A HISTORY OF 30 YEARS OF INDUSTRY SERVICE – THE WEST TEXAS A&M UNIVERSITY BEEF CARCASS RESEARCH CENTER

by

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ABSTRACT

In the first analysis, the West Texas A&M University Beef Carcass Research Center (BCRC) carcass grading database (n = 1,079,880) generated from 1992 to 2021 was used to identify carcass outcomes, trends, and associations. Carcass data was collected at 44 federally inspected beef abattoirs in the United States and Canada. Outcomes included hot carcass weight (HCW), loin muscle area (LMA), adjusted 12th rib fat thickness (AFT), calculated yield grade (YG), LMA to HCW ratio (RATIO), marbling score (MARB), hair coat color and sex. Mean carcass outcomes were: YG (2.9), AFT (1.3 cm), HCW (369.7 kg), LMA (87.2 cm^2), KPH (2.1%), RATIO (0.2446 cm^2/kg) and MARB ($Small^{23}$). Regression equations were calculated to determine change in carcass outcomes over time. Mean HCW, LMA, YG, and AFT were determined to annually ($P < 0.01$) increase linearly by 2.35 kg, 0.42 cm^2, 0.0062 units and 0.012 cm whereas RATIO decreased ($P < 0.01$) in a linear manner by 0.00014 cm^2/kg, whereas MARB increased ($P < 0.01$) in a quadratic manner by 0.22 units. Based on these annual trends, predicted means values for carcass outcomes at the year 2050 are as follows: HCW (477.0 kg), LMA (107.1 cm^2), AFT (1.8 cm), MARB (Slightly $Abundant^{78}$), YG (3.15), and RATIO (0.2377 cm^2/kg). These data illustrate strong association ($P < 0.01$) between YG and carcass outcomes. As YG increased by one unit (i.e. YG 2.0 to 3.0), AFT, HCW, and MARB increased ($P < 0.01$) by 0.5 cm, 14.6 kg, and 3.9 units, whereas LMA and RATIO decreased ($P < 0.01$) by 7.2 cm^2 and 0.0304 cm^2/kg. Hot carcass weight was also influential ($P < 0.01$) upon carcass outcomes. As HCW increased by 100

kg, YG, AFT, LMA and MARB increased ($P < 0.01$) by 0.51 units, 0.3 cm, 12.7 cm^2 and 3.01 units, whereas RATIO decreased by 0.0304 cm^2/kg. Similarly, as AFT increased by 0.254 cm, YG, HCW and MARB increased ($P < 0.01$) by 0.33 units, 5.7 kg, and 1.6 units, whereas LMA and RATIO decreased by 0.54 cm^2 and 0.0054 cm^2/kg. Quality grade was also strongly associated ($P < 0.01$) with carcass outcomes; as quality grade increased from Select to Choice, YG (+0.38 units), AFT (+0.22 cm), and HCW (+8.6 kg) increased ($P < 0.01$), whereas LMA (-1.5 cm^2) and RATIO (-0.0756 cm^2/kg) decreased. Likewise, as quality grade increased from Choice to Premium Choice, YG (+0.27 units), AFT (+0.18 cm), and HCW (+4.1 kg) increased ($P < 0.01$), whereas LMA (-1.0 cm^2) and RATIO (-0.0054 cm^2/kg) decreased. Furthermore, as QG increased from Premium Choice to Prime, YG (+0.22), AFT (+0.16 cm), and HCW (+3.2 kg) increased ($P < 0.01$) and LMA (-2.9 cm^2) and RATIO (-0.0105 cm^2/kg) decreased. Steers exhibited greater ($P < 0.01$) YG (2.88 vs 2.81), and HCW (360.63 vs 334.15 kg) and less ($P < 0.01$) LMA (86.17 vs 86.64 cm^2), AFT (1.24 vs 1.40 cm), MARB (Small^{22} vs Small^{44}) and RATIO (0.2412 vs 0.2606 cm^2/kg) than heifers. The effect of railout status was assessed; carcasses that had been railed off-line for enhanced trimming exhibited lesser ($P < 0.01$) YG (-0.19), AFT (-0.12 cm), LMA (-2.50 cm^2), MARB (-2.10 units) and dramatically lighter HCW (-18.23 kg), but increased RATIO (+0.0074 cm^2/kg) compared to non-railout carcasses. Black hided cattle were determined to have increased ($P < 0.01$) YG (3.04 vs 2.67), AFT (1.35 vs 1.15 cm), HCW (357.5 vs 350.6 kg), KPH (2.15 vs 2.09), and MARB (Small^{43} vs Small^{06}) and lesser LMA (85.21 vs 87.15 cm^2) and RATIO (0.2394 vs 0.2497 cm^2/kg) compared to non-black hided cattle. Probability of carcasses grading Choice (CH), Premium Choice (PrCH), or Prime (P) was calculated. As HCW increased from 400 to 500 kg, the probability of grading CH, PrCH, or P increased by 12, 9, and 1.4%, respectively. Likewise, as AFT increased from 1.5 to 2.5 cm, an increase of 21.9, 23.5, and 4.1% occurred in the probability of grading CH, PrCH, and P. In contrast, as LMA increased from 90 to 100 cm^2, a decrease of 3.5, 1.9, and 0.20% occurred in the probability of grading CH, PrCH, and P. These data serve as excellent indicators of the future of beef production to be used by beef producers and processors.

In the second analysis, the association of liver abnormalities with carcass performance was evaluated on data from 1,542,533 carcasses housed in 2 databases at the West Texas A&M University Beef Carcass Research Center, collected between 2010 and 2021. Liver abnormalities were observed during harvest and scored as: edible liver; A- = 1 to 2 small abscesses or inactive scars; A = 1 to 2 large abscesses or multiple small abscesses; A+ = multiple large abscesses; A+AD = liver adhered to diaphragm; A+OP = open liver abscess; A+AD/OP = adhered to diaphragm with an open liver abscess; cirrhosis, flukes, and telangiectasis. Liver abnormality rates in database 1 were A- = 7.4%, A = 2.7%, A+ = 2.4%, A+AD = 3.9%, A+OP = 1.4%, A+AD/OP = 0.8%, cirrhosis = 0.2%, flukes = 3.6%, telangiectasis = 0.7%, with 77.0% of livers being edible. Liver abnormality rates in database 2 were A- = 7.3%, A = 5.3%, A+ = 4.8%, A+AD = 6.2%, A+OP = 1.7%, A+AD/OP = 1.3%, cirrhosis = 0.1%, flukes = 1.3%, and telangiectasis = 0.6%, with 67.0% of livers being edible. For carcasses with severe abscesses (A+, A+AD, A+OP, A+AD/OP) and cirrhotic livers, HCW was 13.0 kg and 42.5 kg less ($P < 0.01$) compared to carcasses with edible livers. Carcasses with any abnormality other than telangiectasis had reduced ($P < 0.05$) HCW. All liver abnormalities resulted in reduced ($P < 0.05$) LM area, with the exception of telangiectasis, which was determined to be

similar ($P = 1.0$) to edible livers. Less ($P < 0.05$) 12th-rib subcutaneous fat was observed for carcasses with A-, A, A+, A+AD, and cirrhosis abnormalities compared to carcasses with edible livers. Estimated KPH was less ($P < 0.05$) for carcasses with livers identified with flukes or cirrhosis abnormalities. Calculated yield grade was less ($P < 0.03$) for carcasses with A+AD liver scores and cirrhosis than those with edible livers. For both database 1 and 2, geographical location had an effect ($P < 0.01$) on liver abscess prevalence. In database 1 and 2, the greatest liver abscess prevalence was observed at Toppenish, WA (37.12%) and Arkansas City, KS (68.33%), respectively. Furthermore, seasonality of liver abscesses by month was reported to be lowest in January (14.09 and 24.08%). For database 2, liver abnormality was affected ($P < 0.01$) by sex class; steers had increased rates of all abscess outcomes compared to heifers. Additionally, cattle type was also observed to have an effect ($P < 0.01$) on prevalence of liver abscesses. Native cattle exhibited total abscess prevalence of 23.02%, compared to 16.81, 39.24 and 50.18% for Mexican, Holstein and beef x dairy cattle. Beef x dairy cattle exhibited the highest rates for A- (14.21%), A (7.94%), A+ (8.29%), A+OP (4.00%), and A+AD/OP (3.43%) liver abscess categories. These data indicate liver abnormalities, especially severely abscessed, adhered, open and cirrhotic livers, greatly effect HCW, an important economic factor effecting carcass merchandising, and other carcass outcomes. Liver abscess rate had no detrimental effect on marbling score, which may indicate the timing to which liver abscesses are developed during the feeding period compared to deposition of intramuscular fat. These results indicate control of liver abscesses is important in order to prevent losses in carcass value.

In the third analysis, the association of lung abnormalities with carcass performance was evaluated on data from 60,843 carcasses housed in the West Texas A&M University Beef Carcass Research Center database and collected from 2010 to 2021 to quantify the relationship of lung health and carcass performance. Lung outcomes were scored for severity of consolidation (N = Normal and < 5% consolidation, 1 = 5 to 15% consolidation, 2 = 15 to 50% consolidation, 3 = >50% consolidation) and presence of fibrin tags (N = None, M = Minor fibrin, E = Extensive fibrin). Lung consolidation had a strong and detrimental effect ($P < 0.01$) on hot carcass weight, with lung scores of 1, 2, and 3 resulting in 4.2, 13.3, and 29.9 kg less carcass weight compared to carcasses with normal lungs. Minor and extensive fibrin tags (3.5 kg and 7.1 kg, respectively), independent of consolidation, resulted in lighter carcasses ($P < 0.01$) compared to those with normal lungs. Lung score did not have an effect on marbling score. Both lung tissue consolidation and presence of fibrin tags affected 12th rib fat thickness; lung consolidation scores of 1, 2, and 3 (-0.09, -0.21 and -0.09 cm, respectively) and fibrin tags prevalence of minor and extensive (-0.14 and -0.19 cm) resulted in less ($P < 0.01$) 12th rib fat thickness compared to carcasses with normal lungs. Similarly, LM area was reduced ($P < 0.01$) in carcasses with lung consolidation (-1.5, -3.8, and -5.5 cm^2) or presence of fibrin tags (-2.3 and -2.7 cm^2) compared to carcasses with normal lungs. Additionally, severity of lung consolidation and presence of fibrin tags reduced ($P < 0.01$) calculated yield grade; lung consolidation and fibrin tags resulted in a 0.08 to 0.20 and 0.09 to 0.13 reduction in overall yield grade, respectively. In addition to lung outcomes, liver abscess outcomes were also collected and analyzed for synergistic effect on carcass outcomes with severity of lung scores. The greatest proportion of carcasses

within lung consolidation and presence of fibrin tags (47.67 and 48.88%) exhibited edible livers with a normal lung. Whereas the lowest proportion of carcasses (1.12 and 1.89%) exhibited a 3 lung consolidation score and extensive prevalence of fibrin tags with a major abscess outcome. Severity of lung consolidation was determined to have a more dramatic effect on carcass weight than presence of fibrin tags within liver abscess categories. Within the edible, minor and major abscess category, as lung consolidation increased from normal to 3 and presence of fibrin tags increased from normal to extensive, a decrease in carcass weight (21.4, 30.9, and 50.1 kg; 5.5, 7.4, and 5.4 kg), LM area (4.7, 3.9, and 6.3 cm^2; 2.0, 3.1, and 1.6 cm^2), and AFT (0.02, 0.18, and 0.13 cm; 0.12, 0.30, and 0.24 cm) was observed. These data indicate that lung health is an important factor that impacts carcass performance, particularly carcass weight muscling and yield grade outcomes.

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To Forest, there are no words to describe what you mean to me and the support that you've provided to me during my time here at WT. Our late night FaceTime dates running statistics, talking about research and you providing much need counsel. We've spent the majority of our relationship long-distance while both of us chase our own career paths and education, but I am so excited for the future and cannot wait to be your wife.

DEDICATION

This master’s thesis is dedicated to:

Dr. Theodore H. “Doc” Montgomery,

I will cherish our memories together for the rest of my life. I am so blessed that I was able to make the final months of your life a little bit brighter by allowing you to reminisce on your experiences and time at West Texas A&M University and the Beef Carcass Research Center. I learned about your family, where you grew up, your favorite music, your travels with Lorita, and everything in between. Everything that the BCRC has done and accomplished is because of your vision and tenacity to see it succeed. No amount of awards, letters following my name, positions, or success could ever amount to the pride I feel knowing that I was able to be your “last student”.

Table of Contents

Chapter III

Chapter IV

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Collection of information and data to receive feedback in order to make necessary changes and corrections is vital for any industry wishing to improve upon themselves. The beef industry is no different and utilizes a wide-range of tools to accomplish this. At any stage of beef production, from the cow-calf sector to the feedlot, the end-goal of beef production is to produce a safe, nutritious and satisfactory product that the consumer will be inclined to purchase and subsequently repurchase. Therefore, efforts have been made all throughout beef production history to create consistency and meet consumer's demands. While demands of the consumer have changed since commercialized beef production first began, recent efforts have maintained that improving quality, while also decreasing waste-fat remains a goal of beef producers to appease consumers wants. Furthermore, the efforts of research scientists tasked with creating products and techniques for improving the efficiency of animals through genetics, breed types, growth-promoting implants, feed additives, and animal health products has remained a large area of animal production research as we continually struggle with the outside perceptions of the very consumers that we feed.

The access of information through efforts such as the National Beef Quality Audits, expected progeny differences (EPDs), slaughter closeouts, and carcass data collection, provides benchmarks on which to improve areas of production to reach identified goals. A primary goal identified after the 1974 USDA Market Consist Report was the excess production of waste-fat. Furthermore, Savell et al. (1991) and Morgan et al. (1991) identified wide variation in beef composition and palatability outcomes at the retail level following The National Beef Market Basket Survey and The National Beef Tenderness Survey. In addition, The Value Based Marketing Task Force, a joint meeting of industry leaders representing all facets of beef production from the cow-calf sector to the retail level converged to discuss efforts which could be made to improve upon beef production. From the meeting it was also identified the need to improve lean production while concurrently maintaining the palatability qualities of beef (Engler, 1993).

Since these efforts, it is apparent that great strides have been taken to improve upon these identified areas of shortcomings as shown by reoccurring NBQAs. As quality has remained more consistent, a consequence of our continual selection and management towards quality and growth has been a lack of attention towards understanding health outcomes. Liver abscesses in fed-beef cattle was identified as a serious issue in the late 1970s by beef processor leadership as expressed to Dr. Ted Montgomery, then, Director of the Beef Carcass Research Center at West Texas State University, and still remains a great area of industry research attention currently, forty-seven years later. Similarly, the industry has made little to no improvement in controlling the detrimental effects that Bovine Respiratory Disease has made on the fed-beef industry. A balance between maintaining consistent quality in cattle, while concurrently minimizing health disruptions is vital to capitalizing on maximum efficiency in beef production.

CHAPTER II

REVIEW OF LITERATURE

2.1 History of the Beef Carcass Research Center, West Texas A&M University

Long before the Beef Carcass Research Center, Dr. Theodore H. Montgomery came to West Texas State University as a young faculty member in the fall of 1975. Dr. Montgomery quickly realized the value WT had due to its location to three of the major beef processors in the Texas panhandle, and thus the era of carcass data collection was born. At this point in time, all measures of animal performance were measured via live outcomes such as average daily gain and feed efficiency. Therefore, as long as the feedyards received a check for their cattle from the processor, no interest was placed on how the animals performed on the rail and the burden of poor performing cattle was placed on the processor rather than the feedlot. Likewise, the feedyards were not receiving premiums for superior performing cattle, and therefore had no knowledge of which pens were underperforming or outperforming others. This is where carcass data changed the game. After Dr. Montgomery settled into his new role as a meat science faculty, he visited with managers at the Monfort, IBP, and Excel beef processing facilities in the panhandle and offered his services if they were ever needed due to his close proximity. The manager at IBP expressed his concern regarding liver abscesses and asked

Dr. Montgomery for his assistance. Dr. Montgomery spoke with Paul Engler, a large cattle feeder in the area, and asked if he could collect liver data on his cattle to get an idea of the severity of liver abscesses. Dr. Montgomery looked back on this event stating, “The liver abscess deal opened the door to the value of data collection.” Regarding the interest of liver health data, Dr. Montgomery published several abstracts along with a graduate student’s thesis work (Osman Atil) over liver abscesses which he recalled as the “big break” for WT in the world of carcass data. The publication of the liver data caught the attention of Elanco Animal Health, and they collaborated on a liver project which was published in 1985 entitled “The Influence of Liver Abscesses Upon Beef Carcass Yields”. This corresponded with the marketing of Tylan, a now common antibiotic fed to control liver abscesses in beef cattle.

Following the popularity of liver abscess work, the BCRC was also fundamental in collecting data for new growth-promoting implants from various animal health companies.

Carcass data is demonstrably an invaluable tool for the development and improvement of the beef industry. At the forefront of carcass data collection has been West Texas A&M University via the leadership of Dr. Ted Montgomery through what we now know as the Beef Carcass Research Center. The development of the Beef Carcass Research Center is a robust history which will be reviewed in this thesis. The Beef Carcass Research Center was formally recognized as a center by the University in 1991 prior to their involvement with the Cattleman’s Carcass Data Service, an entity of the National Cattleman’s Beef Association. The purpose of the CCDS was to provide a service to beef producers to gain insight into the quality of cattle they were sending to beef processors across the United States. Since 1992, a network of coordinators located at academic institutions including Colorado State University, Garden City Community College, Kansas State University, Texas Tech University, and University of Nebraska as well as private contractors not affiliated with universities collected data on behalf of the CCDS and covered their respective areas of the beef production industry. Due to financial trouble, the CCDS reached out to the universities asking if any were interested in taking over the data collection service and West Texas A&M University assumed responsibility for the CCDS in 1996, utilizing other universities and third party cooperators that would report carcass data through WT. The mission of the Beef Carcass Research Center has always been to provide the collection of neutral third-party data for the commercial cattle feeding industry, and the non-biased investigation of questions related to the cattle feeding and beef industries. Currently, the Beef Carcass Research Center at West Texas A&M University has collected data on over one million cattle since 1992, and has assisted the industry in understanding the performance of cattle once harvested, assisted with development of beef marketing programs, pharmaceutical development and post-approval research, and theses and dissertations from universities across the nation and the development of the grid-based marketing system for the sale of carcasses. In addition to carcass data collection, liver outcome data has always been a point of interest, and the BCRC has assisted pharmaceutical companies and research entities in collecting lot-based liver data on over one million head of cattle since 2013.

In addition to liver-outcome data, the BCRC has been called upon numerous times to assist the industry in animal health research regarding bovine respiratory disease through lung scoring. Presently, the BCRC has expanded their involvement in research requests beyond the means of simple carcass data collection. Due to the extensive knowledge of the interworking's of beef processors, the BCRC has adapted to collecting samples for unique research requests by collecting subiliac lymph nodes, blood, liver abscess samples, kidney tissue, ovaries, muscle samples, rumen samples, strip loins for tenderness assessment, and more, all while providing the customer with individual animal information, all at the chain speed of a commercial harvest facility. No request is ever too large or too outrageous, and the BCRC can usually find the means to meet requests from the customer, all while maintaining the professionalism and attention to detail that the BCRC is known for world-wide. Evidently, the BCRC is the best at what they do and is ever-adapting to the wants and needs that are reflective of current-industry research.

2.1.2 Dr. Ty E. Lawrence era

In 2004 Dr. Ted Montgomery decided to retire from his position as a meat science faculty at West Texas A&M University. With this, came the process of searching for his replacement. With the success and reputation of the Beef Carcass Research Center and meat laboratory in mind, it was clear that someone who was a product of the program and understood the work and dedication it took to maintain the "machine" that was, and still is, the meat science department at West Texas A&M University was necessary. A former graduate student, Ty Lawrence, was the individual who answered the call to come home to WT. Dr. Lawrence had continued his education at Kansas State University in meat science under Dr. Michael Dikeman after the conclusion of his master's degree and undergraduate employment with Dr. Montgomery. Following his time at Kansas State University, he was employed with Smithfield Foods before returning to WT. Dr.

Lawrence was hired as a meat science professor in July of 2004 and hit the ground running without skipping a beat.

Dr. Lawrence described his goal for the BCRC and meat science department as "wanting to put WT on the map". Everything that Dr. Lawrence did as a young faculty was to accomplish this goal. He rarely said no to a collaboration or research project and travelled many miles and spent long hours, just as he did as a student with Dr. Montgomery, continuing the work that was set before him. Due to this, many people referred to Dr. Lawrence as the "energizer bunny", solidifying Dr. Montgomery's choice in a replacement.

