SORTING BEEF SUBPRIMALS BY RIBEYE SIZE AT THE PACKER LEVEL TO MAXIMIZE UTILITY AND PRODUCT UNIFORMITY IN FOODSERVICE AND RETAIL SECTORS

A Thesis

by

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ABSTRACT

The National Beef Quality Audit–2000 cited "low overall uniformity and consistency of cattle, carcasses, and cuts" as the greatest quality challenge for the fed beef industry. In subsequent years, cattle, carcasses, and cuts have continued to increase in size, and the consistency of boxed beef has remained variable. The objectives of this study were to evaluate if sorting beef carcasses at the packer level by ribeye size, also known as loin muscle area (LM area), using instrument grading technology, would increase consistency of three boxed beef products for foodservice and retail sectors of the industry. USDA Choice sides (n = 100) and USDA Select sides (n = 100) were selected and stratified into five LM area groups ranging from 74.8 cm^2 to 106.4 cm^2. Beef ribeyes and strip loins were fabricated from the USDA Choice sides and tenderloins were fabricated from the USDA Select sides. Ribeyes (n = 97), strip loins (n = 98), and tenderloins (n = 95) were scanned with a Marel Portioner (M Series 3000; Lenexa, KS) that captured visual images and dimensional analyses. Data from the Marel were analyzed by equipment software to determine multiple portioning outcomes for each subprimal. Data were generated for each subprimal based on cutting to a variety of targeted portion weights, as well as cut to various portion thicknesses.

After analysis, it was determined that subprimal utility varied across targeted portion weights and thicknesses within each LM area category. For the ribeye and strip loin subprimals, optimal portion weight and thickness combinations were observed more frequently in LM area categories 1 (74.8 to 80.6 cm^2) and 2 (81.3 to 87.1 cm^2) than for

the three larger LM area categories. After analysis of the tenderloin data, LM area categories played a lesser role in identifying optimization of steak portion weight and thickness combinations. The findings of this study demonstrate that creating categories of beef subprimals based on LM area as opposed to subprimal weight might provide a unique sorting method that would improve boxed beef product consistency and uniformity in various sectors of the beef industry.

DEDICATION

To LCE. Thank you for being there, on the good days and the bad. For setting the standard. For pushing me to be my best. For showing me what it means to be an Aggie. I couldn't have done it without you.

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CHAPTER 1

INTRODUCTION

Industry efforts related to beef quality and palatability are driven by consumer expectation of a consistent, high-quality eating experience in both retail and foodservice settings. The National Beef Quality Audit is an industry-led and data driven initiative aimed at identifying trends in the U.S. beef industry. Over time, these audits have revealed progressively heavier and more variable beef carcass weights (Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012; Boykin et al., 2017a). Heavier carcass weights create a unique challenge for beef packers and purveyors and make it difficult to provide uniform products to various segments of the beef supply chain. Due to the variable weights of beef carcasses supplying the foodservice and retail segments of the industry, new strategies are needed to ensure that the value chain is supplied with consistent beef products that promote a favorable eating experience for the consumer.

Currently, a number of beef subprimals are sorted by weight at the packer level during boxing into “lights” and “heavies” to signify whether the box contains products that are above or below a certain weight threshold. As carcass weights have increased, subprimal weight thresholds have increased as well. Sorting subprimals by weight in this manner does little to provide retailers and foodservice operators with uniform products due to the size variability that remains within and between boxes. Creating a uniform

product at the packer level may allow these segments of the industry to better utilize beef products and provide the end-user with the consistent eating experience they expect.

Today, all major beef packers have implemented instrument grading technology to efficiently and effectively measure carcass traits including loin muscle area (LM area). Instrument technology could be utilized to sort carcasses based on LM area rather than sorting subprimals by weight as previously described. Greater information of the effectiveness of sorting carcasses by LM area could improve the uniformity of boxed beef products for end-users. This study sorted beef carcasses into five LM area categories before carcasses were fabricated into ribeyes, strip loins, and tenderloins for further analysis. Use of technology to assess both LM area through instrument grading and portioning options through state-of-the-art computer-assisted portioning systems allowed options to obtain data that have only existed in recent time.

CHAPTER II

REVIEW OF LITERATURE

2.1 Increased beef carcass weights and loin muscle area size

Over the course of the last twenty years, there has been a steady increase in beef hot carcass weights as documented by several National Beef Quality Audits (Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012; Boykin et al., 2017b). This increase in carcass weight has created a more variable product at the packer level and has presented unique challenges with subprimal fabrication and utility further in the beef supply chain. The average carcass weight reported by Boleman et al. (1998) in the National Beef Quality Audit–1995 (n = 11,799 carcasses) was 338.4 kg. According to Boykin et al. (2017b), the average carcass weight in the National Beef Quality Audit–2016 (n = 9,106 carcasses) was 390.3 kg. This is a significant increase in average carcass weight of over 45 kg over a 20-year time span.

In more recent NBQA reports, 44.1 percent of carcasses weighed 408.23 kg or greater (Boykin et al., 2017b), an increase of 20.7 percent when compared to the National Beef Quality Audit–2011: In-plant survey (n = 9,802). To reflect the changing landscape of the cattle supply, many packers have decreased the price per cwt discount for heavy carcasses. According to the USDA (2016a), from 2001-2002 the average discount for a carcass between 408 kg (900 lbs) and 454 kg (1000 lbs) was $6.82 per cwt. This same discount was reduced to $1.59 per cwt in 2014-2015. Several certified branded beef programs, most notably Certified Angus Beef, have raised their maximum

carcass weight threshold for program qualification to reflect the current beef supply (Suther, 2006).

Along with an increase in carcass weight, there has been an increase in numerical yield grade, adjusted fat thickness, marbling score, quality grade, and LM area (Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012; Boykin et al., 2017b). NBQA–2011: In-plant survey revealed that when segmented into carcass weight groups (<226.8 kg; 226.8 to 272.1 kg; 272.2 to 317.5 kg; 317.5 to 362.8 kg; 362.9 to 408.2 kg; 408.2 to 453.5 kg; and >453.5 kg), the heaviest carcass weight group also possessed the highest USDA yield grade (3.6), greatest LM area (97.8 cm^2), highest USDA quality grade (USDA Choice; 702) and highest marbling score (Small[81]; 481).

While several of these associations, notably marbling score and quality grade, are favorable, there are several negative impacts on yield grade factors. Evaluating the data from the NBQA–1991 to the NQBA–2011, the correlation between mean carcass weight and mean LM area was 0.97 (Maples et al., 2018). From the NBQA–1991 to 2016, the mean carcass weight has increased from 345 kg to 393.6 kg and conversely the mean LM area has increased from 83.0 cm^2 to 88.9 cm^2 (Lorenzen et al., 1993). In the NBQA–2016, 24 percent of carcasses possessed a LM area greater than 96.77 cm^2 (Boykin et al., 2017a). This increase in LM area can create challenges further along in the supply chain, particularly in regard to steak portion size and thickness. Increased weight and size was a top quality challenge outlined by the NBQA–2016 and the face-to-face interview portion of the audit cited “size consistency was more important than size increase, large

carcasses are making it harder for many further processors to meet customer specifications for thickness and weight" (National Cattlemen's Beef Association, 2017).

