

THESIS

ASSOCIATION BETWEEN BEEF RIBEYE AREA MEASUREMENTS AND STEAK
PORTION SIZE

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ABSTRACT

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As cattle weights have increased over the past decades, hot carcass weight and ribeye area (REA) have also increased. The REA is an important determinant of carcass value as it impacts the thickness of steaks when portioned to a pre-determined weight. Additionally, previous research has indicated that steak thickness impacts consumers' eating experience potentially due to its impact on the degree of doneness. The objective of this study was to examine the relationship between carcass REA and steak portion size. Beef carcasses ($n = 100$) were selected from a commercial beef harvesting facility based on REA in 1 in^2 (6.45 cm^2) increments ranging from less than 11 in^2 (70.97 cm^2) to greater than 19 in^2 (122.58 cm^2) based on a United States Department of Agriculture-approved camera (E+V) with 10 total categories. Data (hot carcass weight, back fat thickness, and marbling) were collected from each selected carcass. The REA measurements were obtained using the grading camera, a manual grid, and pen tracing and measured using ImageJ software. Strip loins (IMPS#180) from selected carcasses were collected, and weight, length, and three width (anterior, middle, and posterior) measurements of the strip loins were measured manually. Each strip loin was then scanned through a Marel I-Cut 56 portion cutter to determine the thickness of 12 oz (340.19 g) and 16 oz (453.59 g) portions and to determine the weight of a 1-in (2.54 cm) thick portion. To quantify and describe the relationship between steak thickness (cut to 12 oz and 16 oz portions) and steak weight (cut at 1-in. thickness), linear regression models were developed using traced REA as the

independent variable. Additionally, more exhaustive linear regression models were developed to predict steak thickness or weight based on the traced REA, hot carcass weight, fat thickness, strip loin weight, strip loin length, strip loin width, and average maximum height of the strip loin. Each model was evaluated separately for the main effects of each variable, with significance determined at $\alpha=0.05$. There was a significant ($P < 0.001$) correlation and linear relationship ($P < 0.05$) between traced REA measurement and 12 oz ($R^2 = 0.71$), 16 oz ($R^2 = 0.71$), and 1-in.-thick ($R^2 = 0.75$) portions examined in this study. For 12 oz steaks, the steak thickness decreased by an estimated 0.055 in. (0.14 cm) for every 1-in. increase in REA. Similarly, for the 16 oz steaks, the steak thickness decreased by an estimated 0.074 in. (0.19 cm) for every square in. increase in REA. The 1-in. steak portions had a mean weight of 340 g, and the steak weight increased an estimated 18 g for each square in. increase in REA. In addition, using the strip loin measurements, linear regression models were able to predict steak thickness for 12 oz and 16 oz portions with an R^2 of 0.95 each and predict the steak weight for the 1-in. portion with an R^2 of 0.98. As expected, REA strongly correlated with the portion size of strip loin steaks cut to a specified weight or thickness. Additionally, our results indicated that the weight and length of the strip loin were good predictors of steak thickness (for 12 oz and 16 oz portions) or steak weight (for 1-in.-thick portions). Further research exploring consumer acceptance and degree of doneness for steaks with varying thicknesses would provide data to determine REA ranges and targets that would optimize steak portion sizes and consumer acceptability.

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CHAPTER 1

REVIEW OF LITERATURE

Understanding the impact of cattle size on beef processing and consumer experience is crucial for beef packers, producers, and consumers alike. Beef packers, for instance, determine a carcass's value based on characteristics such as quality grade (marbling, maturity of lean and bone), hot carcass weight (HCW), fat thickness, kidney, pelvic and heart fat (KPH), and ribeye area (REA). In a processing plant, the carcass value is typically determined by a camera that measures the fat thickness and REA and predicts quality, which allows packers to pay producers based on the carcass's value. On the other hand, consumers often make steak purchasing decisions based on the steak's appearance, and that can ultimately affect consumers' willingness to pay for the steak. Consumers will often look for consistency between steaks by seeking out branded beef programs. Some of these branded beef programs use REA as a way to control the size of the steak and create product consistency. Moreover, the size of a steak is one of many factors that could contribute to a consumer's eating experience, often influencing their decision to repurchase. However, with the increase in cattle sizes, the size of primals and subprimals of the carcass has also been changing, which impacts the size of steaks. This literature review aims to provide an overview of the evolution of cattle size over the years, the use of yield grade to predict cutability, REA measurement methods, and the profound impact of steak thickness on marketability, processing, and, most importantly, consumer experience.

1.1 Change in Cattle Sizes

Cattle sizes have continued to increase throughout time (USDA ERS, 2024), with average HCW increasing from 345 kg in 1991 to 390.3 kg in 2016 (Boykin et al., 2017). Several factors likely contribute to this trend, including animal growth-promoting technologies, selective breeding, and other new technologies (Lusk, 2013). Previous studies have indicated that diet during the backgrounding phase had no impact on HCW or REA (Loken et al., 2009); however, other factors such as implants, beta agonists, sex, and finishing diet do impact HCW and REA. Increasing the average daily gain and decreasing the number of days on feed may increase production efficiency, which can decrease the cost of raising cattle when feed prices are high (Wilken et al., 2015). This allows producers the ability to keep cattle longer if needed whether it is to increase the amount of marbling in the cattle or keep inventory higher when market prices are lower, or another reason which causes an increase in cattle size when harvested.

Another factor that might have led to an increased cattle size over the years might be how cattle prices are determined by beef processing plants. Traditionally, cattle were sold based on a cash system, and some are still marketed this way. However, since the late 1990s, the industry has shifted towards formula or grid-based contracts (Bolotova, 2022). These grids typically focus on carcass quality or yield (Tatum et al., 2006). Initially, the grid system incentivized producers to raise heavier cattle for higher prices (Arango & Van Vleck, 2002) because they are based on a price per hundred pounds. This trend continued until significant discounts were implemented for carcasses exceeding specific weight limits (USDA Economics, Statistics and Market Information System, 2024a). Currently, heavy carcass discounts apply to weights above 408 kg, with even steeper penalties for carcasses exceeding 476 kg. Importantly, these discounts can fluctuate based on processing plant capacities (USDA Economics, Statistics and Market Information System, 2024a).

While larger HCW may benefit producers financially (until discounts are applied), it presents challenges for processors. However, discounts on heavier carcass may decrease if packing plants are below capacity. Also with increased carcass size steak processor have adapted the use of innovation cuts that would minimize the impact of the subprimals becoming too large. Facilities designed for handling smaller carcasses face difficulties during processing, particularly when it comes to chilling (Agbeniga & Webb, 2018). Previous studies have shown that heavier carcasses have a slower cooling rate and lower initial temperature after an hour compared to lighter counterparts (Djimisa et al., 2022) whereas Agbeniga and Webb (2018) reported a higher postmortem temperature in heavier carcasses after 45 minutes and 24 hours. Previous research has also reported that heavier carcasses took more time to process and ultimately required more labor on a per carcass basis, but would have an increased yield (West et al., 2011). These authors further reported that even with higher saleable yield, the steak portioned by thickness in a retail setting may weigh too much, causing the unit price to be too high for customers to afford. When a survey evaluating the impact of change in carcass size on beef subprimals at a retail level, the round and loin were indicated as the most problematic because of their size being too large for the trays or that larger loins have problems with the appearance of the sirloin and T-bone steaks (Cross, 2018). Which ultimately has resulted in retail chains' lower use or modify the traditional cuts from the uniform retail meat identification standards because the inability of some of the cuts to fit on the tray (Cross, 2018). However, the exact impact of cattle weight on processing efficiency requires further investigation.

As the average HCW increases, so does the average REA, which is often used as a key indicator of the muscle composition of the rest of the carcass. The 2016 National Beef Quality Audit determined that the correlation between HCW and the longissimus muscle area (REA) was

positive ($r = 0.40$), and the average REA increased from 83.4 cm² in 1991 to 89.5 cm² in 2016 (Boykin et al., 2017). However, the strength of the association between HCW and REA is unclear, as some studies have shown a weak correlation between the two (Epley et al., 1970; Crouse et al., 1975), while Lawrence et al. (2008) reported the relationship to be quadratic instead of linear. On the other hand, Bruns et al. (2004) reported that HCW and REA were related linearly. Using live animals with varying factors such as breed, sex, age, and growth-promoting technology application may have led to different results between the studies.