While the carcass data collection never stopped during this transition, Dr. Lawrence was approached by Elanco Animal Health to assist with the post-approval work for Optaflexx. An opportunity like this was due in part to the relationships that Dr. Montgomery had established in the industry and the reputation that the BCRC had for their professionalism and "failure is not an option" attitude around data collection. In 2005, the BCRC participated in their first new animal drug approval without the supervision of Dr. Montgomery, a product now known as Revalor-XS. Henceforth, new animal drug approvals would become a large part of the service that the BCRC provided the industry for years to come. In 2006 through 2007, the BCRC assisted with approval work in Canada and post-approval work in the U.S. for Zilmax. The BCRC also assisted in the approval work for Synovex-One. Dr. Lawrence knew the value in being a part of the National Beef Quality Audits (NBQA), and approached the necessary persons to make sure that WT would be involved in the 2005 audit. Since then, WT has assisted in, and lead the training for every NBQA since.

In between countless miles driving and flying, late nights and early mornings in beef kill floors and coolers, graduate students worked synergistically with the BCRC and meat laboratory to conduct their respective thesis and dissertation work. The meat science department at WT has maintained close working relationships with industry partners to allow students the opportunity to explore areas of the industry while providing pharmaceutical companies with valuable insight and data into the products they provide. While there have been numerous graduate students come through the program, there are a few studies that stand out by exemplifying the necessary collaboration between academia and industry and the value they provide to both entities. Through a study sponsored by Merck Animal Health in 2014, the effect of zilpaterol hydrochloride on carcass composition, energy retention, and supply chain value of serially harvested calf-fed Holstein steers, was completed in the WT meat laboratory and Caviness Beef Packers in Hereford, TX. An additional study sponsored by Merck Animal Health was completed in 2015 and evaluated the effect of zilpaterol on energy and protein metabolism and empty body composition of serially slaughtered beef steers. During this time, the era of the PrimeOne project began. Arguably, one of the more well-known projects to be born out of the meat science department at WT due to its media attention from the public, outside of the typical industry interest with most research projects. The PrimeOne cloning project started as an idea from Dr. Lawrence. “What if we could find the rarest combination of grading attributes, a USDA Prime, Yield Grade One carcass, and clone it to capitalize on the genetics that were lost?” Dr. Lawrence did exactly that and one late night in a beef processing facility one of these rare carcasses rolled right past him on the grade chain at Tyson Foods in Amarillo, TX and Dr. Lawrence knew this was his chance. Thus began the PrimeOne project at WT. A chance to create breeding stock from carcasses that you already know have outperformed all others. From the project, a bull was cloned named Alpha. Soon after, three heifer carcasses were cloned to produce Gamma 1, 2, and 3, and another bull was cloned named Delta. Another groundbreaking event occurred when Alpha, the original clone, and the Gamma heifers, were utilized to create the first calf born from two cloned parents, named AxG1. Two graduate students produced their thesis work over the performance of both Alpha and AxG1's progeny compared to other leading U.S. industry sires in 2018 and 2019, respectively.

2.1.3 Changes to WT Meat Science and future

Meanwhile, through these extremely labor intensive studies came the realization that the current facilities at the WT meat laboratory were quickly being outgrown and would limit the program to participate in any more complicated and intensive projects in the future. Thus the conversations surrounding building a new meat laboratory began. As the conversations about a new meat laboratory became more serious, Dr. Lawrence realized that his one-man show would quickly need to become a two-man show to assist with the growth and development of the program he was trying to build. Thus after an intense hiring process, Dr. Trent McEvers, a graduate of the meat science program at WT with his B.S., M.S. and Ph.D., was hired in 2016. The discussions about a new meat laboratory sparked additional conversations about constructing an entirely new agricultural complex for the department of agricultural sciences at WT. Therefore, it was decided that in addition to a new meat laboratory, a new agricultural complex would be built surrounding the meat laboratory. The ground for the new Ag Complex was broken in the fall of 2016, and faculty and students moved into the new building in August of 2018.

Dr. McEvers accepted a job with Dean Cluck Feedyard in the spring of 2017, and another WT meat science alumni, Dr. Travis Tennant, was hired in the fall of 2018 as the transition to the new building began. Dr. Tennant offered a diverse expertise in not only beef-related meat science, but also processed meats, culinary science, and pork production from his experiences at North Carolina State University for his Ph.D. and extension work. Soon after, Dr. Loni Lucherk, a product of the well-known Texas Tech University meat science program, was hired in the spring of 2020 to take the helm on youth programs, undergraduate advising and coaching the meat judging teams in addition to teaching undergraduate courses. As of 2021, the meat science program at WT has three faculty members, one meat lab manager hired in 2020, seven graduate students, and 20 undergraduate employees whom all work closely together to handle meat laboratory activities and responsibilities, and beef processor data collection across the panhandle and the rest of the country, short courses and industry outreach, graduate student research projects, and judging teams.

2.2 Carcass Data Collection

The collection and utilization of data, in any industry, is fundamental in identifying areas where change and improvement need to be made. Collection of carcass data for animal science research purposes began at the university level. This still holds true today, where universities continue to conduct their own research, often in collaboration with industry members in a mutually beneficial manner. University faculty and students were able to enter slaughter facilities to collect carcass data on their own trials, and built working relationships with beef processors, even collecting data and providing counsel to improve areas of concern.

Prior to camera grading, the only way to receive information on a group of cattle was to enter the facility and collect the information firsthand. Feedlots and other beef producers realized this importance and universities began to offer their knowledge and experience in carcass data collection as a service. Outside of universities providing data collection services, the United States Department of Agriculture offers two services – the Carcass Evaluation Service and the Beef Carcass Data Service. The purpose of these two services are to provide producers with carcass information from their cattle in order to make improvements in genetics or management. To utilize the services provided, the producer must provide the location and time of slaughter, provide identification via eartag or tattoo, and provide the area USDA meat grading supervisor with the information prior to slaughter. To use the Beef Carcass Data Service, the producer must use eartags provided by the Texas Agricultural Extension Service. Both of these services are a paid service (Hale et al., 1988).

The National Cattleman's Association (NCA) developed the Cattlemen's Carcass Data Service (CCDS) in order to provide valuable carcass data to producers. The NCA recruited the assistance of universities to cover multiple slaughter facilities across the United States. In 1996, the CCDS responsibilities were transferred to West Texas A&M University in Canyon, TX, and CCDS became a sole entity of West Texas A&M University, merging with the existing Beef Carcass Research Center, directed by Dr. Ted Montgomery until 2004 when Dr. Ty Lawrence took over. The Beef Carcass Research Center at West Texas A&M University employs 20-25 students and utilizes 3rd party cooperators in Kansas, Colorado, and Nebraska to cover northern plants for liver auditing purposes.

The beef industry is no different and the miraculous improvement of beef quality in such a short amount of time can be credited to the ability of producers to receive feedback for their efforts. Prior to the implementation of the value-based marketing system we know today, producers were paid on a weight basis and were not rewarded for the improvement of genetics and producing a more palatable product for consumers. Therefore, there was no incentive to produce superior quality cattle and no penalization for producing substandard cattle. The only way for producers to know how their cattle are performing is through the access of information in order to make improvements. Data collection, whether from the beef processor or third party evaluators is the gateway to the accessibility of this information. In addition to improvements in meat quality and carcass performance, the value of data collection spans across the beef industry from animal health products to feed technologies. Dr. Ted Montgomery, founder of the Beef Carcass Research Center at West Texas A&M University, reflected on carcass data collection as "adding value to its clients' cattle through the use of information". Since its inception, this has been one of the main goals of the Beef Carcass Research Center. This access to data fostered the growth of many of the branded-beef programs that are dominating the markets today, such as Certified Angus Beef. Additionally, carcass data proved invaluable to those that wished to improve industry efficiencies through hormone growth implants and beta-adrenergic agonists.

2.3 Beef Grading

The implementation of beef grading was employed as a marketing system to assist in uniformly segregating beef into "grades" in order to determine value. Grading standards for beef were tentatively outlined in 1916 and were put in place as a service in 1917. The first standards were published in 1924 in the United States Department of Agriculture's (USDA) Bulletin No. 1246 "Market Classes and Grades of Dressed Beef" (Davis and Whalin, 1924). The publication outlined the necessities for the system to work and described the standards to which the system would follow to assign beef to the differing grades. It was necessary to develop a system that was logical and workable, specific, and had permanence. The bulletin referred to beef as a difficult commodity to grade due to a wide variation in carcasses and absolute exactness could never be achieved. At the time, there were no devices to assist the grader. Therefore, abiding by the standards was only done by observation and referencing pictures. The publication described the seven grades of beef. Those being, in order of desirability, Prime, Choice, Good, Medium, Common, Cutter, and Canner and the corresponding numerical grades being No. A1, No. 1, No. 2, No. 3, No. 4, No. 5, and No. 6. These seven grades applied to both steer and heifer beef, whereas cow, bull, and stag beef were only designated 6 grades, starting with Choice or No.1 as the highest grade a cow, bull, or stag could receive, excluding them from being able to grade Prime or No. A1. Carcasses were graded on three factors: confirmation, finish, and quality, where quality was identified as the most important. To determine quality, the grader would assess the firmness, color, and texture of the meat, would determine the age by observing the color and hardness of bones, and would take note of marbling, or lack of marbling in the muscle tissue.

Voluntary grading began in 1927 following the revision of Davis and Whalin's standards in 1926. Grading standards have changed several times since inception to reflect changes in consumer acceptance and for simplification. In 1939, the grades Medium, Common, and Lower Cutter were changed to Commercial, Utility, and Canner. In 1941 the standards were changed for all slaughter cattle to grade Prime, Choice, Good, Commercial, Utility, Cutter, and Canner. In 1949, fat color was eliminated from grading standards. In 1950, beef grading standards were changed to lower quality standards by one grade. Therefore, Prime and Choice became Prime, Good became Choice, and Commercial was divided into two grades, Good being the upper half and Commercial being the lower half. The top half for Commercial grades was again replaced in 1956 to Standard. In 1971 to 1976, the quality grade standards were changed to require less marbling in younger maturity cattle and the muscling confirmation score was eliminated from beef grading. In 1987, USDA Good was renamed to USDA Select. In 1997, the marbling requirement for Choice cattle with B maturity changed Small^{00} marbling to Modest^{00}, with B-maturity carcasses no longer being eligible for Select grades. More recently, in 2017, the USDA put into place that cattle with two or fewer permanent incisors are eligible for young quality grades unless they exhibit evidence of D or E maturity.

2.3.1 USDA Yield grade

While confirmation was included as a characteristic for these grading standards, it was reported by Murphey et al. in 1960, there was significant variation of muscle yield between carcasses of the same grade. In the study, 162 carcasses inclusive of steer, heifer, and cow carcasses across Prime through Canner grades were divided into groups of similar weight and quality grades. Carcass measurements were taken including length of body and hind leg, circumference of round, depth of body, length and width of the ribeye muscle between the 12^{th} and 13^{th} rib, area of ribeye, and thickness of fat over the ribeye at three differing locations. Carcasses were fabricated into retail cuts, and weights were recorded. This resulted in selecting carcasses within 10 yield groups with a 3% range in yield. It was concluded from this study that measurements of external fat thickness were all highly correlated with carcass yield, with fat thickness over the ribeye being nearly as highly correlated as the average of the three fat thickness measurements taken in the study. The resulting regression equation calculated from the data provided a basis for a new yield grading system:

Percentage Boneless retail cuts from round, loin, rib, and chuck = 51.34 – 5.78 (single fat thickness over ribeye, in) – 0.462 (percent kidney fat) +0.740 (area of ribeye, square in.) – 0.0093 (carcass weight, lbs).

It is important to note that this equation does not include the brisket, plate, or flank subprimals, which would still be relevant in terms of overall carcass yield. In Murphey's equation, the resulting yield grades were 1 through 10. With yield grades 1 and 2, the highest yielding carcasses, at 53.1% of boneless retail cuts, and yield grades 9 and 10, the lowest yielding carcasses, at 34.7% of boneless retail cuts.

Through this study, the idea of developing a dual-grading system, one for assessment of quality and one for assessment of yield of major boneless retail cuts was investigated. In 1965, it was required that all beef be ribbed at the 12^{th} and 13^{th} rib in order to be graded. Additionally, in 1965, the dual grading system was established including standards for determining cutability in addition to quality grading. Today, the

USDA Yield Grades include five grades, 1 through 5. The equation to calculate yield grade was developed from the equation described earlier by Murphey et al. (1960). The USDA Yield Grade equation is:

Yield Grade = 2.50 + (2.50 x adjusted fat thickness, inches) + (0.20 x percent KPH) + (0.0038 x HCW, pounds) – (0.32 x REA, square inches).

Cattle have changed drastically since the development of Murphey's equation. At the time, small-framed Hereford cattle accounted for the majority of the fed cattle population, whereas today there is a much greater variety in the types of cattle including dairy and dairy crosses, slow growing, large framed Brahman-influence, fast-growing Angus, heavy muscled Charolais, and crosses of all. In addition to the current use of growth-promoting technology utilized by the majority of cattle feeders, the finished weight to which we feed cattle has increased exponentially, and will continue to increase. Therefore, it has been noted that the current USDA Yield Grade equation may not be an accurate representation for the cattle it is being used for and should be considered to be a poor tool to estimate the actual red meat yield of carcasses (Lawrence, 2017).

12th rib fat thickness has been determined to be a valuable predictor of beef carcass cutability across multiple studies (Murphey et al., 1960; Epley et al., 1970; Crouse et al., 1975) In the early 1960s, the need for developing a system for determining differences in muscling and yield of wholesale cuts of beef was identified (Brungardt and Bray, 1963). Through this need, equations were developed by Brungardt and Bray in 1963 to determine the relationships between linear measurements of beef carcasses and wholesale cuts with the yield of closely trimmed retail cuts from the round, loin, rib, and chuck. Linear measurements included left-side carcass weights, fat thickness over the chuck, rib, and loin at various locations, one of these including body wall thickness at the 12th and 13th rib 7 ½ inches below the ventral end of the *longissimus dorsi*, and length, depth and thickness of the round and loin were taken at various locations. Carcasses were fabricated into wholesale cuts and trimmed to approximately 3/8-in fat depth, then cut into retail cuts. All yields of wholesale, trimmed wholesale, and retail cuts were calculated as a percentage of the chilled weight of the carcass side. The 9th, 10th and 11th rib section was evaluated via the Hankins and Howe method. Currently, the USDA Yield Grade equation utilizes ribeye area, hot carcass weight, percentage kidney, pelvic, and heart fat, and 12th rib fat thickness. The 1963 study by Brungardt and Bray indicated that total lean from the round served as the best predictor of total yield for the carcass. While LM area had a highly significant association with carcass weight, there was a large variation that existed within weight groups. Additionally, LM area was reported as a poor predictor of carcass yield, accounting for 45% of the variation. The authors recommended that to more accurately predict carcass yield, more indicators of carcass muscle other than the LM should be added to the regression equations.

2.3.2 Instrument Grading

Traditional grading of beef carcasses is a subjective process dependent upon the individual grader's opinion of a particular quality grade, and visual assessments of yield attributes. The introduction of instrument grading was designed to change the system from a subjective one to an objective one to further increase the uniformity, expectations from a consumer standpoint, and reduce human error. Cross et al. (1980) reported human error occurred at a greater rate in yield grading assessment than quality grading. With the assistance of the National Aeronautics and Space Administration, the USDA began a project in 1978 to develop an instrument designed to objectively assess the quality and yield grade traits of beef carcasses. Through the project, video image analysis was determined to have the best opportunity for its intended purpose. In 1980, Kansas State University was awarded a contract to pursue testing on a Video Image Analyzer due to their already on-going work on a video image prototype.

The video image analysis (VIA) instrument was tested from 1981-1983 at USDA Meat Animal Research Center in collaboration with Kansas State University. Results from the comparison of the VIA to the Hankins and Howe (1946) method proved the VIA to be a reliable tool, especially in carcass yield prediction (Cross et al., 1983). In the 1980s, the focus on developing the VIA technology was halted as other means for objectively evaluating quality and yield parameters were explored including ultrasound and CAT-scan. Interest was picked up again in 1994 by researchers at the U.S. Meat Animal Research Center. Shackelford et al. (1998) developed a VIA system for predicting retail weight and yield of steaks collected from carcasses and theorized that this technology could be used to accurately characterize beef cutability and longissimus muscle area for yield grading. In 2003, the USDA-AMS released standards for VIA technology to determine longissimus muscle area, followed by yield grade in 2005 and marbling score in 2006. The first VIA instrument for determination of USDA yield grade was approved in 2007 (Woerner and Belk, 2008). Currently, the implementation of VIA instrument grading has increased the functionality of the grid-based marketing system in use today. Currently, VIA technology has maintained widespread use in commercial beef processing facilities to determine USDA YG and QG under the approval of a USDA grader and functions to maintain repeatability across carcasses and increasing the accuracy of the measurements taken.

2.3.3 Value-Based Marketing

Traditionally, the marketing of beef cattle was done by a cattle buyer visually evaluating pens of live cattle to determine their eventual value on the rail. Paul Engler, the man most notably responsible for bringing commercialized cattle feeding to the Texas Panhandle, realized the potential for rewarding cattle producers for quality cattle and represented the cattle feeding industry in the Value Based Marketing Task Force meeting among cow-calf producers, packer-processors, purveyors and retailers. One of the goals discussed during this meeting was the importance of distinguishing and quantifying value differences within the cattle population and passing on price incentives to the cattle producer and feeder to produce higher value cattle (Engler, 1993). By implementing incentives for higher quality cattle, it would benefit all parties involved in the beef industry by creating a higher demand for beef. Value-based marketing (VBM), also known as grid-based pricing, was developed to reward or penalize producers for the quality of their cattle. Value-based prices are based on quality specifications implemented through a grid pricing system. The grid utilizes a base-price, or the price before premiums and discounts are applied. For most grids, the base-price is a Choice, YG 3, 550 to 900-pound carcass (USDA-AMS, 2022). Schroeder et al. (1998) reported several differing types of base prices being utilized by the packer. The base prices included the average price of cattle purchased by the processor usually the week prior or week thereof. Additionally reported were specific market reports such as the highest reported price for a specific market for the week prior or week of slaughter. One base price was derived from live cattle futures prices, and some base prices were negotiated. Likewise, some base prices were determined by a carcass weight basis, while others were reported on a live weight basis from yields of the cattle harvested. Lastly, Schroeder et al. (2005), reported that many packers will establish their base price on the average quality grades and dressing percentages of cattle harvested during the week.

The implementation of the grid based marketing system suddenly placed an emphasis on quality and yield grade attributes as the primary driver for animal revenue rather than the single variable of animal weight. The primary driver of beef quality is marbling, and consumers recognize higher marbling scores to be related to a better eating experience, and will therefore pay more for greater quality grades (Umberger et al., 2000). In a sensory evaluation and consumer survey conducted by Platter et al. (2003), the probability of consumer purchase increased synergistically with increased marbling score and consumers tended to be willing to pay more for increased quality grades. Grid-based marketing was designed to reward cattle feeders for better quality cattle, inherently incentivizing producers to make necessary changes to improve beef quality to take advantage of the premiums available. Since the implementation of grid-based marking, we have observed a significant improvement in the quality of cattle. This observed change in beef quality is apparent as reported by past National Beef Quality Audits. The percentage of cattle grading Choice has significantly increased since the 1991-NBQA (52.7%; Lorenzen et al., 1993) to the 2016-NBQA (67.3%; Boykin et al., 2017). Whereas the percentage of cattle grading Select has decreased from the 1991-NBQA (36.9%; Lorenzen et al., 1993) to the 2016-NBQA (23.2%; Boykin et al., 2017). Through grid-based marketing, producers are able to receive feedback on their cattle, resulting in subsequent changes in management and genetic selection to improve quality grades to receive an increased premium. Currently, marbling score EPDs are available on seedstock bulls and have assisted producers with selecting genetics with the increased potential for marbling (Bertrand et al., 2001).

2.4 National Beef Quality Audits

Prior to the initial NBQA in 1991, the United States Department of Agriculture (USDA) conducted a similar survey of the current status of beef production at 68 beef processing facilities from November 1973 to October 1974 which consisted of 18,257 beef carcasses. The survey was conducted by USDA personnel (Abraham, 1977).

The National Beef Quality Audit (NBQA) was developed and organized for the industry to provide an overview of the current status of beef production in the United States. Every major beef slaughter facility in the United States is audited by participating universities, evaluating a variety of outcomes for an entire day. Harvest floor assessments included hide defects, viscera condemnation, head and tongue condemnation, and bruising. Cooler floor outcomes included yield and quality grade factors and discounted characteristics such as blood splash. The National Beef Quality Audit began in 1991, and after the success of the first audit in identifying the shortfalls of beef production, it was recommended that the industry should continue to monitor its progress every five years (National Cattleman's Association, 1992). The initial goal of the first NBQA was to identify shortcomings in beef production and to provide a baseline as which to improve those shortcomings. The National Beef Quality Audit's have continually been some of the most cited publications in animal science literature. The frequency of citations for each NBQA conducted since 1991 are reported in table 1.1.

