EFFECTS OF GRILLING TEMPERATURE ON TENDERNESS, JUICINESS, AND FLAVOR OF RIBEYE, STRIP LOIN, AND TOP SIRLOIN STEAKS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE

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August 2017

Major Subject: Animal Science

ABSTRACT

The objective of this study was to characterize the impact of grilling temperature on ribeye, top loin and top sirloin steaks. Boneless ribeye rolls, top loin and top sirloin butt subprimals (n = 16 each, 48 total) were purchased from a local meat supplier. After aging 21 d post-processing, 2.54-cm-thick steaks were hand cut and randomly assigned a grilling temperature treatment (177°C, 205°C, or 232°C), vacuum-packaged, and frozen at -10°C until testing. Steaks were grilled to an internal temperature of 71°C on a commercial flat top grill set at 177° C, 205° C, or 232° C. Consumers (n = 80) were served nine samples and prompted to rate their liking of overall, tenderness, juiciness, appearance, and flavor on a 9-point hedonic scale. Steaks cooked for Warner-Bratzler shear force were held over night at 4° C before removing six cores 1.3 cm in diameter from each steak. Steaks were also cooked and served to a sensory panel trained on flavor and texture attributes. Samples from the steaks used for trained sensory panel analysis were quick-frozen in liquid nitrogen and stored at -80° C for GC/MS – olfactory analysis. Results were analyzed as a 3x3 factorial completely randomized design. No differences ($P > 0.05$) in consumer overall, tenderness, juiciness, appearance, and flavor liking were detected between steak type or grill temperature. The center color of ribeye steaks was lighter ($P < 0.05$) than top loin and top sirloin steaks. The ribeye steaks also had a greater ($P < 0.05$) hue angle than top sirloin steaks. Strip loin steaks had 0.27 kg less shear force ($P < 0.05$) than ribeye and top sirloin steaks. Ribeye and strip loin steaks

received greater ($P < 0.05$) muscle fiber tenderness and less ($P < 0.05$) connective tissue scores. Grill surface temperature had no effect ($P > 0.05$) on trained panel tenderness scores. Of the volatiles present during an aroma event (n = 67), pyrazine compounds were most influenced by grill surface temperature. The tenderness and juiciness of steaks grilled at differing temperatures were not perceived to be different by consumers; however, grilling temperature impacted the flavor of the final product by generating more pyrazine compounds.

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a thesis committee consisting of Drs. Chris Kerth (Chair) and Rhonda Miller of the Department of Animal Science, and Dr. Christine Alvarado of the Department of Poultry Science. Drs. Chris Kerth and Rhonda Miller of the Department of Animal Science supervised the data analyzed, and the student completed all other work directed for the thesis independently. This graduate study was supported by a research grant from the Beef Check-Off program.

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1. INTRODUCTION

Of the eating attributes associated with meat, tenderness is twice as variable as flavor and juiciness (Koohmaraie et al., 1996), yet tenderness drives consumer acceptance and satisfaction with steaks. Destefanis et al. (2007) reported a study in which consumers were able to discriminate very tough steaks from the five categories, and they were more accurate (62.3% correct) in segregating the combination of very tender and tender categories from others. Thus, consumers are effectively able to distinguish tenderness without any prior information, so guaranteeing tenderness of a steak would be advantageous to the beef industry. Accordingly, tenderness has risen as a concern for consumer acceptance of steaks, and the pursuit of a guaranteed tender product has become an objective for the beef industry.

Tenderness is an attribute consumers are willing to pay a premium for. Lusk et al. (2001) determined American consumers were willing to pay a premium for tender steaks. Using a bid-style study where consumers were asked to evaluate a steak and offer an amount they would be willing to pay in addition to a given amount for a guaranteed tender steak of comparison, half of the participants were willing to pay 49.6% more per pound after tasting a guaranteed tender product when provided information about the tenderness. Boleman et al. (1997) determined consumers were willing to pay a $1.10/kg difference between top loin steaks categorized by pre-determined shear force values. Consumer scores for juiciness, flavor, and overall like were also found to be greater for more tender steaks. Miller et al. (2001) conducted consumer testing in three locations in each of five cities, analyzing different pre-determined categories of tender steaks,

ranging from very tough to very tender. The data supported that 100% of the consumers were satisfied with very tender steaks, and only 25% of consumers were satisfied with steaks from the very tough category. Moreover, nearly four out of five consumers would be willing to pay a premium for a guaranteed tender steak, which was determined to grant a $66.96 profit per carcass in the very tender category over very tough.

Evidence exists that the temperature at which a beef muscle is cooked impacts the tenderness of that muscle. However, much of this research is confounded by cookery method (Lawrence et al., 2001; Woerner, 2014) or reports research cookery methods that may not be representative of commercial applications (Berry, 1993; King et al., 2003). Nevertheless, this research indicates that increasing the temperature of cookery, and therefore the rate of cooking, increases cooking loss and reduces tenderness of various muscles (Berry, 1993; King et al., 2003; Lawrence et al., 2001).

Additionally, the final internal temperature of a cooked steak, or the degree of doneness, can influence tenderness ratings of steaks greatly. Cox et al. (1997) described the interaction between consumers and degree of doneness to be significant as consumers whom received a higher degree of doneness steak than requested gave the steaks lower for liking scores on average. Lorenzen et al. (2005) found Warner-Bratzler shear force values, cooking time, and cook loss (%) to be less for steaks cooked to lower degrees of doneness (very rare to medium rare). Consumer liking scores for tenderness and juiciness were also higher for steaks at a very rare to medium rare degree of doneness. However, overall like and flavor like scores were statistically similar ($P > 0.05$) for steaks regardless of end point temperature treatment. Thus, consumers can

detect a difference in the tenderness and juiciness of differing degrees of doneness, yet they will still prefer the steak cooked to the degree of doneness they like overall.

Time of exposure to the grill can impact flavor development and tenderness as it pertains to degree of doneness. However, the impact of the grill surface temperature on consumer perception of tenderness has not been investigated. Kerth (2016) determined steaks cooked to the same degree of doneness at increasing grilling temperatures had increased steak surface temperature at time of flip and end point. With these greater steak surface temperatures, a crust can form and change the transfer of heat and energy via water exchange. Kerth and Miller (2015) found the tenderness and juiciness of steaks of greater thicknesses grilled at greater surface temperatures to be liked less than those grilled at lesser surface temperatures. Therefore, the objective of the present study was to examine the impact of grill surface temperature on the consumer perception of tenderness and juiciness. The hypothesis of this study was steaks grilled at greater surface temperatures would be tougher than those grilled at lower grill surface temperatures and will yield greater volatile compounds from the Maillard reaction.

2. LITERATURE REVIEW

2.1 Value of tenderness

Of the eating attributes associated with meat, tenderness is twice as variable as flavor and juiciness (Koohmaraie et al., 1996). Yet tenderness drives consumer acceptance and satisfaction of steaks, as the Beef Consumer Satisfaction survey (Boleman et al., 1997) confirmed the heavy influence tenderness has in consumers' overall satisfaction with a beef product. Destefanis et al. (2007) served untrained consumers (n = 220) samples of *longissimus thoracis* from the rib of 30 beef carcasses. The samples were representative of different commercial quality, breed of animal and aging times, and steaks were classified into one of five categories, varying from very tender to very tough based on Warner-Bratzler shear force values. Consumers were able to discriminate very tough steaks from the five categories, and they were more accurate (62.3% correct) in segregating the combination of very tender and tender categories from others. Thus, consumers were able to distinguish tenderness without any prior information, so guaranteeing tenderness of a steak would be advantageous to the beef industry. Accordingly, tenderness has risen as a concern for consumer acceptance of steaks, and the pursuit of a guaranteed tender product has become an objective for the beef industry.

Tenderness is an attribute consumers have repeatedly shown to be willing to pay a premium. In fact, Froehlich et al. (2009) determined Canadian consumers would be willing to pay up to a 15.5% premium for steaks that fell into a guaranteed tender eating

quality category. Lusk et al. (2001) determined American consumers were willing to pay a premium for tender steaks. Using a bid-style study where consumers were asked to evaluate a steak and offer an amount they would be willing to pay in addition to a given amount for a guaranteed tender steak of comparison, half of the participants were willing to pay 49.6% more per pound after tasting a guaranteed tender product when provided information about the tenderness. Boleman et al. (1997) determined consumers were willing to pay a $1.10/kg difference between top loin steaks categorized by pre-determined shear force values. Consumer scores for juiciness, flavor, and overall like were also greater for more tender steaks. Miller et al. (2001) conducted consumer testing in three locations in each of five cities, analyzing different pre-determined categories of tender steaks, ranging from very tough to very tender. They reported that 100% of the consumers were satisfied with very tender steaks, and only 25% of consumers were satisfied with steaks from the very tough category. Moreover, nearly four out of five consumers would have been willing to pay a premium for a guaranteed tender steak, which was determined to grant a $66.96 profit per carcass in the very tender category over very tough. Additionally, Schroeder et al. (1998) reviewed the potential value tenderness would have in pricing fed cattle on a grid system and determined there to be great prospective earnings for retailers and cattle producers alike in selling a guaranteed tender product.

2.2 Measuring and certifying tenderness

Realizing the value in determining a standard and/or certification in tenderness has led research efforts to have valid practices in determining consumer acceptance

thresholds. Consumer acceptance can be defined as the willingness of a consumer to pay the asking price for a product. Many methods (Cross et al., 1986; Wheeler et al., 1997; Wheeler et al., 2004) have been explored to determine how to gauge consumer acceptance, measuring both objectively and subjectively. The combination of these tests allow for a threshold of consumer acceptance to be determined for tenderness and processes that increase tenderness and palatability of steaks to be validated.

Objective measurements of tenderness acceptance include slice shear force, Warner-Bratzler shear force and a trained descriptive panel. Slice shear force was developed as a quick and repeatable procedure (Shackelford et al., 1999). Steaks are cooked to the same internal degree of doneness (70°C), and a slice is obtained 12.7 cm from the lateral end of each the *longissimus* muscle. The center of the slice is then cut to the breaking point. The values of the maximum of force needed to accomplish the breaking point at the same location on each steak can be compared directly. While slice shear force is a highly repeatable process for measuring tenderness, Warner-Bratzler shear force is nearly equivalent (Wheeler et al., 1997) and a more prevalent process among researchers. Warner-Bratzler shear force is a similar process to that of slice shear force; however, six 1.3 cm cores are taken across the muscle of the steak, making certain the core is taken parallel to the muscle fibers after reaching the same internal temperature (70°C). Each of these cores are sheared, and the average of the force is compared for a relative value of tenderness for each steak. Moreover, Kerth et al. (2002) determined steaks to have different tenderness measurements within the same steak mass; therefore, the variability of location that the Warner-Bratzler shear force

procedure captures gives a more encompassing value of tenderness for a steak. Parameters for a consumer threshold for tenderness were proposed by Shackelford et al. (1991) to be 4.6 kg of force for a steak undergoing a Warner-Bratzler shear force test to be considered "slightly tender". Moreover, trained descriptive sensory panels have been utilized to objectively quantify myofibrillar tenderness, connective tissue presence, and overall tenderness, anchored by different references of intensity (Cross et al., 1986). Panelists are trained on how to scale attributes based on intensity as per the universal scale for scaling intensities, followed by references anchored at a specific intensity value for that attribute. Each attribute is isolated in a given sample and scored on the intensity scale. In the end, samples can be compared to each other based on given values for each attribute tested.

Warner-Bratzler shear force is one of the most common objective measurements used for analyzing tenderness in meat samples and sorting steaks into tenderness categories. Shackelford et al. (1991) used shear force and consumer sensory panel data from top loin steaks in order to determine a tenderness threshold for foodservice and retailers to be 3.9 and 4.6 kg, respectively. These values were determined to be 88.6% accurate in predicting consumers' ratings of tenderness for steaks to be "slightly tender" (a value of 6 on a 9-point scale) or better when validated using the National Consumer Retail Beef Study data (Savell et al., 1987). Appropriately, these values were determined to be highly predictive in consumers' likelihood of rating a steak as "slightly tender" or above. Steaks that have larger average tenderness liking scores have also been proven to have a larger overall liking score (Huffman et al., 1996). Correspondingly, consumer

acceptance rates were highest for steaks that score a 6 or more on a 9-point hedonic scale. Additionally, steaks classified as tender using the suggested threshold should result in greater consumer acceptance of steaks as established by consumer sensory tests.

The most common subjective measurement of consumer acceptance is consumer sensory panels in which consumers are able to define their preference and/or liking of a product. From this type of survey, researchers are able to determine consumer perception of tenderness and better understand what properties may or may not make a meat product desirably tender. Liking is determined from a hedonic scale where consumers can mark their overall liking of a particular attribute of the meat product in relation to three anchors: extreme dislike, neutral, and extreme like (Resurreccion, 2004). Consumer ratings for tenderness are a subjective measurement, for researchers prompt consumers with questions such as, "how much do you like the tenderness of this steak?" Thus, the repeatability of information gained from consumer sensory panels was in question by Wheeler et al. (2004). The data exhibited much variation for an individual untrained consumer panelist for tenderness ratings; however, using a panel mean increased the repeatability of tenderness scores (mean of 4, $r = -0.82$; mean of 16, $r = -0.92$). Accordingly, studies examining consumer acceptance of steaks have been validated by using the panel means as a determining factor of differences between steaks.