2.2 Use of technology in beef carcass grading

Over the last 30 years, technology has been developed in the beef industry to provide an objective measurement of carcass attributes necessary to assign a yield and quality grade. In 1978, in a report to congress completed by the Comptroller General, the USDA outlined opportunity to "increase research efforts to develop instruments to accurately measure beef carcass characteristics" (Comptroller General of the United States, 1978). In subsequent years, federal funding was offered to complete research on the use of video image analysis (VIA) and ultrasound technology in the beef industry. VIA technology grew in popularity after it was identified as the first priority in research and funding by a subcommittee of the National Live Stock and Meat Board in the first National Beef Instrument Assessment Plan (NBIAP) in 1994. The subsequent two NBIAP (2002 and 2007) have offered opportunities and challenges for the beef industry with regard to using technology as an objective measurement of carcass attributes.

Initial research of VIA for assessment of yield grade began in the early 1980's. Early findings from Cross et al. (1983) and Wassenberg et al. (1986), identified actual and adjusted fat thickness as the most important traits to be measured subjectively. These measurements can be easily influenced by slaughter defects and irregularities, therefore reducing the accuracy of VIA outputs. In later research, Belk et al. (1998) evaluated the difference in yield grade designation by on-line systems versus expert graders and found that 94.4% of the carcasses evaluated in the study required

adjustments to the preliminary yield grade (PYG) to accurately represent overall carcass fatness. As a result of the study, Belk suggested a yield grade augmentation system that utilized the ability for USDA graders to determine adjusted preliminary yield grade (APYG) and the VIA ability to accurately and efficiently measure and calculate other factors such as ribeye area and overall yield grade.

There are a number of studies that support the use of VIA technology in the beef industry as an accurate method of measuring carcass attributes and overall yield grade (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Shackelford et al., 2003; Steiner et al., 2003). Many of those same studies echo support of VIA used in an augmented system to increase accuracy and utilize subjective determination of APYG. In the early 2000's, the USDA Agricultural Marketing Service released VIA technology performance standards to the industry for determination of LM area (USDA - Agricultural Marketing Service, 2003), yield grade (USDA - Agricultural Marketing Service, 2005), marbling score (USDA - Agricultural Marketing Service, 2006) , and approved the first VIA instrument for yield grade application in 2007 (National Cattlemen's Beef Association, 2007).

Beginning in 2011, the National Beef Quality Audit: Survey of instrument grading assessments of beef carcass characteristics was able to compare data from in-plant surveys with instrument data collected from a variety of plants around the country (Gray et al., 2012). The instrument grading assessment was the first time seasonal yield and quality trends could be mapped over the course of a year using a large number of carcasses (n = 2,427,074). This assessment also offered an opportunity to compare

carcass trait means from instrument data to data collected in the in-plant survey (n = 9,802) (Moore et al., 2012). The data sets were surprisingly similar, instrument assessment means: yield grade – 2.95; fat thickness – 1.30 cm; hot carcass weight – 374.0 kg; LM area – 88.77 cm^2; and marbling score – 440, and in-plant survey means: yield grade 2.86; fat thickness – 1.20 cm; hot carcass weight – 371.3 kg; LM area – 88.45 cm^2; and marbling score – 450. These similarities added credibility with producers and packers that the VIA technology was offering a level of precision comparable to expert USDA graders.

Those results were able to be replicated, perhaps with even greater accuracy, by Boykin et al. (2017a) in the National Beef Quality Audit–2016: Survey of carcass characteristics through instrument grading assessments. Means for the instrument assessment (n = 4,544,635) were strikingly similar to those of the carcasses evaluated (n = 9,106) during the in-plant survey (Boykin et al., 2017b). Means for the instrument assessment: yield grade – 3.1; fat thickness – 1.4 cm; hot carcass weight – 390.3 kg; LM area – 89.5 cm^2; KPH – 1.9%; and marbling score – 470. Means for the in-plant survey: yield grade – 3.1; fat thickness – 1.37 cm; hot carcass weight – 393.6 kg; LM area – 88.9 cm^2; KPH – 2.1%; and marbling score – 475. The ability to replicate the consistencies found in NBQA–2011 instrument assessment also lends confidence to the accuracy of previous NBQA findings.

Video image analysis technology has also been utilized to predict economic trends. Hoelscher et al. (2010) evaluated which carcass composition characteristics present at the $12^{th}/13^{th}$ rib interface would most accurately predict boxed beef value.

Eighty-four cattle were evaluated for hot carcass weight (HCW), marbling score, LM length, LM width, LM area, subcutaneous fat thickness and area, iliocostalis muscle area, ratio of subcutaneous fat thickness to side hot carcass weight, ratio of LM area to side hot carcass weight, ratio of LM area to subcutaneous fat area, ratio of LM width to subcutaneous fat thickness, and ratio of LM area to subcutaneous fat thickness. Prediction equations were developed to attempt to predict carcass side value per 45.35 kg, primal round value, primal loin value, primal rib value, primal chuck value, and collective primal brisket-plate-flank-plate-shank value. As was expected, hot carcass weight was the most highly correlated variable since boxed beef is sold by the pound (r = 0.94). HCW was followed by LM area (r = 0.73) and LM length (r = 0.70). HCW, LM area, and LM length were also highly correlated with carcass value per 45.35 kg, primal rib value, primal loin value, primal round value, and primal chuck value. Surprisingly, marbling was only moderately correlated with several values. The study found that the prediction model that provided the greatest accuracy in predicting boxed beef value was a 4-variable model including HCW, marbling, LM area, and subcutaneous fat thickness (at 100% of carcass weight in kg). Use of VIA technology to record these carcass traits can provide the industry a more efficient, accurate way to determine value of beef carcasses.

2.3 Innovative subprimal fabrication and merchandising

According to the National Beef Quality Audit–2005, six of the top ten quality challenges were related to "non-conforming" beef attributes such as low uniformity of cattle, too heavy carcasses and cuts, and inappropriate LM area size. A research need

identified at the non-conforming beef research summit was to "identify alternative/innovative fabrication styles to increase value from heavier weight/larger frame carcasses" (Savell, 2007). In the years since, several studies have been completed to investigate novel fabrication styles and merchandising methods.

A study by Bass et al. (2009) evaluated non-conforming carcasses relationship with portion size acceptability of other muscles in the carcass. Bass et al. (2009) fabricated 14 individual muscle cuts from carcasses of varying LM area size (67.74 to 116.13 cm^2) and found that while the LM area was not commercially acceptable, many of the muscle cuts were still considered acceptable to merchandisers. This would suggest that LM area is not an accurate predictor of size and acceptability of individual muscle cuts and subsequent beef carcass value (Bass et al., 2009).

West et al. (2011) also determined that LM area was not a good predictor of size and acceptability of other muscles. West et al. (2011) collected top sirloin butt, ribeye, and strip loin subprimals from average weight carcasses (318 to 363 kg) and heavy weight carcasses (454 to 499 kg). These subprimals were then fabricated based on conventional retail style or innovative retail merchandising style. For the ribeyes and strip loins, it was found that cuts from the heavy carcass group produced higher saleable yield for both cutting styles, but heavy ribeyes required a significantly longer processing time when compared to the average carcass weight group (West et al., 2011). This should be a consideration for retailers when fabricating larger subprimals, especially from the rib and loin regions, with innovative techniques.