Table 1.1 Frequency of citations by NBQA publication.

NBQA-Year	Times Cited[1]
1991-NBQA[2]	162
1995-NBQA[3]	214
2000-NBQA[4]	266
2005-NBQA[5]	180
2011-NBQA[6]	246
2016-NBQA[7]	151

[1]Citations reported from Google Scholar.
[2]Lorenzen et al. (1993).
[3]Boleman et al. (1998).
[4]McKenna et al. (2002).
[5]Garcia et al. (2008).
[6]Moore et al. (2012); Gray et al. (2012); McKeith et al. (2012); Igo et al. (2012).
[7]Boykin et al. (2017a); Eastwood et al. (2017); Boykin et al. (2017b); Harris et al. (2017a); Harris et al. (2018b); Hasty et al. (2017).

2.4.1 1991 NBQA

Results from the 1991 NBQA indicated during the 17 year difference between the USDA Market Consist Report of 1974, overall yield grade decreased as well as yield grade attributes such as 12th rib fat thickness and kidney, pelvic and heart fat percentage also decreased while longissimus muscle area and hot carcass weight increased (Lorenzen et al., 1993). While the current fat values were still considered to be too wasteful, improvement since the 1974 USDA Market Consist Report was evident. The selection of cattle for trimmer carcasses inherently resulted in decreased marbling scores from the 1974 report. The authors attributed this to a greater selection of European draft cattle that were heavier muscled and produced leaner carcasses, although falling short in marbling potential compared to British breeds.

2.4.2 1995 NBQA

The industry reception of the initial NBQA was positive and led to improvements even between the 1991 and 1995 audits. Results from the 1995 audit indicated further improvements in overall carcass yield including decreased yield grade and yield grade attributes including 12^{th} rib fat thickness, and kidney, pelvic, and heart fat. Additionally, unlike the increase in hot carcass weight between the 1974 report and the 1991 NBQA, hot carcass weight decreased between the 1991 and 1995 audit. Additionally, average marbling score and quality grade were both lower from the 1991 audit. The authors indicated although quality grade was lower, the percentage of carcasses falling under the USDA Standard grade was less than the 1991 audit, yet there was a decrease in the proportion of carcasses that fell within the USDA Prime and Choice grades.

2.4.3 2000 NBQA

By the 2000 NBQA, an increase in quality and consistency of cattle was attributed to the management and marketing changes influenced by the two prior NBQAs in 1991 and 1995. The 1995 audit was the first to record hide color of cattle, due to branded beef programs utilizing hide color as a main characteristic for qualification. Certified Angus Beef was increasing in popularity during this time with a 51% black hair coat being a primary factor for qualification. McKenna et al. (2002) reported out of the cattle audited, 45.1% were determined to be predominantly black (51% black-hided, a standard for CAB), whereas solid black represented 32.0% of the population (McKenna et al., 2002). The authors observed an increased in number of branded beef programs, and an increase in participation in producer education programs such as the Beef Quality Assurance program. Between the 1995 and 2000 NBQA marbling score and quality grade increased, as well as overall yield grade (McKenna et al., 2002). While the increase in quality grade was promising, the values of the 2000 NBQA were still lower than the 1991 NBQA. Likewise, McKenna et al. (2002) reported an average hot carcass weight of 356.9 kg, an increase from Boleman et al. 1998 who reported an average hot carcass weight of 338.4 kg and an increase in longissimus muscle area from 82.6 cm^2 (Boleman et al., 1998) to 84.5 cm^2 (McKenna et al., 2002). The increase of longissimus muscle indicates an improvement in carcass muscling likely resulting from the selection of European draft breeds and use of growth promotants such as trenbolone acetate. These results showcase the pressure that the outcomes of the NBQA has had on the industry to make management and genetic changes to improve carcass performance.

2.4.4 2005-2016 NBQA

Since the inception of the NBQA, from the 2005, 2011, and 2016 audits, yield grade (YG) became more consistent and remained relatively the same (YG 2.9, 2.9, and 3.1), whereas hot carcass weight (359.9 kg, 370.0 kg, and 390.3 kg), marbling score ($Small^{32}$, $Small^{40}$, and $Small^{70}$), and longissimus muscle area (86.4 cm^2, 88.8 cm^2, 89.5 cm^2) increased. Additionally, the proportion of carcasses grading USDA Choice and Prime were greater, and lesser carcasses fell in the USDA Standard category. Moore et al. (2012) attributed the increase in hot carcass weight to the growing popularity of the use of growth promoting technologies from 2005 to 2011 such as beta-adrenergic agonists.

There have been multiple additions and changes to outcomes evaluated by the NBQA to reflect industry events and the need to increase collection of certain types of information. In the 2005 audit, dentition was added as a data collection point after bovine spongiform encephalopathy was found in an animal in the United States in 2003 (Garcia et al., 2008). In the 2011 audit, a separate report auditing camera grading was implemented in order to measure carcass quality factors over the course of a year due to the increasing use of grading technology in commercial facilities (Gray et al., 2012). More recently, in the 2016 audit, frequency of cattle/carcasses dragging and touching the floor or equipment were recorded due to the increasing size of live animals since previous audits (Eastwood et al., 2017).

2.5 Liver Abscess Complex

The development of liver abscesses in beef cattle has proved to be a costly burden to both the cattle feeder and beef processor, contributing to 70% of all liver condemnations (Brown and Lawrence, 2010). Liver abscesses occur in all types of cattle, including dairy and range cows, but pose the greatest economic challenge to feedlot cattle. Nagaraja and Chengappa (1998) attributed the rates of abscessed livers to an aggressive feeding program. Likewise, many studies have shown rates of abscessed livers are greater with high-starch, low-roughage diets due to the highly fermentable nature of starch and increased incidence of ruminal acidosis (Brent, 1976; Gill et al., 1979; Zinn and Plascienca, 1996). Liver abscesses in beef cattle have been referred to as a “complex” or “dogma” in the literature (Amachawadi and Nagaraja, 2016; Lawrence, 2020; Reinbold, 2020). This is due to the multiple factors to which liver abscesses in beef cattle have been attributed to outside of ruminal acidosis from high-starch diets, such as management practices, days on feed, and breed-type (dairy versus beef) (Elam, 1976; Reinhardt et al., 2015; Amachawadi and Nagajara, 2016). Liver abscess research holds great importance for the industry mainly due to the lost performance in average daily gain, feed intake, carcass weight, quality grade and carcass trim in those cattle which exhibit liver abscesses (White and Montgomery, 1985; Brink et al., 1990; Nagajara and Chengappa, 1998; Fox et al., 2009; Brown and Lawrence, 2010).

Liver abscesses have been reported to mainly be caused by feeding practices, a major factor influencing the rates and severity of abscesses (Nagaraja and Chengappa, 1998). Feedstuffs considered “highly-fermentable” such as wheat, barley, high-moisture corn, and steam-flaked corn have been reported to result in greater reductions in ruminal pH leading to rumen metabolic issues resulting in liver abscesses (Zinn et al., 1996). Low-roughage diets lack the ability to stimulate rumination through physical scratching, altering the ruminal papillae resulting in damage. Additionally, high-starch diets lower the pH of the rumen, damaging the rumen epithelium providing a pathway for ruminal bacteria to enter the bloodstream and travel to the liver (Reinhardt et al., 2015). The primary bacteria found in the rumen known to cause liver abscesses is *Fusobacterium necrophorum*, with *Trueperella pyogenes* being the second most isolated pathogen from the rumen (Berg and Scanlan, 1982; Nagajara et al., 1998).

2.5.1 Tylosin use

The use of tylosin phosphate has assisted with mitigating the adverse effects of liver abscesses in beef cattle, having been reported to reduce abscess rates in various amounts (Brown et al., 1973; Brown et al., 1975; Pendlum et al., 1978; Heinemann et al., 1978, Potter et al., 1985). Tylosin phosphate, a feed-grade antibiotic fed to cattle to reduce liver abscesses, is marketed as Tylan by Elanco Animal Health. Tylosin phosphate received it’s U.S. Patent in 1965 by Hamill et al with the Eli Lilly and Company, now known as Elanco Animal Health under the U.S. Patent No. 3,178,341. Tylosin was derived from soil samples taken in Nongkhai, Thailand. The novel organisms capable of producing tylosin were permanently placed with The Culture Collection of the Northern Utilization Research and Development Branch of the U.S. Department of Agriculture, Peoria, Illinois and were assigned the culture numbers NRRL 2702 and NRRL 2703.

The Elanco Liver Check Service guidelines for liver scoring are as follows: 0 = No abscesses – a normal, healthy liver; A = 1 to 2 small abscesses or up to two to four well-organized abscesses, which are generally under one inch in diameter. The remainder of the liver is healthy in appearance; A+ = 1 to 2 large abscesses, along with inflammation of liver tissue surrounding the abscess. Often, portions of the diaphragm are adhered to the surface of the liver and have to be trimmed to separate the liver from the carcass.

After tylosin went off-patent, Huvepharma developed and began marketing Tylovet for the control of liver abscesses in fed beef cattle. Much like Elanco Animal Health provides a liver auditing service to their clients, Huvepharma utilizes the West Texas A&M University Beef Carcass Research Center and third party cooperators to collect liver data for their clients.

2.5.2 Liver Scoring System

The Eli Lilly and Co. (Elanco) liver scoring system was first described by Brown et al., 1975. The system differentiated liver outcomes by severity, with (0) being no abscess, (A-) having one or two small abscesses or inactive scars, (A) having one or two large abscesses or several small abscesses, and (A+) having multiple large abscesses often involving collateral tissue (adhesions). The Elanco liver scoring system was designed to assist in the marketing of Tylan (Elanco Animal Health). Since its development, the Elanco Liver Scoring System has assisted the industry in collecting information on liver abscesses in fed-beef cattle and understanding the complex behind the development of liver abscesses. Elanco has reported auditing livers on over 54 million head of cattle since 1985 (Personal communication – Phil Rincker, Elanco Animal Health).

2.6 Bovine Respiratory Disease and Lung Health

Bovine Respiratory Disease (BRD) has proved to be one of the most costly diseases to confined cattle feeding (Griffin, 1997), resulting in decreased performance and death loss. Bovine respiratory disease is often referred to as a complex, due to multiple factors which may attribute to its cause. Immunosuppression, being one of the initial factors attributing to the infection of other viral or bacterial-BRD causative agents, is caused by stressors (weaning, castration, transport, and commingling). A majority of the cattle in the United States originate from beef herds with between 50 and 100 cattle (APHIS, 2011). Therefore, the cow-calf operation is not likely the sole-income for their household, but rather a supplemental income. According to the USDA-APHIS, small-scale U.S. Cow-calf operations in 2011, only 60% of operations with 1 to 49 head vaccinated any adult cattle or calves. In addition to vaccination at the ranch origin, small beef producers are less likely to perform necessary management strategies that would mitigate a calf's susceptibility to BRD. These include weaning prior to transport, bunk-training, and castration. All of these processes are stressful to the calf, and instead of occurring over a longer time period prior to arrival to a feedyard, they are performed upon arrival during an already stressful time, greatly suppressing the animal's immune system. Additionally, calves coming from small-scale operations are often sold in single groups, or groups of two to three. Therefore they are commingled at multiple places before finally being placed in a home pen in a feedyard. Commingling increases the opportunity to be infected with a BRD causative agent from another animal, and with cattle being social animals, the stress of interacting with new, unfamiliar animals compounds their already suppressed state. Vaccinating calves upon arrival to the feedyard is a common arrival process. While this may be the common practice, previous research has indicated stress and previous exposure to BRD pathogens via commingling may reduce vaccine efficacy (Blecha et al., 1984).

2.6.1 Causative agents of BRD

There are differing causative agents of both viral and bacterial nature which contribute to BRD. The five viruses primarily associated with BRD are bovine herpesvirus-1 (BHV-1), bovine viral diarrhea virus (BVDV) types 1 and 2, parainfluenza-3 virus (PI3V), and bovine respiratory syncytial virus (BRSV). There are four bacterial agents associated with BRD: *Mannheimia haemolytica, Pasteurella multocida, Histophilus somni, and Mycoplasma bovis.* These bacteria are considered to be commensal in a nature, and unproblematic in healthy, unstressed cattle (Confer, 2009). It is understood that when calves are already stressed and affected by viral respiratory tract infections those can become further complicated by these bacterial agents (Schneider et al., 2010). Infection with these bacterial pathogens result in severe inflammatory and immune response which leads to tissue damage and resulting lesions in the lung (Confer, 2009).

2.6.2 Diagnosis of BRD

BRD is typically detected in the live animal via visual observation for signs of respiratory illness. These include: depression, nasal discharge, coughing, reduced feed intake, and isolation from the group of cattle. Visual detection is dependent on the knowledge and experience of the individual tasked with identifying suspect cattle and variation and misdiagnosis is likely to occur. Lung lesions present in the lung tissue of cattle indicate prior inflammation caused by the previously mentioned viral or bacterial agents. Cause of death by respiratory illness can be diagnosed during a field necropsy, and up until Bryant et al. (1999) developed a system for scoring lung lesions at a slaughter abattoir, this was the only way to truly diagnose an animal with BRD. The scoring system developed by Bryant et al. (1999) to quantify lung lesions, an indicator of lung health, and was the first system published for scoring lung health at chain speed at a commercial slaughter plant. Lung health was categorized as: lesions that were sequels to cranioventral bronchopneumonia, other lesions and no lesions. Cranioventral bronchopneumonia included collapse/consolidation, adhesions, missing lobe, abscesses, parenchymal fibrosis, and emphysema. Later, Tennant et al. (2014) did further work on a lung scoring system to be used at commercial slaughter plants. Their system included scoring the lungs based on observing the dorsal and ventral surfaces of the lungs for the presence of consolidated tissue. Additionally, the cranial, caudal, and accessory lobes were manually palpated to detect the presence of fibrin tags and the absence of lung tissue due to adhesion to the thoracic cavity was noted. The subsequent scores are as follows: NORM = normal, no lesions observed; FIB = presence of fibrin tag formation or interlobular adhesions between lobes; 5CON, 15CON, 50CON, and ALLCON indicate the percentage of consolidation in the lung tissue, presence of mycoplasma-like lesions in the lung tissue, or missing portions of lung tissue.

It is well understood based on previous research that incidences of respiratory disease are economically devastating to the feedlot industry due to losses in feedlot performance and lesser quality and yield grade outcomes (Gardner et al., 1999; Schneider et al., 2009; Tennant et al., 2014). Gardner et al. (1999) reported a 4% decrease in ADG, 1.7% decrease in final BW, and a 2.6% decrease in hot carcass weight in steers treated for BRD. Additionally, Tennant et al. (2014) reported steers with lung lesion scores of 15CON, 50CON and ALLCON had lower HCW than NORM, FIB, or 5 CON, and steers with ALLCON scores had lesser LM area than all other lung score categories. Furthermore, the study also reported steers with 50CON and ALLCON had decreased marbling scores compared to other lung outcomes.

Conclusion

It is extremely apparent that the beef industry is affected by a wide variety of factors and has adapted and evolved to maintain profitability at all sectors. The collection of data at every level of beef production has assisted the industry at improving upon themselves through services such as the Beef Carcass Research Center at West Texas A&M University and audits such as the National Beef Quality Audits. Beef grading has experienced many changes over time, including revisions to grading standards, implementation of camera grading to provide more objective assessments of carcass attributes, and recommendations to change the current yield grade system to more accurately represent the current cattle population. Methods to which cattle are marketed have changed since the inception of the now widely-utilized value based marketing system based on premiums and discounts according to carcass characteristics. The beef industry has made tremendous strides to improve quality grades and red meat yield by selecting for early-maturing cattle with increased marbling scores and growth potential, but this observed improvement has been achieved synergistically with depressed animal health outcomes as a consequence of single trait selecting for improved terminal characteristics.

The liver abscess and BRD complex are two animal health issues that are both economically devastating to the beef industry in their own regard (Griffin, 1997; Brown and Lawrence, 2010). They both have shown little improvement over the years even with antibiotics and vaccines being developed and used for the treatment and prevention for both complexes. The scoring of livers and lungs have assisted the industry with identifying trends and possible causations, but these only occur post-mortem. Liver abscesses and respiratory illness in feedlot cattle have proven to result in decreased live and carcass performance due to the resulting depression in liver and lung function and less energy towards growth of the animal (Gardner, 1999; Tennant et al., 2014; Herrick et al., 2022). If efforts are not made to include health parameters as traits to select for in addition to quality and growth of beef animals, we will not see notable improvements in the aforementioned complexes. Additionally, the use of feed-grade and injectable antibiotics for control and prevention of liver abscesses and bovine respiratory disease will become less of a common practice for fear of antimicrobial resistance due to their use (Hoelzer et al., 2017). Therefore, for the future, genetic selection for health outcomes is a likely mitigation tool in addition to management practices.

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CHAPTER III

A HISTORICAL META-ANALYSIS OF CARCASS DATA COLLECTED FROM 1992-2021 BY THE WEST TEXAS A&M UNIVERSITY: BEEF CARCASS RESEARCH CENTER.

3.1 Abstract

The West Texas A&M University Beef Carcass Research Center (BCRC) carcass grading database (n = 1,079,880) generated from 1992 to 2021 was used to identify carcass outcomes, trends, and associations. Carcass data was collected at 44 federally inspected beef abattoirs in the United States and Canada. Outcomes included hot carcass weight (HCW), loin muscle area (LMA), adjusted 12th rib fat thickness (AFT), calculated yield grade (YG), LMA to HCW ratio (RATIO), marbling score (MARB), hair coat color and sex. Mean carcass outcomes were: YG (2.9), AFT (1.3 cm), HCW (369.7 kg), LMA (87.2 cm^2), KPH (2.1%), RATIO (0.2446 cm^2/kg) and MARB (Small^{23}). Regression equations were calculated to determine change in carcass outcomes over time. Mean HCW, LMA, YG, and AFT were determined to annually ($P < 0.01$) increase linearly by 2.35 kg, 0.42 cm^2, 0.0062 units and 0.012 cm whereas RATIO decreased ($P < 0.01$) in a linear manner by 0.00014 cm^2/kg, and MARB increased ($P < 0.01$) in a quadratic manner by 0.22 units. Based on these annual trends, predicted means values for carcass outcomes at the year 2050 are as follows: HCW (477.0 kg), LMA (107.1 cm^2), AFT (1.8 cm), MARB (Slightly Abundant^{89}), YG (3.15), and RATIO (0.2377 cm^2/kg).

These data illustrate strong association ($P < 0.01$) between YG and carcass outcomes. As YG increased by one unit (i.e. YG 2.0 to 3.0), AFT, HCW, and MARB increased ($P < 0.01$) by 0.5 cm, 14.6 kg, and 3.9 units, whereas LMA and RATIO decreased ($P < 0.01$) by 7.2 cm^2 and 0.0304 cm^2/kg. Hot carcass weight was also influential ($P < 0.01$) upon carcass outcomes. As HCW increased by 100 kg, YG, AFT, LMA and MARB increased ($P < 0.01$) by 0.51 units, 0.3 cm, 12.7 cm^2 and 3.01 units, whereas RATIO decreased by 0.0304 cm^2/kg. Similarly, as AFT increased by 0.254 cm, YG, HCW and MARB increased ($P < 0.01$) by 0.33 units, 5.7 kg, and 1.6 units, whereas LMA and RATIO decreased by 0.54 cm^2 and 0.0054 cm^2/kg.

Quality grade was also strongly associated ($P < 0.01$) with carcass outcomes; as quality grade increased from Select to Choice, YG (+0.38 units), AFT (+0.22 cm), and HCW (+8.6 kg) increased ($P < 0.01$), whereas LMA (-1.5 cm^2) and RATIO (-0.0756 cm^2/kg) decreased. Likewise, as quality grade increased from Choice to Premium Choice, YG (+0.27 units), AFT (+0.18 cm), and HCW (+4.1 kg) increased ($P < 0.01$), whereas LMA (-1.0 cm^2) and RATIO (-0.0054 cm^2/kg) decreased. Furthermore, as QG increased from Premium Choice to Prime, YG (+0.22), AFT (+0.16 cm), and HCW (+3.2 kg) increased ($P < 0.01$) and LMA (-2.9 cm^2) and RATIO (-0.0105 cm^2/kg) decreased.