Combining the results of these tests for tenderness, researchers have been in pursuit of determining a specific threshold for tenderness in order to offer a guarantee to the consumer. As such, marketing claim requirements have been developed in order to

label meat as either "certified tender" or "certified very tender" (ASTM, 2011). Standards in place for meat products to qualify for these labeling premiums include: (1) must be a minimum 90 % lean by weight; (2) must contain the *longissimus* muscle or a neighboring muscle; and (3) must surpass the minimum tenderness threshold value of 4.4 kg for Warner-Bratzler shear force as modified by Wheeler et al. (2004). "Certified tender" and "certified very tender" are the only certified marketing statements that may appear on meat labels rather than actual branded programs. Current meat marketing or branded programs, such as Certified Angus Beef and 44 Farms Premium Natural Black Angus, do not have specifications for tenderness (AMS, 2016). Conversely, the programs rely on the rating of quality grades as not only a determinant of tenderness but palatability as a whole.

2.3 Animal factors contributing to tenderness

Quality grades are predictors of eating quality and overall palatability of the individual steak. Palatability is a measurement of overall experience, taking into account the tenderness, flavor, juiciness, and consumer satisfaction. Although palatability is most often influenced by tenderness (Miller et al., 2001), quality grades are most often used as a treatment or block in studies to narrow the window of variation in tenderness and flavor for comparisons. Quality grades are dependent upon the amount and deposition of marbling, or intramuscular fat, as well as maturity of the animal. Marbling alone has been shown to account for as little as 5% (Wheeler et al., 1994) and up to approximately 15% of the variation in tenderness (Thompson, 2004).

Marbling is a moderately heritable trait and can influence the breeding values and, therefore, the selection criterion for beef cattle (Magolski et al., 2013). While it can be directly measured in the live animal with ultrasound, the cost and inefficiency of capturing images and sorting is not practical for large production systems; instead, quality grades are used as a partial representative of the relative amount of marbling to classify the final meat product. Still, an abundance of variation exists across and between quality grades due to other known and unknown contributing tenderness factors. This variation can be identified as many studies select a quality grade but create blocks of tenderness gradients within it (Boleman et al., 1997; Miller et al., 2001; Shackelford et al., 1991). Accordingly, quality grades are only estimates of an acceptable eating experience (Smith et al., 1987). For this reason, many studies control for variation by utilizing USDA quality grades either as treatments or selection criteria.

2.4 Handling factors contributing to tenderness

Post-mortem handling has a significant impact on muscle fiber tenderness. With the conversion of muscle to meat, the proteins begin to degrade within the system, weakening the sarcomere (Koohmaraie et al., 1996). The process of protein proteolysis, the reason for aging meat, increases the tenderness of steaks over time. In order to understand the mode in which aging works in meat systems, Lonergan et al. (2010) reviewed the environmental shift that occurs with the conversion of muscle to meat. The blood supply is lost through exsanguination, and thus, the oxygen availability is restricted. Muscle metabolism then experiences a shift from aerobic metabolism to anaerobic metabolism, or from the use of the electron transport chain to the TCA cycle.

Not only is the generation of ATP molecules reduced nearly 5-fold in TCA, but pyruvate is the final substrate produced and converted to lactic acid (Khan and Lentz, 1973). The accumulation of the lactic acid leads to a sharp decline in pH within the muscle tissues. While glycolytic enzymes function well at the physiological pH of 6.9, the enzymes are extremely pH sensitive and are inhibited as the meat system reaches a final pH, nearing 5.6. At the completion of this process known as rigor mortis, ionic strengths of the actin-myosin bridges are weakened and other enzyme systems are promoted. With the weakening of these bonds, the sarcomere lengthens. The relaxed state of the muscle increases the tenderness of the final meat product due to the reduction in density of proteins. Additionally, membrane potentials weaken, creating opportunity for ions such as calcium to leak out of sequestered areas. These ions act as initiators for specific enzyme systems. More importantly, calcium ions at 0.1mM concentration are an initiator of the m-calpain system (Sorimachi et al., 1996). Calpain is an enzyme that degrades the Z-disk, or "backbone" of the sarcomere. The greatest post-mortem tenderization occurs during the first 3 or 4 days, yet the Z-disk is not degraded during this time despite the increased activity of the calpain system (Taylor et al., 1995). Desmin, a protein that attaches the Z-disks of myofibrils together, has been utilized as a marker protein for measuring degradation within a steak, for it has a strong correlation to tenderness panel ratings after 14 days of aging ($r = 0.80$; Wheeler et al., 2002). However, desmin has not been proven to be directly related to tenderness and is thus employed only as an indicator of overall postmortem proteolysis (Lonergan et al., 2010).

While actin and myosin are not known to have deterioration within normal aging times (Koohmaraie et al., 1996), many of the structural proteins exhibit degradation. Structural proteins include titin, nebulin, desmin, troponin t, and vinculin. The specific order in which proteins are degraded and the confidence in which protein is the greatest contributor to meat tenderness is still unclear (Lonergan et al. 2010). However, desmin is the most commonly used marker for myofibrillar degradation in meat systems. Troponin t degradation has also been measured, but the degradative products are more challenging to capture using immunoblotting and can lead to erroneous results. Despite being able to determine the exact protein or proteins contributing to the tenderness differences in myofibrillar fractions, it is known that aging meat yields greater tenderness ratings over time (Diles et al., 1994; Huff-Lonergan and Lonergan, 1999; Mandell et al., 2001).

2.5 Aging applications

Changes in muscle fiber tenderness have been monitored by day of age with Warner-Bratzler shear force, slice shear force, and trained sensory panels in addition to Western blotting for desmin degradation. The greatest change in muscle fiber tenderness is exhibited within the first week of aging (Taylor et al., 1995). Smith et al. (1978) determined aging beyond day 11 had no significant impact on palatability of steaks when oven-broiled to an internal temperature of 75°C. However, additional muscle tenderness can be gained with greater aging times. Koohmaraie et al. (1996) described the relationship between the tenderness of steaks and aging times as variable, for it is highly dependent on the extent and rate of proteolysis. Consequently, aging times of beef in retail in the U.S. average 25.9 days for beef steak products (Henderson, 2016), and

therefore, overcome much of the variation in rate of proteolysis to rely on just the endpoint value of tenderness. Conversely, aging time is also dependent upon the muscle location, for the composition of the muscle differs across the animal (Henderson, 2016).

Two types of aging processes are used in the beef industry: wet and dry aging. Wet aging is a process in which the meat product is placed in a package and the air is vacuumed out to be stored at refrigerated temperatures for some amount of time. With this, the system stays continuous and can be stored as shipped. Dry-aging is the process by which the meat product is shelved for a set amount of time at refrigerated temperatures and standard humidity without packaging. Smith et al. (2008) summarized why dry aging has been proven to be a very costly process to complete. Meat stored in the open inherently generates large amounts of shrink due to moisture migration and excessive waste due to the "crust" development that must be trimmed off. Dry-aged meat is also more susceptible to oxidation, for there is no oxygen barrier to the meat. The products of oxidation can yield more "earthy, musty, and sour" flavors and aromas, which drive the consumer demand for dry-aged meat (Sitz et al., 2006). There is a limited market for dry-aged beef due to the cost of the production and thus number of consumers willing to pay for it. Accordingly, wet aging is the most common method (Henderson, 2016) due to the lower inherent risk of microbial contamination, lower cost with reduced space requirements, and higher yields.

Aging, and tenderness as a whole, is also dependent upon the contractile state of the muscle. The standard for the beef industry is to suspend a carcass after harvesting by the Achilles tendon. Upon doing so, muscles within the carcass are contracted or

stretched depending on their association and approximation to the Achilles tendon in addition to the force of gravity. Muscles in the round are stretched via this process; whereas, those in the loin are contracted or bunched (Kerth et al., 1999). Muscle fiber diameters are accordingly smaller in the round and larger in the loin portions, based on the mode of suspension. Larger muscle fiber diameters are found to be tougher than smaller diameter fiber of the same muscle. With larger fiber diameters, the proteins are denser and have less free space within the muscle. Consequently, protein degradation can take longer, for enzyme systems have less availability to work within the system. Herring et al. (1967) determined muscles from the contracted state of both A- and E-maturity groups to have unacceptable tenderness values even after 10 days of aging. Moreover, the bunched muscles in the contracted state had a lesser proportion of connective tissue than those that were stretched. Thus, led to the thought that bunched muscles have denser connective tissue, negatively impacting tenderness as well.

Noting the tenderness implications associated with suspending carcasses by the Achilles tendon, Texas A&M University developed the process known as the Tenderstretch (Hostetler et al., 1970). This method proposes suspending carcasses from the ischium, placing the hook through the obturator foramen in order to increase the tenderness of contracted portions of the carcass when traditionally suspended. These portions are more valuable middle cuts of the carcass, and the Tenderstretch method yields longer sarcomeres and less peak shear force requirements with no limitation to the acceptability of other cuts (Hostetler et al., 1970). By suspending by the ischium, pressure is placed on the skeleton rather than muscles connected to the Achilles tendon.

Ferguson et al. (1999) compared carcass sides hung by the Tenderstretch method to the traditional Achilles method. While the *longissimus thoracis* was the only muscle impacted by the Tenderstretch method in the forequarter, the palatability scores of the *longissimus lumborum, gluteus medius, semimembranosus, biceps femoris,* and *rectus femoris* were determined to be greater for Tenderstreched sides than Achilles when both were exposed to electrical stimulation. Sørheim et al. (2001) determined the effects of chilling rate using the Tenderstretch, tendercut and control methods on tenderness for carcasses without exposure to electrical stimulation. The Tenderstretch method was determined to have larger sarcomere lengths, lower Warner-Bratzler shear force values, and more positive trained sensory scores when chilled at a rapid rate (constant air temperature of 2°C; chilling monitored in *m. longissimus* 10 h post mortem). Accordingly, Tenderstretch decreases muscle fiber diameters and de-bulks the round allowing the carcass temperature to decrease more evenly and increase palatability characteristics. However, the Tenderstrecth method is not used in the U.S. beef industry due to the complications with orientation of the carcass. Suspending from the ischium causes the hind quarter to be perpendicular to the body and occupy more horizontal area. The space each carcass would occupy in the cooler would force packers to either store fewer carcasses on a rail or buy a new railing system, neither of which are offset by the potential increased tenderness values of the muscles in the round.

2.6 Intrinsic factors impacting tenderness

Tenderness is also impacted my muscle fiber type. Calkins et al. (1981) determined a high correlation values to exist between marbling and shear force and

trained panel tenderness scores, especially when there were fewer Type II fibers and smaller percentage area of Type II fibers. Ouali (1990) reviewed the different aging rates of muscle fiber types, for slow twitch white muscles degrade quicker than fast-twitch red muscles. High correlations of Warner-Bratzler shear values and myofibrillar fragmentation index with muscle fiber size have been determined to exist at early periods of post-mortem aging. However, these correlations become insignificant after 14d, suggesting muscle fiber type may only be responsible for variation in tenderness during early proteolysis rather than sustained variation (Crouse et al., 1991).

It is known that animal diet, breed, and age can impact tenderness (Ferguson et al. 2001) but to a varying degree (Warner et al., 2010). However, intrinsic factors can have a significant impact on consumer preference. Two major functional classifications of skeletal muscle in a beef animal are locomotive and support. Muscles are comprised of cells termed muscle fibers. The fundamental elements of the fibers differ based on the function of the muscle itself. The classification of muscle fibers, or muscle fiber typing, has been determined by histochemistry for myosin heavy chains, for the isoforms of myosin are highly correlated to the functionality of the muscle fiber (Lefaucher, 2010). Brooke and Kaiser (1970) determined the classification of type I, IIA and IIB, and Schiaffino et al., (1989) offered evidence of a fourth, type IIX. While four variations of muscle fibers exist, marketing strategies targeting the general public describe the differences in muscles as either “red” or “white”. Locomotive muscles are directly involved in the movement of the animal. Due to the demands of the muscles to make the animal motive, the muscle consists of a Type I and IIA muscle fiber (Lefaucher, 2010).

These fibers contain more myoglobin – appearing redder – and more mitochondria in order to sustain oxidative metabolism. Additionally, energy is stored in the form of triglycerides and used as free fatty acids. Support muscles, such as the *longissimus thoracis*, are those involved in reinforcing the skeleton of the animal and are often found along the dorsal side of the animal. The function of these muscles is mostly suspensory rather than movement; therefore, the fiber type of these muscles is predominantly Type IIX and IIB. These fibers use glycogen stores for glycolytic metabolism for quick movements such as twitches. Thus, these slow-type muscle fibers tend to have less lipid content and lipoprotein lipase activity (Hocquette et al., 1998).