1.2 Yield Grade

The REA has been a critical factor in determining carcass cutability since the introduction of yield grading in the late 1950s (Murphey et al., 1960). Early research on yield grading focused on predicting retail cut percentages using various carcass traits, and a regression model that incorporated fat thickness, kidney fat percentage, carcass weight, and REA proved most accurate (Murphey et al., 1960). The regression equation was specifically used in a dual grading system that divided yield grade into 10 sections, which differs from the system that we know now, which has 5 groups. Then, in 1965, the Agricultural Marketing Service (AMS) implemented yield grades from 1 to 5 to reflect the differences in the cutability of the carcasses (USDA AMS, 1996). Further research by Abraham et al. (1968) confirmed the importance of the four factors used in the USDA yield grade equation: hot carcass weight, fat thickness, KPH, and REA. The authors also reported that hot carcass weight accounted for the majority of the variation. Abraham et al. (1980) later reevaluated the factors within the yield grade equation to determine if new coefficients were needed in the equation to improve the accuracy of the equation because carcasses were yielding higher than predicted. However, they found no improvement over the existing equation. However, when it was evaluated again in 2008, it was determined that the current yield grade equation favors

lighter carcasses and if carcass weight increases there would be an increase in carcasses classified as yield grade 4 and 5s (Lawrence et al., 2008).

The yield grade remains a major factor in carcass value, especially under grid-based pricing systems used by numerous packers. The USDA National Weekly Direct Slaughter Cattle's Premiums and Discounts assigns premiums for yield grades below 3.0 and discounts for grades above 4.0. Specifically, a yield grade 5 carcass had a discount of \$17.45 per one hundred pounds (cwt) as of April 29, 2024 (USDA Economics, Statistics and Market Information System, 2024a).

Currently, yield grading remains the primary method for assessing beef carcass cutability in the United States. It is calculated based on four key factors: REA, HCW, the thickness of the fat over the ribeye measured $\frac{3}{4}$ th the distance of the ribeye from the chine bone (subcutaneous fat thickness), and the percentage of the KPH (USDA AMS, 2017). Yield factors have been used to estimate the number of boneless closely trimmed retail cuts with minor changes such as the change of measuring KPH to using a standardized estimate or the use of camera technology augmented with human graders to create a more reliable yield equation from its development (Lawrence, 2017). The yield grade equation states the only factor that decreases the yield grade within the equation is the REA, and every square inch increase in REA would result in a decrease in the yield grade by 0.32 (Bakker, 2022). Whereas an inch increase in fat thickness, a 1% increase in KPH, and 1 pound increase in HCW would result in an increase of 2.5, 0.2, and 0.0038 of the carcass' yield grade, respectively (Bakker, 2022). However, since only the exposed ribeye on each half of a beef carcass is used for yield grading, the yield grade offers a limited view of how other subprimal cuts would yield. The European Union utilizes a different system called EUROP. This 15-point system incorporates conformation (excellence to poor, denoted by letters E to P) and fatness (scores 1 to 5) to categorize carcasses into 10 subclasses (Craigie et al., 2013).

1.3 Ribeye Area Measurement Methods

The REA measures the longissimus muscle between the 12th and 13th rib and is used to predict carcass cutability. Over the years, the REA has been evaluated using many methods, such as ultrasound imaging, grid, camera, or tracing.

1.3.1 Ultrasound Ribeye Area Measurements

Ultrasound is a technology that allows a producer to estimate carcass traits in order to make breeding selections for terminal traits. Its first documented use in cattle was in 1956 (Temple, 1956). It is often used because it can be done on live animals and is fast and inexpensive. Since the procedure is not invasive, it can be used on cattle to estimate the composition of the animal to select for genetic improvement in the terminal traits (Ribeiro et al., 2014). Some seedstock operations and packing plants have largely adopted it to make genetic decisions.

Ultrasound works by using a real-time ultrasound machine operated by an ultrasound technician. The ultrasound machine sends sound waves into the muscle tissue through a transducer that is applied to the skin of the animal. These sound waves, which are too high of a frequency for human hearing, are reflected back and are used to generate an image (Silva & Cadavez, 2012). Each tissue type (e.g., fat or lean) has a different density, which allows the tissues to be differentiated on the image because of different shades on the image. When evaluating live steers ultrasound ribeye measurements compared to traced measurement of the carcass REA on acetate paper (measured with a planimeter), there was a high correlation between the two measurements (Greiner et al., 2003). Studies have attributed the variations in the correlation between different ultrasound technicians and laboratories to a large group of factors such as the type of ultrasound machine, the technician, the laboratory that reads the image, transducers, and scanning techniques (Schmidt et al., 2020).

1.3.2 Grid Measurements

Another method to measure REA utilizes a grid. The grid is a transparent plastic sheet marked with squares of a known area (typically 0.645 cm² or 0.1 in²) and dots in the center of the square (Steiner et al., 2003a). Researchers commonly employ this grid as a rapid method for estimating REA. According to the USDA AMS method (2011), the grid used to measure REA should be aligned with the long axis of the ribeye. The interior dots within the perimeter of the longissimus muscle are counted, followed by the dots along the boundary of the ribeye. The number from the boundary is then divided by two, added together with the interior dots, and multiplied by 0.1 to get the REA. Additionally, the AMS method also notes that this method tends to overestimate the actual REA and could result in sampling bias due to lining up the grid on the long axis. However, when gridded measurements were compared to tracing the ribeye on acetate paper and using a planimeter, there was no statistically significant difference (Hillers, 1970).

1.3.3 Camera Ribeye Measurements

The most common method used in beef packing plants in the United States to determine the official REA for the yield grade equation is using a camera for ribeye measurements, fat thickness, and quality grading (Newman, 1984). Traditionally, REA in packing plants was determined by human graders using grid overlays. However, the 1980s saw the introduction of video image analysis technology, also referred to as a camera, which provided a more automated and objective approach. Cross et al. (1983) analyzed the use of the video image analyzer (VIA) as a tool to predict the composition of the carcass when evaluated at the 9th and 10th rib. These authors concluded that the VIA was more accurate than machine-less measures and implied there was a need for more information on VIA as it had a high potential for use in the beef industry. However, it was not until the 1990s and early 2000s that camera technology was implemented in packing plants.

Early VIA systems like the BCC-1 in Europe required bulky cabinets and produced black-and-white images. Advancements led to camera systems like the BCC-2 that didn't require cabinets, captured color images, and improved fat thickness measurement (Borggaard et al., 1996). The improved dual-component VIA system was implemented to essentially capture REA, fat thickness, and the quality of the carcass all from one image at chain speed (Cannell et al., 2002) with the help of a human grader. This VIA system works by placing the camera head unit over the ribeye between the 12th and 13th rib, which captures an image.

Jones et al. (1995) compared the Australian VIA system (VIASCAN), which is composed of two parts (an image of the carcass as it moves from the slaughter floor and an image of the chilled cross-section of the ribeye), as individual parts and a whole system, to the Canadian procedure of using a grading ruler for predicting the yield of the carcass on 493 carcasses. The study found that the grading ruler explained only 10% of the variation in saleable meat yield, whereas the VIA chilled portion explained 28%, and the combination of both the whole carcass assessment and the chilled portion explained 69% of the variation. The VIA system was also found to explain 91% of the variation of the REA. The authors concluded that the VIA system showed promising results and has the potential to become a fully automated system that creates a standard worldwide. However, these authors also noted that the camera speed needed to increase from 250 carcass/hr. to 400 carcass/hr. to become useful for the industry.

Tong et al. (1999) evaluated the Canadian Visual System (CVS) to determine its accuracy and precision in predicting the saleable yield of the carcass and REA measurements. The CVS also had two parts: a scan of the hot carcass and an image of the REA from the chilled carcass. The authors reported that CVS had a high level of accuracy and precision for scanning the longissimus muscle. However, CVS had the greatest correlation when both parts of the CVS were used to make

predictions. When evaluating CVS measurements to expert graders on their ability to predict yield, Cannell et al. (2002) reported that CVS accounted for 55% of the variability in yields and REA was correlated with yields ($r = 0.63$). It was also found that CVS REA measurements were highly correlated to the actual REA that was determined by four experts with plastic grids ($r = 0.93$). These results indicated that CVS combined with human graders was more accurate than by human graders alone.