Steers exhibited greater ($P < 0.01$) YG (2.88 vs 2.81), and HCW (360.63 vs 334.15 kg) and less ($P < 0.01$) LMA (86.17 vs 86.64 cm^2), AFT (1.24 vs 1.40 cm), MARB (Small^{22} vs Small^{44}) and RATIO (0.2412 vs 0.2606 cm^2/kg) than heifers. The effect of railout status was assessed; carcasses that had been railed off-line for enhanced trimming exhibited lesser ($P < 0.01$) YG (-0.19), AFT (-0.12 cm), LMA (-2.50 cm^2), MARB (-2.10 units) and dramatically lighter HCW (-18.23 kg), but increased RATIO

(+0.0074 cm^2/kg) compared to non-railout carcasses. Black hided cattle were determined to have increased ($P < 0.01$) YG (3.04 vs 2.67), AFT (1.35 vs 1.15 cm), HCW (357.5 vs 350.6 kg), KPH (2.15 vs 2.09), and MARB ($Small^{43}$ vs $Small^{06}$) and lesser ($P < 0.01$) LMA (85.21 vs 87.15 cm^2) and RATIO (0.2394 vs 0.2497 cm^2/kg) compared to non-black hided cattle. Probability of carcasses grading Choice (CH), Premium Choice (PrCH), or Prime (P) was calculated. As HCW increased from 400 to 500 kg, the probability of grading CH, PrCH, or P increased by 12, 9, and 1.4%, respectively. Likewise, as AFT increased from 1.5 to 2.5 cm, an increase of 21.9, 23.5, and 4.1% occurred in the probability of grading CH, PrCH, and P. In contrast, as LMA increased from 90 to 100 cm^2, a decrease of 3.5, 1.9, and 0.20% occurred in the probability of grading CH, PrCH, and P. These data serve as excellent indicators of the future of beef production to be used by beef producers and processors.

3.2 Introduction

The identification of shortcomings of the beef industry has been necessary to implementing changes desirable to beef producers, processors, and consumers. The collection of data, particularly over time, has proven to be an effective tool for this purpose via the National Beef Quality Audits, conducted approximately every five years beginning in 1991 and most recently in 2016 (Lorenzen et al., 1993; Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012; Boykin et al., 2017). The West Texas A&M University Beef Carcass Research Center houses a large database of carcass data collected since 1992 as a service for beef producers, pharmaceutical companies, research entities, and other universities. There have been many changes implemented into beef production including growth-technologies, fluctuating British, Continental, dairy and *Bos indicus* breeding proportions and fed-Holsteins, in addition to consumer pressures such as desire for less fat (Koch and Algeo, 1983; Crawford et al., 2022). Additionally, the cattle market is greatly affected by fluctuations in overall economy, feedstuff availability, weather events, and cattle population (Schnepf, 2011; Buddhika Patalee and Tonsor, 2021). Therefore, the objective of this study was to quantify the changes in carcass outcomes over time and identify trends for the future of beef production.

3.3 Materials & Methods

No Institutional Animal Care and Use Committee was necessary due to no live animals being involved in this study.

3.3.1 In-Plant Carcass Data Collection

Carcass data was collected as part of a third-party auditing service provided by the Beef Carcass Research Center (BCRC) from 1992 – 2021 at 44 federally inspected beef processing facilities in the United States and Canada (Table 3.1) by BCRC personnel. Customers included pharmaceutical and feed companies, research feedlots, universities, and beef producers. Hot carcass weights (HCW) were recorded from the hot carcass weight scale or from beef processor records. Longissimus muscle area (LMA) images were captured by using electrophoretic blotting paper (LS601-4657, Life Science Products Inc., Frederick, CO) and measured using USDA ribeye area grids, or computer-assisted drawing boards. Adjusted 12th rib subcutaneous fat (AFT) was measured using USDA preliminary cutability grade ruler (C02616, NASCO Education, Fort Atkinson, WI), and percentage of kidney, pelvic, and heart fat (KPH) and marbling score were evaluated by trained scorers. Individual visual eartag and/or electronic identification was recorded in the order in which cattle moved through the processing facility post-slaughter, an individual sequence number was assigned to the carcass via a numbered printed tag and shroud pin on the leading side of the carcass prior to hide removal to track individual carcasses through the slaughter and grade processes.

3.3.2 Compilation of Carcass Database

Carcass datasets housed in the West Texas A&M University Beef Carcass Research Center files were individually compiled into a master file in Microsoft Excel (Microsoft Corporation, Redmond, WA), with each row (n = 1,079,880) consisting of an individual animal. Data compiled included harvest and grade date, processor name and location, individual eartag and/or electronic identification, processor identification, hide color, sex, HCW, LMA, preliminary yield grade (PYG) and adjusted preliminary yield grade (APYG), AFT, KPH percentage, marbling score, and calculated yield grade. Data was thoroughly quality checked for entry errors and data determined to be biologically impossible was removed (i.e. LMA of 8.0 cm^2 instead of 80.0 cm^2).

3.3.1 Statistical Analysis

All analyses were performed using SAS (SAS Inc., NC) and Microsoft Excel. Individual animal was the experimental unit (n = 1,079,880) and data were analyzed via the GLIMMIX procedure of SAS with Kenwood–Rogers degrees of freedom approximation. Least squares means were generated and separated using the PDIFF option with a Bonferroni adjustment to control for type I error between multiple comparisons. The MEANS procedure of SAS was used to determine descriptive statistics of each carcass outcome. The LOGISTIC procedure of SAS was used to determine probability of reaching Choice, Premium Choice, and Prime by carcass outcomes. Regression equations were used to determine change in carcass outcomes over time.

3.4. Results and Discussion

3.4.1 In-Plant

The mean YG for these data was 2.9 (Table 3.2). For comparison, means for USDA YG were 3.2 for NBQA-1991 (Lorenzen et al., 1993), 2.8 for NBQA-1995 (Boleman et al., 1998), 3.0 for NBQA-2000 (McKenna et al., 2002), 2.9 for NBQA-2005 (Garcia et al., 2008), and NBQA-2011 (Moore et al., 2012), and 3.1 for NBQA-2016 (Boykin et al., 2017). The mean of independent measures used to calculate YG were AFT (1.3 cm), HCW (369.7 kg), LMA (87.2 cm^2), RATIO (0.2446 cm^2/kg) and KPH (2.1%). Mean AFT was numerically similar to those reported by the 2005 and 2011 NBQAs (1.3 cm), but was numerically lesser than the 1991 and 2016 NBQAs (1.5 and 1.4 cm, respectively). Furthermore, HCW was numerically greater compared to the 1991, 1995, 2000, and 2005 NBQAs (345.0, 339.2, 356.9, and 359.9 kg), but was numerically lesser than the 2011 and 2016 NBQAs (374.0 and 390.3 kg). Likewise, LMA was also numerically greater compared to the 1991, 1995, 2000, and 2005 NBQAs (83.4, 82.6, 84.5, and 86.4 kg), but was also numerically lesser than the 2011 and 2016 NBQAs (88.8 and 89.5 kg). Additionally, KPH was numerically similar, with subtle differences, for all NBQAs, possibly due to the subjective nature to which KPH percentage is determined and the use of a constant KPH value used by processing facilities after the wide-spread use of camera grading began.

The limitations of the current USDA YG equation and its ability to accurately predict red meat yield have been reported by Lawrence (2017). These limitations are primarily attributed to the stark differences in the current cattle population compared to the era in which the yield grade formula was developed. The modern cattle population consists of a wide variety of crossing between different breeds, most of which have been born out of need to develop cattle that are faster-growing, have the ability to produce larger carcasses in shorter amounts of time, and produce more pounds of red meat per animal. Additionally, dairy influence cattle make up a much greater percentage of the current fed-beef population than years ago (Boykin et al., 2017). Seventy years ago, when purebred Hereford dominated the cattle population, these cattle yielded smaller carcasses and a greater percentage of waste-fat. Like-wise, the current yield grade equation (USDA, 2017) assumes the relationship between HCW and LMA to be linear, whereas Lawrence et al. (2008) demonstrated this relationship to be quadratic rather than linear.

Identification of changes over time have proven to be a key tool for predicting the future of the beef industry. In the current study, the wide range of years and the robust size of the cattle population included provide an excellent view into the changes of the beef industry during the past thirty years, the most identifiable being HCW change over time (Figure 3.1). In the current study, HCW increased numerically by 2.38 kg per year since 1992. This agreed with the findings of past NBQAs, in which HCW increased by 45.3 kg from 1995 to 2016 (Lorenzen et al., 1993; Boykin et al., 2017).

When comparing years (1995, 2000, 2005, 2011, and 2016) the NBQA was conducted to the respective years within this study, all HCW values were numerically similar to those reported by the NBQA of that year (Figure 3.1). Rate of change per year was calculated via regression equations and HCW was determined to increase by 2.38 kg/year. From this equation, we determined that the average HCW will increase to 473.5 kg by the year 2050. This can be attributed to changes in cattle genetics, an influx of draft-breed cattle such as Limousin, Charolais, and Simmental, known for their growth potential, and large-framed, slower growing cattle such as Holstein and Brahman, the use of growth technologies such as implants and beta-agonists, and longer days on feed. Currently, most marketing grids have discounts for heavy weight carcasses, typically a discount is applied to carcasses weighing greater than 408.2 kg (USDA AMS – Market News Service), with larger discounts occurring the heavier the carcass past that weight. There is a possibility with the continuing trend for increased HCW, we may see the discounts for heavyweight carcasses lessened or thresholds increased to allow for heavier weights.

It is interesting to note that during the year 2020, the greatest mean HCW of all years (n = 30) was identified (417.6 kg), a 31.78 kg increase over the year prior, 2019 (385.8 kg). This is likely due to the COVID-19 pandemic, whereby processing facility closures and supply-chain disruptions caused cattle feeders to hold cattle and then ship to slaughter well-past the ideal window, resulting in larger cattle being processed for the majority of 2020.

Because HCW has increased historically, it is logical to assume LMA increased as well due to the relationship between HCW and LMA within the USDA YG equation. From 1992 to 2021, LMA has increased by 9.61 cm^2. Based on the regression equation calculated for rate of LMA change over time, LMA should increase by 0.42 cm^2 per year (Figure 3.2). Therefore, the projected LMA in 2050 is predicted to reach 107.06 cm^2. The current USDA YG equation requires a 45.35 kg increase in HCW for every 7.7 cm^2 increase in LMA for par muscle to weight relationship. Data from the current study indicates a poor relationship between HCW and LMA (r = 0.24) and results from regression equations indicate a 45.35 kg increase in HCW for every 5.7 cm^2 increase in LMA. The relationship between LMA and HCW has been extensively researched, and reported in the 2016-NBQA that a larger HCW does not always result in a larger LMA as the YG equation would suggest (Boykin et al., 2017). The ratio between LMA and HCW (RATIO), an indicator of carcass muscling, was observed to be highly variable across years. Resulting regression equations indicated a negative relationship between RATIO and change over time, and predicted a 0.00014485 cm^2/kg decrease in RATIO per year (Figure 3.3). Therefore, the RATIO is predicted to reduce to 0.2377 cm^2/kg by 2050.

In the 1991 NBQA, an identified problem in the beef industry was excess fat trim (Lorenzen et al., 1993). Additionally, Savell et al. (1989) reported consumers prefer closely trimmed beef cuts at the retail level. Means for AFT (Figure 3.4) increased by 0.26 cm from 1992 to 2021 (1.22 cm vs 1.48 cm). Based on developed regression equations, AFT is predicted to increase by 0.012 cm per year, and is on target to reach 1.82 cm by 2050. This observed increase in AFT over time has been a negative consequence of selecting genetics and managing cattle for greater marbling scores to reach USDA Choice and higher. Marbling score (Figure 3.5) has also been observed to increase synergistically with AFT over time (Small^{16} in 1992 to Small^{88} in 2021). Likewise, results from regression equations indicated a quadratic increase in marbling score annually, with marbling score predicted to reach Slightly Abundant^{89} by the year 2050. Therefore, as we feed cattle to an optimum grade of Choice, we are also inherently producing more waste-fat. For many Premium Choice boxed-beef marketing programs, the minimum marbling requirement for entry into the program is Modest^{00}, based on these predicted trends, a larger percentage of cattle will be qualifying for these programs as well as Prime.

The least squares means for carcass traits within USDA YG are reported in Table 3.3. Increasing YG was determined to be associated with other carcass outcomes. As YG increased by one unit (i.e. YG 2.0 to 3.0), AFT, HCW, KPH% and MARB increased ($P < 0.01$) by 0.5 cm, 15 kg, 0.1% and 3 units, whereas LMA and RATIO decreased ($P < 0.01$) by 5.4 cm^2 and 0.0304 cm^2/kg. Being that most factors are within the USDA YG equation, these results were expected and agreed with findings from past NBQAs (Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012), other than KPH, which Boykin et al. (2017) reported as similar between USDA YG 4 and 5. Additionally, marbling score increased ($P < 0.01$) as YG increased, which differs from the results of Boykin et al. (2017), who reported that there was no difference in marbling score between USDA YG 4 and 5, but is similar to those findings of Lorenzen et al. (1993), Boleman et al. (1998), McKenna et al. (2002), Garcia et al. (2008), and Moore et al. (2012). Unlike other outcomes, there was not a consistent increase in YG over time (Figure 3.6). This was also observed in past NBQAs (Lorenzen et al., 1993; 3.2), (Boleman et al., 1998; 2.8), (McKenna et al., 2002; 3.0), (Garcia et al., 2008; 2.9), (Moore et al., 2012; 2.9), and (Boykin et al., 2017; 3.1). The variability in YG over time, especially from 2016 to 2021 in the current study, is likely due to an influx of dairy genetics into the fed cattle industry, volatility in market conditions and Choice – Select boxed beef spread, increased feed costs, resulting in much larger cattle at slaughter with and increased fat thickness. Calculated regression equations exhibited a poor relationship (r = .004) between YG and change over time, but estimated a subtle 0.0062 unit increase in YG per year, resulting in YG to reach 3.1 by 2050. Additionally, KPH was observed to remain relatively stagnant over time as observed by past NBQAs (Lorenzen et al., 1993; 2.2), (Boleman et al., 1998; 2.1), (McKenna et al., 2002; 2.4), (Garcia et al., 2008; 2.3), (Moore et al., 2012; 2.3), and (Boykin et al., 2017; 1.9). This was also observed in the current data, where KPH was highly variable between years and was not observed to follow a trend over time (Figure 3.7). Therefore, the calculated regression equation for predicting KPH over time was a poor predictor (r = 0.39) and indicated a negative relationship between KPH and change over time, resulting in a decrease in KPH by 0.00116% per year and predicted that KPH would be 2.02% by 2050. Visual estimation of KPH percentage is a subjective assessment, which indicates the wide variation observed in these data. Therefore, accurate means of objectively assessing KPH percentage through weighing should be used rather than the subjective manner to which KPH is assessed industry-wide.

Carcass weight was influential on carcass outcomes (Table 3.4). As HCW increased by 100 kg, YG, AFT and KPH% increased by 0.51 units, 0.3 cm and 0.06%. Mean marbling score increased as carcass weight increased, increasing by 3.01 units for every 100 kg increase in carcass weight. Additionally, mean LMA increased ($P < 0.01$) by 12.69 cm^2 with every 100 kg increase in carcass weight. An indicator of carcass muscling, RATIO, was negatively associated with increasing HCW, decreasing by 0.0304 cm^2/kg as HCW increased by 100 kg. There were slight increases in KPH% between 183.6 and 272.1 kg, but differences in KPH% were not observed as HCW increased past 272.1 kg. Based on linear regression equations, as HCW increased by 100 kg, KPH% increased by 0.06273%. Marbling, being the key component of quality grades for beef carcasses, is correlated to deposition of subcutaneous fat, but antagonistic to the growth of muscle tissue as an animal ages. Therefore, the identified “ideal” carcass, one that will deposit sufficient marbling to grade Choice or higher, while also remaining within lean yield grades (1 and 2), is an industry rarity due to the antagonistic nature between muscle and fat deposition over time.

As AFT increased (Table 3.5), USDA YG and marbling score increased ($P < 0.01$). As AFT increased by 0.254 cm, USDA YG, and marbling score increased ($P < 0.01$) by 0.33 units and 1.6 units, whereas LMA and RATIO decreased by 0.54 cm^2 and 0.0054 cm^2/kg. There was a positive relationship between HCW and AFT, where HCW increased by 5.7 kg as AFT increased by 0.254 cm.

According to Priyanto et al. (1997), subcutaneous fat thickness was strongly correlated with carcass weight. A study by Dockerty et al. (1973) reported that significant deposition of subcutaneous fat did not occur until after carcasses reached 341 kg, with heavy deposition of fat occurring between 341 and 454 kg. Additionally, marbling score increased by 1.6 units ($P < 0.01$) as AFT increased by 0.254 cm. Boykin et al. (2017) reported a poor correlation (r = 0.24) between AFT and marbling score, indicating that while AFT and marbling are related, greater AFT does not always result in greater marbling scores. Likewise, we observed a poor relationship (r = 0.12) between AFT and marbling score.

The mean marbling score in this data was Small^{23} (Table 3.2). Means for marbling score were 42.4 for NBQA-1991 (Lorenzen et al., 1993), 40.6 for NBQA-1995

(Boleman et al., 1998), 42.3 for NBQA-2000 (McKenna et al., 2002), 43.2 for NBQA-2005 (Garcia et al., 2008), 44.0 for NBQA-2011 (Moore et al., 2012), and 47.0 for NBQA-2016 (Boykin et al., 2017). As QG increased from Select to Choice, YG (+0.38 units), AFT (+0.22 cm), and HCW (+8.6 kg) increased ($P < 0.01$), whereas LMA (-1.5 cm^2) and RATIO (-0.0756 cm^2/kg) decreased (Table 3.6). Likewise, from Choice to Premium Choice, a smaller response on carcass outcomes was denoted compared to Select to Choice whereas YG (+0.27 units), AFT (+0.18 cm), and HCW (+4.1 kg) increased ($P < 0.01$), and LMA (-1.0 cm^2) and RATIO (-0.0054 cm^2/kg) decreased (Table 3.6). Furthermore, as QG increased from Premium Choice to Prime an even smaller response was exhibited compared to Select to Choice and Choice to Premium Choice whereas YG (+0.22), AFT (+0.16 cm), and HCW (+3.2 kg) increased ($P < 0.01$) and LMA (-2.9 cm^2) and RATIO (-0.0105 cm^2/kg) decreased. This agrees with past NBQA reports, all of which observed an increase in HCW and decrease in LMA as QG increased from Select to Prime (Lorenzen et al., 1993; Boleman et al., 1998; McKenna et al., 2002; Garcia et al., 2008; Moore et al., 2012; Boykin et al., 2017).

Figure 3.8 contains the distribution of carcasses by QG and YG in the years 1992 to 1994, 2005 to 2007, and 2019 to 2021. In years 1992-1994, the greatest proportion of carcasses (22.03%) fell within Select YG 2, followed by Choice YG 2 and 3 (17.40 and 17.83%). Whereas, in years 2005-2007, the greatest proportion of carcasses (18.87%) fell within Select YG 2, followed by Choice YG 2 (18.69%). Between 1992-1994 and 2005-2007, the proportions of carcass within Select YG 2 lessened (18.87%) and Choice YG 2 and 3 increased (18.69 and 16.93%). By 2019-2021, the greatest proportion of carcasses (16.19%) fell within Choice YG 2, followed by Premium Choice 3 (15.34%). From 1992-

1994, 2005-2007, and 2019-2021, the proportions of carcasses within Select YG 2 decreased substantially (8.06%) as did Choice YG 2 and 3 (16.19 and 13.65%). Additionally, the proportion of carcasses within Premium Choice 2 and 3 was observed to be 11.16 and 15.34%, a substantial increase compared to the 1992-1994 and 2005-2007 results (3.91 and 6.46%; 4.30 and 5.70%). Likewise, the proportion of carcasses grading Prime increased whereas the proportion of carcasses determined to be ungraded decreased from 1992 to 2021 (0.75 to 5.53%; 2.83 to 0.45%).

Logistic regressions were used to determine the probability of grading Choice, Premium Choice, and Prime by carcass outcome and are reported in figures 3.9 through 3.14. As HCW increased from 400 to 500 kg, the probability of grading Choice, Premium Choice, and Prime increased by 12, 9, and 1.4%, respectively (Figure 3.9). Likewise, as AFT increased from 1.5 to 2.5 cm, an increase of 21.9, 23.5, and 4.1% occurred in the probability of grading Choice, Premium Choice, and Prime (Figure 3.10). In contrast, as LMA increased from 90 to 100 cm^2, a decrease of 3.5, 1.9, and 0.20% occurred in the probability of grading Choice, Premium Choice, and Prime (Figure 3.11). Furthermore, as RATIO increased from 0.24 to 0.26 cm^2/kg, a decrease of 2.0, 3.2, and 0.40% occurred in the probability of grading Choice, Premium Choice, and Prime (Figure 3.12). Yield grade was determined to be a sufficient estimate of the probability of grading Choice, Premium Choice, and Prime. As YG increased from 2 to 3, an increase of 20.1, 8.3, and 0.84% occurred in the probability of grading Choice, Premium Choice, and Prime (Figure 3.13). Additionally, as KPH increased from 2 to 3%, an increase of 11.6, 9.2 and 1.4% occurred in the probability of grading Choice, Premium Choice and Prime (Figure 3.14).

