beef tenderness and muscle characteristics. *Livestock Science*, *155*(2–3), 424–434.

COMA, V. (2008). Bioactive packaging technologies for extended shelf life of meat- based products. *Meat Science*.

Fu, Q. Q., Liu, R., Zhou, G. H., & Zhang, W. G. (2017). Effects of Packaging Methods on the Color of Beef Muscles Through Influencing Myoglobin Status, Metmyoglobin Reductase Activity and Lipid Oxidation. *Journal of Food Processing and Preservation*, *41*(1).

Giusto, N. M., Pasquaré, S. J., Salvador, G. a, & Ilincheta de Boschero, M. G. (2010). Lipid second messengers and related enzymes in vertebrate rod outer segments. *Journal of lipid research*, *51*(4), 685–700. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2842151&tool=pmcentr ez&rendertype=abstract

Grebitus, C., Jensen, H. H., Roosen, J., & Sebranek, J. G. (2013). Fresh meat packaging: consumer acceptance of modified atmosphere packaging including carbon monoxide. *Journal of food protection*, *76*(1), 99–107. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23317863

Hoyle, a R., Brooks, J. C., Thompson, L. D., Palmore, W., Stephens, T. P., & Brashears,M. M. (2009). Spoilage and safety characteristics of ground beef treated with lactic acid bacteria. *Journal of food protection*, *72*(11), 2278–2283.

Huff-Lonergan, S. a. (2005). Water-Holding Capacity of Fresh Meat. *Pork Information Gateway*, 1–8.

Hughes, J. M., Oiseth, S. K., Purslow, P. P., & Warner, R. D. (2014). A structural approach to understanding the interactions between colour, water-holding capacity and tenderness. *Meat Science*, *98*(3), 520–532.

Hunt, M. C., King, A., Barbut, S., Clause, J., Cornforth, D., Hanson, D., Lindahl, G., et al. (2012). *AMSA meat color measurement guidelines*. *American Meat Science Association, Champaign, Illinois USA* (Vol. 61820).

Hunter, C. L., Lloyd, E., Eltis, L. D., Rafferty, S. P., Lee, H., Smith, M., & Mauk, A. G. (1997). Role of the heme propionates in the interaction of heme with apomyoglobin and apocytochrome. *Biochemistry*, *36*(5), 1010–1017.

Ke, S., Huang, Y., Decker, E. A., & Hultin, H. O. (2009). Impact of citric acid on the tenderness, microstructure and oxidative stability of beef muscle. *Meat Science*, *82*(1), 113–118.

Lee, K. T. (2010). Quality and safety aspects of meat products as affected by various physical manipulations of packaging materials. *Meat Science*.

Lepetit, J., Salé, P., Favier, R., & Dalle, R. (2002). Electrical impedance and tenderisation in bovine meat. *Meat Science*, *60*(1), 51–62.

Li, C., Li, J., Li, X., Hviid, M., & Lundström, K. (2011). Effect of low-voltage electrical stimulation after dressing on color stability and water holding capacity of bovine longissimus muscle. *Meat Science*, *88*(3), 559–565.

Limbo, S., Torri, L., Sinelli, N., Franzetti, L., & Casiraghi, E. (2010). Evaluation and predictive modeling of shelf life of minced beef stored in high-oxygen modified atmosphere packaging at different temperatures. *Meat Science*, *84*(1), 129–136.

Liu, Y., Lyon, B. G., Windham, W. R., Realini, C. E., Pringle, T. D. D., & Duckett, S. (2003). Prediction of color, texture, and sensory characteristics of beef steaks by visible and near infrared reflectance spectroscopy. A feasibility study. *Meat Science*, *65*(3), 1107–1115.

Lyford, C., Thompson, J., Polkinghorne, R., Miller, M., Nishimura, T., Neath, K., Allen, P., et al. (2010). Is willingness to pay (WTP) for beef quality grades affected by consumer demographics and meat consumption preferences? *Australasian Agribusiness Review - Australasian Agribusiness Review*, *1818*, 1–17.

Mancini, R. (2013). Meat Color. *The Science of Meat Quality* (pp. 177–198).

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. *Meat Science* (Vol. 71, pp. 100–121).