The formation of volatiles from lipid substrates elicits greater flavor intensity in meat products. Consequently, sensory traits, as influenced by free fatty acid content, differ across muscle fiber types. Lefaucheur (2010) suggested the possibility of selecting live animals for their genetic makeup for muscle fiber types in addition to exercise in order to promote the conversion of fiber types and to positively impact flavor. Accordingly, genetic tests and gene markers may be developed for muscle type and flavor in the future.

Another intrinsic factor impacting meat tenderness by muscle type is the amount of connective tissue present (Purslow, 2005). Collagen is the predominant protein found in connective tissue; it has a helical structure that reinforces the structure of the muscle. Collagen presence within the muscle tissue decreases meat tenderness. The cross-links that stabilize the triple helix structure increase and become more heat stable over time (Purslow, 2005). Thus, steaks from older animals prepared under the same conditions as

steaks from younger will have higher amounts of heat-insoluble collagen, resulting in tougher meat. Connective tissue presence is higher in locomotive muscles than support muscles in order to support and reinforce movement in the animal (Purslow, 2005). Therefore, locomotive muscles are often scored lower for tenderness values than that of support muscles (Belew et al., 2003).

2.7 Cooking applications

The final internal temperature of a cooked steak, or the degree of doneness, can influence tenderness ratings of steaks greatly. As more research was conducted to insure the safety of meat cooked to lower degrees of doneness, consumers began to eat meat cooked to lower final internal temperatures (Huffman et al., 1996). In 1995, research guidelines for cooking beef steaks changed from 75°C to 71°C (AMSA, 1995). Cox et al. (1997) described the interaction between consumers and degree of doneness to be significant as consumers who received a higher degree of doneness steak than requested and gave the steaks lower liking scores on average. Lorenzen et al. (2005) found Warner-Bratzler shear force values, cooking time, and cook loss (%) to be less for steaks cooked to lower degrees of doneness (very rare to medium rare). Consumer liking scores for tenderness and juiciness were also higher for steaks at a very rare to medium rare degree of doneness. However, overall like and flavor like scores were statistically similar for steaks regardless of end point temperature treatment. Thus, consumers can detect a difference in the tenderness and juiciness of differing degrees of doneness, yet they still prefer the steak cooked to their preferred degree of doneness.

Consumer liking scores are also impacted by preparation and cooking procedures, including cooking application, steak thickness, and initial steak temperature (Berry and Leddy, 1990; Huffman et al., 1996; Lawrence et al., 2001). Each of these factors also influences consumer perception and objective measurement scores of tenderness. Berry and Leddy (1990) selected steaks of different marbling scores to thaw at either 10.5°C or 4.1°C in order to evaluate the impact of thawing on tenderness when cooked to an internal temperature of 70°C. Steaks thawed at 10.5°C, regardless of marbling score, were determined to be more tender, more juicy, have a lower degree of doneness, less cook loss and required less cook time. Although, the cooking method was uncontrolled, for the electric open hearth broiler had a broad range of surface temperature of 215 - 235°C. Still, steaks with a greater initial temperature were exposed to the broiler for less time. With less time exposed to direct heat, the protein denaturation and moisture migration was less severe than those with an internal temperature of 4.1°C, as the tenderness and degree of doneness ratings suggested.

2.8 Crust development

Over the years, cooking methods have changed and have impacted tenderness. Lawrence et al. (2001) cooked five beef muscles on an electric broiler, forced air convection oven, and belt grill set at three different grill surface temperatures. While muscles required greater Warner-Bratzler peak shear force at greater belt grill temperatures, the final internal temperature was not controlled, resulting in greater degrees of doneness for steaks cooked at greater temperatures. Correspondingly, these steaks also had the greatest cook loss (%), which confound the tenderness results. Kerth

et al. (2003) investigated the repeatability of the clamshell grill compared to oven roasting and oven broiling. Beef steaks were cooked to the same internal degree of doneness. Steaks cooked with the clamshell grill had less cook time duration than oven roasting and broiling (7.0 min vs 22.83 and 17.50, respectively). Despite the difference in the cook time for each apparatus, no differences were detected in Warner-Bratzler shear force values with high repeatability (r = 0.88). Differences in the temperature steaks were cooked may have confounded the results of cook time to some degree. However, the lack of differences detected in steak tenderness may be due to little to no surface contact with the steak as the clamshell grill was "ribbed". A "crust" from searing the steak most likely did not impact moisture migration or tenderness.

The formation of a "crust" is a key contributor to managing moisture migration. Wheeler et al. (1997) analyzed the effects of using a belt grill in comparison to an open hearth broiler, seeking validation for the Warner-Bratzler shear protocol. Steaks grilled on the belt grill had less cooking loss (%) than the open hearth broiler when steaks were cooked for both trained sensory panel and Warner-Bratzler shear force testing. The direct contact between the steak and the grill elicits a formation of the "crust" that acts as a barrier for moisture migration. Although this crust did not impact Warner-Bratzler values, steaks cooked on the belt grill received higher trained sensory panel scores for juiciness (6.0 vs. 5.1 using an 8-point scale). The formation of a "crust" may be an important point of control for influencing consumer liking and perception of the juiciness and tenderness of a steak. The formation of a crust is dependent upon the time the steak is exposed to direct contact with a grill. Kerth (2016) reported the differences

in flavor development for 1.3, 2.5, and 3.8 cm-thick steaks exposed to grill surface temperatures of 177, 204, or 232°C. Steaks tended to take more time to cook when grilled at 177°C, but thickness of steak impacted total time exposed to the grill, where the 1.3 cm-thick steak took the least time to reach an internal temperature of 71°C and 3.8-cm thick took the longest. While the development of a crust is needed to seal in moisture and drive consumer liking, the rate at which the crust is formed is dependent upon the grill surface temperature. King et al. (2003) reported longer sarcomere lengths, higher percent cook yield, and higher percent desmin degradation in muscles cooked at a slow rate (93°C surface temperature) compared to muscles cooked at a fast rate (260°C surface temperature). Nevertheless, this research indicated that increasing the temperature of cookery, and therefore the rate of cooking, increased cooking loss and reduces tenderness of various muscles (Berry, 1993; King et al., 2003; Lawrence et al., 2001).

2.9 Protein denaturation during cooking

Understanding the process of protein unfolding and denaturation is crucial in comprehending the cooking process of meat. Protein structure is classified in four different structural phases (Richardson, 1981; Wright and Dawson, 1999). The primary structure refers to the amino acid sequence of a protein, where amino acids are the recognized “building blocks” or basic component of a protein. Peptide bonds are the only bonds present. Secondary structure can influence the shape of the final protein, for it is the interaction of hydrogen bonds between amino acid side chains. Depending on the amino acids involved, different potentials for these bonds, and according folding

patterns, exist. In amino acid sequences with higher frequencies of polar and non-polar side chains, alpha helical structures are predominant secondary structures (Tornberg, 2005). Helical structures provide a core that non-polar side chains tend to fold into and a polar exterior that promote polar side chains. The hydrogen bonding between these side chains promotes the stability of the structure. Whereas, amino acids with neutral, acidic and basic side chains tend to have greater bonding potential to form beta sheets and turns. These sheets allow side chains to align in parallel strands and promote hydrogen bonding between two strands, forming a straighter alignment. Tertiary structure indicates the overall three-dimensional shape of the protein subunit as the secondary structures interact. The tertiary structure of a protein is highly influenced by the chemical properties of the amino acid side chains. Finally, the quaternary structure refers to the interaction of multiple protein subunits to each other. The quaternary structure will change with shifts in the tertiary structure of the subunits. Shifts in the shape of the protein can be caused by external or environmental factors that may impact bonding potential such as pH and temperature.

Protein degradation has been discussed as it occurs post-mortem and is influenced by pH. However, the denaturation of proteins is the final driver of consumer liking and overall satisfaction. Many reactions take place during the cooking process, for the proportion of substrates present in meat; composition by weight is approximately 17% protein, 3-5% lipid, 1% carbohydrate (predominantly in the form of glycogen), 1% ash, and 75-77% water (Aberle et al., 2012). While each substrate plays an important role in flavor development, the interaction between protein and water is significant as it

influences tenderness of a meat product. Denaturation of proteins occurs with an increase in exposure to heat, disrupting the hydrophobic bonds of the protein (Hummer et al., 1998). As meat is cooked on a flat top grill, it is directly exposed to a high heat source. The denaturation of proteins is the non-uniform unfolding of proteins, breaking hydrogen bonds but not peptide bonds. As denaturation occurs, the protein bonds of the quaternary, tertiary and secondary structure are dehydrated, and the loss and mobilization of water occurs.

Neurath and Bull (1936) determined the relationship between density and percent water to be inversely related in surface-denatured and heat-denatured ovalbumin. This relationship can also describe the change in protein contraction upon denaturing. As water migration increases with increased temperatures, the proteins lose stability, begin to denature and unfold, and contract to have greater density. This process is often monitored or measured by cook loss or cook yield. Cooked steaks have higher density of proteins and lead consumers to believe steaks are tougher (Millar, 1994).

The degree of doneness and degree of marbling can influence the perception of the density of the steak; however, moisture migration and crust development can as well. Portanguen et al. (2014) analyzed the development of a steak crust by monitoring the temperature and water activity over time using an open jet system and different temperatures. At the conclusion of the study, it was determined that the crust is formed as the water component of this surface is transitioned to a vapor front, and temperature is allowed to increase beyond that of boiling temperature. The elevated temperatures are conductive to the rest of the water component of the steak and drive the vapor front

through the cooking process. Additionally, Portanguen et al. (2014) recognized significant crust structure developments different from that of the hypothesized uniform porous material. Rather, the structure was quite complex with different sized porosities and evaporative steam channels influenced by dried muscle fibers. Thus, the angle the muscle fiber comes into contact with a heat source may influence the development of the crust, and potentially, the perceived tenderness of the beef steak.

Time of exposure to the grill can impact flavor development and tenderness as it is cooked to a particular degree of doneness (Kerth, 2016; Portanguen et al. 2014). However, the impact of the grill surface temperature on consumer perception of tenderness has not been investigated. Kerth (2016) determined steaks cooked to the same degree of doneness at increasing grilling temperatures had increased steak surface temperature at time of flip and end point. With these greater steak surface temperatures, a crust can form and change the transfer of heat and energy via water exchange. Kerth and Miller (2015) found that the tenderness and juiciness of steaks of greater thicknesses grilled at greater surface temperatures were liked less than those grilled at lower surface temperatures by consumer sensory panels. The objective of their study was to investigate flavor, so Warner-Bratzler shear force was not conducted. Accordingly, a need was presented for a study to analyze the differences in both objective and subjective measures of tenderness of steaks grilled at different grill surface temperatures. Therefore, the objective of the present study was to examine the impact of grill surface temperature on the consumer perception of tenderness and juiciness.

2.10 Flavor

More recently, consumer research has determined that after a certain threshold for tenderness, consumer preference is driven by flavor (Resurreccion, 2004). Flavor is detected by receptors on the tongue, in the mouth, and in the nasal cavities (Kerth and Miller, 2015). The taste of a product, or the flavor, is the combination of the basic tastes – sweet, sour, salty, bitter, and umami – detected in the mouth, aromas by the olfactory bulb, and the somatosensory perception by trigeminal nerves. The basic tastes are developed from the breakdown of amino acids, peptides, nucleic acids, acids and minerals that are water-soluble and present in the meat system (Dashdorj et al., 2015). However, the additional flavors common to meat products like buttery, brown/roasted, and grassy are attributed to other lipid and sugar precursors as well as their interaction with proteins. While the process of flavor development is very complex, there are two primary reactions that occur and are important to flavor development when cooking meat products: lipid degradation and Maillard reaction.

2.11 Flavor precursors

The generation of volatile compounds is dependent on the inherent lipid material. Triacyglycerides are the predominant form of lipid in meat products, for fatty acids are stored as triacylglycerides in adipose tissue (Hornstein et al., 1961). Triacylglycerides are composed of a glycerol "backbone" molecule and up to three fatty acids connected by an ester bond formed between the alcohol group of the glycerol and the carboxylic group of the fatty acid. The fatty acids attached to the triacylglyceride influence the functional properties and compounds produced. Fatty acids bonded to triacylglycerides

are predominantly saturated fatty acids, or those that are saturated in hydrogen atoms with no double bonds. These straight chain fatty acids increase the hydrogen bonding potential and thus the ability to stack and be stored efficiently (Mottram and Edwards, 1983). Additionally, these fatty acids are neutral and make the triacylglycerides non-polar. Phospholipids make up the other lipid fraction. Phospholipids are similar to triacylglycerides in structure; however, they have a phosphate group in place of one alcohol group on the glycerol and tend to have more unsaturated fatty acids. Unsaturated fatty acids are those that have one or more double bonds. These double bonds cause bends in the structure and greater fluidity of the molecule. The phosphate group also causes the molecule to have polar properties, allowing them to be soluble in aqueous solutions. Thus, phospholipids tend to be found in the membranes of cells. The saturated fatty acids generate long chain alkanes that are able to interact with other compounds within the meat system; whereas, unsaturated fatty acids tend to elicit short chain alkanes due to the susceptibility of the double bond (Mottram and Edwards, 1983).