Linear regression was used to determine specific points at which a carcass reaches USDA Choice. The average carcass was determined to reach USDA Choice at 283.2 kg. Nour et al. (1983) reported a 3 unit increase in marbling score for every 100 kg increase in carcass weight. These results align with the outcomes from the current data, whereas a 3 unit increase in marbling score was observed for every 100 kg increase in carcass weight, linearly. Meanwhile, based on logistic regression equations, at 283.2 kg, a carcass would exhibit a 46.9% probability of a carcass reaching UDSA Choice or better. The probability of grading Choice or better occurred concomitant with each 7.2 kg change in carcass weight, while an increase of 13.995 and 103.885 kg resulted in a 1% increase in the probability of grading Premium Choice and Prime, respectively.

On average, a carcass achieved USDA Choice at 0.91 cm of 12th rib subcutaneous fat depth. Based on logistic regression equations to predict probability of grading UDSA Choice or better, a carcass with 0.91 cm of AFT would have a 47.06% probability of grading UDSA Choice or better. Between 0 and 2 cm of 12th rib subcutaneous fat, a 1% increase in the probability of grading Choice occurred with the addition of 0.0362 cm of AFT. However the increase in grading Choice or better slowed in relation to subcutaneous fat accrual between 2 and 3 cm of 12th rib fat depth; a 1% increase in Choice or better grading required the addition of 0.0489 cm of AFT. Furthermore, between 0 and 2 cm of 12^{th} rib subcutaneous fat, a 1% increase in the probability of grading Premium Choice occurred with the addition of 0.1678 cm of AFT, but increased from 2 to 3 cm, with a 1% increase in probability occurring with 0.0376 cm of AFT. Subcutaneous fat thickness accrual as a predictor of quality grade was determined to be a poor indicator of achieving Prime until a carcass reached 4 cm of

AFT. A 1% increase in the probability of grading Prime occurred with the addition of 0.56611 cm of AFT between 0 and 2 cm, whereas between 3 and 4 cm of backfat, the addition of 0.03683 cm of AFT resulted in a 1% increase in the probability of grading Prime.

The relationship of quality grade and the primary carcass metric of muscling, LMA, is known to be antagonistic in nature. Carcass were determined to reach UDSA Choice at 123 cm^2 of LM area. At 123 cm^2 of LM area, a carcass exhibited a 44.93% probability of grading UDSA Choice or better. As LMA increased, the probability of grading USDA Choice or better decreased; a 1% change in probability of grading Choice occurred with a 2.9 cm^2 change, while a 1% change in the probability of grading Premium Choice occurred with a 3.898 cm^2 change in LMA. A 1% change in the probability of grading Prime or better occurred with a 49.18 cm^2 change in LMA. The average carcass achieved USDA Choice at a yield grade of 2.3 and accrued 1% increase in Choice carcasses with each additional 0.06134 units of yield grade. A 1% increase in Premium Choice carcasses occurred with each additional 0.25481 units of yield grade, whereas a 1% increase in Prime grading occurred with each additional 1.7614 units of yield grade.

The probability of a carcass grading Choice or better decreased as the RATIO increased. According to the expected RATIO reported on a USDA dot grid, a carcass is required to have 7.7 cm^2 of LMA for each 45.35 kg of HCW. The average carcass reached USDA Choice at a RATIO of 0.28 cm^2/kg, exhibited a 46.38% probability of grading USDA Choice or better. A carcass with a RATIO of a 0.26 cm^2/kg, the standard expected from the USDA LMA:HCW relationship used in yield grading, had a 52.95%

probability of grading Choice or better, whereas a 1% change in Choice or better was caused by a 0.004843 unit change in RATIO. Additionally, a 1% change in Premium Choice and Prime was caused by a 0.0044 and 0.0151 cm^2/kg change in RATIO.

Frequency distributions of quality grades by carcass outcomes are reported in Figures 3.15 through 3.18. As fat thickness increased, the percentage of Choice, Premium Choice and Prime increased, and the percentage of Select carcasses decreased (Figure 3.15). Likewise, as carcass weight increased, the percentage of Choice and Premium Choice increased until 544.2 kg, where a sharp decrease in percentage of Choice carcasses (47.1 to 33.3%) were observed between 453.6 to 544.3 kg (Figure 3.16). Additionally, as carcass weight increased, the percentage of Select carcasses increased from 226.8 to 272.1 kg, but decreased as carcass weight increased past 272.1 kg. As YG increased from 1 to 5, percentage of Choice, Premium Choice and Prime increased whereas Select decreased (Figure 3.17). Furthermore, as LMA increased, percentage Prime remained stagnant, indicating the poor relationship between muscle and fat accretion. As LMA increased, the percentage of Select increased, whereas Choice and Premium Choice decreased (Figure 3.18).

The least squares means for carcass outcomes within sex class are reported in Table 3.7 Steers were determined to have greater YG (2.88 vs 2.81) and HCW (360.6 vs 334.2 kg), but lesser LMA (86.17 vs 86.64 cm^2), KPH (2.04 vs 2.10), AFT (1.24 vs 1.40 cm) and marbling scores ($Small^{22}$ vs $Small^{44}$) compared to heifers ($P < 0.01$). Brown and Lawrence (2010) reported steers to have lesser yield grades (2.83 vs 3.11) and larger LMA (89.4 vs 83.4 cm^2) compared to heifers. While similar to the current study, Boykin et al. (2017) reported heifers to have greater LMA (90.6 vs 88.9 cm^2) but reported no difference in YG in steers compared to heifers. Observed cattle had sex frequencies of 79.96% steers and 20.04% heifers. These findings are similar to past sex frequencies reported by Brown and Lawrence (2010), in which they reported the frequency of steers was 83.5% and the frequency of heifers was 16.5%. These results were not similar to past NBQAs, where the frequency of heifer carcasses were greater (66.5%) and frequency of steers (20.42%) was less than the reported frequency of the current study (Boykin et al., 2017).

Railout status of carcasses within the database were identified and carcass outcomes are reported in Table 3.8. Carcasses determined to be railed out had decreased ($P < 0.01$) YG (-0.19), AFT (-0.12 cm), HCW (-18.3 kg), LMA (-2.50 cm^2), KPH (-0.17%), and marbling score (-2.10 units) but increased RATIO (+0.007 cm^2/kg) compared to non-railed out carcasses. Carcasses are railed off for further trimming, typically due to excessive bruising, digesta or abscess contamination, carcasses falling or being pulled off the rail at the hide puller, or adhesion of lung tissue to the inside of the carcass. The reported decrease in carcass weight for railed out carcasses is a result of trimming to remove contamination, and lighter body weights due to pre-existing conditions that may impact animal performance and require trimming of carcass tissue such as lung adhesion from inflammation. This was also observed by Kirk et al. (2020), who reported a 16.2 kg trim loss in Holstein slaughter cow carcasses identified as being railed-out at slaughter due to bruising. In this study, 2.1% of carcasses were identified as railouts. This was similar to outcomes reported by Davis et al. (2002), who reported a rate of 2.4% for railed out carcasses at slaughter.

Hide color was divided into two categories: black hided and non-black hided and carcass outcomes are reported in Table 3.9. Black hided cattle were determined to have increased ($P < 0.01$) YG (3.04 vs 2.67), AFT (1.35 vs 1.15 cm), HCW (357.5 vs 350.6 kg), KPH (2.15 vs 2.09), and MARB (Small^{43} vs Small^{06}) and lesser LMA (85.2 vs 87.2 cm^2) and RATIO (0.2394 vs 0.2497 cm^2/kg) compared to non-black hided cattle. These results are similar to the findings of Brown and Lawrence (2010). The proportion of black-hided, of the population of cattle where hide color was recorded, was 59.71%. Brown and Lawrence (2010) reported a frequency of 50.0% black from their data. Since the inception of the Certified Angus Beef Program and the resulting premiums for black-hided cattle, the proportion of black-hided cattle on feed in the U.S. has increased to capitalize on this premium. According to the USDA National Steer and Heifer Estimated Grading Percent Report as of April 25th, 2022, the percentage of cattle offered under GLA was 69.51%, whereas the percentage of cattle qualifying for Certified Angus Beef was 32.09% (USDA-AMS). Garcia et al. (2008) observed an increase (45.1% to 56.3%) of the frequency of black hided cattle in the fed-beef population between the 2000 and 2005 NBQA.

3.5 Conclusions

The ability to identify shortcomings and changes in the beef industry has been necessary for improving carcass traits for the future. The use of growth-promoting technologies and changes to beef genetics has contributed to these improvements. Cattle are being fed to heavier weights and are therefore producing more beef per animal than in the past. Changes over time identified in this study were increased HCW, increased LMA, increased MARB, increased AFT, and increased YG. The beef industry has made miraculous strides in improving quality grade, a main contributor to consumer demand. The percentage carcasses grading Choice and Premium Choice has increased, whereas the proportion of Select and Standard carcasses has decreased. Additionally, the proportion of carcasses grading Prime has increased considerably in the past 29 years. Our results coincide with past NBQAs, which have served as benchmarks for beef production for the past thirty years. These data indicate that the beef industry has made great strides to improve the quality and uniformity of beef, while implementing necessary technology to produce more beef with less resources.

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Table 3.1. Company and location of beef processing facilities.

Company	Location
IBP/Tyson	Amarillo, TX
Creekstone	Arkansas City, KS
Aurora Packing	Aurora, IL
IBP	Boise, ID
Booker Packing/Preferred Beef	Booker, TX
Brawley Beef/One World Beef	Brawley, CA
Monfort/Con Agra/Swift & Company/JBS	Cactus, TX
XL Foods	Calgary, AB
G C Packing	Colorado Springs, CO
IBP/Tyson	Dakota City, KS
IBP/Tyson	Denison, IA
Excel/Cargill	Dodge City, KS
National Beef	Dodge City, KS
IBP/Tyson	Emporia, KS
Excel/Cargill	Ft Morgan, CO
Excel/Cargill	Friona, TX
Frontier Meats	Ft Worth, TX
Monfort/Con Agra	Garden City, KS
IBP/Tyson	Holcomb, KS
Monfort/Con Agra/Swift & Company/JBS	Grand Island, NE
Monfort/Con Agra/Swift & Company/JBS	Greeley, CO
Cargill	Guelph, ON
Central Valley	Hanford, CA
Caviness Beef Packers	Hereford, TX
Packerland	Hospers, IA
JBS	Hyrum, UT
IBP/Tyson	Joslin, IL
IBP/Tyson	Lexington, NE
National Beef	Liberal, KS
Coleman Natural Meats	Limon, CO
Beef America	Norfolk, NE
Greater Omaha	Omaha, NE
Nebraska Beef	Omaha, NE
IBP/Tyson	Pasco, WA
Excel/Cargill	Plainview, TX
Excel/Cargill	Schuyler, NE
Moyer Packing/JBS	Souderton, PA
Excel/Cargill	Sterling, CO
JBS/Smithfield Beef Group	Tolleson, AZ
AB Foods/Washington Beef	Toppenish, WA
IBP	West Point, NE
Clint and Sons	White Deer, TX
Caldwell Packing	Windom, MN
Taylor Packing/Cargill	Wyalusing, PA

Table 3.2. Means, standard deviations, and minimum and maximum values for carcass traits

Trait	*n*	Mean	SD	Minimum	Maximum
USDA Yield Grade	676,006	2.85	0.84	-1.19	7.99
Adjusted Fat Thickness, cm	672,511	1.27	0.52	0	5.08
HCW, kg	958,815	369.72	48.31	117.01	685.71
LMA, cm^2	670,502	87.16	11.56	25.48	156.64
KPH, %[1]	656,782	2.08	0.46	0	7.54
Marbling Score[2]	673,739	42.3	9.32	10	99
LMA, cm^2/HCW, kg	654,497	0.24	0.03	0.06	0.82

[1]KPH was subjectively estimated.

[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.3. Least squares means for carcass traits (SEM) within Yield Grade.

Trait	Yield Grade					SEM	*P*-value
	1	2	3	4	5		
n	100,059	287,892	232,324	50,202	5,304	-	-
USDA Yield Grade	1.56[e]	2.54[d]	3.41[c]	4.34[b]	5.30[a]	0.01	<0.01
Adjusted Fat Thickness, cm	0.71[e]	1.08[d]	1.53[c]	2.11[b]	2.83[a]	0.01	<0.01
HCW, kg	343.2[e]	353.1[d]	366.6[c]	384.9[b]	402.9[a]	0.09	<0.01
LMA, cm^2	98.47[a]	88.52[b]	82.52[c]	78.92[d]	76.87[e]	0.02	<0.01
KPH, %[1]	1.92[e]	2.04[d]	2.15[c]	2.25[b]	2.32[a]	0.01	<0.01
Marbling Score[2]	37.0[e]	41.1[d]	44.7[c]	47.5[b]	49.9[a]	0.02	<0.01
LMA, cm^2/HCW, kg	0.2887[a]	0.2518[b]	0.2259[c]	0.2057[d]	0.1914[e]	0.01	<0.01

[a-f]Means within a row that do not have a common superscript letter differ ($P < 0.05$).
[1]KPH was subjectively estimated.
[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.4. Least squares means for carcass traits (SEM) within carcass weight groups.

Trait	Carcass weight group								SEM	P-value
	<226.8	226.8 to 272.1	272.2 to 317.5	317.6 to 362.8	362.9 to 408.2	408.3 to 453.5	453.6 to 544.2	>544.3		
n	1,420	16,781	115,767	300,074	319,651	164,605	40,295	222	-	-
USDA Yield Grade	1.82^{h}	2.28^{g}	2.55^{f}	2.77^{e}	2.98^{d}	3.16^{c}	3.46^{b}	4.48^{a}	0.01	<0.01
Adjusted Fat Thickness, cm	0.72^{h}	0.94^{g}	1.10^{f}	1.22^{e}	1.34^{d}	1.47^{c}	1.64^{b}	1.87^{a}	0.01	<0.01
HCW, kg	204.9^{h}	258.1^{g}	300.6^{f}	342.3^{e}	384.5^{d}	427.0^{c}	473.3^{b}	558.9^{a}	0.03	<0.01
LMA, cm^2	70.93^{g}	74.56^{f}	79.90^{e}	84.81^{d}	90.11^{c}	95.99^{b}	101.43^{a}	100.82^{a}	0.03	<0.01
KPH, %[1]	1.83^{c}	1.95^{b}	2.04^{a}	2.08^{a}	2.10^{a}	2.10^{a}	2.14^{a}	2.14^{a}	0.01	<0.01
Marbling Score[2]	34.7^{h}	38.3^{g}	40.5^{f}	41.9^{e}	43.1^{d}	43.9^{c}	45.5^{b}	49.1^{a}	0.02	<0.01
LMA, cm^2/HCW, kg	0.3417^{a}	0.2891^{b}	0.2662^{c}	0.2483^{d}	0.2352^{e}	0.2257^{f}	0.2152^{g}	0.1787^{h}	0.01	<0.01

$^{a\text{-}h}$Means within a row that do not have a common superscript letter differ ($P < 0.05$).

[1]KPH was subjectively estimated.

[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.5. Least squares means for carcass traits (SEM) within fat thickness group.

	Fat Thickness, cm											
Trait	<0.51	0.51 to 0.75	0.76 to 1.01	1.02 to 1.26	1.27 to 1.51	1.52 to 1.77	1.78 to 2.02	2.03 to 2.28	2.29 to 2.53	>2.54	SEM	*P*-Value
n	23,915	78,166	100,092	153,298	105,236	114,772	41,339	30,540	11,575	13,578		
USDA Yield Grade	1.56^{j}	1.98^{i}	2.33^{h}	2.66^{g}	3.03^{f}	3.32^{e}	3.66^{d}	3.95^{c}	4.31^{b}	4.74^{a}	0.01	<0.01
Adjusted Fat Thickness, cm	0.28^{j}	0.62^{i}	0.88^{h}	1.12^{g}	1.38^{f}	1.61^{e}	1.88^{d}	2.12^{c}	2.43^{b}	2.81^{a}	0.01	<0.01
HCW, kg	333.6^{j}	346.0^{i}	351.3^{h}	356.5^{g}	361.0^{f}	366.7^{e}	372.6^{d}	378.8^{c}	385.4^{b}	387.4^{a}	0.16	<0.01
LMA, cm^2	88.96^{b}	89.32^{a}	88.52^{c}	87.52^{d}	86.24^{e}	85.92^{f}	85.56^{g}	85.46^{g}	85.66^{fg}	84.74^{h}	0.04	<0.01
KPH, %[1]	1.93^{g}	1.98^{f}	2.05^{e}	2.07^{e}	2.12^{c}	2.13^{d}	2.15^{b}	2.16^{b}	2.19^{b}	2.17^{a}	0.01	<0.01
Marbling Score[2]	34.6^{j}	37.6^{i}	39.8^{h}	41.7^{g}	43.6^{f}	44.9^{e}	46.0^{d}	47.1^{c}	48.0^{b}	49.0^{a}	0.03	<0.01
LMA, cm^2/HCW, kg	0.2691^{a}	0.2602^{b}	0.2538^{c}	0.2472^{d}	0.2404^{e}	0.2359^{f}	0.2311^{g}	0.2271^{h}	0.2235^{i}	0.2204^{j}	0.01	<0.01

[a-j]Means within a row that do not have a common superscript letter differ ($P < 0.05$).

[1]KPH was subjectively estimated.

[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.6. Least squares means for carcass traits (SEM) within USDA quality grades.

Trait	USDA Quality Grade					SEM	*P*-value
	Prime	Premium Choice	Choice	Select	Other[1]		
n	11,214	104,959	272,740	267,141	17,687		
Yield Grade	3.47^{a}	3.25^{b}	2.98^{c}	2.60^{d}	1.98^{e}	0.01	<0.01
Adjusted Fat Thickness, cm	1.68^{a}	1.52^{b}	1.34^{c}	1.12^{d}	0.73^{e}	0.01	<0.01
HCW, kg	370.1^{a}	366.9^{b}	362.8^{c}	354.2^{d}	330.7^{e}	0.04	<0.01
LMA, cm^2	85.3^{e}	85.7^{d}	86.7^{c}	88.2^{b}	88.4^{a}	0.03	<0.01
KPH, %[2]	2.24^{a}	2.18^{b}	2.10^{c}	2.03^{d}	1.89^{e}	0.01	<0.01
Marbling Score[3]	75.9^{a}	55.9^{b}	43.8^{c}	35.1^{d}	26.0^{e}	0.01	<0.01
LMA, cm^2/HCW, kg	0.2324^{e}	0.2352^{d}	0.2406^{c}	0.2511^{b}	0.2699^{a}	0.01	<0.01

$^{a-f}$Means within a row that do not have a common superscript letter differ ($P < 0.05$).

[1]Includes quality grades Standard, Commercial, Utility, and No Roll.

[2]KPH was subjectively estimated.

[3]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.7. Least squares means for carcass traits (SEM) within sex class.

	Sex class			
Trait	Steer (n = 192,313)	Heifer (n = 48,205)	SEM	*P*-value
Yield Grade	2.88	2.81	0.01	<0.01
Adjusted Fat Thickness, cm	1.24	1.40	0.01	<0.01
HCW, kg	360.6	334.2	0.14	<0.01
LMA, cm^2	86.2	86.6	0.04	<0.01
KPH, %[1]	2.04	2.10	0.01	<0.01
Marbling Score[2]	42.2	44.4	0.04	<0.01
LMA, cm^2/HCW, kg	0.2412	0.2606	0.01	<0.01

[a-b]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]KPH was subjectively estimated.

[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.8. Least squares means for carcass traits (SEM) of carcasses by plant railout status.

	Railout Status			
Trait	Railout (n = 16,809)	No Railout (n = 827,761)	SEM	*P*-value
Yield Grade	2.68	2.87	0.01	<0.01
Adjusted Fat Thickness, cm	1.19	1.31	0.01	<0.01
HCW, kg	359.4	377.7	0.22	<0.01
LMA, cm^2	86.3	88.8	0.07	<0.01
KPH, %[1]	1.90	2.07	0.01	<0.01
Marbling Score[2]	40.8	42.9	0.06	<0.01
LMA, cm^2/HCW, kg	0.2516	0.2442	0.01	<0.01

Means within a row lacking a common superscript letter differ (*P* < 0.05).
[1]KPH was subjectively estimated.
[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

Table 3.9. Least squares means for carcass traits (SEM) of carcasses by hide color.