Merchandising style can also have an influence on yield and fabrication times as outlined by Weatherly et al. (2001). Subprimals were fabricated to targeted foodservice portion-sized cuts to generate mean cutting yields and labor requirements. It was determined as target portion size decreased, total number of steaks from the subprimal increased, causing foodservice yield to decrease and total processing time to increase (Weatherly et al., 2001). Similar conclusions for relationship between product yield and processing time were found by McNeill et al. (1998).

2.4 Consumer preference – retail sector

The beef-eating experiences and preferences of consumers is a major driver of quality targets in the beef supply chain. According to the Consumer Beef Index Survey conducted in March 2017, consumers have increased the importance of value, consistency, and taste of beef products in retail (The Beef Checkoff, 2017). There have been a variety of studies completed in the area of consumer preference, especially in regard to steak thickness and portion size in the retail sector.

The National Beef Tenderness Survey conducted by Martinez et al. (2017) provided a benchmark for the industry on tenderness of steaks in both foodservice and retail, while also providing data on steak thickness, steak weight, and overall liking by a consumer sensory panel. The study surveyed retail cases over a 12-month period in a broad range of cities including New York, NY; Philadelphia, PA; Los Angeles, CA; Denver, CO; Las Vegas, NV; Tampa, FL; Atlanta, GA; Kansas City, MO; Houston, TX; Chicago, IL; and Seattle, WA. The study sampled foodservice establishments in six cities including Houston, TX and Dallas, TX; Tampa, FL; Denver, CO; Las Vegas, NV;

and Philadelphia, PA. Steak thickness and steak weight were obtained from a variety of retail cuts including the ribeye, lip on, boneless, and the top loin steak. The least squares means (± SEM) for thickness of the ribeye, lip on, boneless steak in retail (n = 311) was 2.87 cm (± 0.03) and in foodservice (n = 160) was 2.91 cm (± 0.03). The least squares means (± SEM) for thickness of the top loin steak in retail (n = 321) was 2.97 cm (± 0.03) and in foodservice (n = 136) was 2.80 cm (± 0.03). The least squares means (± SEM) were also calculated for steak weight of the ribeye, lip on, boneless steak in retail (n = 311) was 0.40 kg (± 0.01) and in foodservice (n = 160) was 0.43 kg (± 0.01). The least squares means (± SEM) were also calculated for steak weight of the top loin steak in retail (n = 321) was 0.36 kg (± 0.01) and in foodservice (n = 136) was 0.35 kg (± 0.01). When compared to thinner, lighter weight cuts from the round and sirloin, the ribeye and top loin cuts possessed a greater level of overall like/dislike when evaluated by consumer sensory panelists. This study offered insight into the average thicknesses and weights of a variety of steaks found in the retail and foodservice sectors and provided a benchmark for the industry.

Maples et al. (2016) conducted an investigation in which consumers completed several surveys related to steak type, surface area, thickness, and price influence choice in a retail setting. It was revealed that respondents were willing to pay $7.07/package less for a 64.52 cm^2 (10 in^2) ribeye and $3.51/package more for a 116.13 cm^2 (18 in^2) ribeye, compared to a 90.32 cm^2 (14 in^2) ribeye, respectively. The same survey suggested consumers would be willing to pay $18.67/package less for the 1.27 cm (0.5 in) thick ribeye and $4.66 more for the 3.81 cm (1.5 in) ribeye when compared to a 2.54

cm (1 in) ribeye. Additionally, around 90 percent of respondents were negatively influenced by the 1.27 cm (thin cut) steaks when compared to the 2.54 cm (average cut) steaks.

A recommendation put forth by Maples et al. (2016) was to divide steaks with a larger surface area into several sections to maintain an acceptable level of thickness while still meeting the target package price at retail. It was evident in this study that consumers almost unanimously prefer at least an average 2.54 cm (1 in) thickness steak and thin cut steaks would likely yield a lower willingness to pay compared to thicker-cut steak options. Maples et al. (2016) found the drastic increase in carcass weight over the last several decades led to a $8.6 billion loss in consumer welfare resulting from changes in steak size and thickness. In order to maintain positive eating experience and address consumer preference, the sectioning of large steaks into smaller portion sizes while maintaining adequate thickness could be a potential outlet for oversized products in retail and foodservice establishments.

Sweeter et al. (2005) further investigated the concept of portioning large LM area steaks in a retail setting. In the first phase of the study, ribeye steaks cut to a standard thickness of 2.5 cm were stratified into five LM area groups; 61 to 68 cm^2 (A); 70 to 78 cm^2 (B); 80 to 90 cm^2 (C); 92 to 103 cm^2 (D); and 105 to 199 cm^2 (E) and placed into a retail meat case. Steaks were tallied for time spent in the retail case and were pulled if they did not sell within an allotted time period. In the second phase of the study, steaks from two LM area categories; 80 to 90 cm^2 (average) and 105 to 119 cm^2 (large) were cut to 2.5 cm thickness.

Results from Sweeter et al. (2005) suggest there is a slightly higher demand at retail for larger LM area steaks when compared to smaller or average LM area steaks. Consumers were willing to pay a premium of $1.50/kg for large LM area steaks, and discounted steaks cut in half by $1.01/kg when compared to average LM area steaks, respectively. This study suggested there was not a clear-cut optimum LM area size for retail consumers but there was a slight trend toward a preference for larger LM area steaks compared to smaller LM area steaks similar to findings from (Dunn et al., 2000; Leick et al., 2011).

Behrends et al. (2009) supported Sweeter et al. (2005) in their evaluation of consumer preference of steak thickness when cut to a constant weight in retail. Behrends et al. (2009) found consumers ranked thickness as their number one priority 26.9%, 32.2% and 33% for ribeye, strip loin, and sirloin steaks, respectively. Additionally, it was observed that over 50% of consumers would pay at least $1.00 premium for thicker steaks. It was identified that annual income also had an effect on the thickness and price/lb they were most likely to select (Behrends et al., 2009).

A series of retail store audits were completed by Cross (2016) and reflected the lack of supply consistency and size irregularities. The audits revealed retailers struggled to meet tray size and cost per serving requirements, forcing them to cut steaks thinner than desired by the consumer. Cross (2016) also found purveyors were not satisfied with the size and uniformity of primal cuts at receiving.

2.5 Consumer preference – foodservice sector

Beef cuts are an important component of the foodservice industry to drive traffic and profitability in the restaurant setting. According to the 2017 Foodservice Volumetric Study, 97 percent of foodservice operations surveyed were serving beef on their menus (Technomic, 2018). The same study revealed 45 percent of respondents stated that having a strong steak presence on the menu ranked as important or very important for increasing traffic and 53 percent stated steak drives the check average. The study also cited a growing trend of back-of-house fabrication of steaks as an innovative way to offer guests new eating experiences. Today, consistency in the foodservice beef eating experience is of great importance to the consumer (The Beef Checkoff, 2017).