2.12 Lipid thermal degradation

Lipid degradation is a process by which fat is broken down into volatile compounds by oxidation or heat. Oxidative reactions can occur when a reducing agent is present or free radicals are formed from high-energy exposure such as light or heat (Betteridge, 2000). Oxidation can occur at any temperature, though it is expedited by heat. At lower temperatures, oxidation of lipids yields negative, off-flavor descriptors; whereas, thermal degradation of lipids produces pleasant and favorable flavor descriptors (Willemot et al., 1985). Exposure to heat, a source of high energy, can also

lead to the degradation of lipids without oxidizing. Non-oxidative heat reactions that lead to the breakdown of lipids can include dehydration, carbon-carbon cleavage, hydrolysis of the ester bond, decarboxylation, and dehydrogenation. These processes generally favor phospholipids in order to generate shorter chain fatty acids from the cleaving of double bonds. The decreased hydrogen bonding potential in unsaturated fatty acids – due to the bends in the structure – makes degradation of phospholipids more accessible. The primary types of compounds generated from lipid degradation are hydrocarbons, alcohols, aldehydes, ketones, and 2-alkylfurans. These compounds can be present in the final meat product alone, yet it is common for these to interact with intermediates from the Maillard reaction to yield pyrazines, thiols, and thiazines (Dashdorj et al., 2015).

2.13 Maillard reaction

The Maillard reaction describes the interaction of free amino acids with a reducing sugar to create the iconic browning of meat, which generally occurs in the presence of high heat conditions (Mottram, 1998). This reaction is very complex due to the multitude of intermediates that are produced, which is indicative of the environmental conditions from which they are produced. Dashdorj et al. (2015) reviewed the general process of volatile production from the Maillard reaction and the interaction of the intermediates involved. A sugar will reduce a free amino acid and condense to form an N-substituted glycosylamine. In meat systems, this is typically the interaction of a ribose sugar with cysteine or methionine (Elmore et al., 2002; Farmer and Mottram, 1992). The product will then spontaneously undergo the Amadori rearrangement, which

is irreversible, and will form reductones and dehydroreductones in addition to furfural or hydroxyl-methylfurfural, depending on whether a pentose or hexose is involved at a pH < 7 (Martins et al., 2000). The ketone products are a branching point in flavor development, for many outcomes are plausible from here depending on what is present in the system. In the presence of ammonia and dihydrogen sulfide, the generation of furans, pyranones, pyrroles, and thiophenes occurs. Depending on pH and temperature conditions, the ketones may form sugar aldehydes or hydroxy-ketones. The ketones may also interact with α -amino acids that have undergone Strecker degradation (Rizzi, 2008). Strecker degradation is the oxidation of α–amino acids into their corresponding aldehyde. The resulting aldehydes, aminoketones, methional, and heterocyclization products are significant Maillard intermediates. They have the potential to interact with lipid thermal degradation products, producing pyrazines, thiazoles, and thiols. And, the intermediates have the potential to interact with other intermediates to form thiazoles, pyrroles, imidazoles, pyrazines, oxazoles, and thiols.

While water-soluble proteins, minerals, and acids presence influence the basic tastes, lipid thermal degradation and Maillard products enhance the depth of flavor. The volatiles produced from these reactions can drive or inhibit consumer liking. It is known that these reactions are catalyzed by dry heat; however, the differences in the development of volatiles and consumer preferences for flavor of steaks grilled at increasing grill temperatures has not been investigated. Therefore, a second objective of the present study was to examine the impact of grill surface temperature on consumer preference for flavor and associated volatile compounds.

2.14 Summary

Tenderness and flavor are both major factors in consumer satisfaction and liking. Many factors influence tenderness, including aging, muscle type, collagen presence, and marbling. Yet, the degree of doneness and cooking method can greatly influence consumer preference for beef steaks, for flavor and tenderness are dependent upon cooking application and duration. When a steak is exposed to high heat on a flat surface for a longer period of time, there is an increased potential for a crust and Maillard products to develop. Consumer preferences for these have not been investigated. The hypothesis for this study is that steaks grilled at greater surface temperatures will be tougher than those grilled at lower grill surface temperatures and will yield greater volatile compounds from the Maillard reaction.

3. MATERIALS AND METHODS

3.1 Steak selection

This research was approved by Texas A&M University IRB (IRB2016-0256M). USDA Choice boneless ribeye rolls (IMPS 112A, USDA, 2014), boneless strip loins (IMPS 180), and boneless top sirloin butts (IMPS 184; n = 16 each, 48 total) were purchased from a local meat supplier in Bryan, TX. The vacuum-packaged subprimals were aged 21 d post-processing date at refrigeration temperature (4°C) before being hand-cut into 2.54-cm-thick steaks. The cut surface of the end used to square off the first steak was allowed to bloom for 30 min before taking color measurements (L*, a*, and b*) with a Minolta Chroma-meter CR-400 (D65 light source with a 2* Observer; Konica Minolta, Grand Rapids, MI) and pH using a portable pH meter (Model: HI98163; Hanna Instruments, Carrolton, TX USA) in triplicate. The Minolta was calibrated using a white tile (Y: 93.80; x: 0.3158; y: 0.3324) every 10 samples. The pH meter was calibrated using the pH standards (Hannah Instruments, Carrolton, TX USA) of 4.0, 7.0 and 10.0 every 10 samples. Within each subprimal, steaks were randomly assigned to type of analysis and a grill temperature treatment (117, 205, or 232°C), labeled accordingly, and individually packaged in 5 x 12 vacuum-package-bags (Cryovac B2470, Sealed Air Food Care, Duncan, SC). After packaging, steaks were frozen (-10°C) for a minimum of 24 h and held at -10°C after boxing. Steaks remained frozen for up to 3 mo until analyses were performed.

3.2 Cooking

Steaks were thawed in refrigerated storage (4°C) for 12 to 24 h and cooked on a 2.54-cm-thick flat top Star Max 536TGF 91.44cm Countertop Electric Griddle with Snap Action Thermostatic Controls (Star International Holdings Inc. Company, St. Louis, MO) set at 117, 205, or 232°C within a range of ± 2.8°C for each treatment. Grill temperature was monitored by randomly selecting locations within the set temperature range using a handheld instantaneous surface thermometer (Pro-Surface ThermaPen, SKU: #THS-231-279, ThermoWorks, American Fork, UT). Steaks were turned at an internal temperature of 35°C and removed at 71°C (medium degree of doneness). Internal steak temperatures were monitored by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the steak geometric center, and temperatures were displayed using an Omega HH501BT Type T thermometer (Omega Engineering, Stanford, CT). The grill surface temperatures were taken with a Pro-Surface Thermapen (Model No: THS-231-279; Thermoworks, Inc., UT USA).

3.3 Trained Sensory Panel

An expert trained beef flavor descriptive attribute panel with over 200 hours of training and 10 years of experience consisting of six panelists was trained on 10 basic flavors and 5 texture attributes from the beef lexicon (Adhikari et al., 2011) as defined in Table 1 for 6 d prior to testing. Panelists were trained to scale each attribute on a 16-point intensity scale (0 = none and 15 = extremely intense). Table 1 lists the definition and references for each attribute. Each day, panelists were served two "warm up" samples, which were discussed verbally to insure proper scaling and precision of scoring

at the beginning of each day. Panelists were served two random and representative cubes (1.3 cm x 1.3 cm x steak thickness), avoiding the edges and fat kernels of the steak, in a plastic soufflé cup while in a breadbox style booth under red lighting. Saltless crackers and double distilled were offered as palette cleansers. Panelists tested 12 samples per day with a minimum of 4 min between each sample with a break after the sixth sample for 12 d total. Extra representative cubes from each sample, excluding the edges, were wrapped in aluminum foil, quick frozen in liquid nitrogen, and stored at -80° C for GC/MS analysis.

3.4 Consumer Sensory Panel

Consumer testing was conducted in a series of four sessions with 20 consumers per session (n = 80 consumers total). Consumers were recruited from a consumer bank and screened, using beef-eaters with no food allergies over the age of 18 as the only stipulations. Demographic information collected included gender, age, ethnicity, number in household, household income, and employment range. Upon completion of demographic information, panelists were served two 1.3 x 1.3 cm x steak thickness representative cubes per sample, avoiding the edges and fat kernels of the steaks, and given saltless crackers and double distilled water as palette cleansers. Each panelist was served samples under red lights in five-minute increments with a break between the fifth and sixth sample. Each panelist evaluated a total of nine samples, and five panelists evaluated each sample in a session. Panelists were prompted to rate their opinion of each of the samples on a 9-point hedonic scale for overall, juiciness, flavor, tenderness, and appearance liking where 0 = dislike extremely and 9 = like extremely. Panelists also

provided written comments on the positive and negative attributes of the samples. Color measurements (L*, a*, b*) were taken using a Minolta Chroma-meter CR-400 (D65 light source with a 2° Observer; Konica Minolta, Grand Rapids, MI) on the ends cut off to square off the cooked steak sample. Calibration was completed using a white tile (Y: 93.80; x: 0.3158; y: 0.3324) between each consumer session. Triplicate readings were taken from the middle of the cut side of each steak. Hue angle was calculated using the formula: 360*arctangent([a*/b*]/6.2832), where all b* and a* values were observed to be > 0. Chroma was calculated using the formula: $\sqrt{}([a^*]^2+[b^*]^2)$.

3.5 Warner-Bratzler Shear Force

After steaks were removed from the grill, they were stored over night at 4°C. Up to six cores, 1.3 cm in diameter, were removed parallel to the muscle fibers, avoiding excessive fat or connective tissue areas that were not representative of the steak. Each core was sheared once, perpendicular to the muscle fibers, on a United Testing machine (United SSTM-500, Huntington Beach, CA). The crosshead speed was 200 mm/min using a 500 kg load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak. The peak force (kg) needed to shear each core was recorded and the mean peak shear force of the six cores was used for statistical analysis.

3.6 Gas Chromatography/Mass Spectrometry

The frozen extra cubes (1.3 cm x 1.3 cm x steak thickness) from the trained panel were weighed and placed in a 473 mL glass jar with a Teflon lid to be placed in a water bath held at 70°C, about the normal holding temperature for sensory analyses. After equilibrating for 60 min, a solid-phase micro-extraction (SPME) portable field sampler

(Supelco 504831, 75 μm carboxen/polydimethylsiloxane [PDMS], Sigma-Aldrich, St. Louis, MO) was inserted through the lid in order to collect the headspace above each meat sample in the glass jar for 2 h. After collection, the SPME was removed from the jar and injected into the injection port of a gas chromatograph (GC; Agilent Technologies 7920 series GC, Santa Clara, CA), where the sample was desorbed at 280°C for 3 min. The sample was then loaded onto the multi-dimensional gas chromatograph into the first column (30 m × 0.53 mm ID/BPX5 [5% phenyl polysilphenylene-siloxane] × 0.5 μm, SGE Analytical Sciences, Austin, TX). Through the first column, the temperature started at 40°C and increased at a rate of 7°C/min until reaching 260°C. Upon passing through the first column, the compounds passed on to a second column (30 m × 0.53 mm ID [BP20 — polyethylene glycol] × 0.50 μm, SGE Analytical Sciences). The GC column then went to a mass spectrometer (MS; Agilent Technologies 5975 series MS, Santa Clara, CA) for quantification and identification using the Wiley Chemical Library. Up to two technicians were present per sample to record aromatic events (AromaTrax) via the olfactory port. Chemicals present during an aroma event and exceeding a quality report from the MS of 80 were used for analysis.

3.7 Statistical Analysis

The data was analyzed as a completely randomized design, using steak cut and grill temperature as fixed effects for each analysis with the alpha value set at 5% using JMP12 (SAS Institute, Inc. Cary, NC) and SAS (v9.4, SAS Institute, Inc. Cary, NC). Weight of sample was used as a covariate for GC/MS results. Consumer testing was blocked by day, and order the sample was served was included as a random effect.

Trained panel results were analyzed using PROC GLM. Panelist effect was tested to determine any bias for treatment but was insignificant. Panelists' scores were averaged over treatment with order included as random effect and blocked by day in the model. Raw weight was included in the model as a covariate for cooking times. Least squares means of steak type and grilling temperature were reported. The alpha value was set at 0.05, and P – values between 0.05 and 0.10 are discussed as trends. When F-test was determined to be significant, Student's t-test was utilized for mean separation of treatments. Interactions were included in the model for analysis. Interactions determined to be insignificant ($P > 0.25$) were only removed from the model for trained panel analysis.

4. RESULTS AND DISCUSSION

4.1 Initial Color and pH

Table 2 depicts the average color and pH measurements of the subprimals after aging 21 d post-processing. The top sirloin butt subprimals were lighter (l*; $P = 0.049$) than the strip loins. Top sirloin butts were an average of 3.4 units redder (a*) and 2 units more yellow (b*) than the ribeye and strip loin subprimals ($P < 0.001$). The top sirloin butts were an average of 0.05 pH units lower ($P < 0.001$) than the ribeye and strip loin. The average pH of beef subprimals ranged between 5.4 and 5.7 (Viljoen et al., 2002). As meat ages, it can increase in pH (Boakye and Mittal, 1993); however, the pH of the subprimals was considered within an acceptable range at 21 d post-processing.