	Hide Color			
Trait	Black-Hided (n = 99,898)	Non-Black Hided (n = 67,404)	SEM	*P*-value
Yield Grade	3.04	2.67	0.01	<0.01
Adjusted Fat Thickness, cm	1.35	1.15	0.01	<0.01
HCW, kg	357.5	350.6	0.15	<0.01
LMA, cm^2	85.2	87.2	0.04	<0.01
KPH, %[1]	2.15	2.09	0.01	<0.01
Marbling Score[2]	44.3	40.6	0.03	<0.01
LMA, cm^2/HCW, kg	0.2394	0.2497	0.01	<0.01

[1]KPH was subjectively estimated.

[2]Scores are as follows: 10 = Practically Devoid^{00}, 20 = Traces^{00}, 30 = Slight^{00}, 40 = Small^{00}, 50 = Modest^{00}, 60 = Moderate^{00}, 70 = Slightly Abundant^{00}, 80 = Moderately Abundant^{00}, 90 = Abundant^{00}.

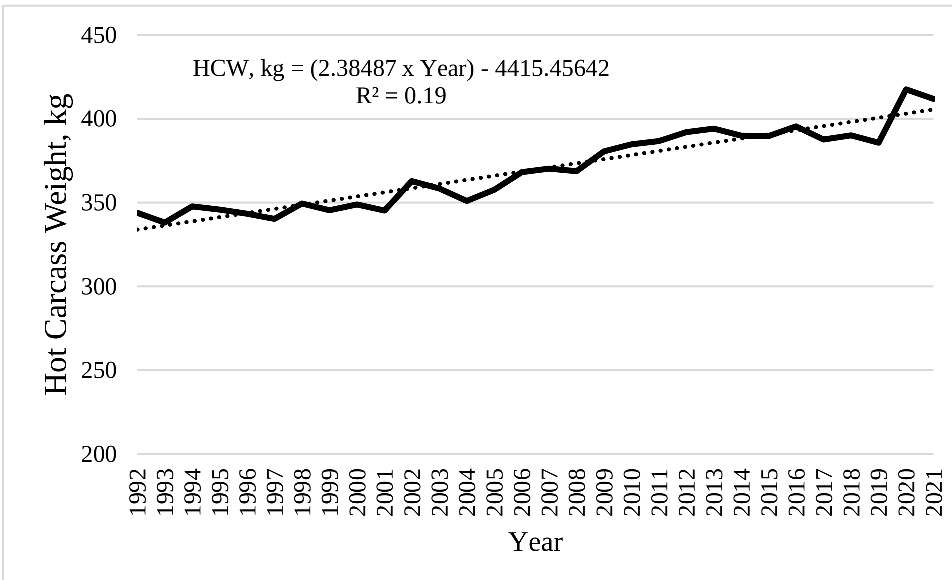

Figure 3.1. Change in hot carcass weight, kg from 1992 to 2021.

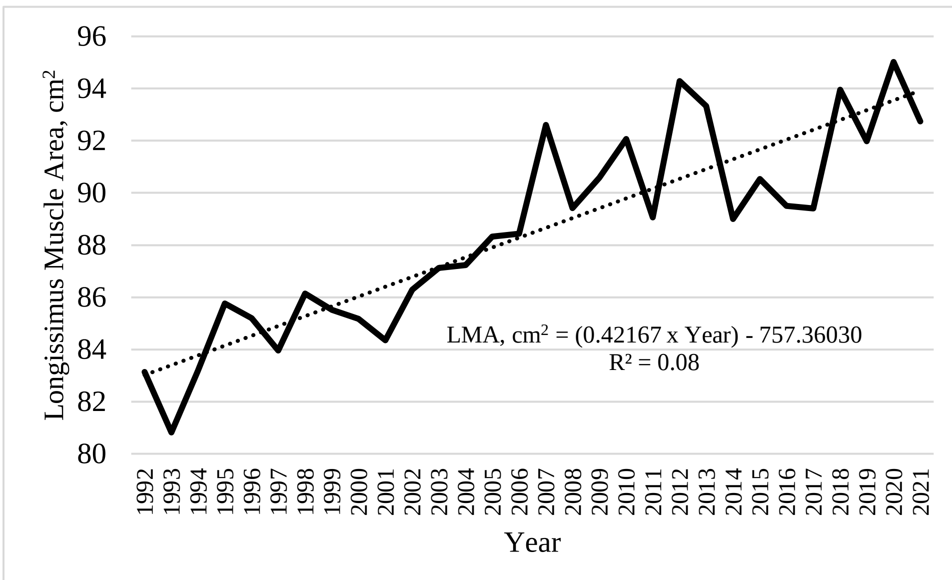

Figure 3.2. Change in longissimus muscle area, cm^2 from 1992 to 2021.

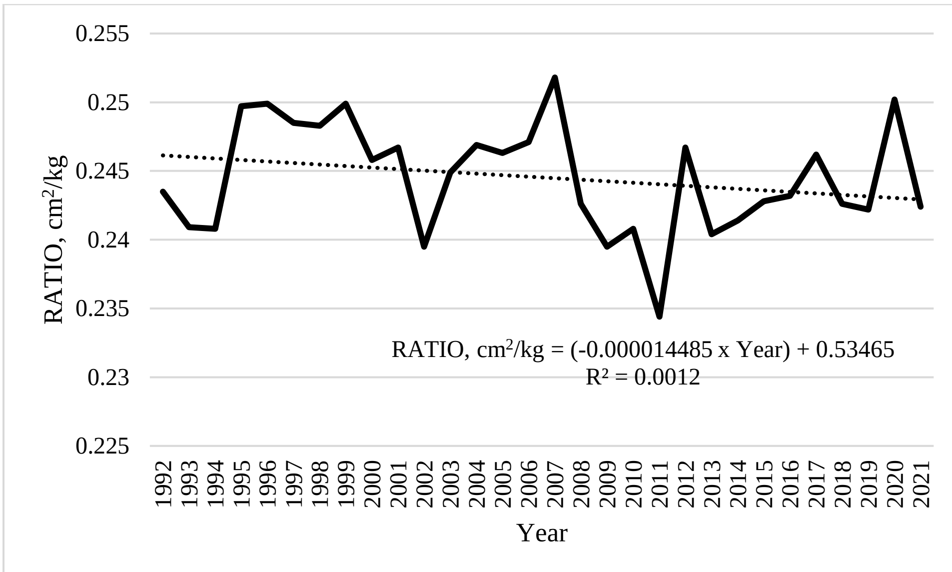

Figure 3.3. Change in RATIO from 1992 to 2021.

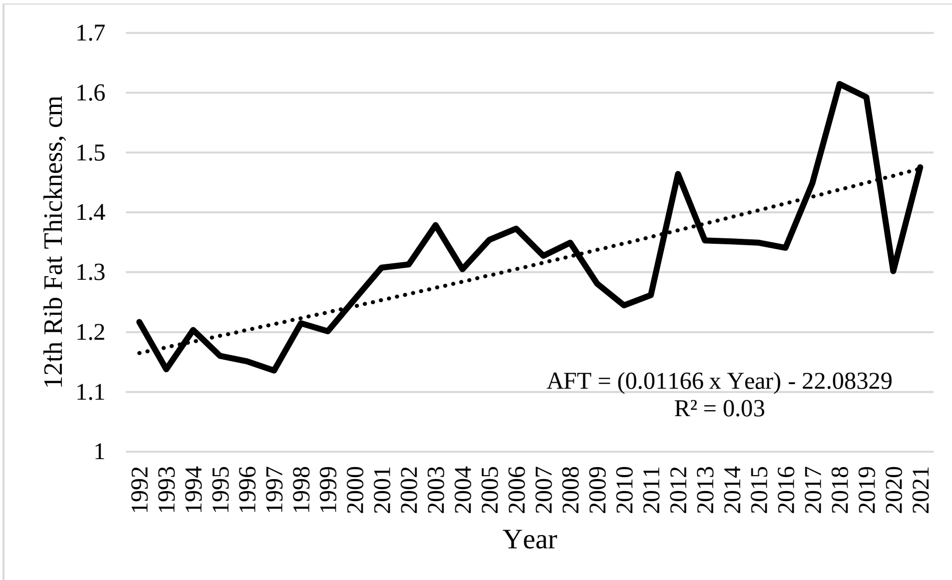

Figure 3.4. Change in 12th Rib Fat Thickness, cm from 1992 to 2021.

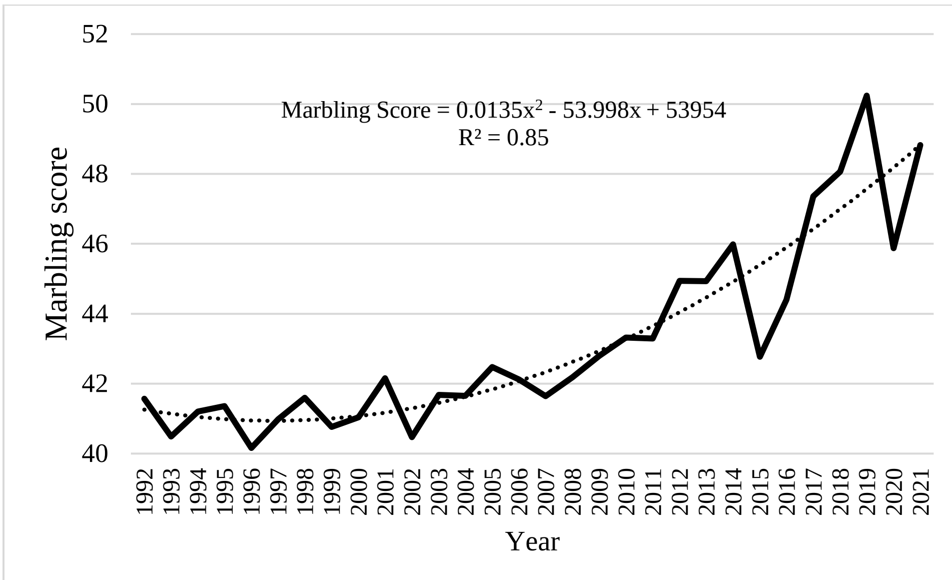

Figure 3.5. Change in marbling score from 1992 to 2021.

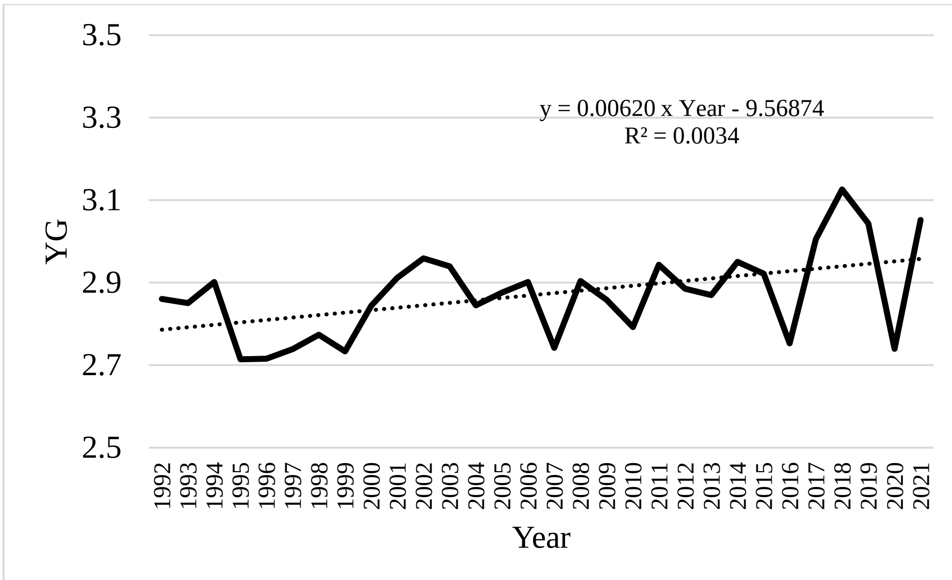

Figure 3.6. Change in YG from 1992 to 2021.

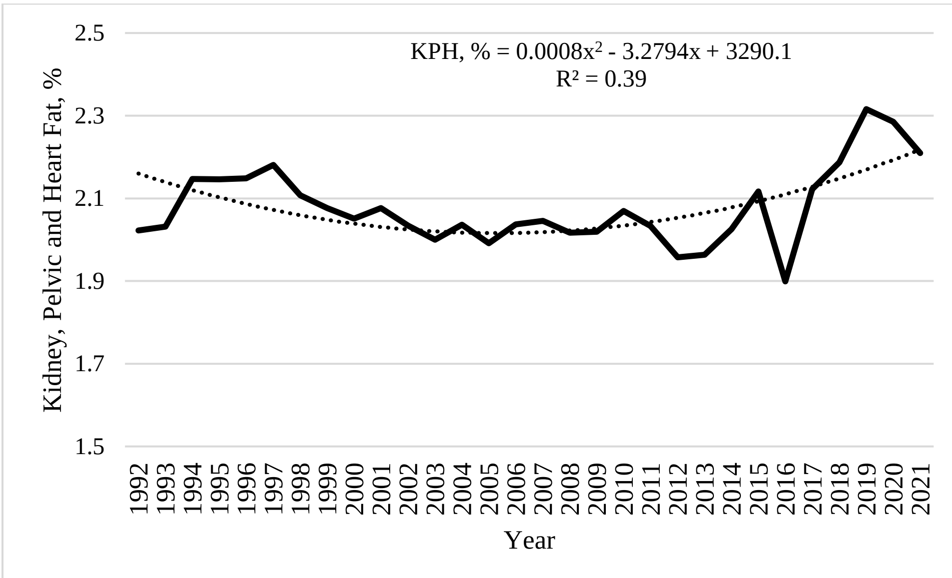

Figure 3.7. Change in KPH, % from 1992 to 2021.

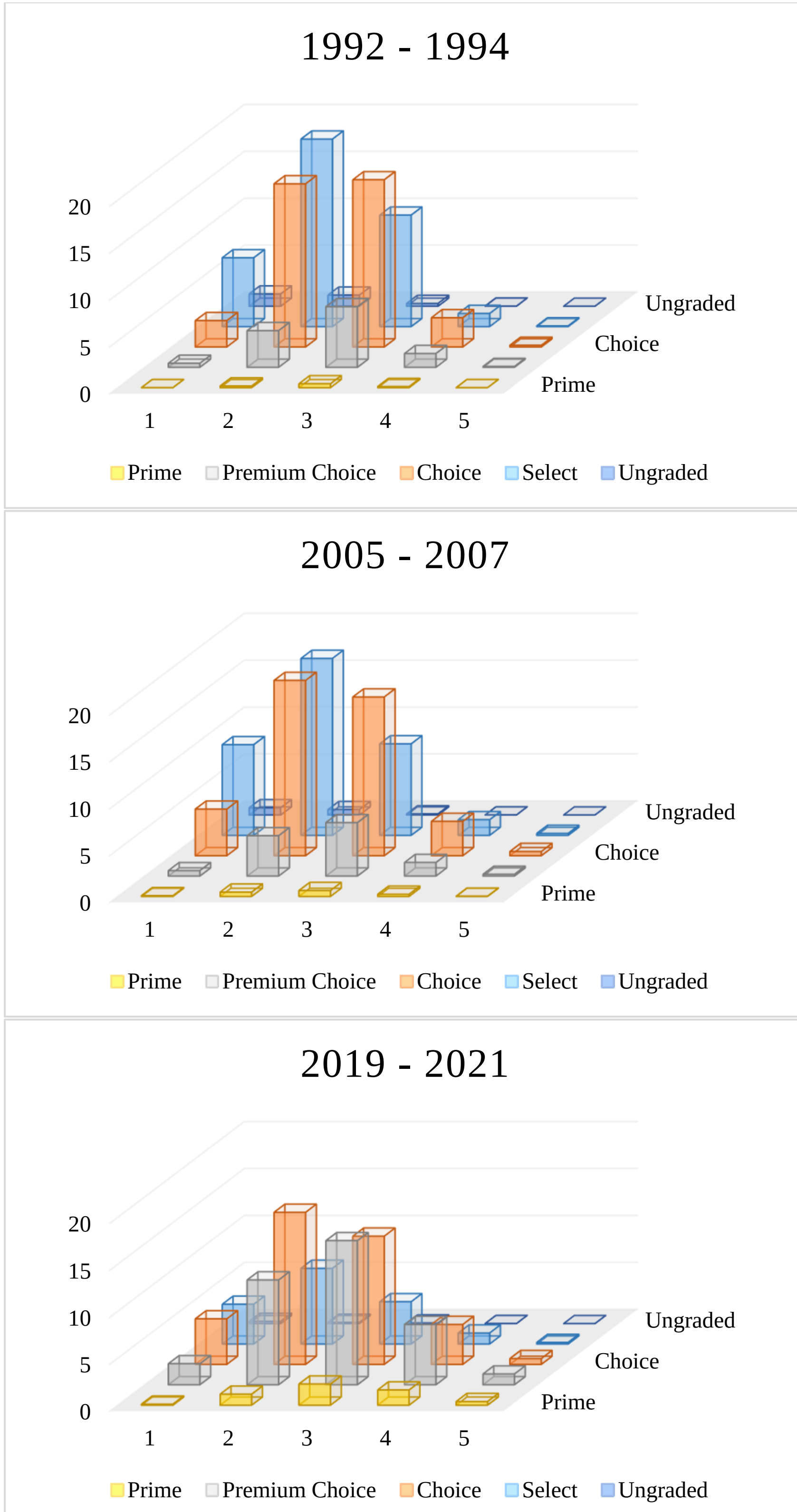

Figure 3.8. Frequency distributions of quality and yield grade in time groups.

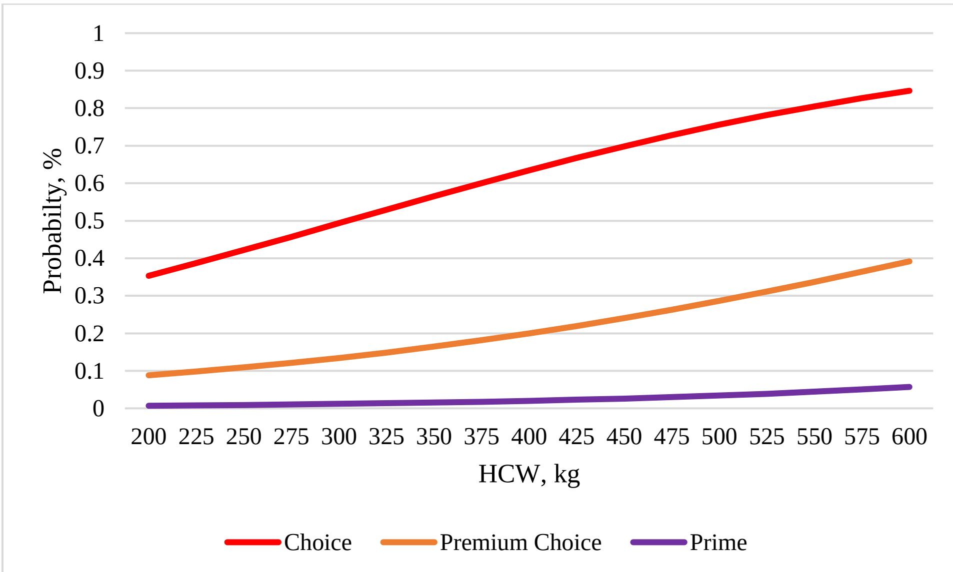

Figure 3.9. Probability of grading Choice, Premium Choice and Prime by HCW, kg.

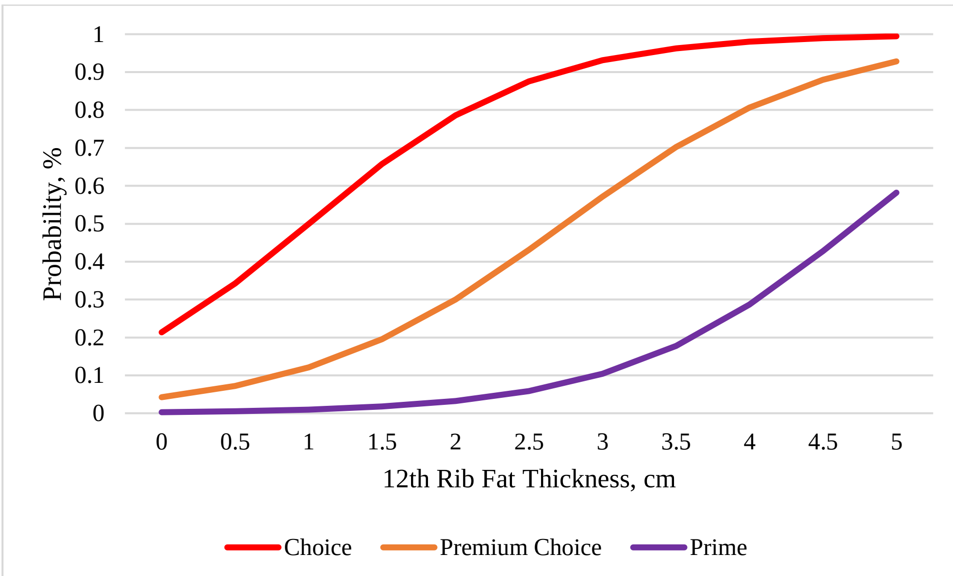

Figure 3.10. Probability of grading Choice, Premium Choice and Prime by 12th Rib Fat Thickness, cm.