In the United States, Cannell et al. (1999) compared VIASCAN to expert graders (given unlimited time to determine factor measurement) and online graders (graders determining factor measurement at line speed) and evaluated how the VIASCAN can be used to augment the process. Findings of the study were similar to those of Jones et al. (1995). The authors reported that REA from the VIASCAN was highly correlated with the REA measurements from the expert graders and that the VIASCAN measurements from the chilled carcass would account for 64% of the variation in closely trimmed subprimals. However, when augmented with human graders, it explained 74% of the variation in closely trimmed subprimals.

In 2001, the CVS and Research Management Systems were approved for the United States Standards for Grades of Carcass Beef by AMS for measuring REA (USDA AMS, 2017). Further, in 2003, the AMS released new standards for REA size that approved the use of e+v technology (Woerner & Belk, 2008). In 2006, the USDA AMS worked towards approving the use of VIA systems for marbling and reported that the four major beef packers in the US were transitioning to using VIA systems from e+v Corporation (Wheeler et al., 2006). Eventually, VIA systems were approved for use to determine yield grade in 2007 by USDA AMS. Overall, the VIA systems allow for a larger number of cattle to be graded for quality and yield with a high degree of accuracy.

No technology has been found to completely replace a human grader because of the VIA's limited ability to measure the fat thickness correctly. Therefore, the industry uses VIA to augment the grading process (Belk et al., 1998). Belk et al. (1998) also found that there was no improvement in the accuracy of the yield grade when using VIA for all the factors and was only more accurate when only REA was taken from the VIA. Steiner et al. (2003b) built upon these findings by exploring how VIASCAN and CVS, two VIA systems, could enhance yield grade accuracy through augmentation (combining VIA with human graders). Their research confirmed that both systems measured REA highly accurately (correlation of 0.94 and 0.83 compared to experts), which indicated that VIA could be used to measure the REA without loss of accuracy. When combined with VIA-measured REA, online grader adjusted preliminary yield grade (APYG), and other carcass data (actual KPH percentage and HCW), the R-squared value for yield grade significantly increased compared to using online graders alone (0.89 for CVS and 0.81 for VIASCAN vs. 0.67 for online graders). However, when augmentation was applied in real-time to determine yield grade with an augmentation touch panel, which allowed the USDA grader to input the APYG while the VIA system input the REA, it was found that CVS and VIASCAN were highly correlated to the expert yield grade ($r = 0.90$ and $r = 0.86$). The authors indicated that the touch panel may have introduced errors due to the novelty of the touch panel and the errors would decrease as graders became more familiar with the touch panel.

The most common VIA systems used in the United States are the VBG2000 and VBS2000 from e+v company. Currently, about 95% of fed cattle are graded with the VBG2000 in North America (e+v Technology GmbH & Co. KG, 2021). The VBS2000 had the highest saleable meat yield percentage in EUROP evaluation and was not significantly different from the other two VIA systems, BCC-2 and VIASCAN (Allen and Finnerty, 2000). The VBS2000 was also found to be

correlated with the cut yield of 14 different cuts when dividing into four groups by value (Pabiou et al., 2011). Similarly, the VBS2000 was evaluated for its use as an objective measurement in the EUROP system in Poland, and the results indicated that it has the potential to replace the human evaluator (Wnęk et al., 2018). Craigie et al. (2013) investigated how the VBS2000 applied to EUROP classification would predict saleable meat from the sirloin and the filet, and it was found that the VBS2000 system has similar accuracy to human evaluators in predicting the saleable meat for sirloins and filets.

As new technology continues to emerge, it will have to go through the USDA approval process to ensure that all the measurements are consistent. USDA has set guidelines for these technologies that they should be able to predict yield grades within 0.5 yield grade 95% of the time of what the expert graders calculate (USDA AMS, 2024a). The USDA AMS is also looking into how the camera on a cell phone can be used to snap an image of the ribbed area, and a remote USDA grader can evaluate and determine a quality grade for smaller packing plants (USDA AMS, 2024c). As technology progresses, this may allow smaller processors to apply USDA quality and yield grades to their carcasses without having a USDA grader onsite. Research in this area will continue to develop with the advent of new VIA systems or replacement items for VIA systems.

1.4. Relationship Between REA and Steak Thickness

One of the main factors that could be affected by REA is the thickness of the steaks, especially when they are portioned to a target weight. Previous studies have indicated that the variations in steak thickness or weight can be minimized if carcasses are sorted by the REA; however, this is very subprimal-dependent (Bass et al., 2009). Bass et al. (2009) further reported that the weight of infraspinatus, longissimus thoracis, latissimus dorsi, gluteus medius, longissimus lumborum, biceps femoris, and semitendinosus portioned by thickness were all related

to the REA. However, most of the subprimals with the muscle dimension variables (muscle maximum height, width, and length, face length, and face width) in the linear regression model had only weak correlations to the REA. Additionally, there was a significant difference between the thickness of the strip loin and T-bone steaks when portioned by weight among the REA categories when carcasses were sorted by REA before processing (Dunn et al., 2000). The relationship was considered reasonable as both steaks contained the longissimus muscle, which is directly measured to evaluate REA and would have a direct and proportional effect (Dunn et al., 2000; Steele et al., 2020). Furthermore, ribeyes and strip loins were heavier from the larger REA category compared to the smaller REA categories when portioned into steaks with 31.8 mm thickness (Steele et al., 2020). It was also reported that the optimal REA range to get the most tender steaks for foodservice was 77.4 to 96.6 cm² (Dunn et al., 2000).

Foodservice plays a critical role in the beef industry because 60% of steaks are utilized in the foodservice industry whereas only 40% of steaks are utilized in the retail sector (2021 State of Consumer, 2022). During the most recent National Beef Quality Audit, it was determined that weight and size, specifically of subprimals, was more important to the foodservice industry than retail sector, packer, further processors, or government or trade organizations (Smith, 2024). It was noted that they specifically want standardized cuts and 18% of the foodservice companies interviewed specified that wanted subprimals of a desired weight (Smith, 2024). In the past foodservice industry typically focused on the middle meats but there has been more innovative cuts from the chuck and round. It was also found that when a portion size decreased, the number of steaks and processing time increased while the yield decreased (Weatherly et al., 2001). Steele et al. (2020) evaluated strip loin portioned to 12 oz and 14 oz as if for food service with the goal

of determining what REA portioned to a 12 oz or a 14 oz would yield a 1 inch thick steak. They reported that smaller REA had a better chance of being a 12 oz and 1 inch thick.

1.5 Impact of Steak Thickness on Marketability of Beef

While beef processing plants assign carcass value based on objective grading systems, consumer value only materializes at the retail level. Typically, consumers base their steak purchase decisions on what they can see at the retail level (Leick et al., 2011). Research has shown that when given a choice between color, marbling, texture, or thickness, 26.9%, 32.2%, and 33% of consumers chose thickness as their number one priority for ribeye, strip loin, and sirloin steaks, respectively. When the price was later included as a choice, the steak thickness still remained one of the top choices along with marbling and color, but the percentages dropped slightly (22.6%, 27.9%, and 26% for rib, strip loin, and sirloin steaks respectively; Behrends et al., 2009). Leick et al. (2012) reported similar results, with consumers ranking thickness as more important than price; however, they selected the thinnest ribeye, which was also the least expensive ribeye. While thickness is important, the ideal thickness may vary depending on the cut, cooking method, and even individual preferences. Behrends et al. (2009) investigated consumer acceptance and consumer's willingness to pay based on the thickness of strip loin, ribeye, and top sirloin steaks and reported that the thinnest ribeye steaks were selected most often. These authors hypothesized that the larger surface area may have caused the consumer to believe the product was heavier than its actual weight (Behrends et al., 2009). Overall, consumers selected the strip loins with medium thickness most often and indicated that they would be willing to pay a minimum of \$1 per pound more for the steaks they selected (Behrends et al., 2009).

Sweeter et al. (2005) evaluated if REA influenced how long steaks remained in a retail display case and reported that there was no significant difference in time spent in the retail case

based on REA. Similarly, Maples et al. (2018) separately evaluated the impact of surface area and thickness on consumers and reported that consumers preferred steaks with a larger surface area. These authors reported that consumers are heterogeneous in preferences but overall had a strong dislike for the thinnest steaks and tended to value a change in thickness more when the surface area is held constant, compared to a change in surface area when the thickness is held constant. The authors hypothesized that with the increase in cattle size, the middle meats might not become more attractive to consumers because steaks must be thinner to maintain a certain weight or price.