A major challenge for foodservice operators is lack of consistency of steaks cut to a specific portion weight. As LM area sizes become more variable, the subsequent thickness of steak cuts become thinner as the LM area increases. Dunn et al. (2000) conducted a study evaluating the optimal ranges in LM area for portion cutting of beef steaks. Seventy-one low-Choice carcasses were selected and were categorized into seven LM area groups. Results of the study showed strip loin steaks with 96.7 cm^2 LM area size or greater reached their target end-point temperature more quickly than remaining LM area groups. LM areas 77.4 cm^2 to 96.6 cm^2 cooked on average 26 percent more quickly than LM areas less than 77.3 cm^2 (Dunn et al., 2000). Regression analysis from the study demonstrated that steak thickness was responsible for much of the variation in cook time in both strip steaks (r = .52) and t-bones (r = .33) and indicated that thickness had a greater influence on cook time than LM area. Dunn et al. (2000) reported steaks

obtained from carcasses with a LM area of 77 – 97 cm^2 were observed to have the optimum tenderness rating and cooking times. Selecting for product of a consistent size should reduce variation in cook time and offer more confidence for foodservice cooks to achieve appropriate degree of doneness to yield a desirable eating experience (Dunn et al., 2000).

A study completed by (Leick et al., 2011) evaluated consumer acceptance of ribeye, top loin, and top sirloin steaks from various hot carcass weight and LM area groups when cut to a constant steak weight. Leick segmented carcasses (*n* = 25) into five groups based on hot carcass weight and LM area restrictions Group 1 (G1) – 226 to 271 kg/ 70.9 to 78.1 cm^2; Group 2 (G2) – 272 to 316 kg/ 78.7 to 85.8 cm^2; Group 3 (G3) – 317 to 361 kg/ 86.5 to 93.5 cm^2; Group 4 (G4) – 362 to 407 kg/ 94.2 to 101.3 cm^2; Group 5 (G5) – 408 to 452 kg/ 101.9 to 109.3 cm^2. Subprimals were trimmed to specification at a foodservice purveyor and cut on an automated portioning machine to constant weight. Consumers were asked to rank: marbling, color, thickness, texture, and other, in order of importance (1 = most important, 5 = least important). Leick et al. (2011) found that as HCW and LM area increased, steak thickness decreased. The greatest percentage of consumers (26.7%) chose large LM area steaks from group 5 and the lowest percentage of consumers (14.1%) chose small LM area steaks from group 1. This finding could be as a result of G5 steaks having a larger surface area and consumers perceived the smaller LM area steaks as being too thick (on average 1.7 cm thicker than G5). Nearly 27% of consumers ranked thickness as their most important steak buying criteria. The greatest percentage of consumers (25.2%) selected top loin steaks from

group 4 and the lowest percentage (14.1%) selected top loin steaks from group 5. Thickness of top loin steaks was ranked as the primary selection criteria by 33.8% of consumers. Leick et al. (2011) demonstrated that beef consumers develop individualized preferences related to steak thickness and predicted eating experience.

A study by Berto (2015) evaluated consumer attitudes toward flavor aromas from steaks of different thicknesses, quality grades, and cooking surface temperatures. USDA Top Choice and USDA Select top loin steaks were cut to 1.3 cm or 3.8 cm thickness and were cooked on a flat-top grill at 177ºC or 232ºC and evaluated by a trained attribute panel, consumer panel, and gas chromatography for aroma. It was revealed interactions between thickness and temperature had the greatest impact on aroma. The 3.8 cm thick steaks cooked at 177ºC had the greatest level of positive beef flavor attributes (Berto, 2015). The findings of this study suggest a potential for greater beef-eating experience for the consumer with thicker steaks compared to thinner counterparts under similar cooking procedures.

2.6 Beef demand

The United States has developed one of the most productive and sustainable beef production systems in the world. In 2007, U.S. farmers and ranchers produced the same amount of beef with 33% fewer cattle than they did in 1977 (Capper, 2011). While productivity has increased, beef demand has remained relatively flat over the last several decades. U.S. beef demand sustained a downward trend in the 1980's and early 90's but rebounded with the lean protein diets of the late 1990's. Beef demand has demonstrated a flat to slightly declining trend in the years since (Tonsor et al., 2009) with the

emerging popularity of pork and poultry products. Over the same period, beef quality has continued to improve with a greater percentage of cattle grading Prime and Choice compared to the leaner Select option.

In the several decades prior to the 1990's, the beef industry transitioned into buying and selling product as boxed beef as a method to reduce shipping cost and allow merchandisers to purchase volume of select cuts that they could sell in their area. Today, the vast majority of beef is sold in boxed form and this merchandising form has streamlined beef procurement. Lusk et al. (2001) identified the importance of boxed beef, more specifically USDA graded boxed beef, to the wholesale market. Lusk et al. (2001) revealed retail beef price has a strong positive relationship with USDA Choice and Select boxed beef demand.

Speer (2015) reported in early 2015 the eight-week moving average for Prime/branded (combined) beef sales surpassed that of Select for the first time, accounting for 17 and 14 percent of sales, respectively. In earlier research, Speer (2013) noted from the years 2003-2013 value of combined USDA Prime and branded beef increased nearly 400%. This increase in branded beef sales could be attributed to the establishment of 89 USDA Certified Branded Beef Programs since 1978 (United States Department of Agriculture - Agricultural Marketing Service, 2018). The availability of USDA Choice boxed beef has decreased slightly to 70.8 percent of cattle down from 71.6 percent in 2017, while USDA Prime is up to 8.9 percent from 7.1 percent and USDA Select is up to 17.4 percent versus 15.3 in 2017 (Anderson, 2018). It is clear from

USDA market reporting there is a vast and complex market for quality beef products for consumers.

CHAPTER III

MATERIALS AND METHODS

3.1 Carcass selection

Beef sides were selected from a commercial beef harvest and processing facility. Instrument grading technology was utilized to identify 100 USDA Choice, yield grade 2 and 3 sides and 100 USDA Select, yield grade 2 and 3 sides that were further sorted into one of five LM area categories (n = 20 carcass sides per category; Table 1). Selected sides were tagged, and establishment carcass side identification numbers were recorded.

3.2 Carcass fabrication

All carcass sides were fabricated to produce subprimals that complied with the Institutional Meat Purchase Specifications (IMPS), as described by the North American Meat Institute (USDA, 2014). Beef rib, ribeye, lip-on (IMPS, 112A) and beef loin, strip loin, boneless (IMPS 180) were obtained from each USDA Choice side. Additionally, a beef loin, tenderloin, full, side muscle on, partially defatted (IMPS, 189B) was removed from each USDA Select side. All subprimals were vacuum packaged, boxed, and shipped to a commercial foodservice operator.