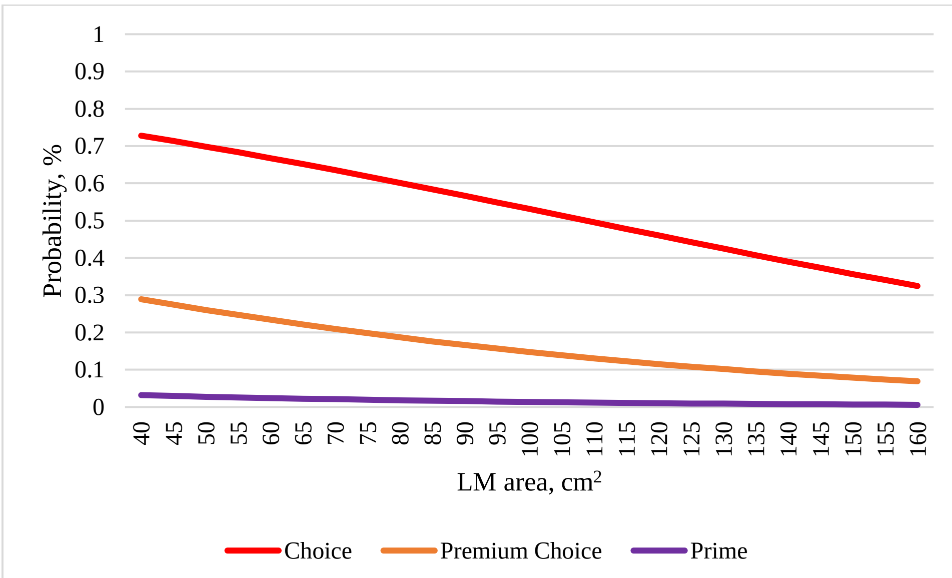

Figure 3.11. Probability of grading Choice, Premium Choice and Prime by LMA, cm^2.

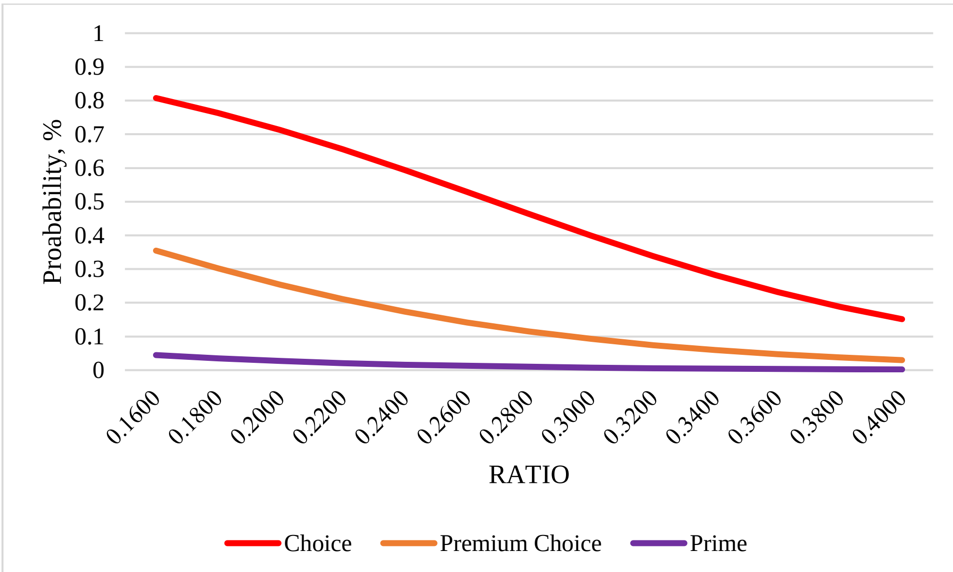

Figure 3.12. Probability of grading Choice, Premium Choice and Prime by RATIO cm^2/kg.

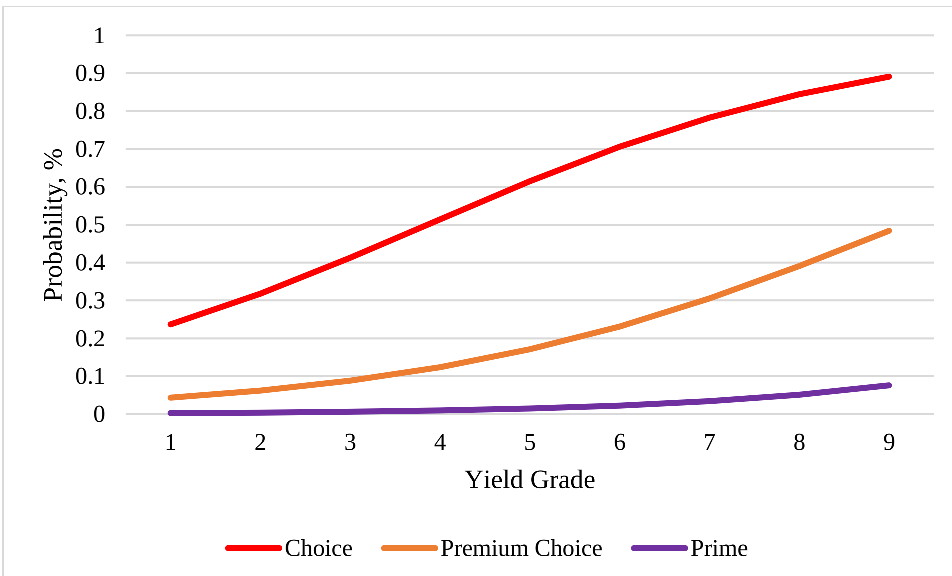

Figure 3.13. Probability of grading Choice, Premium Choice and Prime by YG.

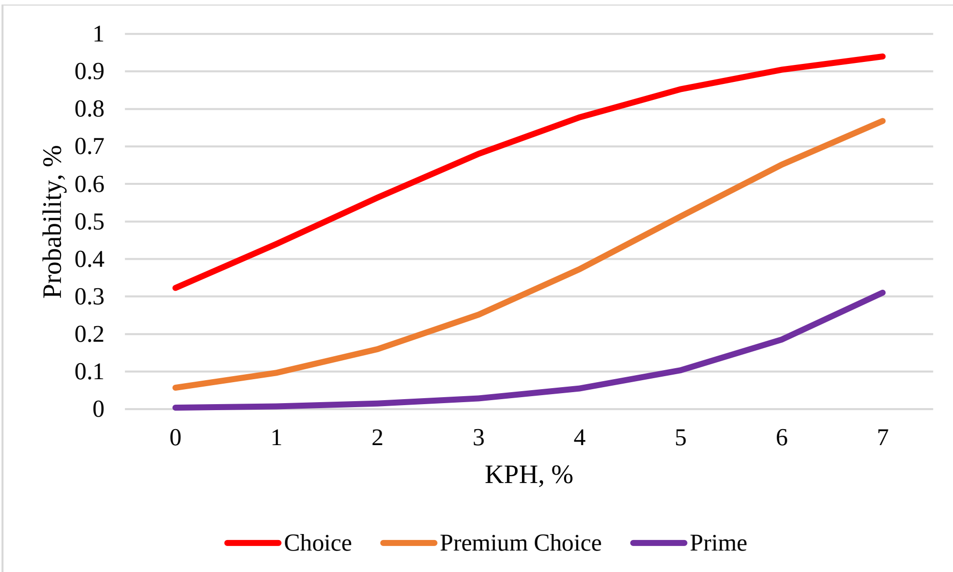

Figure 3.14. Probability of grading Choice, Premium Choice and Prime by KPH, %.

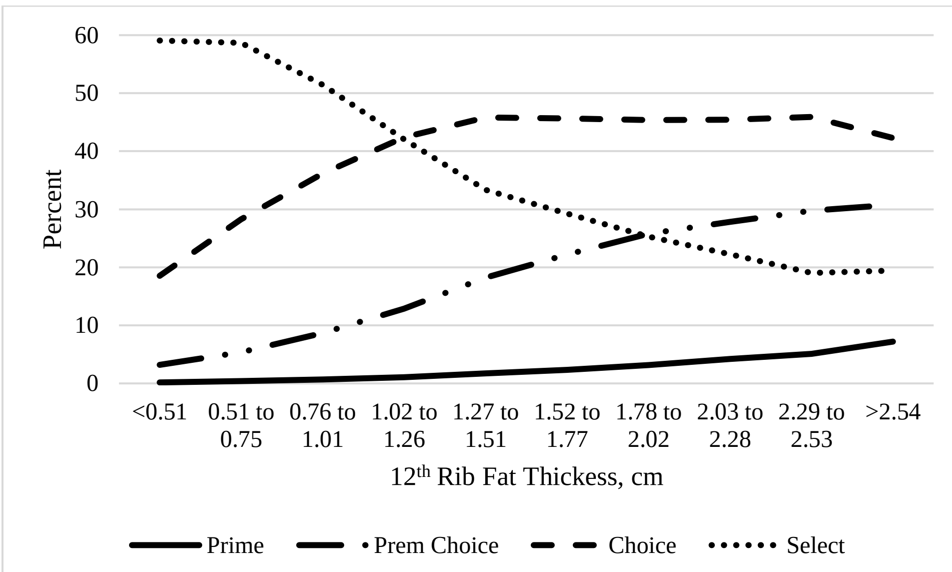

Figure 3.15. Frequency distribution of quality grades by 12th rib fat thickness.

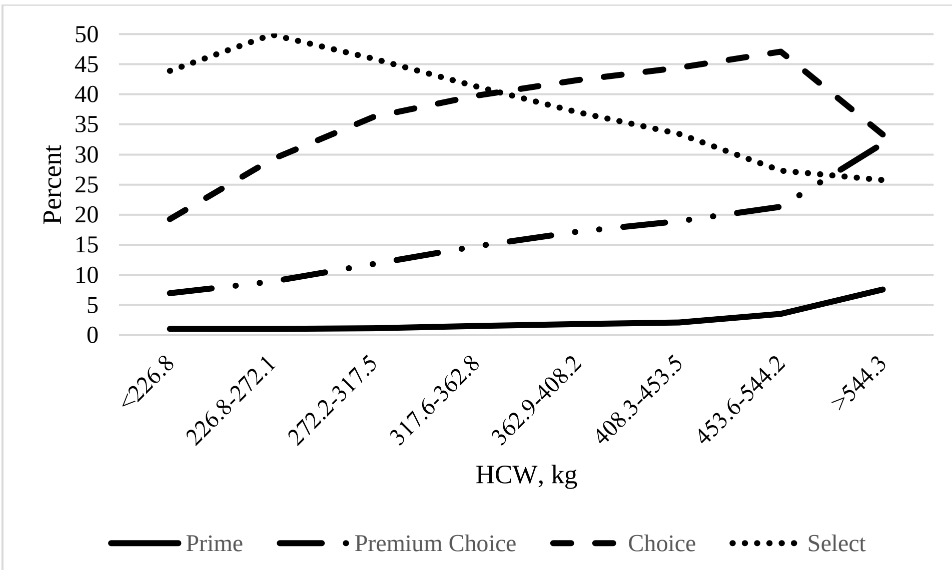

Figure 3.16. Frequency distribution of quality grades by carcass weight.

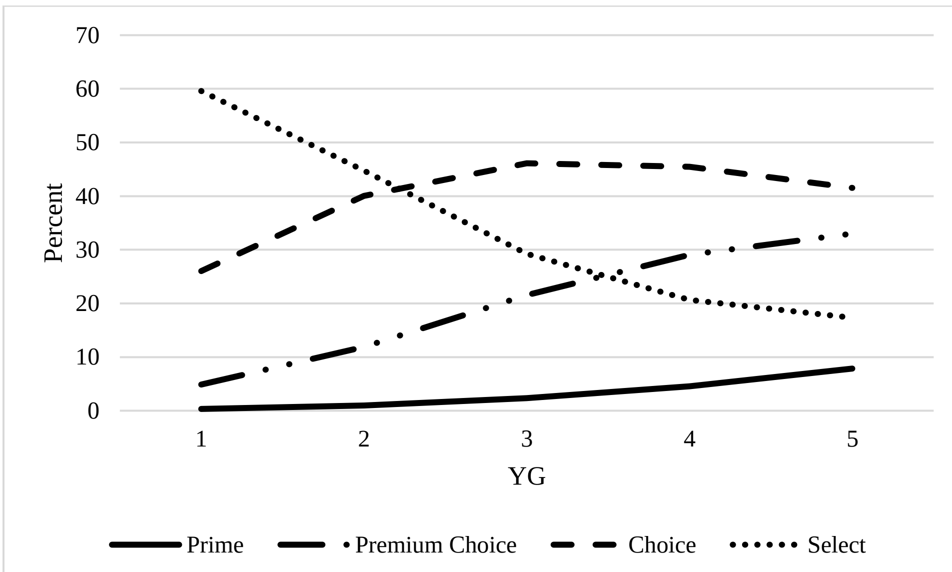

Figure 3.17. Frequency distribution of quality grades by yield grade.

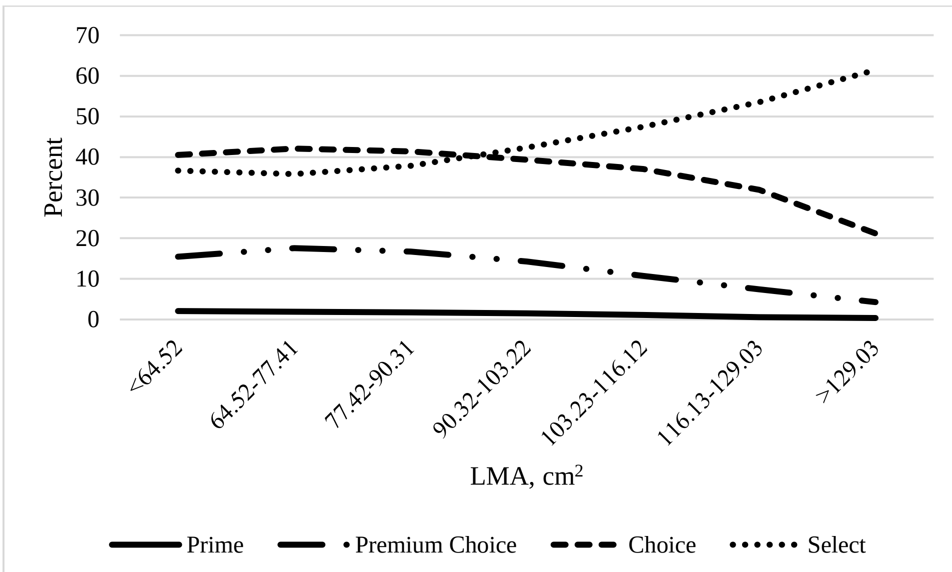

Figure 18. Frequency distribution of quality grades by LMA, cm^2.

CHAPTER IV

RELATIONSHIP OF LIVER ABNORMALITIES WITH CARCASS PERFORMANCE

4.1. Abstract

The association of liver abnormalities with carcass performance was evaluated on data from 1,542,533 carcasses housed in 2 databases at the West Texas A&M University Beef Carcass Research Center, collected between 2010 and 2021. Liver abnormalities were observed during harvest and scored as: edible liver; A- = 1 to 2 small abscesses or inactive scars; A = 1 to 2 large abscesses or multiple small abscesses; A+ = multiple large abscesses; A+AD = liver adhered to diaphragm; A+OP = open liver abscess; A+AD/OP = adhered to diaphragm with an open liver abscess; cirrhosis, flukes, and telangiectasis. Liver abnormality rates in database 1 were A- = 7.4%, A = 2.7%, A+ = 2.4%, A+AD = 3.9%, A+OP = 1.4%, A+AD/OP = 0.8%, cirrhosis = 0.2%, flukes = 3.6%, telangiectasis = 0.7%, with 77.0% of livers being edible. Liver abnormality rates in database 2 were A- = 7.3%, A = 5.3%, A+ = 4.8%, A+AD = 6.2%, A+OP = 1.7%, A+AD/OP = 1.3%, cirrhosis = 0.1%, flukes = 1.3%, and telangiectasis = 0.6%, with 67.0% of livers being edible. For carcasses with severe abscesses (A+, A+AD, A+OP, A+AD/OP) and cirrhotic livers, HCW was 13.0 kg and 42.5 kg less ($P < 0.01$) compared to carcasses with edible livers. Carcasses with any abnormality other than telangiectasis had reduced ($P < 0.05$) HCW. All liver abnormalities resulted in reduced ($P < 0.05$) LM area, with the exceptio

of telangiectasis, which was determined to be similar ($P = 1.0$) to edible livers. Less ($P < 0.05$) 12th-rib subcutaneous fat was observed for carcasses with A-, A, A+, A+AD, and cirrhosis abnormalities compared to carcasses with edible livers. Estimated KPH was less ($P < 0.05$) for carcasses with livers identified with flukes or cirrhosis abnormalities. Calculated yield grade was less ($P < 0.03$) for carcasses with A+AD liver scores and cirrhosis than those with edible livers. For both database 1 and 2, geographical location had an effect ($P < 0.01$) on liver abscess prevalence. In database 1 and 2, the greatest liver abscess prevalence was observed at the Toppenish, WA (37.12%) and Arkansas City, KS (68.33%) locations, respectively. Furthermore, seasonality of liver abscesses by month was reported to be lowest in January (14.09 and 24.08%). For database 2, liver abnormality was affected ($P < 0.01$) by sex class; steers had increased rates of all abscess outcomes compared to heifers. Additionally, cattle type was also observed to have an effect ($P < 0.01$) on prevalence of liver abscesses. Native cattle exhibited total abscess prevalence of 23.02%, compared to 16.81, 39.24 and 50.18% for Mexican, Holstein and beef x dairy cattle. Beef x dairy cattle exhibited the highest rates for A- (14.21%), A (7.94%), A+ (8.29%), A+OP (4.00%), and A+AD/OP (3.43%) liver abscess categories. These data indicate liver abnormalities, especially severely abscessed, adhered, open and cirrhotic livers outcomes, greatly effect HCW, an important economic factor effecting carcass merchandising, and other carcass outcomes. Liver abscess rate had no detrimental effect on marbling score, which may indicate the timing to which liver abscesses are developed during the feeding period compared to deposition of intramuscular fat. These results indicate control of liver abscesses is important in order to prevent losses in carcass value.

4.2. Introduction

Liver abscesses have been proven to be a costly burden to the fed-beef industry through losses in animal performance, carcass weight, and liver condemnations. Nagaraja and Chengappa (1998) attributed rates of liver abscesses to aggressive feed programs, consisting of high-concentrate, low-roughage diets. High-starch diets are rapidly fermentable in the rumen, resulting in increased incidence of ruminal acidosis (Brent, 1976; Gill et al., 1979; Zinn and Plascienca, 1996). Liver telangiectasis results in liver condemnation by UDSA personnel, resulting in monetary loss at slaughter. Ingestion of telangiectasis-affected beef liver has been reported to cause paralysis, growth failure, and spontaneous fractures in the limbs when fed to weanling rats (Pavcek et al., 1945). The resulting toxicity was reported to be caused by a high amount of vitamin A present in telangiectasis-affected beef liver (Pavcek et al., 1945). Telangiectasis is theorized to be caused by high levels of vitamin A or ischemic injury of hepatocytes in the liver (Atasever et al., 2002). Liver flukes (distoma) are flatworms (*Fasciola hepatica* or *Fasciola magna*), leaf-like in shape and are parasitic in nature. The term “distoma” is commonly used interchangeably with “flukes” to describe an infestation of the liver. It is an old term that translates to “two-mouthed”. Liver flukes are common in moist, humid areas of the United States and cause liver tissue damage and in severe infestations, flukes can leave the liver and burrow through the diaphragm to the pericardium, infesting lung tissue. Due to the tissue damage and resulting negative implications on liver function, liver flukes have been reported to cause a decrease in carcass weight (Brown and Lawrence, 2010). In regards to liver cirrhosis, it is characterized by a small, shrunken liver with a mottled blue color, but exact cause of cirrhosis has not been recorded in the literature. There have been numerous theories for the cause of liver cirrhosis, but many believe what we categorize as cirrhosis, may in actuality be representative of congestive heart failure (CHF), misdiagnosed as cirrhosis due to a similar color. While there is extensive literature on carcass outcomes from liver abscesses, there is limited literature reporting the implications of other liver abnormalities such as telangiectasis, liver flukes, and cirrhosis on carcass outcomes. Additionally, there is little to no data published on liver outcomes of beef x dairy cattle compared to native and Holstein cattle. Therefore, the objective of this study was to evaluate the association of liver abnormalities with carcass characteristics, utilizing an extensive database of information collected during the past 12 years.