In partial agreement, the 2022 National Beef Quality Audit Phase 1: face-to-face interview indicated that there was a decrease in the importance of weight and size across all sectors (food service, government trade organizations, packer, retailer, and further processor) compared to the previous National Beef Quality Audits (Lorenzen et al., 1993; Nelson et al., 1995; Roeber et al., 2002; Shook et al., 2008; Igo et al., 2013; Hasty et al., 2017; Smith et al., 2024). The decrease in importance in the packing sector could be attributed to packing plants being able to source cattle of similar weight and size (Smith et al., 2024). When comparing the sectors of the beef industry to each other, weight and size were more important in the food service area (as it focuses on cutting steaks) and the government trade organizations (Smith et al., 2024).

1.5.1 Branded Beef Programs

Branded beef programs play a critical role in beef marketing as they create familiarity and are perceived as a promise of consistency (Singley & Wachenheim, 1999). The first branded beef program was established in 1978 because of the inconsistency in the quality of steaks (Certified Angus Beef, 2024). Branding also adds value as it indicates quality and sets the product apart from others. In the beef industry, branded beef programs are used to identify beef quality through live animal and carcass specifications (Singley & Wachenheim, 1999). Currently, there are 71 USDA

Certified Beef Programs that carcasses can possibly qualify for at slaughter (Agricultural Marketing Service, 2024b). These programs are most prominent in the steak market (Schulz et al., 2012). Since consumers are unable to evaluate attributes such as flavor and tenderness at the point of sale, they perceive branded beef programs as a method to ensure these traits (Brocklebank & Hobbs, 2004). Giacomazzi et al. (2017) reported that 58.3% of consumers had some understanding of a certified beef program. Today, most packing plants will pay a premium for carcasses that qualify for branded beef programs. For example, carcasses that qualify for Certified Angus Beef receive a premium of \$4.14 per hundred pounds, and an all-natural program would qualify for a premium of \$33.28 per hundred pounds (USDA Economics, Statistics and Market Information System, 2024a). However, the premiums may vary based on branded beef programs.

1.5.2 Certified Angus Beef

The Certified Angus Beef program is one of the most widely used branded beef programs and has 10 carcass specifications for predominantly black hided beef animals. These 10 specifications are divided into three distinct categories: (1) quality, appearance, and tenderness, (2) consistent sizing, and (3) marbling and maturity. The quality, appearance, and tenderness specifications are superior muscling, practically free of capillary rupture, no dark cutters, and no neck hump exceeding two inches, and work to eliminate dairy cattle and Bos indicus cattle. The consistent sizing category is focused on creating consistent subprimals and steak thicknesses, and is vital to the food service industry and retailers, ensuring consistent subprimal cuts and steak thicknesses. The Certified Angus Beef Program requires a 10 to 16 square-inch REA, HCW less than or equal to 1,100 pounds, and less than or equal to one inch of fat opposite the ribeye (USDA AMS, 2022). The specifications focused on marbling and maturity directly impact the eating experience (flavor, juiciness, and texture). The program requires modest or higher marbling, medium to fine marbling texture, cattle under 30 months old, and A maturity lean. When Certified

Angus Beef top loin steaks were compared to Choice and Select top loin steaks, it was reported that Certified Angus Beef was more tender, more flavorful, and juicier, according to trained panelists (Claborn et al., 2011). Moreover, the REA specification has major economically impact to the producer. because 22.9% of cattle will not qualify because of the REA specification that otherwise would have if there was no REA specification (Certified Angus Beef, 2024). This means that producers are missing out on premiums due to the REA specification.

1.6. Impact of Steak Thickness on Cooking and Consumer Sensory Perception

The beef cooking process is affected by steak thickness, which in turn affects the consumer's sensory perception. Previously, Foster et al. (2021) reported that when steaks were portioned to constant weight, they had significantly different thicknesses, which led to a shorter cooking time for the thinner steaks. The cook time is only controlled by steak thickness, not the weight of the steak, because of the slower diffusion of heat into the thicker pieces of meat (Dunn et al., 2000; Saha et al., 2019). The small portioned and smaller REA steaks tended to have a higher degree of doneness, suggesting that they only had a small margin for error when cooked to a specified endpoint temperature (Dunn et al., 2000). Similarly, Kerth et al. (2016) also reported that as steak thickness increased, the cooking time increased when cooked with a skillet. However, when using radio frequency heating, it took a longer time for thinner steaks to be cooked (Rincon et al., 2015). This indicates that both the cooking time and cooking method recommendation to reach a satisfactory eating experience might be impacted by steak thickness (Woerner, 2014).

Steak thickness not only impacts cookery, but it may also impact the tenderness of the steak. Consumer panels indicated that thicker steaks had less consumer tenderness liking, which agreed with the expert panel that thinner steaks were slightly more tender than thicker steaks (Miller et al., 2019a). When the shear force was evaluated for steaks portioned by REA, the steaks

with the smallest REA (greatest thickness) had the lowest Warner Bratzler shear force (Foster et al., 2021).

It has also been reported that steak thickness can impact the perceived flavor. Thicker steaks were found to have less bloody flavor and more beef identity and roasted flavors when evaluated using consumer and trained panels (Miller et al., 2019a). Additionally, small REA (thicker) steaks had a higher overall liking when portioned to a constant weight (Foster et al., 2021). The differences in flavor could be attributed to the difference in volatile aroma compounds, with thinner steaks having more volatiles that come from lipid degradation from the shorter cooking time (Kerth, 2016).

With the known impact of portion sizes on consumer perception and eating experience, it is critical to understand the relationship between REA and steak portion sizes as cattle size continues to increase. Branded programs also rely on REA as a specification to keep steaks consistent with the shift in cattle sizes. Many of the previous studies focused on the relationship between REA, steak thickness, and consumer perspective. However, only limited studies have focused on the relationship between REA and steak portion size. Therefore, this research focused on quantifying and creating prediction models to explain the relationship between REA and three different strip loin steak portions (12 oz, 16 oz, 1-inch thickness).

CHAPTER 2

ASSOCIATION BETWEEN BEEF RIBEYE AREA MEASUREMENTS AND STEAK PORTION SIZE

2.1 Introduction

The average beef carcass weight has continued to increase over the past 30 years (USDA Economic Research Service, 2024). This has led beef processors to apply discounts on beef prices (when purchased on a grid-based marketing system) when carcasses are over 408 kg and additional discounts for carcasses over 476 kg (USDA Economics, Statistics and Market Information System, 2024a). Along with the increase in the hot carcass weight (HCW), the average ribeye area (REA) has also increased over the years. Specifically, the 2015 National Beef Quality Audit indicated that the average HCW has increased by 45.3 kg from 1991 (average HCW of 345.0 kg) to 2016 (average HCW of 390.3 kg), while the REA increased by 6.1 cm² (0.95 in²) from 1991 with the average REA of 89.5 cm² (13.9 in²) in 2015 (Boykin et al., 2017). In general, the REA is used to calculate the yield grade to predict cutability, but it could also impact the thickness of whole muscle steaks.

Previous consumer surveys have reported that consumers prefer to purchase thicker steaks (Maples et al., 2018). Moreover, steak thickness can influence consumer eating experience. Miller et al. (2019) evaluated the interaction between steak thickness and grill temperature on consumer's perceived liking and flavor of the beef steaks and the trained expert panel found that thickness impacted beef flavor ID, roasted flavor, and tenderness. Similarly, Kerth et al. (2016) reported that the steak thickness influenced the generation of volatile compounds during cooking, with the

thinnest steaks (1.3 cm thick) having more volatile compounds than the thicker steaks (2.5 cm thick and 3.8 cm thick). The difference in volatile compounds generated could impact the perceived flavor which changes the perceived overall liking of the steak. Additionally, Dunn et al. (2000) reported that steak thickness affected consumer perception and eating quality with thicker steaks having a more intense flavor compared to thinner steaks. Due to this association between REA and eating quality, previous studies have tried to utilize the REA to predict steak thickness (Bass et al., 2009; Steele et al., 2020) with mixed success.