3.3 Subprimal fabrication

On the day of portioning and data collection, tenderloins were organized by individual identification number, and inventory was taken to determine the number of positively identified subprimals (n = 95). Tenderloins were unboxed, unbagged, and weighed using two identical Marel M Series 1100 Scales (Marel, Lenexa, KS) to yield a

pre-trimmed subprimal weight. Tenderloins were trimmed to specification by trained establishment employees and re-weighed. Each subprimal then was passed through a Marel Portioner – M Series 3000 (Marel, Lenexa, KS) to obtain a visual image and dimensional analysis. Scan data were used by Marel IPM3 Simulation software (Marel, Lenexa, KS) to calculate optimal or desired cut configurations, allowing determination of multiple portioning outcomes for each subprimal. On the day of analysis, strip loins were identified (n = 98), un-boxed, un-bagged, and weighed using an Adam Equipment WBW 18a, max 8 kg (Adam Equipment, Inc., Oxford, CT) (TAMU identification number 1-50) and a Gainco Infiniti Digital scale, max 8 kg (Gainco, Inc., Gainesville, GA) (TAMU identification number 51-100) scale. Trained establishment personnel trimmed strip loins to facility specifications and subprimals were re-weighed. Each strip loin then was passed through a portioner (Marel) as previously described. On the day of analysis, n = 97 ribeyes were positively identified. Ribeyes then were handled using the same methods described above.

3.4 Statistical analysis

Data were analyzed using JMP Pro software (version 14.0, SAS Institute Inc., Cary, NC). Data were generated and reported by portion weight by LM area category using JMP. Data then were analyzed by portion thickness by LM area category using the same methods. Qualitative assessments were made of the appropriateness of each portion and method within and across the LM area categories. The Fit Y by X function was used for ANOVA, and least squares means comparisons were conducted using

Tukey-Kramer HSD. Correlations were determined using the multivariate functions. Mean values were determined using the distribution function.

CHAPTER IV

RESULTS AND DISCUSSION

Mean carcass attributes for USDA Choice carcasses (n = 100), USDA Select (n = 100), and combined quality grades (n = 200) are shown in Table 2. The combined mean hot carcass weight was 361.2 kg, with USDA Choice carcasses being lighter weight on average (357.7 kg) and USDA Select carcasses being heavier (364.7 kg). The mean hot carcass weights for this study were lighter than the mean hot carcass weight of 393.6 kg determined in the most recent NBQA – 2016 instrument survey (Boykin et al., 2017b). This finding could be a result of the defined LM area categories limiting the number of large and small carcasses, not meeting the LM area requirements, from being included in the study. Both sets of carcasses included in the study were selected on the grading chain for LM area, yield grade, and quality grade (marbling score). Means for those traits in the USDA Choice carcasses were 90.52 cm^2, 2.8, and 445.4, respectively. Mean traits for the USDA Select carcasses were 91.22 cm^2, 2.6, and 367.3, respectively. The NBQA – 2016: in plant survey revealed a positive correlation (r = 0.40) between hot carcass weight and LM area (Boykin et al., 2017a). In this investigation, the USDA Choice carcasses correlation between hot carcass weight and LM area was r = 0.72, and USDA Select carcasses expressed a slightly weaker, but still moderate relationship of r = 0.56.

Based on input from our foodservice collaborators, a benchmark portion thickness of 31.75 mm (1.25 in) for both ribeye and strip loin steaks was targeted as optimal. Portioning outcomes for ribeyes stratified by portion weight within LM area category are shown in Table 3. The table illustrates that in category 1, both a 340.2 g (12

oz) and 396.9 g (14 oz) portion would achieve an acceptable thickness. Acceptable thickness was achieved in categories 2 through 4 in a 396.9 g (14 oz), and no portion sizes in category 5 would yield a steak of desirable thickness for the end-user. Percentage steak yield, percentage trim, and percentage waste did not notably vary between LM area categories. Table 4 shows results for ribeyes stratified by portion thickness within LM area category. LM area categories 1 and 2 yielded the most utility with 31.8 mm (1.25 in) and 38.1 mm (1.50 in) thick portions being an acceptable 396.9 g (14 oz) portion weight. LM area categories 3, 4, and 5 achieved acceptable thickness and portion weight at 31.8 mm (1.25 in) thickness but revealed excess portion weight upwards of 452.5 g (16 oz) when portioned at 38.1 mm (1.50 in) thickness.

Table 5 shows portioning outcomes for strip loins stratified by portion weight within LM area category. Similar to the ribeyes, acceptable thickness was more easily achieved in the smaller LM area categories. Categories 1 and 2 showed acceptable thickness in both the 340.2 g (12 oz) and 396.9 (14 oz) portion weights. The remaining categories achieved acceptable thickness in a 396.9 g (14 oz) portion weight. Percentage steak yield, lean trim, and waste did not vary greatly between portion weights or LM area category. When stratified by portion thickness, as shown in Table 6, the smaller LM area categories continued to out-perform the larger categories. Acceptable thickness and weight was achieved at the 31.8 mm (1.25 in) and 38.1 mm (1.50 in) thicknesses in categories 1 and 2. Acceptable parameters were met at the 31.8 mm (1.25 in) thickness in LM area categories 3, 4, and 5.

In tenderloins, a benchmark thickness of 44.5 to 50.8 mm (1.75 to 2.00 in) was targeted as optimal. When compared to strip loins and ribeyes, adequate utility was more consistently realized over all five LM area categories within tenderloins, with 198.4 g (7 oz), 226.8 g (8 oz), and 255.1 g (9 oz) portions combining optimal portion weight and thickness to the highest degree (Tables 7 and 8). Steak yield, lean trim, and waste did not vary greatly across portion weights or LM area categories. There was a slight trend for greater percentage of lean trim in the larger portion weights. As would be expected, portion number decreased as portion weight and thickness increased within each category, in each subprimal type.

Least squares means for portion number stratified by portion weight in ribeyes are shown in Table 9 and stratified by portion thickness in Table 10. Significant differences (P <0.0001) were present across all portion weights and portion thicknesses. Table 11 shows least squares means for portion number stratified by portion weight in strip loins. Significant differences (P < 0.0001) were found across all portion weights within LM area categories. When stratified by portion thickness in strip loins (Table 12) significant differences were found in the 19.1 mm (0.75 in) thickness (P = 0.0073), 25.4 mm (1.00 in) and 31.8 mm (1.25 in) thicknesses (P < 0.0001), and 38.1 mm (1.50 in) thickness (P = 0.0208).

In tenderloins, least squares means for portion number by portion weight in Table 13 revealed significant differences between all categories (P < 0.05) with the exception of the 198.4 g (7 oz) portion weight (P = 0.0596). Table 14 shows no differences in least

squares means for portion number by portion thickness within LM area category in tenderloins.

Tables 15 through 17 show least squares means for subprimal weight and trimmed subprimal weight for ribeyes, strip loins, and tenderloins, respectively. Differences (P <0.0001) were found across LM area categories for each subprimal, illustrating as LM area increased, so did subprimal weight.

Based on historical and current sorting methods of subprimals at boxing, weight break thresholds were estimated (as shown in Table 18) and data were sorted based on subprimal weight above and below the determined threshold. These data were generated to evaluate if sorting subprimals by weight is an effective method to predict LM area size and consistency. Weight break thresholds, sorting method, and implementation vary by processor and subprimal type. Historically, ribeyes were sorted at boxing at 7.71 kg (17 lbs), strip loins at 6.80 kg (15 lbs), and tenderloins at 3.18 kg (7 lbs). These data suggest sorting by subprimal weight is not an effective method of predicting LM area size range within a box. As subprimal weight increased, so did average LM area size but the variation within box ranged widely by as much as 30.97 cm^2 ribeyes and 29.03 cm^2 in strip loins. In tenderloins, percentage of the n was more evenly split at the weight break and the variation in light vs. heavy boxes was particularly noteworthy. This finding suggests sorting carcasses by LM area does little to predict subsequent weight of the tenderloin.