4.2 Cooking Times and Yield

Tables 3 & 4 depict the average raw weight, cooking time steaks took for side one time (initial placement on grill until internal temperature reached 35°C), side two time (flipping time at internal temperature of 35°C to endpoint temperature of 71°C), total time, and cook yield (%). No significant interactions ($P > 0.05$) were detected. Cook time did not differ ($P > 0.32$) amongst steak types for side one, side two, or total times despite the difference in size, as the top sirloin steaks were the smallest ($P < 0.001$) by raw weight in size. Moreover, the cook yields among steak type did not differ ($P = 0.47$).

The cook time on side one of steaks grilled on different grill surface temperatures did not differ ($P = 0.20$). However, steaks grilled on a surface temperature of 205°C took the longest ($P = 0.034$) time on side two (432 s), and those grilled on a surface

temperature of 232°C took the shortest time (365 s). However, cook yield was not affected ($P = 0.18$) by grill surface treatment. These cooking time results for sides one and two as well as total cook time are similar to those found by Berto (2015). Berto (2015) reported the grill surface temperatures at time of flip and endpoint time to be less than the initial grill surface temperature. Accordingly, the grill surface temperature may have decreased by heat transfer mechanisms such as evaporative cooling and moisture from the steaks. The grill used in the present study was the same grill used in Berto (2015), but a third grill surface temperature was utilized in the present study. The addition of a grill surface temperature of 205°C created a greater range of total and side two cook times, which may be a key observation in understanding the relationship between time and temperature as it pertains to the development of a crust. At greater heating surface temperatures, a thicker crust develops (Portanguen et al., 2014) in addition to the build up of a vapor steam front. This front may have enough heat energy to drive temperatures up quicker at steaks grilled at 232°C, and may be hindered at steaks grilled at 205°C. Additionally, flavor development has a time and temperature relationship (Dashdorj et al., 2015), and there may be a need to investigate these relationships further.

4.3 Trained Sensory Panel

Table 3 illustrates the flavor and tenderness scores averaged across the trained sensory panel. No significant interactions ($P > 0.05$) were detected. The ribeye, strip loin, and top sirloin steaks were given similar ($P > 0.19$) trained sensory panel scores for bloody/serumy, fat-like, green-haylike, salty, sour aromatics, green, and overall

tenderness. Burnt tended ($P = 0.063$) to be greater for the strip loin steaks compared to ribeye and top sirloin steaks. Bitter tended ($P = 0.059$) to be greater for top sirloin steaks than strip loin and ribeye steaks. Beef identification was highest ($P < 0.001$) for strip loin steaks, followed by ribeye steaks, and lowest for top sirloin steaks (11.0, 10.7, and 10.3, respectively). Glascock (2014) found similar scores for beef identity attributes between cuts and determined beef identity was most influenced by degree of doneness that was controlled in this study. Brown/roasted was greater ($P < 0.001$) for ribeye and strip loin steaks than top sirloin steaks. Steaks with higher brown/roasted flavor aromatics were cooked to higher degrees of doneness with more marbling and had higher consumer overall liking (Berto et al., 2016; Glascock, 2014). Metallic, liver-like, and sour flavors were higher ($P < 0.001$) for top sirloin steaks than ribeye and strip loin steaks.

Scores for umami, overall sweet, and sweet attributes were higher ($P < 0.014$) for ribeye and strip loin steaks than top sirloin steaks. Kerth and Miller (2015) presented these attributes to be grouped with steaks that had a greater presence of intramuscular fat in a partial least squares regression analysis ($r^2 = 0.87$), but top sirloin steaks are not prominent in fat and generally yield a leaner product (Garrett and Hinman, 1971). Strip loin steaks were juicier ($P = 0.01$) than ribeye and top sirloin steaks (10.8, 10.5, and 10.3, respectively). The strip loin steaks tended ($P = 0.082$) to cook for the longest total time but did not differ in cook yield ($P = 0.47$; Table 3). Portanguen et al. (2014) describes the development of a crust in layers, where the outermost layer is the driest and the innermost layer has the greatest water activity. The outermost layer of the strip loin steaks may have developed more as a barrier rather than individual channels

between muscle fibers as reported by Portanguen et al. (2014), thus acting more so as a "seal" to the water vapor, resulting in the largest scores for juiciness. Ribeye and strip loin steaks were more tender with less ($P < 0.03$) connective tissue amount than top sirloin steaks. These results were expected due to the differences in tenderness of support and locomotive muscles (Belew et al., 2003).

Bloody/serumy, fat-like, metallic, liver-like, green-haylike, umami, overall sweet, sweet, sour, salty, sour aromatics, and green flavor attributes did not differ ($P > 0.12$) due to grill surface temperature treatments (Table 4). Bitter tended ($P = 0.062$) to be less in steaks grilled at 205°C than those grilled at 177 or 232°C. Brown/roasted and burnt flavor attributes were higher ($P < 0.001$) for steaks grilled at 232°C compared to those grilled at 177 or 205°C. These attributes were most likely driven by the generation of pyrazines and pyrroles, products of the Maillard reaction as a result of dry, high temperature cooking (Kerth and Miller, 2015). Beef identity flavor was lower ($P = 0.001$) for steaks grilled at 177°C than those grilled at 205 or 232°C (10.4 vs. 10.8 and 10.9, respectively). Juiciness scores were higher ($P = 0.043$) for steaks grilled at 232°C than 205°C. However, no differences ($P > 0.23$) were detected in steaks grilled at three different surface temperatures in muscle fiber tenderness, connective tissue amount, and overall tenderness. These results were not expected. Berto et al. (2016) determined steaks cooked at 176°C were tougher than those cooked at 232°C. Conversely, the tenderness scores for these steaks were greater than 11, so the steaks were very tender despite the grill surface treatments. The steaks were very tender to begin with due to being aged 21 d post-processing. Therefore, grill temperature may cause differences in

crust development (Portanguen et al., 2014) but does not result in tenderness differences once steaks surpass a certain tenderness threshold.

4.4 Warner-Bratzler Shear Force

No significant interactions were detected with steak type by grill temperature for Warner-Bratzler shear force ($P > 0.05$). Strip loin steaks had 0.26 kg less ($P = 0.033$) peak shear force than ribeye and top sirloin steaks (Table 4; 2.58 vs. 2.84 and 2.85 kg shear force, respectively). Similarly in the 2015 National Beef Tenderness Survey, food service ribeye and top sirloin steaks averaged 3.0 kg of shear force; whereas, top loin steaks averaged 2.5 kg of shear force (Henderson, 2016). Grill surface treatment had no effect ($P = 0.82$) on peak shear force. Greater grill surface temperatures yield a greater crust development and drier surface (Portanguen et al., 2014). However, meat from that experiment was aged for only 12 d, and tenderness was not evaluated. Additionally, tenderness measurements by Warner-Bratzler shear force evaluate the peak force needed to break the muscle fibers at the center of the core, thereby effectively avoiding the crust when measuring. The average peak shear force ranged from 2.72 to 2.79 kg for the grill surface temperature, which are similar to the national average for shear force across meat cuts (Henderson, 2016). These measurements were lower than the minimum tenderness threshold value by more than 1 kg shear force and would thereby qualify the meat products for the "certified very tender" labeling (ASTM, 2011).

4.5 Consumer Sensory Panel

Consumers (n = 80) were recruited to participate in the study if they were beef-eaters with no known food allergies. Table 5 depicts the demographics of the consumer

base. Consumers were predominantly female (52.5 %), under the age of 36 (58.75 %), Caucasian (85 %), with 2 people in their household (35 %), and employed full-time (61.25 %).

No significant interactions between steak type and grill temperature were detected ($P > 0.05$). Consumers liking did not differ ($P > 0.31$) for appearance, tenderness, juiciness, flavor, and overall liking by steak type (Table 6). In fact, average hedonic scores for liking numerically ranged by no more than 0.2 points for each attribute. Consumer scores for appearance, tenderness, juiciness, flavor, or overall liking also did not differ ($P > 0.21$; Table 7) with grill surface temperature treatments. The average hedonic liking score had a narrow numeric range of no more than 0.3 for each of the attributes. While a consumer preference for grill surface temperature was not detected in this study, consumers may have a preference for grill surface temperature of steaks. Berto (2015) determined an interaction between grill temperature and thickness of steak to exist for overall, overall flavor, beef flavor, grill flavor, and juiciness liking and there to be a tendency for an interaction of tenderness liking amongst consumers. Accordingly, consumers may give steaks grilled at the preferred grill surface temperature a larger liking score, for consumers have a strong affinity for steaks cooked to their desired preparation such as degree of doneness (Cox et al., 1997; Savell et al. 1987).

The center color of cooked ribeye steaks was lighter (L*; $P = 0.04$) than center color of strip loin and top sirloin steaks by nearly 1.5 units. The hue angle of ribeye steaks was greater ($P = 0.03$) than top sirloin steaks (Table 8; 57.97 vs. 48.77). However,

the redness, blueness and color saturation (a*, b*, and chroma value, respectively) did not differ ($P > 0.18$) between steak type. Table 9 presents the least squares means for L*, a*, and b*, and color space values of hue angle and chroma for the center color of the steaks by grill surface temperature treatments. Steaks grilled at a surface temperature of 177°C tended ($P = 0.052$) to be less yellow than those grilled at 205 or 232°C (12.04 vs. 12.51 and 12.64, respectively). No difference ($P > 0.50$) was detected between grill surface treatments of the other center color measurements. Color is a measure of light reflectance from a surface and is greatly influenced by water content (Qiao et al., 2001). The transfer of heat and energy can influence water content. The similarity in the center color of cooked steaks can indicate the migration of moisture from the center of the steak, which was controlled by cooking steaks to a final internal temperature. The center color of the steaks may have been different if steaks had all been cooked to a set time parameter instead. Additionally, the state and presence of myoglobin and its bound ligand can influence the color of meat. Steaks cooked to higher degrees of doneness have a greater proportion of myoglobin denaturation, leading to greying at the center of the steak (Bernofsky et al., 1958). Myoglobin denaturation is highly dependent on temperature and occurs between 60 (rare degree of doneness) and 80°C (well done degree of doneness; Meersman et al., 2002), which yields the difference in the center color of steaks grilled to internal temperatures within this range. Although myoglobin was not measured in the present study, center color did not indicate a difference in myoglobin denaturation amongst grill surface temperatures.

4.6 Gas Chromatography – Mass Spectrometry

Volatiles present during an aroma event (n = 65) are presented by cut and grill surface temperature in Tables 10 and 11, respectively. Volatile compounds were classified by their major functional groups and included seven alcohols, 26 aldehydes, four alkanes, two furans, five ketones, 11 pyrazines, two pyrroles, five sulfur-containing compounds, and three other compounds.

(E)-2-Decenal (waxy, orange odor), sulfur dioxide, 3-dodecenal (fatty odor), and 2-ethyl-3,5-dimethyl-pyrazine (toasted nut, sweet woody, roasted cocoa; Burdock, 2016) had significant interactions. (E)-2-Decenal (Figure 1) was lowest ($P = 0.049$) in strip loin and ribeye steaks and highest for top sirloin steaks grilled at 177°C. In fact, the volatile was produced in increasing ($P < 0.05$) amounts at increasing grill temperatures for ribeye and strip loin steaks, but it decreased ($P < 0.05$) at increasing grill surface temperatures for top sirloin steaks. The waxy odor of (E)-2-decenal may be attributed to lipid degradation that would be generated at higher surface temperatures and in steaks with higher lipid content such as marbling (Dashdorj et al., 2015). This compound may also have been the result of cleaving a polyunsaturated fatty acid. Yancey et al. (2006) determined significant, though low, correlations to exist (r = -0.20) between livery scores and 16-, 17-, and 18-carbon fatty acid chains in steaks aged between 7 and 35d. Yancey et al. (2006) also found that (E)-2-decenal was present in higher concentrations in high scoring livery steaks. The top sirloin steaks were highest for livery and metallic flavors in the present study. Sulfur dioxide was present ($P = 0.002$) in top sirloin steaks grilled at 177°C (Figure 2). 3-Dodecenal was highest ($P = 0.032$; Figure 3) in top sirloins

grilled at 177°C and decreased with increasing grill surface temperature for top sirloin steaks. 3-Dodecenal tended to increase as grill surface temperatures increased above 232°C for strip loin steaks. 3-Dodecenal was variable and statistically similar ($P > 0.05$) in the ribeye steaks. 3-Dodecenal can be a product of lipid oxidation or Maillard reaction, which may explain the resulting variability. 2-ethyl-3,5-dimethyl-pyrazine (Figure 4) was highest ($P = 0.049$) in top sirloin steaks grilled at 177°C and ribeye steaks grilled at 205°C. It tended to decrease with increasing grill temperatures in top sirloin steaks and was not detected in strip loin steaks. This compound is generated from the reaction of glucose and glutamate in the presence of sodium hydroxide (Maga, 1992); therefore, it is a unique product of the Maillard reaction but may only be detected at lower grill temperatures, as secondary products may not have had time to develop.