The REA is also used as a metric for inclusion into the branded beef programs in the United States, which could offer a higher price for carcasses that meet their specifications. For example, the Certified Angus Beef program (CAB) has a specification for carcasses to have 10 in² (64.52 cm²) to 16 in² (103.23 cm²) REA based on measurements taken from the grading camera to be included in their program. This helps them to ensure consistently sized steaks across the subprimals and gives the producers an average premium of \$4.14 per hundred-pound weight as of March 4, 2024 (USDA Economics, Statistics and Market Information System, 2024a). Therefore, understanding the relationship between REA and steak thickness/weight is critical to ensure the consistency of beef products. The objective of this study was to evaluate the effect of differing REA on the steak dimension of longissimus lumborum (LL) muscle cut to various weights (12 oz [340.19 g] and 16 oz [453.59 g]) or thickness (1 in. [2.54 cm]) specifications.

2.2 Materials and Methods

2.2.1 Carcass Selection

Beef carcasses ($n = 100$) were selected from a commercial beef harvesting facility based on ribeye area (REA), categorized as 1 in² (6.45 cm²) increments ranging from less than 11 in² (70.97 cm²) to greater than 19 in² (122.58 cm²) based on a United States Department of Agriculture

(USDA) approved camera (e+v) with 10 total categories. Carcass collection aimed to achieve an even distribution of carcasses in each REA category. Instrumental carcass data, including the hot carcass weight (HCW), marbling score, and fat thickness, was obtained from the facility. In addition to the REA obtained from the grading camera, the REA was measured using an approved USDA ribeye grid. The traced REA measurement was accomplished using the plain paper copier transparency film (APOLLO, IL, Item #VPP100C) and a permanent marker was used to outline the ribeye area. Tracings were scanned into the computer as .jpg images with a resolution of 1120 x 1696 pixels per image. ImageJ software (Image J 1.54d, Java 1.8.0_345) was calibrated to 1.001 in² with a 1 in² rectangle (1 in. = 208.36 pixels) to calculate the ribeye area. After calibration, the software processed each tracing to obtain the REA.

2.2.2 Strip Loin Collection

Selected beef carcasses were fabricated in the facility, and strip loins (IMPS#180) from the right side were collected from each carcass. Strip loins were then trimmed to approximately ¼ in. of external fat, and vacuum packaged. Each strip loin was boxed and transferred to Marel Center (Marel, Des Moines, IA) and held under refrigeration overnight.

2.2.3 Dimension Data Collection

The external fat of each strip loin was trimmed for uniformity. Then, the weight (kg), length (cm; anterior to posterior), and three width measurements (cm; anterior, midpoint, and posterior) were recorded manually using a tape measure. The strip loins were scanned using the Marel I-Cut 56 portion cutter (Marel), which used a laser to scan each strip loin. The individual strip loins were placed onto the belt with the fat cover on the belt. The I-Cut 56 portion cutter mapped each strip loin's topical area, weight, length, and maximum height (cm). The machine was also programmed to estimate a facing cut of 50 g to help square the remainder of the portioned steaks. Each strip loin was scanned three times with the blades removed to allow for multiple scans to collect data

for 12 oz, 16 oz, or 1 in. portion sizes. Using a calibration for the density of fresh beef, the I-Cut would determine how thick each cut would have been if cuts were made to make the 12 oz (340.19 g), 16 oz (453.59 g), or 1 in. (2.54 cm) portion. Within the I-Cut software, each of the portion's estimated outcomes of thicknesses or weights were recorded. The strip loin's maximum height (depth) was measured at each portion size and averaged for each strip loin at the end.

2.2.4 Statistical Analysis

The correlation between the ribeye area measurements and the three portion size data was calculated using the stats package in R (version 4.2.2). Two initial and final steak portions were excluded from the study to avoid any potential bias due to tapering on the anterior or the posterior end of the strip loins. The remaining portions of the steak's thickness or weight were averaged across each strip loin. The correlation between all the REA measurement methods was significant ($P < 0.001$). However, 34% of carcasses had a 1 inch or greater difference between USDA-approved camera measurements and traced REA measurements; therefore, a linear regression model was developed based on only the traced measurement as a predictor for all three portion sizes as it is considered the true value. An additional extensive model was developed with traced REA measurements and all the other strip loin measurements. The second model used for each portion size was determined using the Akaike Information Criterion (AIC) by eliminating each variable until a model with the lowest possible AIC score that contained traced REA was achieved. The second regression model for predicting the 12 oz model used the following independent variables: traced REA measurement (in^2), weight of strip loin (kg), length of strip loin (cm), and average maximum height of strip loin (cm). Independent variables for the 16 oz portion size model were traced REA measurement (in^2), weight of strip loin (kg), length of strip loin (cm), and average maximum height of strip loin (cm). Traced REA was forced to remain in all the second models. The second regression model for the prediction of 1 in. portion cuts included the following

independent variables: traced REA measurement (in²), the hot carcass weight (kg), subcutaneous fat thickness of ribeye (cm), weight of the strip loin (kg), length of the strip loin (cm), the width of the anterior end of the strip loin (cm), and the average maximum height of the strip loin (cm). Each model was then evaluated separately for the main effects of each variable, with significance determined at $\alpha = 0.05$.

2.3 Results

One hundred carcasses were selected based on USDA-approved camera REA (Camera REA) with REA ranging from 9.8 -19.5 in² (63.2 -125.8 cm²). The distribution of carcasses in each REA bracket followed a normal distribution and the data are presented in Figure 1. The descriptive summary statistics of the carcass data collected are presented in Table 1. The average REA from a USDA-approved camera measurement, gridded measurement, and traced measurement were 14.7 in² (94.8 cm²), 15.0 in² (96.8 cm²), and 14.5 in² (93.5 cm²), respectively (Table 1). The average HCW was 399.0 ± 66.0 kg with a minimum of 262 kg and a maximum of 534 kg. The fat thickness also varied with a minimum of 0.8 cm and a maximum of 3.3 cm. Further, the average strip loin weight was 5.3 ± 1.0 kg with an average length of 41.4 ± 2.6 cm and an average height of 10.0 ± 0.1 cm (Table 1).

The mean thickness or weight of the portioned cuts can be found in Table 2. When evaluating the relationship between traced REA and average portioned cuts, both 12 oz and 16 oz portioned cuts were negatively correlated with the traced REA measurement ($R^2 = -0.71$, $P < 0.001$; Figure 2) meaning that when REA increased, the steak thickness decreased. Conversely, the average of each strip loin when portioned to 1-in. cuts were positively correlated with traced REA ($R^2 = 0.75$, $P < 0.001$; Figure 2), meaning that the average weight of the 1-in.-thick steaks increased with the increase in REA. For example, a 12 oz portioned steak with a 19-in. REA would have

been approximately 2.02 cm thick, while a 12 oz portioned steak with a 9-in. REA would be approximately 3.40 cm thick. Similarly, for the 16-oz portion, a 9-in. REA would result in a 4.55 cm thick steak, whereas a 19-in. REA would result in a 2.69 cm thick steak. On the other hand, steak weights increased as REA increased based on portioning to 1-in.-thick (Figure 2c). For instance, an estimated 9-in. REA would result in a 0.24 kg steak for a 1-in. portion, but for a 19-in. REA, a 1-in.-thick steak would be approximately 0.41 kg. When the Traced REA was compared to the individual steak portion size from each strip loin there was a decrease in the R^2 value (Figure 3). The correlation between all factors measured within this study were compared in Table 3.

The results for the simple linear regression models indicated that Traced REA was significant ($P < 0.001$) for estimating all three portion sizes (Table 4). A 1-in. increase in REA is estimated to decrease the thickness of a 12 oz portion and 16 oz portion by 0.138 cm (95% CI: -0.155, -0.120 cm) and 0.185 cm (95% CI: -0.209, -0.162 cm), respectively. Additionally, a 1-in. increase in Traced REA is estimated to increase the weight of a 1-in.-thick portion by 18 g (95% CI: 15, 20 g).