As carcass weights and subsequent cuts continue to increase in size and weight, boxed beef piece-count boxing methods may become a greater challenge for the

industry. In order to ensure the correct piece-count in each box, packers may resort to mixing large and small subprimals in order to fill boxes which could cause further problems in uniformity for foodservice purveyors and retailers. Additionally, filling boxes with larger, heavier subprimals may cause already heavy boxes to become heavier and offer potential ergonomic problems with lifting and moving boxes. From an independent foodservice and retail operator stand point, heavier boxes mean an elevation in price per box which could present challenges if the price of beef increases dramatically or they do not have the throughput to sell large boxes of subprimals.

CHAPTER V

CONCLUSION

Sorting carcasses at the packer level by LM size can be an effective method to improve product uniformity and utility for retail and foodservice purveyors in the future. Grouping and fabricating carcasses of similar LM area could lead to more consistent size of product in boxed beef and subsequently greater ease of use by the purveyor or retailer. Carcasses in the smaller LM area categories (74.8 to 80.6 and 81.3 to 87.1 cm^2) yielded the greatest acceptable portion weight and thickness options for ribs and strip loins. Tenderloins offered a greater range of utility across LM area categories and more often reached acceptable portion weight and thickness parameters. Sorting beef by LM area using established camera grading technology could be a novel way to improve boxed beef uniformity, product utility for the purveyor, and subsequent eating experience for the consumer. Data collected in this study provide insight into possible improvements to the way beef carcasses are sorted and subsequently boxed in subprimal form. The problems addressed in the study concerning suitability of boxed beef subprimals for purveyor and consumer utilization, in both foodservice and retail settings, will continue to challenge the beef industry in the years to come unless innovative strategies are implemented, perhaps at various stages of the beef supply chain.

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APPENDIX

Table 1. LM area categories and associated acceptable LM area ranges

REA Category	LM area (cm^2)	Allowable range (cm^2)
1	77.4	74.8 to 80.6
2	83.9	81.3 to 87.1
3	90.3	87.7 to 93.5
4	96.8	94.2 to 100.0
5	103.2	100.6 to 106.4

REA categories formed to reflect 12 in^2 (1), 13 in^2 (2), 14 in^2 (3), 15 in^2 (4), and 16 in^2 (5) LM size groups

Table 2. Mean carcass attributes

	Choice (n = 100)	Select (n = 100)	Combined (n = 200)
Hot carcass weight (kg)	357.67	364.72	361.18
LM area (cm^2)	90.52	91.22	90.84
Yield grade	2.75	2.63	2.69
Marbling score[1]	445.35	367.25	406.30
Correlation HCW by LM area	0.72	0.56	0.63

[1]300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00} (USDA, 2016b).

Table 3. Portioning outcomes for ribeyes stratified by portion weight within LM area category[a]

LM area category	Portion weight (g)	Portion number	Average thickness (mm)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	226.8	18.8	21.2	69.2	3.1	27.7
	283.5	15.0	26.6	69.0	3.3	27.6
	340.2	12.4	31.9	68.5	3.9	27.6
	396.9	10.6	37.2	68.0	4.4	27.6
2	226.8	20.2	20.6	70.2	2.9	26.9
	283.5	16.1	25.8	69.7	3.6	26.7
	340.2	13.4	31.1	69.5	3.6	26.9
	396.9	11.5	36.2	70.0	3.1	26.9
3	226.8	21.8	18.9	70.5	2.7	26.9
	283.5	17.3	23.8	70.0	3.1	26.9
	340.2	14.3	28.7	69.2	3.9	26.9
	396.9	12.3	33.4	69.4	3.7	26.9
4	226.8	22.5	18.5	71.3	2.3	26.3
	283.5	17.9	23.4	70.8	3.0	26.3
	340.2	14.8	28.5	70.4	3.3	26.3
	396.9	12.7	32.8	70.2	3.5	26.3
5	226.8	25.1	17.4	71.3	2.6	26.1
	283.5	19.9	22.0	70.9	3.0	26.1
	340.2	16.6	26.5	70.7	3.2	26.1
	396.9	14.1	30.8	70.3	3.6	26.1

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 4. Portioning outcomes for ribeyes stratified by portion thickness within LM area category[a]

LM area category	Portion thickness (mm)	Portion number	Average weight (g)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	19.1	21.2	204.8	70.3	2.1	27.6
	25.4	15.9	272.9	70.2	2.2	27.6
	31.8	12.6	343.4	69.7	2.6	27.6
	38.1	10.4	410.0	69.2	3.2	27.6
2	19.1	22.4	208.2	71.2	1.9	26.9
	25.4	16.7	278.7	71.3	1.8	26.9
	31.8	13.2	348.7	70.7	2.4	26.9
	38.1	10.8	423.8	69.8	3.3	26.9
3	19.1	22.1	226.0	71.3	1.8	26.9
	25.4	16.5	302.8	71.3	1.8	26.9
	31.8	13.1	380.9	71.0	2.1	26.9
	38.1	10.8	458.5	70.4	2.7	26.9
4	19.1	22.7	227.0	72.1	1.6	26.3
	25.4	16.9	305.5	72.0	1.7	26.3
	31.8	13.3	386.6	71.6	2.1	26.3
	38.1	11.1	463.5	71.6	2.1	26.3
5	19.1	23.0	249.7	72.1	1.8	26.1
	25.4	17.2	333.8	71.9	2.0	26.1
	31.8	13.7	418.3	71.7	2.2	26.1
	38.1	11.4	500.9	71.4	2.5	26.1

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 5. Portioning outcomes for strip loins stratified by portion weight within LM area category[a]

LM area category	Portion weight (g)	Portion number	Average thickness (mm)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	226.8	17.5	22.4	69.1	3.5	27.4
	283.5	14.0	28.0	69.0	3.6	27.4
	340.2	11.5	33.7	68.3	4.3	27.4
	396.9	9.8	39.6	67.5	5.1	27.4
2	226.8	17.5	22.2	71.0	3.2	25.8
	283.5	13.9	27.6	70.2	3.9	25.9
	340.2	11.5	33.4	69.7	4.5	25.8
	396.9	9.7	39.0	68.8	5.2	26.0
3	226.8	19.6	20.1	72.0	3.1	24.9
	283.5	15.6	25.3	71.4	3.7	24.9
	340.2	12.9	30.6	70.9	4.2	24.9
	396.9	10.9	35.6	70.7	4.5	24.9
4	226.8	19.2	20.6	68.7	2.9	27.4
	283.5	15.4	25.8	68.9	3.6	27.4
	340.2	12.9	31.3	69.1	3.5	27.4
	396.9	10.8	36.4	68.0	4.6	27.4
5	226.8	21.6	19.6	69.0	2.5	25.2
	283.5	17.1	24.6	70.8	3.9	25.3
	340.2	14.0	29.9	70.4	4.0	25.6
	396.9	11.6	34.6	70.4	4.3	25.3

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 6. Portioning outcomes for strip loins stratified by portion thickness within LM area category[a]