Volatile compounds with an alcohol functional group did not differ ($P > 0.11$) among steak type or grill surface temperature. A larger ($P < 0.037$) total ion count (TIC) of acetaldehyde and nonanal was found in top sirloin steaks than ribeye and strip loin steaks. Acetaldeyde in meat products has a fruity aroma, and nonanal produces a fatty, citrus-like aroma (Burdock, 2016). Nonanal can be an indicator of lipid oxidation that may have occurred to a higher degree in top sirloin steaks due to the greater presence of heme iron (Yancey et al., 2006). Top sirloin steaks also had higher ($P = 0.024$) decanal TIC than ribeye steaks, which may have been associated with a floral or cilantro stem aroma (Burdock, 2016). Phenyl acetaldehyde, with a nuance of rosy and slightly fermented note, was higher ($P = 0.031$) in strip loin and top sirloin steaks than ribeye steaks. (E)-2-Nonenal is associated with dried orange peels, and the TIC tended to be

higher (P = 0.053) in strip loin steaks as well. All other volatiles classified with an aldehyde group did not differ (P > 0.05) among steak type. Additionally, while 2,4-decadienal, an aroma closely related to chicken fat (Burdock, 2016), tended to decrease (P = 0.09) in TIC in steaks grilled at higher surface temperatures. Grill surface temperature had no effect (P > 0.09) on volatiles present with an aldehyde functional group.

Styrene TIC tended to be higher (P = 0.072) in strip loin steaks and tended to increase (P = 0.06) with increasing grill surface temperatures. Styrene has an extremely penetrating aroma similar to that of balsamic, sweet and almost floral (Burdock, 2016). However, all other alkanes did not differ (P > 0.30) among steak type or grill surface temperatures.

Total ion count of 2-furan carboxaldehyde and 2-pentyl-furan did not differ (P > 0.15) among steak type or grill surface temperature. Furan groups have been shown to develop with the Maillard reaction (Dashdorj et al., 2015). Top sirloin steaks had higher (P < 0.012) 2,3-butanedione, known to have a very strong buttery odor, and acetoin, an important Maillard reaction intermediate known to have a bland, woody, yogurt aroma, (Burdock, 2016; Dashdorj et al., 2015) than both ribeye and strip loin steaks. 2,3-Octanedione, with a green-type aroma, was higher (P = 0.014) in ribeye steaks than top sirloin and strip loin steaks. All other volatile compounds classified with a ketone functional group did not differ (P > 0.58) among steak type, and moreover, all volatiles classified as ketones did not differ (P > 0.12) among steaks cooked at different grill

surface temperatures. Additionally, the amount of acetic acid, hexanoic acid, and toluene TIC also were not affected ($P > 0.16$) by steak type and grill surface temperature.

Pyrazine volatile compound TIC did not differ ($P > 0.15$) across steak type. Pyrazines are a common intermediate product of the Maillard reaction and were expected to differ in steaks cooked at different grill surface temperatures as seen in Berto et al. (2016). 2-Ethyl-5-methyl-pyrazine (nutty, roasted, grassy aroma), 2-ethyl-6-methyl-pyrazine (baked potato aroma), 3-butyl-2,5-dimethyl-pyrazine, and trimethyl-pyrazine (no known aroma; Burdock, 2016) were higher ($P < 0.004$) in steaks cooked at a grill surface temperature of 232°C than steaks cooked at 177 or 205°C. 2-Ethyl-5-methyl-pyrazine is produced from the reaction of glucose, sodium hydroxide, and ammonium hydroxide and is a common pyrazine in chicken meat (Maga, 1992). 2-Ethyl-6-methyl-pyrazine is produced by the same reactants, and Mottram (1985) determined it to be one of five pyrazines that were produced in the largest quantities in well-done grilled pork. Trimethyl-pyrazine has been documented to increase in coffee with roasting applications and is formed from glucose and L-leucine (Maga, 1992). MacLeod and Ames (1987) determined trimethyl-pyrazine was one of two pyrazines present in higher concentrations when ground beef samples were defatted. Additionally, 2,3-dimethyl pyrazine (nutty and cocoa-like aroma with a green note) was only present ($P = 0.028$) at a grill surface temperature of 232°C, and it is formed from the reaction of sucrose and threonine (Maga, 1992). 2,5-Dimethyl-pyrazine (earthy and potato-like aroma) was higher ($P = 0.001$) in steaks cooked at a grill surface temperature of 232°C than in steaks cooked with a 205°C or 177°C surface temperature (Burdock, 2016). 2,5-

Dimethyl-pyrazine has been reported to have a highly over roasted flavor in coffee beans at concentrations greater than 1 ppm (Bauermeister, 1981) and is formed from D-glucose and an aminobutyric acid (Maga, 1992). All other pyrazine volatiles were not affected ($P > 0.13$) by grill surface temperature. While the TIC of 1-(1H-pyrrol-2-yl)-ethanone (no known odor) tended to be greater in top sirloin steaks ($P = 0.078$) and steaks grilled at 205°C ($P = 0.096$), volatiles classified as pyrroles were not affected ($P > 0.36$) by steak type or grill surface temperature.

Methanethiol, known to have a decomposing cabbage and garlic aroma, was not impacted ($P = 0.37$) by steak type. Carbon disulfide tended to be highest ($P = 0.096$) in top sirloin steaks and least in strip loin steaks. Thiobis-methane can have a sulfureous, fishy, creamy, vegetable, or fruity aroma (Burdock, 2016) at different detection levels and was higher ($P < 0.0001$) in top sirloin steaks than ribeye or strip loin steaks. 3-(Methylthio)-propanal, with a powerful onion, meat-like odor (Burdock, 2016), was lowest ($P = 0.015$) in ribeye steaks.

While 65 volatile compounds were identified during an aroma event, grilling surface temperature impacted pyrazines, produced by the Maillard reaction of an amino acid and sugar compound, to the greatest degree. The degradation of lipid is most responsible for the generation of hydrocarbons, alcohols, aldehydes and ketones (Dashdorj et al., 2015), which differences were more influenced by steak type rather than grilling surface temperature.

5. CONCLUSIONS

Ribeye, strip loin and top sirloin steaks were grilled on a surface temperature of 177, 205, or 232°C. Consumer sensory panel, trained sensory panel, Warner-Bratzler shear force, and GC/MS-O were performed in order to investigate whether steaks grilled at higher temperatures yielded a tougher steak and to define differences in the Maillard reaction compounds produced. Grill surface temperature did not impact the tenderness of ribeye, strip loin, or top sirloin steaks age 21 d post-processing. Consumers' liking scores did not differ amongst steaks grilled at a particular grill surface temperature. However, grill surface temperature did change the flavor and corresponding volatile compounds of steaks. With increasing grill surface temperature, the production of pyrazines increased; therefore, greater grill surface temperatures yielded greater Maillard reaction products.

Although a consumer preference for grill surface temperature was not detected in this study, consumers still had a preference for how their steaks were prepared. A difference in grill surface temperature generated different flavor attributes in steaks, which should be investigated further to determine the optimal grilling temperature for favorable flavor production when steak tenderness is below the tenderness threshold. Additionally, grill surface temperature may have an impact on the tenderness of steaks aged less than 21 d post-processing.

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APPENDIX A

Table 1. Definition and reference standards for beef descriptive flavor and basic taste sensory attributes and their intensities where 1 = none and 16 = extremely intense from Adhikari et al. (2011).

Attributes	Definition	References
Beef Identity	Amount of beef flavor identity in the sample	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bitter	The fundamental taste factor associated with a caffeine solution	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/ Serumy	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatics.	USDA Choice strip steak = 5.5 Beef brisket = 6.0 Boneless pork chop, 135°F = 2.0
Brown/ Roasted	A round, full aromativ generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0 Pork Fat, cooked and browned = 3.0
Buttery	Sweet, dairy-like aromatic associated with natural butter.	Land O'Lakes unsalted butter = 7.0
Burnt	The sharp/acrid flavor note associated with over-roasted beef muscle, something over-baked or excessively browned in oil	Alf's red wheat Puffs = 5.0
Fat-like	The aromatics associated with cooked animal fat	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0 Chicken fat (thigh), covered with water, cooked in pan with lid, boiled for 20 minutes, remove lid and cooked until the water evaporates = 8.0 Grilled chicken skin in skillet set at 350°F until brown = 5.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut	Fresh parsley water = 9.0

	grass, etc.	
Green-Haylike	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in ~30 mL cup = 6.0
Liver-like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5 Oscar Mayer Braunschweiger liver sausage = 10.0 Pork liver, 71°C = 15.0 Chicken liver, 71°C = 9.0
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall Sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5
Salty	The fundamental taste factor of which sodium chloride is typical	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour Aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of flutamate, salts of amino acids and other molecules called nucleotides	0.035% accent flavor enhancer solution = 7.5
Juiciness	The amount of perceived juice that is released from the product during mastication.	Carrot = 8.5 Mushroom = 10.0 Cucumber = 12.0 Apple = 13.5 Watermelon = 15.0 Choice top loin steak cooked to 58°C = 11.0 Choice top loin steak cooked to

		80°C = 9.0
Muscle Fiber Tenderness	The ease in which the muscle fiber fragments during mastication	Select eye of round steak cooked to 70°C = 9.0 Select tenderloin steak cooked to 70°C = 14.0
Connective Tissue Amount	The component of the muscle surrounding the during mastication	Cross cut beef shank cooked to muscle fiber that will not break down 70°C = 7.0 Select tenderloin cooked to 70°C = 14.0
Overall tenderness	Average of muscle fiber tenderness and connective tissue amount when connective tissue amount is 6 or less	If connective tissue amount is 12 to 15, then overall tenderness = the value of muscle fiber tenderness; if connective tissue amount is less than 12, then overall tenderness is the average of connective tissue amount and muscle fiber tenderness.

Table 2. Least squares means for color and pH of subprimals aged 21 d post-processing date.

Measurement	Ribeye	Strip Loin	Top Sirloin	SEM	*P* > F
L*	45.86[a,b]	45.42[b]	46.68[a]	0.364	0.049
a*	16.00[b]	15.83[b]	19.34[a]	0.290	<0.001
b*	8.77[b]	8.43[b]	10.60[a]	0.217	<0.001
pH	5.52[a]	5.53[a]	5.47[b]	0.008	<0.001

[a,b] LSMeans in the same row with different superscripts differ ($P < 0.05$)

Table 3. Least squares means of trained sensory panel scores for flavor attributes , Warner-Bratzler average peak shear force, and cooking parameters of ribeye, strip loin, and top sirloin steaks.

Attribute	Ribeye	Strip Loin	Top Sirloin	SEM	$P > F$
Bloody/Serumy	2.1	2.1	2.0	0.04	0.72
Beef Identification	10.7[b]	11.0[a]	10.3[c]	0.08	<0.001
Brown/Roasted	10.3[a]	10.6[a]	9.9[b]	0.10	<0.001
Fat-Like	2.1	2.2	2.1	0.04	0.61
Burnt	0.3	0.4	0.2	0.05	0.063
Metallic	2.3[b]	2.5[b]	2.7[a]	0.04	<0.001
Liver-Like	0.2[b]	0.3[b]	0.4[a]	0.03	0.001
Green-Haylike	0.0	0.0	0.0	0.01	0.253
Umami	3.4[a]	3.3[a]	2.7[b]	0.06	<0.001
Overall Sweet	1.2[a]	1.2[a]	1.0[b]	0.03	0.002
Sweet	1.7[a]	1.7[a]	1.6[b]	0.03	0.014
Sour	2.2[b]	2.3[b]	2.7[a]	0.04	<0.001
Salty	2.0	2.1	2.0	0.01	0.65
Bitter	2.0	2.0	2.2	0.06	0.059
Sour Aromatics	0.0	0.0	0.0	0.01	0.37
Green	0.0	0.0	0.0	0.01	0.19
Juiciness	10.5[b]	10.8[a]	10.3[b]	0.10	0.007
Muscle Fiber Tenderness	11.5[a]	11.6[a]	11.0[b]	0.12	0.001
Connective Tissue Amount	12.3[a]	12.2[a]	11.9[b]	0.09	0.030
Overall Tenderness	11.8	11.7	11.5	0.44	0.84
WBSF, kg*	2.84[a]	2.58[b]	2.85[a]	0.08	0.03
Raw Weight, g	360.1[a]	333.7[a]	286.9[b]	11.8	<0.001
Side 1 Cook Time, s**	391	414	404	22.0	0.80
Side 2 Cook Time, s**	370	408	425	24.9	0.34
Total Cook Time, s	760	819	828	35.0	0.32
Cook Yield, %	79.0	79.4	77.9	0.89	0.46

[a,b,c] LSMeans in the same row with different superscripts differ ($P < 0.05$).

* Warner-Bratzler shear force, kg of shear force

** Average cook time steak was on grill to flipping point of 35°C (side 1) and from flipped time to final endpoint temperature (side 2).