Results for the multilinear regression model for estimating a 12 oz portioned steak are shown in Table 5. The weight, length, and height of the strip loin were significant ($P < 0.05$) for predicting the thickness of a 12 oz steak portion. However, REA was not identified as a significant ($P \geq 0.05$) factor when predicting the thickness of a 12 oz portion when used in combination with all the other measurements, which could be due to the co-linearity of the factors. A 1 kg increase in strip loin is estimated to decrease the thickness of a 12 oz portion by 0.441 cm (95% CI: -0.506, -0.375 cm). Similarly, for the 16 oz. steak portion, the weight, length, and height of the strip loin were significant ($P < 0.05$) in predicting the thickness of a 16 oz portioned steak, but traced REA was not ($P \geq 0.05$; Table 5). Regression analysis for predicting the thickness of a 16 oz steak

showed that 1 kg increase in weight would result in an estimated -0.60 cm (95% CI: -0.683, -0.508 cm) change in steak thickness, while an increase in 1 cm. in length would result in an estimated 0.055 cm (95% CI: 0.040: 0.071 cm) thicker 16 oz steak. An increase in 1 cm in the height of the strip loin is estimated to result in a 0.071 cm thinner (95% CI: -0.129: -0.014 cm thinner) 16 oz steak. Prediction variables and their coefficients for the weight of 1-in.-thick steak portion steaks are shown in Table 7. Traced REA, HCW, anterior width of the strip loin, and average maximum height of the strip loin were not significant ($P \geq 0.05$) in the 1 in. multilinear regression model. In contrast, fat thickness opposite the ribeye, weight of the strip loin, and length of the strip loin were significant ($P < 0.05$) in the model. In addition, using the strip loin measurements, linear regression models were able to predict steak thickness for 12 oz and 16 oz portions with an R^2 of 0.95 each and predict the steak weight for the 1-in. portion with an R^2 of 0.98.

2.4 Discussion

Previous studies have demonstrated that beef steak thickness could be related to a consumers' willingness to pay for ribeye, top loin, and top sirloin steaks (Leick et al., 2012). Maples et al. (2018) examined the relationship between portion size and consumers' willingness to pay (WTP) for beef steaks using ribeye and sirloin steaks with three different REA (10 in², 14 in², 18 in²) and three different thicknesses (0.5 in., 1.0 in., 1.5 in.). These authors reported that 90% of consumers perceived the thinnest steaks (0.5 in.) as less desirable compared to the average thickness steaks (1 in.). Additionally, consumers would pay \$7.07 less per package for steaks with a 10 in.² ribeye and \$3.51 less per package for steaks with an 18 in² ribeye when compared to a 14 in² ribeye. When evaluating the impact of steak thickness on consumers' WTP, the authors reported that consumers' WTP decreased by \$18.67 for 0.5-in.-thick steaks compared to a 1-in.-thick steak, whereas consumers were willing to pay \$4.66 more for 1.5-in.-thick steak compared to 1-in.-thick steak (Maples et al., 2018). Moreover, steak thickness also impacts cookery and consumer

perception. Thicker steaks had an overall higher consumer liking compared to thinner steaks (Miller et al., 2019b) cooked the same way, which could be due to the differences in volatile compounds generated during cooking (Kerth et al., 2016). These results indicated that consumers place high importance on REA and steak thickness when making purchasing decisions and could impact their eating experience.

In the current study, the 12 oz portion (340.19 g) strip loin steaks had a mean thickness of 2.62 cm, whereas the 16 oz (453.59 g) portion had a mean thickness of 3.53 cm (Table 2). In agreement with these results, Foster et al., (2021) also reported that portioning steaks by a constant weight resulted in significant variations in thickness, regardless of HCW or REA, while steaks cut to a uniform thickness showed significant differences in weight. Additionally, the steak thickness also affected the shear force and sensory attributes. The overall liking and tenderness liking were highest for steaks from the small REA category compared to large and medium REA categories when portioned by weight, but there were no differences when portioned by thickness. The difference in overall liking of steaks when portioned by weight (different thicknesses) indicates that sorting based on REA and portioning to a specific weight may lead to changes in overall liking of the steak.

The current study also indicated that each of the three portion dimensions (12 oz, 16 oz, and 1 in.) were correlated ($P < 0.001$; $R^2 = 0.71, 0.71, 0.75$, respectively) to the traced REA measurements (Figure 2). Dunn et al. (2000) also categorized REA into 1 in^2 categories, ranging from less than 11 in^2 to greater than 16 in^2 to examine the impact of REA on steak thickness, cooking parameters, and tenderness of the longissimus muscle in strip loin and T-bone steaks. As expected, steak thickness within groups portioned to pre-determined weight decreased with increasing REA, which is in agreement with the results of the current study. These authors also

indicated that REA affected tenderness and the cooking times of both strip steaks and T-bone steaks, with steaks portioned from carcasses with 77.4 cm² (11.9 in²) to 96.6cm² (14.9 in²) having optimal tenderness and cooking times, which reiterates the importance of having consistent steak thickness for the food service industry. On the contrary, Bass et al. (2009) reported that strip loin portion characteristics (whole muscle maximum height, whole muscle maximum width, whole muscle maximum length, face length, and face width) had weak correlations with camera REA, but strip loin whole muscle maximum height had a significant relationship to REA. These previous studies (Dunn et al., 2000; Bass et al., 2009) attributed the variation in the correlation between muscle size correlation and REA to differences in the breed of the cattle, sex, maturity, and management practice of the live animals, which may also be a cause of variation within the current study.

In meat processing facilities in the US, it is important to sort carcasses at the grading chain because this is where premiums and discounts are applied when carcasses are priced on a grid-based system (USDA Economics, Statistics and Market Information System, 2024b). For example, carcasses that conform to boxed beef program standards can be rewarded with a premium price as they try to ensure consistency in steak products. The current study revealed that REA was a reasonably accurate predictor for a steak thickness when portioned to 12 or 16 oz or a specific steak weight when portioned to a 1-in. thickness. However, REA was not the best predictor of portioned cuts if the strip loin dimensions (length and weight) were included in the model, which could be due to the potential co-linearity among the factors. There are a plethora of other factors that could influence the predictors (REA, HCW, fat thickness, etc.) that could be useful for all commercial beef due to differences in cattle production techniques, cattle sex, age class, or breed. For example, Steele et al. (2020) examined whether sorting by REA could be improved by sorting

by weight of the subprimal to increase the consistency of the product. These authors suggested that while weight may minimize some variation, it would not be fully sufficient to minimize most of the intercarcass variation. This might be because these authors separated subprimals only into two categories (heavy and light) based on weight, and additional sorting by weight could minimize the variability (Steele et al., 2020). These results differ from what was observed in the current study which indicated that weight was one of the better predictors. However, as sorting ability increases, the knowledge of subprimal characteristics could lead to more indepth sorting method after the initial sort done at the grading chain to better match strip loin to the correct processing.

2.5 Conclusions

The results of the current study indicated a linear relationship between REA and strip loin weight and thickness and suggested that REA could be used as a predictor for steak thickness of 12 oz and 16 oz portions and weight of 1-inch-thick steaks. Furthermore, additional measurements from the subprimals (such as length and weight) might improve the accuracy of the portion size predictions. The industry could stand to benefit from additional research to determine an optimal REA range based on consumer acceptance and degree of doneness for steaks with varying thickness which could opitimize consumer acceptance and steak portion sies for retail and foodservice.

Table 1. Descriptive summary statistics for variables collected from beef carcasses ($n = 100$) used to create a linear model to predict the thickness or weight of a portioned steak based on the ribeye area.

Characteristic	Mean (\pm SD ¹)	Minimum	Median	Maximum
Camera REA ² (in ²)	14.7 \pm 2.7	9.8	14.5	19.5
Gridded REA ² (in ²)	15.0 \pm 2.4	10.5	14.9	19.6
Traced REA ² (in ²)	14.5 \pm 2.4	10.3	14.3	19.3
HCW ³ (kg) ($n = 98$)	399.0 \pm 66.0	262.0	407.0	534.0
Fat Thickness ⁴ (cm) ($n = 98$)	1.7 \pm 0.5	0.8	1.6	3.3
Marbling Score ($n = 98$)	503.0 \pm 73.0	398.0	486.0	727.0
Weight (kg)	5.3 \pm 1.0	3.3	5.3	7.4
Length (cm)	41.4 \pm 2.6	35.0	41.5	47.0
Anterior Width (cm)	21.0 \pm 1.9	15.0	21.0	26.0
Middle Width (cm) ($n = 99$)	20.7 \pm 1.8	17.0	20.0	25.0
Posterior Width (cm)	24.1 \pm 2.1	19.0	24.0	30.0
Height (cm)	10.0 \pm 0.1	7.7	10.0	11.6

¹SD = standard deviation from the mean

²REA = ribeye area

³HCW= hot carcass weight

⁴Fat Thickness = subcutaneous fat thickness measured at three-fourths the length of the ribeye on the lateral side.

Table 2. The mean (\pm SE), minimum, median, and maximum thickness or weight of the three different portioned sizes from beef strip loins ($n = 100$) from various ribeye areas.