LM area category	Portion thickness (mm)	Portion number	Average weight (g)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	19.1	20.0	201.9	70.3	2.3	27.4
	25.4	14.8	270.0	69.8	2.8	27.4
	31.8	11.8	337.7	69.2	3.3	27.4
	38.1	9.7	404.8	68.5	4.1	27.4
2	19.1	20.0	200.8	71.8	2.4	25.8
	25.4	14.8	269.9	71.5	2.7	25.8
	31.8	11.7	339.0	70.9	3.2	25.8
	38.1	9.7	405.3	70.3	3.9	25.8
3	19.1	20.3	222.0	72.9	2.2	24.9
	25.4	15.1	298.5	72.7	2.4	24.9
	31.8	12.0	372.7	72.3	2.8	24.9
	38.1	10.0	444.0	71.8	3.4	24.9
4	19.1	20.3	219.6	70.3	2.3	27.4
	25.4	15.1	292.7	69.8	2.8	27.4
	31.8	11.9	369.7	69.2	3.4	27.4
	38.1	9.9	441.6	68.7	3.9	27.4
5	19.1	21.2	233.1	72.5	2.2	25.3
	25.4	15.7	313.3	72.0	2.7	25.3
	31.8	12.4	393.4	71.6	3.0	25.3
	38.1	10.3	470.6	71.2	3.5	25.3

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 7. Portioning outcomes for tenderloins stratified by portion weight within LM area category[a]

LM area category	Portion weight (g)	Portion number	Average thickness (mm)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	141.7	12.7	34.1	62.1	3.2	34.7
	170.1	10.4	39.6	61.2	4.0	34.8
	198.4	8.8	45.1	60.6	4.6	34.8
	226.8	7.8	51.8	61.4	3.7	34.8
	255.1	6.8	57.0	60.2	5.0	34.8
	283.5	6.1	62.5	59.2	6.0	34.8
2	141.7	13.2	33.6	61.8	3.1	35.2
	170.1	10.9	39.0	61.0	3.8	35.2
	198.4	9.2	45.0	61.1	3.7	35.2
	226.8	8.0	51.6	59.9	5.0	35.2
	255.1	6.9	56.4	58.9	6.0	35.2
	283.5	6.4	62.8	59.3	5.5	35.2
3	141.7	13.8	31.8	62.5	2.9	34.6
	170.1	11.4	37.5	61.5	3.9	34.6
	198.4	9.1	43.0	61.5	4.0	34.6
	226.8	8.4	49.1	60.8	4.6	34.6
	255.1	7.4	55.0	59.9	5.6	34.6
	283.5	6.6	60.0	59.8	5.6	34.6
4	141.7	14.3	31.5	62.4	2.8	34.8
	170.1	11.8	36.6	61.8	3.3	34.8
	198.4	9.9	42.5	61.7	3.5	34.8
	226.8	8.6	48.4	60.0	5.2	34.8
	255.1	7.6	53.7	59.6	5.5	34.8
	283.5	6.9	58.5	60.3	4.9	34.8
5	141.7	14.9	30.4	63.6	2.9	33.6
	170.1	12.4	35.5	62.9	3.3	33.8
	198.4	10.2	40.6	61.8	4.4	33.8
	226.8	9.2	46.5	62.4	3.7	33.8
	255.1	8.1	51.9	61.8	4.3	33.8
	283.5	7.2	56.3	61.0	5.2	33.8

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 8. Portioning outcomes for tenderloins stratified by portion thickness within LM area category[a]

LM area category	Portion thickness (mm)	Portion number	Average weight (g)	Steak yield[b] (%)	Lean trim[c] (%)	Waste[d] (%)
1	25.4	21.6	86.2	64.2	0.9	34.8
	31.8	17.0	109.3	64.2	1.0	34.8
	38.1	14.1	131.1	64.1	1.1	34.8
	44.5	12.0	154.7	64.1	1.0	34.8
	50.8	10.4	177.8	64.0	1.2	34.8
	57.2	9.1	203.1	63.9	1.3	34.8
	63.5	8.1	226.4	63.8	1.4	34.8
2	25.4	22.3	86.8	63.9	0.9	35.2
	31.8	17.5	110.2	63.8	1.0	35.2
	38.1	14.5	133.3	63.8	1.0	35.2
	44.5	12.4	155.3	63.7	1.1	35.2
	50.8	10.8	177.0	63.8	1.1	35.2
	57.2	9.5	202.8	63.6	1.2	35.2
	63.5	8.5	227.6	63.5	1.3	33.2
3	25.4	21.8	92.6	64.5	0.9	34.6
	31.8	17.4	116.1	64.5	0.9	34.6
	38.1	14.4	140.2	64.5	1.0	34.6
	44.5	12.2	165.4	64.4	1.0	34.6
	50.8	10.7	188.9	64.4	1.0	34.6
	57.2	9.4	213.0	64.3	1.1	34.6
	63.5	8.4	237.8	64.3	1.2	34.6
4	25.4	22.3	93.6	64.3	0.9	34.8
	31.8	17.7	117.2	64.2	1.0	34.8
	38.1	14.7	141.3	64.2	1.0	34.8
	44.5	12.5	167.2	64.1	1.1	34.8
	50.8	10.9	190.9	64.1	1.1	34.8
	57.2	9.6	217.5	63.9	1.3	34.8
	63.5	8.5	242.6	63.8	1.4	34.8
5	25.4	22.1	98.5	65.3	0.9	33.8
	31.8	17.4	124.9	65.2	1.0	33.8
	38.1	14.4	151.1	65.1	1.1	33.8
	44.5	12.3	176.9	65.1	1.1	33.8
	50.8	10.6	203.8	64.9	1.1	33.8
	57.2	9.4	230.7	64.9	1.3	33.8
	63.5	8.4	257.7	64.8	1.4	33.8

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).
[b] Percent saleable steak yield.
[c] Face and end-cuts not meeting portion weight and/or portion thickness specifications.
[d] Percentage of trim loss before portioning.

Table 9. Least squares means (± SEM) for portion number stratified by portion weight within LM area category[a] in ribeyes

	Portion weight (g)			
LM area category	226.8 g	283.5 g	340.2 g	396.9 g
1	18.8d ± 0.4	15.0c ± 0.3	12.4d ± 0.3	10.6d ± 0.2
2	20.2cd ± 0.4	16.1c ± 0.3	13.4cd ± 0.3	11.5c ± 0.2
3	21.8bc ± 0.4	17.3b ± 0.3	14.3bc ± 0.3	12.3bc ± 0.2
4	22.5b ± 0.4	17.9b ± 0.3	14.8b ± 0.3	12.7b ± 0.2
5	25.1a ± 0.4	19.9a ± 0.3	16.6a ± 0.3	14.1a ± 0.2
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 10. Least squares means (± SEM) for portion number stratified by portion thickness within LM area category[a] in ribeyes