Table 4. Least squares means of trained sensory panel scores for flavor attributes, Warner-Bratzler average peak shear force, and cooking parameters of steaks grilled at a surface temperature of either 177°C, 205°C, or 232°C.

Attribute	177°C	205°C	232°C	SEM	*P* > F
Bloody/Serumy	2.0	2.1	2.1	0.04	0.80
Beef Identification	10.4[b]	10.8[a]	10.9[a]	0.08	0.001
Brown/Roasted	10.0[b]	10.2[b]	10.6[a]	0.10	0.001
Fat-Like	2.2	2.1	2.1	0.05	0.34
Burnt	0.1[b]	0.2[b]	0.6[a]	0.06	<0.001
Metallic	2.5	2.5	2.5	0.04	0.64
Liver-Like	0.2	0.3	0.3	0.04	0.14
Green-Haylike	0.0	0.0	0.0	0.01	0.86
Umami	3.0	3.2	3.2	0.06	0.17
Overall Sweet	1.1	1.1	1.1	0.03	0.86
Sweet	1.6	1.7	1.6	0.03	0.13
Sour	2.4	2.4	2.4	0.04	0.94
Salty	2.0	2.1	2.0	0.01	0.45
Bitter	2.1	1.9	2.2	0.07	0.062
Sour Aromatics	0.0	0.0	0.0	0.01	0.51
Green	0.0	0.0	0.0	0.01	0.22
Juiciness	10.6[ab]	10.3[b]	10.7[a]	0.10	0.043
Muscle Fiber Tenderness	11.3	11.2	11.5	0.13	0.23
Connective Tissue Amount	12.1	12.1	12.2	0.10	0.64
Overall Tenderness	11.1	12.0	11.9	0.46	0.30
WBSF, kg*	2.72	2.77	2.79	0.08	0.82
Raw Weight, g	320.7	338.4	321.5	11.8	0.50
Side 1 Cook Time, s**	411	426	372	22.0	0.80
Side 2 Cook Time, s**	406[ab]	432[a]	365[b]	18.3	0.034
Total Cook Time, s	815[a]	855[a]	737[b]	25.6	0.005
Cook Yield, %	79.3	79.5	77.4	0.89	0.18

[a,b,c] LSMeans in the same row with different superscripts differ ($P < 0.05$).

* Warner-Bratzler shear force, kg of shear force

** Average cook time steak was on grill to flipping point of 35°C (side 1) and from flipped time to final endpoint temperature (side 2).

Table 5. Consumer demographic information.

Category	Response, %
Gender	
Male	47.50
Female	52.50
Age	
20 or younger	5.00
21 to 25	28.75
26 to 35	25.00
36 to 45	18.75
46 to 55	8.75
56 to 65	8.75
66 or older	5.00
Ethnicity	
African-American	0.00
Asian/Pacific Islander	2.50
Caucasian	85.00
Latino or Hispanic	10.00
Native American	1.25
Other	1.25
Household Income	
Below $25,000	22.50
$25,001 to 49,999	17.50
$50,001 to 74,999	21.25
$75,001 to 99,999	10.00
$100,000 or more	28.75
Number in Household	
1	21.25
2	35.00
3	17.50
4	17.50
5 or more	8.75
Employment Level	
Not employed	16.25
Part-time	22.50
Full-time	61.25

Consumers (n = 80) were recruited if they consumed beef and had no known food allergy to attend one of four sessions.

Table 6. Least squares means of consumer appearance, tenderness, juiciness, flavor, and overall like of ribeye, strip loin, and top sirloin steaks.

Attribute*	Ribeye	Strip Loin	Top Sirloin	SEM	*P* > F
Overall Like	6.4	6.5	6.3	0.12	0.48
Appearance	6.5	6.6	6.6	0.10	0.61
Tenderness	6.3	6.3	6.1	0.14	0.31
Juiciness	6.0	6.2	6.0	0.17	0.70
Flavor	6.4	6.4	6.3	0.13	0.94

* Attributes were scored on a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

Table 7. Least squares means of consumer appearance, tenderness, juiciness, flavor, and overall like of steaks grilled at a surface temperature of either 177°C, 205°C, or 232°C.

Attribute*	177°C	205°C	232°C	SEM	*P* > F
Overall Like	6.5	6.3	6.3	0.13	0.22
Appearance	6.6	6.5	6.5	0.10	0.74
Tenderness	6.4	6.2	6.1	0.14	0.44
Juiciness	6.2	6.1	5.9	0.17	0.21
Flavor	6.4	6.3	6.3	0.14	0.51

* Attributes were scored on a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

Table 8. Least squares means of center color of ribeye, strip loin, and top sirloin steaks.

Observation	Ribeye	Strip Loin	Top Sirloin	SEM	$P > F$
L*	58.89[a]	57.34[b]	57.45[b]	0.46	0.035
a*	13.47	13.99	14.82	0.52	0.19
b*	12.50	12.51	12.18	0.18	0.35
Hue Angle[c]	57.97[a]	55.07[a,b]	48.77[b]	2.44	0.027
Chroma[d]	18.61	18.98	19.31	0.39	0.47

[a,b] Means within same row with different superscripts differ ($P < 0.05$).
[c] Hue angle was hand calculated using the formula: 360*arctangent((a*/b*)/6.2832), where all b* and a* values were observed to be > 0.
[d] Chroma was hand calculated using the formula: $\sqrt{((a^*)^2+(b^*)^2)}$.

Table 9. Least squares means of center color of steaks grilled at a surface temperature of either 177°C, 205°C, or 232°C.

Observation	177°C	205°C	232°C	SEM	$P > F$
L*	58.02	57.45	57.34	0.46	0.90
a*	14.08	14.45	13.76	0.52	0.65
b*	12.04	12.51	12.64	0.18	0.053
Hue Angle[c]	52.75	52.75	56.30	2.44	0.50
Chroma[d]	18.73	19.27	18.89	0.39	0.62

[a,b] Means within same row with different superscripts differ ($P < 0.05$).
[c] Hue angle was hand calculated using the formula: 360*arctangent((a*/b*)/6.2832), where all b* and a* values were observed to be > 0.
[d] Chroma was hand calculated using the formula: $\sqrt{((a^*)^2+(b^*)^2)}$.

Table 10. Least squares means of total ion counts for volatile aromatic compounds present during aroma events for cooked ribeye, strip loin and top sirloin steaks as detected by GC/MS-O analysis.

Volatile	Ribeye	Strip Loin	Top Sirloin	SEM*	*P* > F
Alcohol					
1-Heptanol	0	1328	1411	722	0.26
1-Octanol	15374	11105	26973	5549	0.12
1-Octen-3-ol	9236	10454	3620	5456	0.66
1-Pentanol	15596	15989	0	8114	0.29
2-(Hexloxy)-ethanol	47980	42414	74225	18790	0.48
3-Methyl-phenol	45	2	0	24	0.29
Benzene methanol	8	37	0	20	0.21
Aldehyde					
(E)-2-Nonenal	2470	13995	6030	3686	0.054
(E)-2-Octenal	5683	91	1273	2579	0.24
2-Heptenal	3784	3638	0	1944	0.19
2-Methyl-butanal	21702	58000	28777	16578	0.22
2-Octenal	6639	16118	701	5222	0.097
2-Undecenal	13288	11926	5936	7399	0.77
2,4-Decadienal	3368	0	1255	1447	0.21
3-Methyl-butanal	56768	77925	56883	21467	0.69
Acetaldehyde	483[b]	0[b]	4447[a]	1306	0.037
Benzaldehyde	1278245	1425441	1911410	212098	0.11
Decanal	61099[b]	80014[a,b]	108799[a]	11867	0.024
Dodecanal	1916[b]	9168[b]	27174[a]	5819	0.011
Heptanal	113227	125375	97649	56467	0.94
Hexanal	1885574	1197765	1208613	438089	0.43
N-Heptanal	188842	187266	197371	70972	0.99
Nonanal	845205[b]	1041740[b]	1679604[a]	171303	0.001
Nonenal	16037	11226	10447	4581	0.64
Octanal	385770	426075	566120	97573	0.42
Pentanal	81480	48969	38612	20326	0.31
Phenyl acetaldehyde	32329[b]	57950[a]	61302[a]	9768	0.031

Tetradecanal	11248	13306	22445	5223	0.31
Tridecanal	2503	2446	15844	4310	0.052
Undecanal	155	4067	7917	4414	0.49
Undecenal	206	6115	5442	3752	0.45
Alkane					
1-Octene	2494	2027	2871	2168	0.97
Octane	11450	23544	7420	9159	0.39
Styrene	2014	4243	2737	751	0.072
Tetradecane	34	19	1438	883	0.45
Furan					
2-Furan carboxaldehyde	780	0	1335	538	0.15
2-Pentyl-furan	19562	11889	28541	7577	0.29
Ketone					
2-Butanone	30494	23078	15301	11531	0.67
2-Heptanone	4336	7767	9875	9875	0.59
2,3-Butanedione	1142[b]	26649[b]	149676[a]	32598	0.005
2,3-Octanedione	4731[a]	49[b]	0[b]	1347	0.014
Acetoin	213575[b]	202192[b]	642186[a]	113642	0.012
Other					
Acetic Acid	25942	36006	54686	10347	0.16
Hexanoic Acid	41455	12490	21701	11197	0.16
Toluene	18144	24626	51403	23996	0.55
Pyrazine					
2-ethyl-3-methyl-pyrazine	764	408	3161	1217	0.24
2-ethyl-5-methyl-pyrazine	21472	25197	24916	5886	0.88
2-ethyl-6-methyl-pyrazine	14983	13830	13016	6888	0.98
2-methyl-pyrazine	19012	10094	0	7189	0.15
2,3-dimethyl-pyrazine	4283	1012	3276	2930	0.69
2,3,5-trimethyl-pyrazine	4163	753	0	2630	0.48
2,5-dimethyl-pyrazine	159235	166356	167856	38456	0.98
3-butyl-2,5-dimethyl-pyrazine	27686	33297	33817	9197	0.87
Methyl-pyrazine	8081	8575	18683	6858	0.50
Trimethyl-pyrazine	94343	81753	82016	25217	0.92

Pyrrole					
1-(1H-pyrrol-2-yl)-ethanone	12889	22472	29308	5009	0.077
3-Acetylpyrrole	73	605	191	321	0.42
Sulfur-Containing Compounds					
Methanethiol	3831	5295	8200	2151	0.37
3-(Methylthio)-propanal	1681[b]	8645[a]	7803[a]	1896	0.015
Thiobis-methane	436[b]	1266[b]	10696[a]	1503	<0.001
Carbon Disulfide	44079	28774	75775	15485	0.096

[a,b,c] LSMeans in a row with different superscripts differ ($P < 0.05$).

* Largest standard error of the mean reported.

Table 11. Least squares means of total ion counts for volatile aromatic compounds present during aroma events for cooked steaks on grill surface temperatures of 177, 205, and 232°C as detected by GC/MS-O analysis.

Volatile	177°C	205°C	232°C	SEM*	*P* > F
Alcohol					
1-Heptanol	1388	350	944	675	0.55
1-Octanol	13168	16826	23458	5185	0.37
1-Octen-3-ol	16480	4658	2171	5098	0.11
1-Pentanol	4835	9580	16654	7583	0.54
2-(Hexloxy)-ethanol	43550	58741	62328	18076	0.74
3-Methyl-phenol	41	0	1	23	0.37
Benzene methanol	0	0	35	18.8	0.29
Aldehyde					
(E)-2-Nonenal	10642	5483	6371	3444	0.53
(E)-2-Octenal	5040	1346	660	2410	0.39
2-Heptenal	4010	1010	1629	1816	0.47
2-Methyl-butanal	18383	29742	60354	15491	0.15
2-Octenal	13238	10156	63	4872	0.14
2-Undecenal	1885	9072	20192	6914	0.18
2,4-Decadienal	1976	641	0	1351	0.086
3-Methyl-butanal	60817	52666	78092	20060	0.66
Acetaldehyde	1371	1380	2133	1220	0.88
Benzaldehyde	1370824	1627387	1616856	198202	0.59
Decanal	71868	99086	78959	11090	0.20
Dodecanal	10293	17704	10260	5437	0.54
Heptanal	60846	118023	157381	52767	0.43
Hexanal	1407849	1630469	1253435	409386	0.81
N-heptanal	241062	183574	148843	66321	0.62
Nonanal	1178545	1129611	1258191	160079	0.85
Nonenal	16239	12358	9113	4281	0.50
Octanal	471581	416789	489595	91180	0.84
Pentanal	51592	75760	41709	18993	0.43
Phenyl acetaldehyde	49846	57477	44258	9024	0.52