Portion size	Mean (\pm SE)	Minimum	Median	Maximum
12 oz portion thickness (cm)	2.62 \pm 0.39	1.95	2.58	3.73
16 oz portion thickness (cm)	3.53 \pm 0.52	2.60	3.48	4.95
1 in. portion weight (kg)	0.34 \pm 0.05	0.23	0.33	0.44

Table 3. Correlations between all factors from a carcass level (traced REA¹, HCW², fat thickness³, marbling score), a strip loin loin level (weight, length, anterior width, middle width, posterior width), and portion size (12 oz, 16 oz, and 1 inch) that were measured.

	Traced REA ¹ (in ²)	HCW ² (kg)	Fat Thickness ³ (cm)	Marbling Score	Weight (kg)	Strip loin Length (cm)	Width Anterior (cm)	Width Middle (cm)	Width Posterior (cm)	12 oz Portion (cm)	16 oz Portion (cm)
HCW ² (kg)	0.836 ^{***}										
Fat Thickness ³ (cm)	-0.058	0.230 [*]									
Marbling Score	-0.083	0.209	0.350 ^{***}								
Weight (kg)	0.867 ^{***}	0.875 ^{***}	0.089	-0.093							
Strip loin Length (cm)	0.581 ^{***}	0.732 ^{***}	0.127	-0.066	0.773 ^{***}						
Width Anterior (cm)	0.790 ^{***}	0.699 ^{***}	0.016	-0.011	0.740 ^{***}	0.473 ^{***}					
Width Middle (cm)	0.688 ^{***}	0.645 ^{***}	-0.008	-0.165	0.771 ^{***}	0.497 ^{***}	0.660 ^{***}				
Width Posterior (cm)	0.624 ^{***}	0.694 ^{***}	-0.004	-0.066	0.796 ^{***}	0.597 ^{***}	0.571 ^{***}	0.662 ^{***}			
12 oz Portion (cm)	-0.843 ^{***}	-0.826 ^{***}	-0.084	0.108	-0.950 ^{***}	-0.608 ^{***}	-0.733 ^{***}	-0.795 ^{***}	-0.764 ^{***}		
16 oz Portion (cm)	-0.843 ^{***}	-0.832 ^{***}	-0.090	0.102	-0.954 ^{***}	-0.619 ^{***}	-0.734 ^{***}	-0.786 ^{***}	-0.770 ^{***}	0.998 ^{***}	
1 inch Portion (kg)	0.864 ^{***}	0.824 ^{***}	0.094	-0.082	0.964 ^{***}	0.610 ^{***}	0.732 ^{***}	0.786 ^{***}	0.787 ^{***}	-0.985 ^{***}	-0.986 ^{***}

¹REA = ribeye area
²HCW= hot carcass weight
³Fat Thickness = subcutaneous fat thickness measured at three-fourths the length of the ribeye on the lateral side.
* P < 0.05; ** P < 0.01; *** P < 0.001

Table 4. Linear regression models for each portion measurement with the average thickness (cm) of 12 oz or 16 oz portioned cuts or the average weight (kg) of 1 in. portion cuts ($n = 100$) as the expected outcome when using the traced ribeye area measurement (in^2) as the predictor.

Predictor Variable	Model Outcome	Estimate \pm SE ¹	Lower Confidence Interval	Upper Confidence Interval	Test Statistic
Traced REA ²	12 oz portion (cm)	-0.138 \pm 0.009	-0.155	-0.120	-15.5 ***
Traced REA ²	16 oz portion (cm)	-0.185 \pm 0.012	-0.209	-0.162	-15.5 ***
Traced REA ²	1 in. portion (kg)	0.018 \pm 0.001	0.015	0.020	17.0 ***

¹SE= standard error

²REA= ribeye area

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 5. Linear regression model with the average thickness (cm) of 12 oz portioned cuts (n = 100) as the expected outcome when forcing the traced ribeye area measurement (in²), and using the weight of the strip loin (kg), the length of the strip loin (cm), and the maximum average height of the strip loin (cm).

Predictor Variable	Estimate ± SE ¹	Lower Confidence Interval	Upper Confidence Interval	Test Statistic
Traced REA ²	0.005±0.008	-0.011	0.020	0.578
Weight	-0.441±0.033	-0.506	-0.375	-13.4 ***
Length	0.044±0.006	0.032	0.056	7.31 ***
Height	-0.059±0.022	-0.102	-0.016	-2.74**

¹SE= standard error

²REA= ribeye area

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 6. Linear regression model with the average thickness (cm) of 16 oz portioned cuts (n = 100) as the expected outcome variable when forcing the traced ribeye area measurement (in²), and using weight (kg), length (cm), and the maximum average height of each strip loin (cm).

Predictor Variable	Estimate ± SE ¹	Lower Confidence Interval	Upper Confidence Interval	Test Statistic
Traced REA ²	0.008±0.011	-0.014	0.029	0.685
Weight	-0.596±0.044	-0.683	-0.508	-13.6***
Length	0.055±0.008	0.040	0.071	6.94***
Height	-0.071±0.029	-0.129	-0.014	-2.48*

¹SE= standard error of the mean

²REA= ribeye area

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 7. Linear regression model with the average weight (kg) of 1 in. portioned cuts (n = 98) as the expected outcome variable when forcing the traced ribeye area measurement (in²), and using hot carcass weight (kg), fat thickness opposite the ribeye (cm), the weight (kg), length (cm), anterior width (cm), and the average maximum height of the strip loin (cm).

Predictor Variable	Estimate ± SE ¹	Lower Confidence Interval	Upper Confidence Interval	Test Statistic
Traced REA ²	0.00127±0.00085	-0.00041	0.00295	1.50
HCW ³	-0.00005±0.00003	-0.00010	0.00001	-1.47
Fat Thickness	0.00416±0.00185	0.00049	0.00784	2.25 *
Weight	0.05890±0.00282	0.05330	0.06450	20.9 ***
Length	-0.00576±0.00054	-0.00683	-0.00469	-10.7 ***
Anterior Width	-0.00107±0.00067	-0.00239	0.00026	-1.60
Height	0.00349±0.00180	-0.00010	0.00707	1.93

¹SE= standard error

²REA= ribeye area

³HCW= hot carcass weight

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

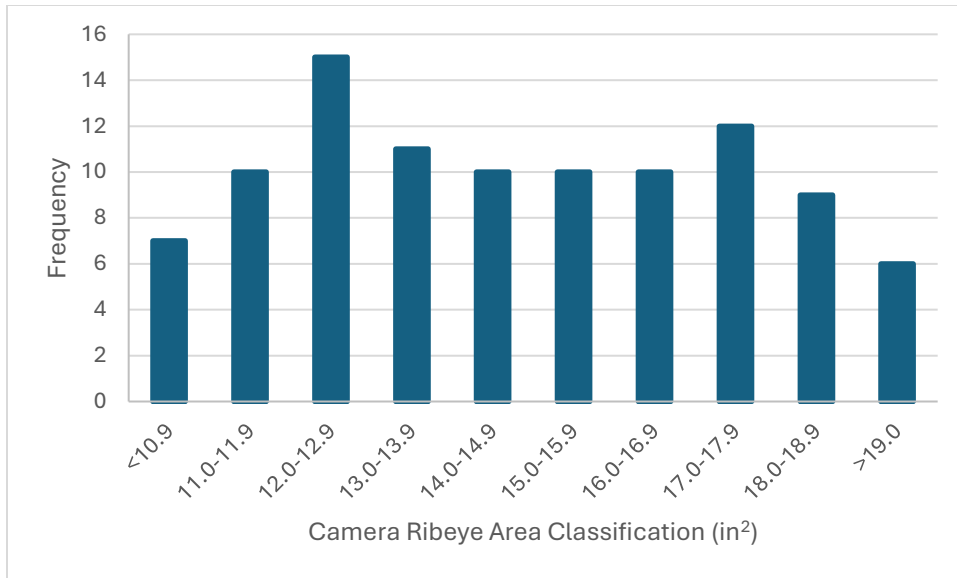


Figure 1. Number of beef strip loins ($n = 100$) within each category of the incremental ribeye area brackets increasing by 1 in^2 from <10.9 through $> 19.0 \text{ in}^2$.