Martinez, S. (2017). *Predicting Water Holding Capacity and Forms of Water Loss In Beef Sources*. Texas State University.

Pereira, P. M. de C. C., & Vicente, A. F. dos R. B. (2013). Meat nutritional composition and nutritive role in the human diet. *Meat Science*.

Puolanne, E., & Halonen, M. (2010). Theoretical aspects of water-holding in meat. *Meat Science*.

Qiao, M., Fletcher, D. L., Smith, D. P., & Northcutt, J. K. (2001). The Effect of Broiler Breast Meat Color on pH, Moisture, Water-Holding Capacity, and Emulsification Capacity. *Poultry Science*, *80*(5), 676–680.

Quevedo, R., Valencia, E., Cuevas, G., Ronceros, B., Pedreschi, F., & Bastías, J. M. (2013). Color changes in the surface of fresh cut meat: A fractal kinetic application. *Food Research International*, *54*(2), 1430–1436.

Rogers, H. B., Brooks, J. C., Martin, J. N., Tittor, A., Miller, M. F., & Brashears, M. M. (2014). The impact of packaging system and temperature abuse on the shelf life characteristics of ground beef. *Meat Science*, *97*(1), 1–10.

Schrecker, S. T., & Gostomski, P. A. (2005). Determining the water holding capacity of microbial cellulose. *Biotechnology Letters*, *27*(19), 1435–1438.

Simopoulos, A. (1996). Handbook of lipids in human nutrition. *Essentials of Food Science* (pp. 51–73). Retrieved from http://trove.nla.gov.au/work/21185967?selectedversion=NBD11660585

Suman, S. P., Hunt, M. C., Nair, M. N., & Rentfrow, G. (2014). Improving beef color stability: Practical strategies and underlying mechanisms. *Meat Science, 98*(3), 490– 504.

Suman, S. P., & Joseph, P. (2013a). Myoglobin Chemistry and Meat Color. *Annual Review of Food Science and Technology*.

Suman, S. P., & Joseph, P. (2013b). Myoglobin Chemistry and Meat Color. *Annual Review of Food Science and Technology, 4*(1), 79–99. Retrieved from http://www.annualreviews.org/doi/10.1146/annurev-food-030212-182623

Suman, S. P., Nair, M. N., Joseph, P., & Hunt, M. C. (2016). Factors influencing internal color of cooked meats. *Meat Science, 120*, 133–144.

Tapp, W. N., Yancey, J. W. S., & Apple, J. K. (2011). How is the instrumental color of meat measured? *Meat Science, 89*(1), 1–5.

Tornberg, E. (2005). Effects of heat on meat proteins - Implications on structure and quality of meat products. *Meat Science* (Vol. 70, pp. 493–508).

Trinderup, C. H., Dahl, A., Jensen, K., Carstensen, J. M., & Conradsen, K. (2015). Comparison of a multispectral vision system and a colorimeter for the assessment of meat color. *Meat Science*, *102*, 1–7.

USDA. (2016). USDA Economic Research Service - Cattle & Beef. *United States Department of Agriculture USDA*.

Vernier, G., Chenal, A., Vitrac, H., Barumandzadhe, R., Montagner, C., & Forge, V. (2006). Interactions of apomyoglobin with membranes: mechanisms and effects on heme uptake. *Protein science : a publication of the Protein Society*, *16*(3), 391–400. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2203327&tool=pmcentrez&rendertype=abstract

Yang, A., Lanari, M. C., Brewster, M., & Tume, R. K. (2002). Lipid stability and meat colour of beef from pasture- and grain-fed cattle with or without vitamin E supplement. *Meat Science*, *60*(1), 41–50.

Zhang, H. (2007). Electrical Properties of Food. *Food Engineering*.

Zhang, W., Xiao, S., & Ahn, D. U. (2013a). Protein Oxidation: Basic Principles and Implications for Meat Quality. *Critical Reviews in Food Science and Nutrition*.

Zhang, W., Xiao, S., & Ahn, D. U. (2013b). Protein Oxidation: Basic Principles and Implications for Meat Quality. *Critical Reviews in Food Science and Nutrition*.

Zhang, W., Xiao, S., Samaraweera, H., Lee, E. J., & Ahn, D. U. (2010). Improving functional value of meat products. *Meat Science*.