Tetradecanal	14273	11968	18757	4880	0.61
Tridecanal	10087	6645	4061	4027	0.57
Undecanal	2461	7701	1977	4126	0.56
Undecenal	672	9197	1894	3507	0.18
Alkane					
1-Octene	3088	0	4306	2026	0.30
Octane	20097	9583	12733	8559	0.68
Styrene	1642	3477	3875	702	0.060
Tetradecane	0	1490	11	825	0.34
Furan					
2-Furan carboxaldehyde	420	931	670	503	0.78
2-Pentyl-furan	23351	15268	21374	7081	0.70
Ketone					
2-Butanone	32800	7036	27538	10776	0.20
2-Heptanone	5889	5357	10731	3514	0.49
2,3-Butanedione	86204	59039	32225	30462	0.46
2,3-Octanedione	3475	1039	30	1259	0.13
Acetoin	506563	210905	340486	106196	0.15
Other					
Acetic Acid	37590	44904	34140	9669	0.73
Hexanoic Acid	20429	35994	19222	10772	0.47
Toluene	20371	22896	50907	22168	0.49
Pyrazine					
2-ethyl-3-methyl-pyrazine	188	886	3259	1137	0.14
2-ethyl-5-methyl-pyrazine	7014[b]	16046[b]	48525[a]	5500	<0.001
2-ethyl-6-methyl-pyrazine	969[b]	9859[b]	31001[a]	6437	0.004
2-methyl-pyrazine	1534	8160	17957	6717	0.23
2,3-dimethyl-pyrazine	0[b]	0[b]	8901[a]	2738	0.028
2,3,5-trimethyl-pyrazine	0	709	4109	2458	0.45
2,5-dimethyl-pyrazine	56918[c]	156922[b]	279606[a]	35936	0.001
3-butyl-2,5-dimethyl-pyrazine	6946[b]	27161[b]	60693[a]	8594	<0.001
Methyl-pyrazine	1683	13986	19670	6408	0.13
Trimethyl-pyrazine	18368[b]	74703[b]	165042[a]	23564	<0.001

Pyrrole					
1-(1H-Pyrrol-2-yl)-ethanone	19178	26613	18878	4681	0.096
3-Acetylpyrrole	0	302	589	300	0.36
Sulfur-Containing Compounds					
Methanethiol	5387	6155	5784	2010	0.38
3-(Methylthio)-propanal	8577	3612	5940	1772	0.23
Thiobis-methane	2618	4517	5262	1388	0.32
Carbon Disulfide	35089	70468	43072	14471	0.20

[a,b,c] LSMeans in a row with different superscripts differ ($P < 0.05$).

* Largest standard error of the mean reported.

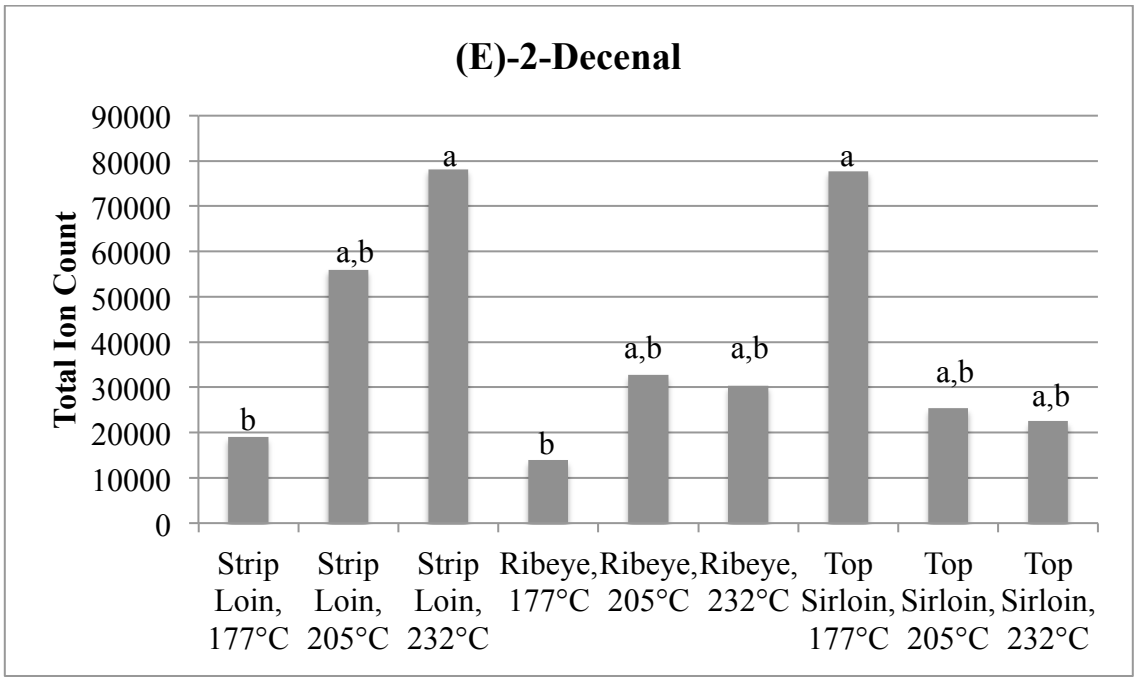

Figure 1. Interaction ($P = 0.049$) of the total ion count for (E)-2-decenal from strip loin, ribeye, and top sirloin steaks grilled at 177, 205, or 232°C. Root mean square error = 78894.

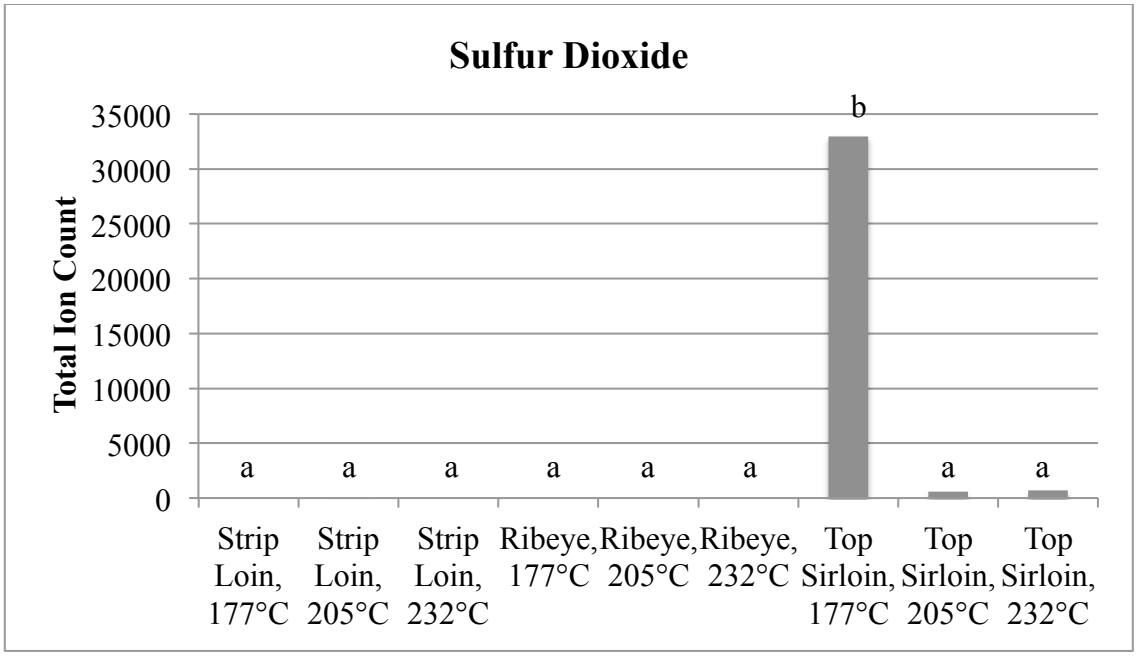

Figure 2. Interaction (P = 0.002) of the total ion count for sulfur dioxide from strip loin, ribeye, and top sirloin steaks grilled at 177, 205, or 232°C. Root mean square error = 19895.

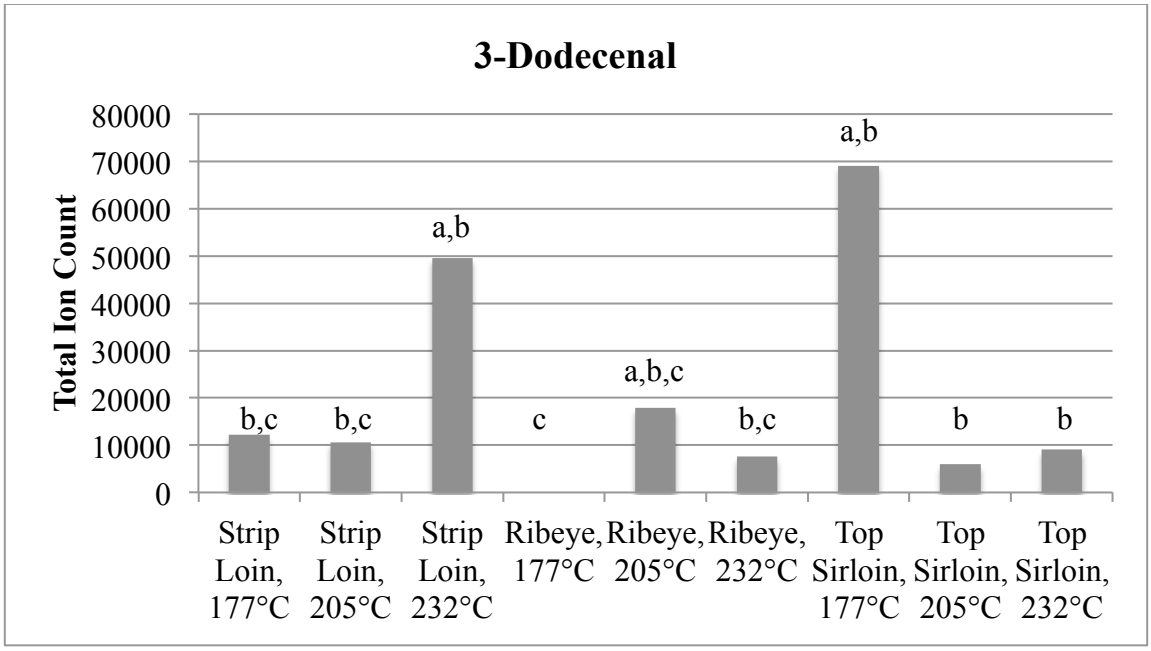

Figure 3. Interaction ($P = 0.032$) of the total ion count for 3-dodecenal from strip loin, ribeye, and top sirloin steaks grilled at 177, 205, or 232°C. Root mean square error = 69767.

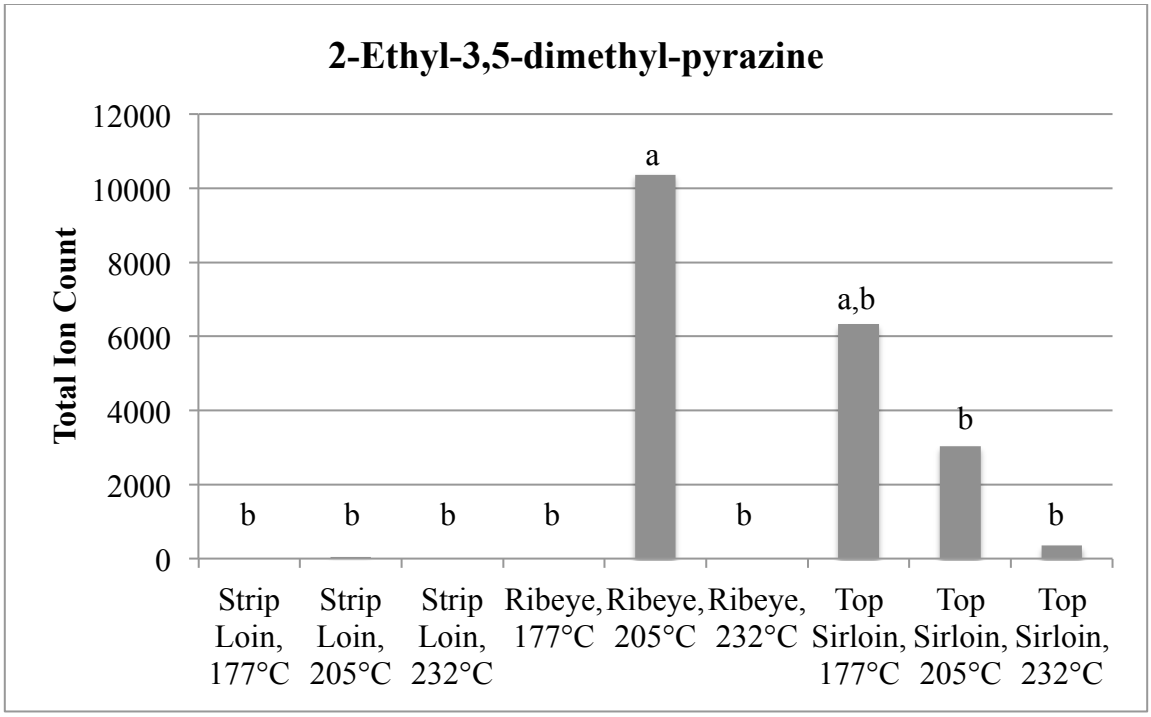

Figure 4. Interaction ($P = 0.049$) of the total ion count for 2-ethyl-3,5-dimethyl-pyrazine from strip loin, ribeye, and top sirloin steaks grilled at 177, 205, or 232°C. Root mean square error = 9770.