	Portion thickness (mm)			
LM area category	19.1 mm	25.4 mm	31.8 mm	38.1 mm
1	21.2b ± 0.2	15.9b ± 0.2	12.6b ± 0.2	10.4c ± 0.1
2	22.4a ± 0.2	16.7a ± 0.2	13.2a ± 0.2	10.8bc ± 0.1
3	22.1a ± 0.2	16.5ab ± 0.2	13.1ab ± 0.2	10.8bc ± 0.1
4	22.7a ± 0.2	16.9a ± 0.2	13.3a ± 0.2	11.1ab ± 0.1
5	23.0a ± 0.2	17.2a ± 0.2	13.7a ± 0.2	11.4a ± 0.1
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 11. Least Squares Means (± SEM) for portion number stratified by portion weight within LM area category[a] in strip loins

	Portion weight (g)			
LM area category	226.8 g	283.5 g	340.2 g	396.9 g
1	17.5c ± 0.4	14.0c ± 0.3	11.5c ± 0.3	9.8b ± 0.2
2	17.5c ± 0.4	13.9c ± 0.3	11.5c ± 0.3	9.7b ± 0.2
3	19.6b ± 0.4	15.6b ± 0.4	12.9b ± 0.3	10.9a ± 0.2
4	19.2b ± 0.4	15.4b ± 0.3	12.9b ± 0.3	10.8a ± 0.2
5	21.2a ± 0.4	17.1a ± 0.4	14.0a ± 0.3	10.3a ± 0.2
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 12. Least squares means (± SEM) for portion number stratified by portion thickness within LM area category[a] in strip loins

	Portion thickness (mm)			
LM area category	19.1 mm	25.4 mm	31.8 mm	38.1 mm
1	20.0b ± 0.3	14.8b ± 0.2	11.8b ± 0.2	9.7b ± 0.1
2	20.0b ± 0.3	14.8b ± 0.2	11.7b ± 0.2	9.7b ± 0.1
3	20.3ab ± 0.3	15.1ab ± 0.2	12.0ab ± 0.2	10.0ab ± 0.1
4	20.3ab ± 0.3	15.1ab ± 0.2	11.9ab ± 0.2	9.9ab ± 0.1
5	21.2a ± 0.3	15.7a ± 0.2	12.4a ± 0.2	10.3a ± 0.1
P-value	0.0073	< 0.0001	< 0.0001	0.0208

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 13. Least squares means (± SEM) for portion number stratified by portion weight within LM area category[a] in tenderloins

	Portion weight (g)					
LM area category	141.7 g	170.1 g	198.4 g	226.8 g	255.1 g	283.5 g
1	12.7c ± 0.4	10.4c ± 0.3	8.8a ± 0.3	7.8b ± 0.2	6.8b ± 0.2	6.1c ± 0.2
2	23.2bc ± 0.4	10.9bc ± 0.3	9.2a ± 0.4	8.0b ± 0.2	6.9b ± 0.2	6.4bc ± 0.2
3	13.8abc ± 0.4	11.4abc ± 0.3	9.1a ± 0.3	8.4ab ± 0.2	7.4ab ± 0.2	6.6abc ± 0.2
4	14.3ab ± 0.4	11.8ab ± 0.3	9.9a ± 0.3	8.6ab ± 0.2	7.6ab ± 0.2	6.9ab ± 0.2
5	14.9a ± 0.4	12.4a ± 0.3	10.2a ± 0.3	9.2a ± 0.2	8.1a ± 0.2	7.2a ± 0.2
P- value	0.0008	0.0003	0.0596	0.0008	0.0005	0.0011

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 14. Least squares means (± SEM) for portion number stratified by portion thickness within LM area category[a] in tenderloins

	Portion thickness (mm)						
LM area category	25.4 mm	31.8 mm	38.1 mm	44.5 mm	50.8 mm	57.2 mm	63.5 mm
1	21.6a ± 0.3	17.0a ± 0.2	14.1a ± 0.2	12.0a ± 0.2	10.4a ± 0.2	9.1a ± 0.1	8.1a ± 0.1
2	22.3a ± 0.3	17.5a ± 0.2	14.5a ± 0.2	12.4a ± 0.2	10.8a ± 0.2	9.5a ± 0.2	8.5a ± 0.1
3	21.8a ± 0.3	17.4a ± 0.2	14.4a ± 0.2	12.2a ± 0.2	10.7a ± 0.2	9.4a ± 0.1	8.4a ± 0.1
4	22.3a ± 0.3	17.7a ± 0.2	14.7a ± 0.2	12.5a ± 0.2	10.9a ± 0.1	9.6a ± 0.1	8.5a ± 0.1
5	22.1a ± 0.3	17.4a ± 0.2	14.4a ± 0.2	12.3a ± 0.2	10.6a ± 0.1	9.4a ± 0.1	8.4a ± 0.1
P- value	0.2397	0.2320	0.1467	0.3817	0.2299	0.1107	0.1735

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 15. Least squares means (± SEM) for subprimal weight and trimmed subprimal weight by LM area category[a] in ribeyes

LM area category	Subprimal weight (kg)	Trimmed subprimal weight (kg)
1	6.2c ± 0.1	4.5c ± 0.1
2	6.5c ± 0.1	4.8c ± 0.1
3	7.0b ± 0.1	5.1b ± 0.1
4	7.2b ± 0.1	5.3b ± 0.1
5	8.0a ± 0.1	5.8a ± 0.1
P - value	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 16. Least squares means (± SEM) for subprimal weight and trimmed subprimal weight by LM area category[a] in strip loins

LM area category	Subprimal weight (kg)	Trimmed subprimal weight (kg)
1	5.7cd ± 0.1	4.2c ± 0.1
2	5.6d ± 0.1	4.2c ± 0.1
3	6.2bc ± 0.1	4.6b ± 0.1
4	6.3b ± 0.1	4.6b ± 0.1
5	6.8a ± 0.1	5.1a ± 0.1
P - value	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 17. Least squares means (± SEM) for subprimal weight and trimmed subprimal weight by LM area category[a] in tenderloins

LM area category	Subprimal weight (kg)	Trimmed subprimal weight (kg)
1	2.9c ± 0.1	1.9c ± 0.1
2	3.0bc ± 0.1	2.0bc ± 0.1
3	3.1abc ± 0.1	2.1abc ± 0.1
4	3.3ab ± 0.1	2.1ab ± 0.1
5	3.4a ± 0.1	2.2a ± 0.1
P - value	< 0.0001	< 0.0001

[a] LM area categories defined as: category 1 (74.8 – 80.6 cm^2), category 2 (81.3 – 87.1 cm^2), category 3 (87.7 – 93.5 cm^2), category 4 (94.2 – 100.0 cm^2), and category 5 (100.6 – 106.4 cm^2).

Table 18. Means for subprimal weight break at boxing for ribs, strip loins, and tenderloins (kg)

	Subprimal weight breaks[a]					
	Ribs (n = 97)		Strip loins (n = 98)		Tenderloins (n = 95)	
	≤ 7.71 kg	> 7.72 kg	≤ 6.80 kg	> 6.81 kg	≤ 3.18 kg	> 3.19 kg
Percentage of n	84.5	15.5	83.6	16.4	57.9	42.1
Average LM area (cm^2)	88.5	102.9	88.4	100.5	87.8	96.2
Minimum LM area (cm^2)	75.1	97.2	75.1	90.3	75.1	75.3
Maximum LM area (cm^2)	105.7	106.3	105.7	106.3	106.1	106.2

[a]Subprimal weight breaks at boxing based on recommendation from major beef packer