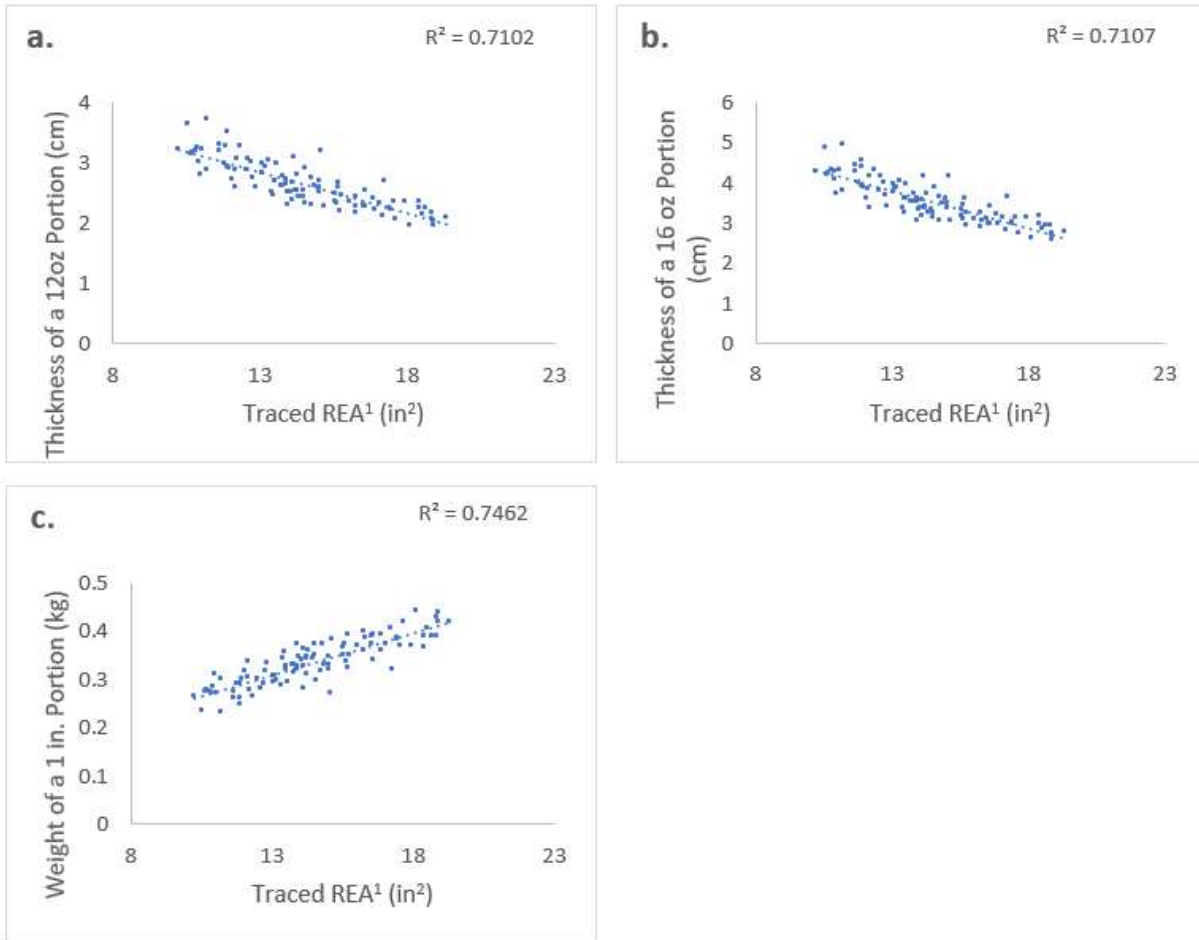


Figure 2. Correlations² between traced ribeye measurements (Traced REA) and three separate portion cut sizes 12 oz, 16 oz, and 1 in. ($n = 100$).

- a. Traced REA vs. the average thickness of a 12 oz portion ($P < 0.001$)
- b. Traced REA vs. the average thickness of a 16 oz portion ($P < 0.001$)
- c. Traced REA vs. the average weight of a 1-in. portion ($P < 0.001$)

¹REA=ribeye area

²Correlated through the R^2 value obtained from the line of best fit and a correlation test in R package stats.

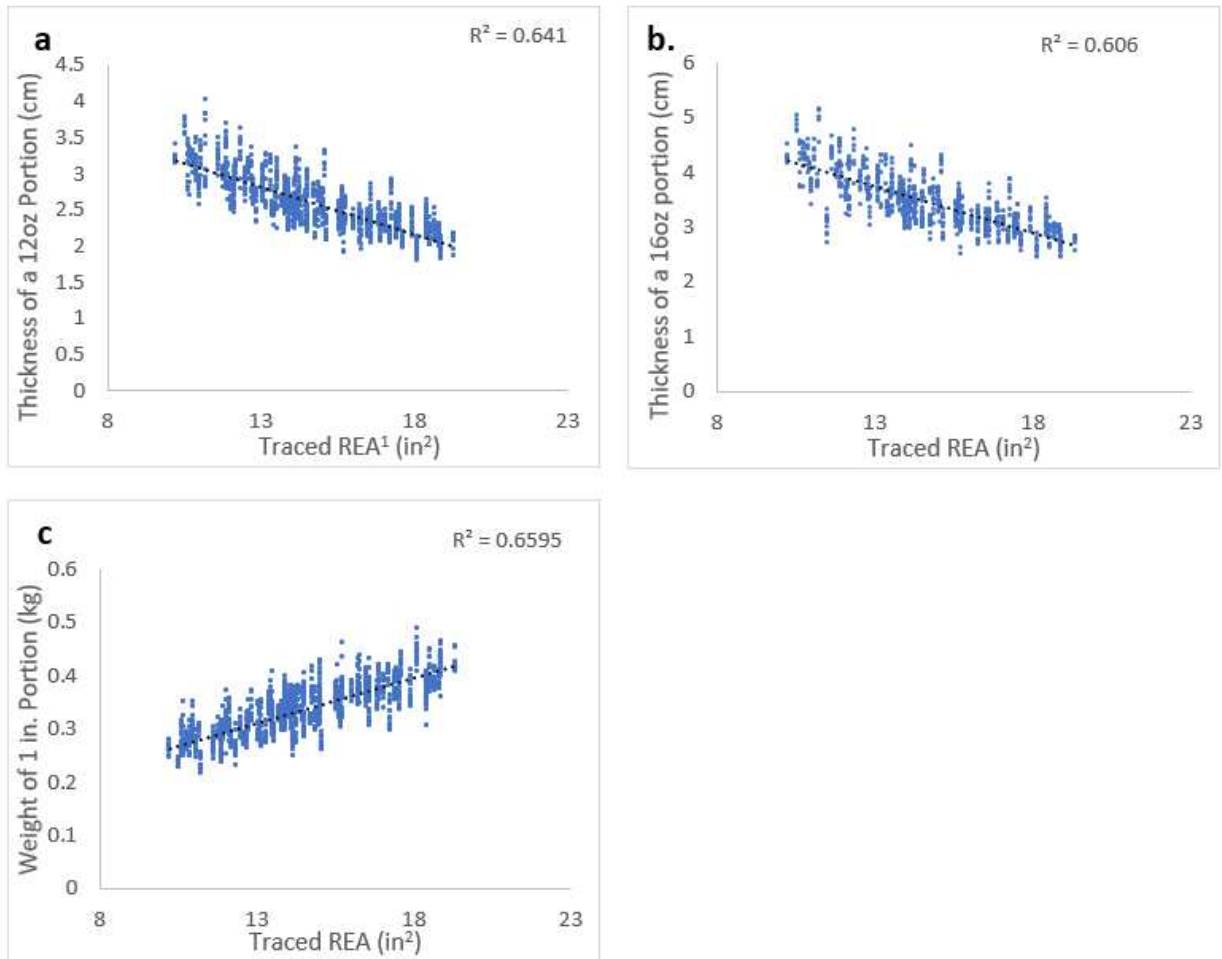


Figure 3. Correlations² between traced ribeye measurements (Traced REA) and individual steaks from the strip loin separated by portion cut sizes 12 oz, 16 oz, and 1 in. ($n = 100$).

- a. Traced REA vs. the individual steak thickness of a 12 oz portion ($P < 0.001$)
- b. Traced REA vs. the individual steak thickness of a 16 oz portion ($P < 0.001$)
- c. Traced REA vs. the individual steak weight of a 1-in. portion ($P < 0.001$)

¹REA=ribeye area

²Correlated through the R² value obtained from the line of best fit and a correlation test in R package stats.

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