4.3. Materials & Methods

No Institutional Animal Care and Use Committee was necessary due to no live animals being involved in this study.

4.3.1. Database 1

Data (n = 371,476) housed in database 1 were collected by the Beef Carcass Research Center at West Texas A&M University from 2010 to 2021. Data housed in this database must have had liver abnormality data in addition to carcass outcomes including carcass weight, calculated yield grade (YG), loin muscle area (LMA), 12th rib fat thickness (AFT), kidney, pelvic, and heart fat percentage (KPH), and marbling score (MARB) on an individual animal basis.

4.3.2. Database 2

Data (n = 1,171,057) housed in database 2 were collected by the Beef Carcass Research Center at West Texas A&M University in years 2013 to 2021. Data was collected on a pen-basis (n = 7,196) at 19 abattoirs in the U.S. and represented 138 different feedlots. Outcomes in the database included harvest date, processor name and location, total count within a pen, sex, cattle type, feedyard, feedyard location, and counts of individual liver abnormality outcomes within a pen.

4.3.3. Liver abnormality assessment

Liver abscess data were assessed using the Eli Lilly Liver Check System (Elanco, Greenfield, IN). Each liver was scored on the size and number of abscesses present (Brown et al., 1975). Livers were scored as follows: Normal = no abscess or abnormality, A- = 1 to 2 small abscesses or inactive scars, A = 1 or 2 large abscesses or multiple small abscesses, A+ = multiple large abscesses, A+AD = liver adhered to part of gastrointestinal tract or diaphragm or both and caused by currently or previously active abscesses, A+OP = Open abscess, A+AD/OP = Combination of A+AD and A+OP score. Other liver abnormalities recorded were cirrhosis/CHF, flukes, and telangiectasis.

4.3.4. Evaluation of Carcass Characteristics

Yield grade attributes including hot carcass weight. kg (HCW), 12^{th} rib subcutaneous fat thickness, cm (AFT), longissimus muscle area, cm^2 (LMA), percentage of kidney, pelvic and heart fat (KPH) and marbling score were evaluated by trained university personnel as part of the service offered by the Beef Carcass Research Center.

4.3.5. Statistical Analysis

Frequency distributions among liver abnormality were calculated using the FREQ procedure (SAS Inst. Inc., Cary, NC). Comparisons of carcass traits across liver abnormality were calculated using the GLIMMIX procedure of SAS. The MIXED procedure of SAS was utilized to compare frequencies of liver abscess outcomes by cattle type. Least squares means were generated and separated using the PDIFF option with a Bonferroni adjustment to control for type I error between multiple comparisons.

4.4. Results and Discussion

4.4.1. Liver abnormality frequency

Cattle from database 1 exhibited liver abnormality rates of A- = 7.2%, A = 2.7%, A+ = 2.3%, A+AD = 3.7%, A+OP = 1.4%, A+AD/OP = 0.8%, Cirrhosis/CHF = 0.2%, Flukes = 3.5%, and Telang = 0.6%, with 77.7% of livers being normal (Table 4.1). Cattle in database 2 exhibited liver abnormality rates of A- = 7.3%, A = 5.3%, A+ = 4.8%, A+AD = 6.2%, A+OP = 1.7%, A+AD/OP = 1.3%, Cirrhosis/CHF = 0.1%, Flukes = 1.3%, and Telang = 0.6%, with 67.0% of livers being normal (Table 4.2). Incidence rates of liver abscesses in database 1 (18.1%) were numerically similar to the 2016-National Beef Quality Audit (17.8%; Eastwood et al., 2017) and data reported by Herrick et al. (2022; 20.3% and 21.4%). The rate of liver abscesses in database 1 were numerically higher than the 12.2% reported by Brown and Lawrence (2010). Rates of liver abscesses from database 2 were numerically greater than those of database 1 (26.6% vs 18.0%). This result was not unexpected as the cattle included in database 2 represented a much greater sample size (n = 1,171,057) compared to database 1 (n = 371,476), and a much greater proportion of cattle from geographical locations associated with increased liver abscess rates. Rates of flukes for database 1 (3.5%) were numerically similar to those reported by Brown and Lawrence (2010; 2.9 and 5.5%), but were numerically higher than those reported by the 2016-National Beef Quality Audit (1.1%; Eastwood et al., 2017) and Herrick et al. (2022; 1.8%). We observed similar rates of telangiectasis to those of Brown and Lawrence (2010); 0.6%). However, we observed lesser rates of telangiectasis compared to the rate (2.3%) reported by Atasever et al. (2002). Rates of cirrhotic livers in the current study (0.2 and 0.1%) were similar to those reported by Brown and Lawrence (2010; 0.4 and 0.1%).

4.4.2 Liver abnormalities by processor location

We evaluated differences in liver abnormalities by beef processor location and determined notable variations within locations for both database 1 and 2. Total abscess rate by location for database 1 and 2 are reported in Figure 4.4. In database 1, the greatest abscess prevalence was observed at the Toppenish and Pasco, WA harvest facilities (37.12 and 31.62%), whereas the greatest abscess prevalence for database 2 was observed at the Arkansas City, KS (68.33%) and Friona, TX (44.89%) harvest facilities. In database 1, Midwestern facilities (Dakota City, NE and Schuyler, NE) were also observed to have greater liver abscess prevalence (30.87 and 27.90%) compared to other locations. This result was somewhat repeated in database 2, where Dakota City, NE had a total abscess prevalence of 29.23%, but Schuyler, NE resulted in a rate of 19.48% for total abscess prevalence. We also observed an increased rate of total abscess prevalence at the Hyrum, UT location (35.54%), and attribute this to a large population of cattle slaughtered at this facility originating from the Pacific Northwest and dairy genetics from

California. Both the Pacific Northwest and Midwestern U.S. are well known for utilizing high-concentrate diets, resulting in metabolic disorders such as acidosis, leading to increased prevalence of liver abscesses. Potato waste is a common low-cost energy source utilized in Northwestern feedlot rations, resulting in explosively fermentable starch in the rumen, increasing the opportunity for ruminal acidosis and thus severe liver abscesses (Bradshaw et al., 2002). In two surveys conducted in 2015 and 2016 by Asem-Hiablie et al., Midwestern feedlots were determined to finish 32% Holsteins compared to 14% in the northern plains. Furthermore, in an additional study conducted by Asem-Hiablie (2015), feedyards in Texas, Oklahoma, and Kansas only reported to finish 9.1% Holsteins. As exhibited in this study and past literature, Holstein cattle are known for having increased rates of liver abscesses compared to native cattle, and the larger proportion of Holstein cattle as reported in the aforementioned surveys, may explain the differences observed in liver abscess prevalence by region.

4.4.3. Seasonality of liver abnormalities

Seasonality by month (Figure 4.1) of each liver abnormality were evaluated for both databases and determined to influence ($P < 0.01$) total abscess rate. In both database 1 and 2, total abscess rate was observed to be the lowest in January (14.09 and 24.08%) compared to other months within the databases, respectively. Total abscess rate in database 1 was highest in August and April (21.42 and 20.87%) but differed from database 2, where May and June (29.12 and 30.07%) was observed to be the highest total abscess rate among months. Cold weather events have been reported to increase dry matter intake and maintenance energy requirements (Hicks et al., 1990). Liver abscess prevalence has been well documented with the association of metabolic disorders such as acidosis (Nagaraja and Chengappa, 1998). Additionally, variation in feed intake, likely observed during cold weather events, has also been documented to be associated with ruminal acidosis, and thus increased liver abscess prevalence (Nagaraja and Chengappa, 1998). Therefore, resulting increases in liver abscess prevalence would not be observed until months later (May, June, and July). Furthermore, Harman et al. (1989) reported incidence of liver abscesses were greater for cattle started on feed during the fall and winter compared to spring and summer. Assuming a 180 d feeding period (Samuelson et al., 2016), cattle started on feed in December would harvest in June, supporting these results.

Like Brown and Lawrence (2010), we observed an association between month and severity of liver flukes (Figure 4.2) in both databases. In both database 1 and 2, severity of flukes peaked in January (4.62 and 1.60%; Figure 4.2 and 4.3) and troughed in September (1.84 and 0.97%; Figure 4.2 and 4.3). These results are similar to the findings of Knapp et al. (1992), who reported incidence of liver flukes to be greatest in cold months (November – January) and lowest in warm months (August – September). Conversely, Brown and Lawrence (2010) reported liver fluke prevalence in cattle to be highest in spring months (April) and lowest in August.

4.4.4. Liver abnormalities by year

Liver abnormalities were assessed by year for both databases and are reported in figure 4.3. In database 1, the highest total abscess rate was identified in the year 2021 (32.51%) compared to the lowest abscess rate which was observed in the year 2012 (12.0%). In contrast, in database 2, total abscess prevalence was highest in 2018 (30.34%) and lowest in 2013 (16.33%). Dairy influence cattle are well-documented to have increased liver abscess prevalence than native cattle (Herrick et al., 2018). In recent years (2018-present), we have observed a greater proportion of cattle on feed in the Texas panhandle consisting of dairy x beef genetics, reflected within both database 1 and 2. The association between dairy influence cattle and increasing rates of liver abscess incidences in 2018 through 2021 is theorized by the authors to be the cause of the resulting abscess rates within years.

4.4.5. Database 1

Carcass weight for carcasses with cirrhotic livers (354.1 kg), A+AD (382.4 kg), A+OP (381.8 kg) and A+AD/OP (375.9 kg) was less ($P < 0.05$) than for carcasses that had normal livers (396.6 kg) (Table 4.1). These results agreed with the findings of Brown and Lawrence (2010), who theorized this reduction in carcass weight is likely due depressed growth associated with cirrhotic livers and excessive trimming due to adhesion and contamination from adhered and open abscesses. Furthermore, White and Montgomery (1985) reported reduced HCW in carcasses that exhibited A+AD liver scores. Presence of liver flukes and telangiectasis resulted in a 4.4 and 3.2 kg less ($P < 0.05$) carcass weight compared to normal livers. Brown and Lawrence (2010) reported similar results (-4.0 and 5.0 kg) regarding effects of flukes and telangiectasis on carcass weight, respectively.

Carcasses with minor (A- and A) and major abscesses (A+, A+AD, A+OP, A+AD/OP) had reduced ($P < 0.01$) LMA (-1.64 cm^2 and -4.18 cm^2) compared to normal livers. Cirrhotic livers were also determined to have a detrimental effect ($P < 0.01$) on LM area, resulting in 10.2 cm^2 less LM area than normal livers (93.3 vs 83.1 cm^2). Brown and Lawrence (2010) also observed a decrease in LM area of carcasses with minor and major abscesses and cirrhotic livers. In contrast to the findings of Brown and Lawrence (2010), no difference in LM area was observed in telangiectasis-affected compared to normal livers. Liver function is vital for the hepatic production of proteins that are involved in protein turnover for the accrual of muscle tissue. Albumin, an export protein of the liver, may be used as anabolic sources by peripheral tissues (Lobley, 2003). When an animal is fighting an infection such as a liver abscess or damage via cirrhosis, metabolic activity is shifted towards the infection and subsequently deprioritizes utilization of amino acids in the liver, resulting in decreased protein synthesis and therefore less muscle accretion compared to healthy animals (Lobley, 2003).

Liver abscess prevalence did not greatly affect marbling score, which may indicate the formation of liver abscesses in relation to intramuscular fat development during the feeding period. Cirrhotic livers resulted in the lowest marbling score (Small^{39}), but was not observed to be different (P > 0.05) from the mean marbling score of normal livers (Small^{41}). Within numerical differences, marbling scores across all liver outcomes remained within USDA Choice. Previous reports of effects of liver abscesses on marbling score indicated similar results to the current study (White and Montgomery, 1985; Davis et al., 2007). Conversely, Brown and Lawrence (2010) reported marbling scores of carcass with A+AD and A+OP to be less in comparison to normal livers.

An indicator of carcass muscling, RATIO, was not different (P > 0.05) between carcasses exhibiting liver abnormalities compared to edible livers. Mean RATIO among all abnormality outcomes remained within 0.2400 cm^2/kg. Furthermore, carcasses exhibiting A-, A, A+, A+AD, A+AD/OP, flukes, and telangiectasis resulted in numerically less RATIO compared to carcasses with edible livers. There were limited differences observed in KPH between liver abnormality outcomes. Mean percentage of KPH was observed to be the highest (2.18%) in carcasses with telangiectasis-affected livers, whereas the lowest (1.95%) was observed in cirrhotic livers. No difference in KPH ($P > 0.05$) was observed between carcasses with edible livers and abscess outcomes. These results were not surprising as the method to which KPH is evaluated across the beef industry is a subjective assessment, where error in estimation is likely to occur.

The greatest mean AFT (1.51 cm) was observed in telangiectasis-affected livers. The least AFT (1.17 cm) was observed in carcasses exhibiting cirrhotic livers. Abscessed livers resulted in decreased ($P < 0.05$) AFT compared to normal livers, with the greatest loss (-0.18 cm) in AFT occurring in A+AD livers. Minimal differences in AFT were observed between abscess outcomes. However, AFT was observed to decrease numerically as abscess severity increased from A- to A+AD, with no differences ($P > 0.05$) observed in AFT between A-, A+OP and A+AD/OP livers. The greatest mean YG (3.02) was observed in carcasses with telangiectasis-affected livers, followed by A+AD/OP (3.00). Among abscess outcomes and edible livers, YG was similar ($P > 0.05$) with the exception of A+AD livers, whereas a -0.11 unit reduction in YG was observed compared to edible livers and other abscess outcomes. The greatest loss in YG was observed in cirrhotic livers, resulting in -0.13 units less ($P < 0.05$) YG compared to edible livers.

Across all carcass outcomes, HCW was determined to be greatly affected by liver abnormalities, especially abscessed and cirrhotic livers. These results are not surprising as presence of liver abscesses has been well-documented to result in detrimental losses in carcass weight (White and Montgomery, 1975; Brown and Lawrence, 2010). Cirrhotic livers were determined to result in the lowest means for each carcass outcome with the exception of RATIO. Presence of cirrhotic livers was especially detrimental on HCW and LMA, with losses occurring 42.5 kg and 10.2 cm^2 less compared to normal livers. These results are important as liver abscesses have remained a concern in the beef industry, but effects of cirrhotic livers have not been documented previously and indicate the importance of understanding the causation and prevention of cirrhotic livers to prevent such losses observed in the current study. There is no previous literature reporting the effects of telangiectasis-affected livers on carcass outcomes, therefore it is interesting to note the overall carcass performance for telangiectasis-affected livers compared to other abnormalities. Telangiectasis-affected livers resulted in increased AFT, LMA, KPH and YG compared to other liver abnormality outcomes. These results indicate that presence of telangiectasis in the liver of beef cattle do not result in depressed performance, but do affect carcass value through condemnation of the liver at harvest.

4.4.6. Database 2

The frequency of carcasses by liver abnormality is reported in Table 4.2. Within the database, 67.0% of livers were considered to be normal, whereas minor (A- and A), and major abscesses (A+, A+AD, A+OP, and A+AD/OP) made up 12.6% and 14.0%, with total abscesses accounting for 26.6% of livers within database 2. Feedyard location had an effect ($P < 0.01$) on total liver abscess and outcomes are reported in figure 4.5. The highest rates of total abscesses were observed in Texas (36.16%), Idaho (35.54%), and Minnesota (34.20%). Of these locations, Idaho exhibited the greatest proportion of minor abscesses (18.5%), followed by Texas (16.6%) and Minnesota (14.4%). Additionally, Texas exhibited the greatest proportion of major abscesses (19.6%), followed by Minnesota (19.4%) and Idaho (17.0%). The lowest rates of total abscesses were observed in Arizona (18.4%) and Oklahoma (19.2%). Of these two states, Arizona had a rate of 8.1% and 10.3% and Oklahoma resulted in 9.2% and 9.9% for minor and major abscesses, respectively. There are many possible reasons for this variability in abscess rate between locations. Feedyards in Texas accounted for 1,260 pens of cattle, whereas Minnesota and Idaho only accounted for 5 and 61 pens within the database. Similarly, Oklahoma accounted for 189 pens and Arizona made up 285 pens within the database. Steam-flaked corn makes up a majority of the primary cereal grain included in feedyard rations in the Texas panhandle (Samuelson et al., 2016). The feeding of high concentrate diets to cattle has been known to result in greater rates of liver abscesses (Nagaraja and Chengappa, 1998). Additionally, potato starch is a common energy source in feedlot rations in the Pacific Northwest, known for being a highly fermentable feedstuff in the rumen.

Sex class had an effect ($P < 0.01$) on total abscess rate (data are reported in figure 4.6). Steers were determined to have greater prevalence ($P < 0.01$) of minor, major and total abscesses (13.08, 16.40, and 29.47%) compared to heifers (11.98, 10.51 and 22.47, %). Additionally, steers were determined to have a greater ($P < 0.05$) prevalence of cirrhotic livers (0.13%) compared to heifers (0.10%). These results were expected as steers have been reported to have increased intake than heifers (Amachawadi and Nagaraja, 2016). Furthermore, steers were observed to have increased ($P < 0.01$) rates of liver flukes (1.41%) compared to heifers (1.15%).

Cattle type had an effect ($P < 0.01$) on prevalence of liver abnormalities. Native cattle exhibited total abscess prevalence of 23.02%, compared to 16.81, 39.24 and

50.18% for Mexican, Holstein and beef x dairy cattle (Table 4.3). These results align with previous results reported for native and Holstein cattle (Amachawadi and Nagaraja, 2016; Herrick, 2018). Beef x dairy cattle exhibited the highest rates for A- (14.21%), A (7.94%), A+ (8.29%), A+OP (4.00%), and A+AD/OP (3.43%), whereas Holsteins exhibited the highest rate for A+AD (13.58%) among cattle type. Beef x dairy exhibited similar ($P \geq 0.05$) rates to Holsteins within the A+AD and A+AD/OP liver categories.

Foraker et al. (2022) suggested liver abscess prevalence in beef x dairy crossbreds may be intermediate to those of purebred dairy influence, but the results of the current study do not support this theory as beef x dairy cattle had increased prevalence of liver abscesses compared to Holsteins (50.18 vs 39.24%). Prevalence of liver abscesses in beef x dairy crossbreds were similar (50.18%) to data reported by Foraker et al. (2022) (40 – 60%). As reported in past literature, the severe prevalence of total abscesses observed in Holstein cattle can be attributed to longer feeding periods compared to native cattle (150 - 180 d vs 300 - 400 d), introduction to concentrate diets at an earlier age, and increased feed intake compared to native cattle (Hicks et al., 1990; Nagaraja and Chengappa, 1998; Herrick, 2018). The reasoning for beef x dairy cattle represented in the current database having substantially greater abscess rates than Holstein cattle are unclear, but may be reflective of an extremely wide variation in genetic source, resulting in inconsistencies in management across calf ranches, and increases in total abscess rates observed across all cattle types in recent years (2018 to 2021) where beef x dairy cattle began to be included in the database rather than Holstein cattle.

4.5. Conclusions

Liver abscess prevalence in beef cattle result from a wide variety of causations and have been proven to be costly for the producer and processor via loss in carcass performance, especially carcass weight, and condemnation of livers and carcass viscera. Liver abscess prevalence varies by region, with the highest rates being observed in the Pacific Northwest and Midwestern U.S. Prevalence of liver abscess rates across years within the database show that the liver abscess problem is not improving, if anything, increasing in severity. Liver abscess severity within cattle type supports previous literature when comparing native to Holstein cattle, but the rates of liver abscesses observed in beef x dairy cattle, a recent addition to commercial cattle feeding, was determined to be greater than Holstein cattle rather than intermediate. In addition to liver abscesses, liver abnormalities such as cirrhosis were determined to be just as detrimental, or worse in regards to liver abscess prevalence on carcass performance.

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Table 4.1. Beef carcass yield and quality attributes of carcasses with normal livers and carcasses with liver abnormalities from database 1.

		Yield and quality attributes[1]						
Liver score	n	HCW, kg	12th-rib subcutaneous fat depth, cm	LM area, cm^2	KPH, %	Yield Grade	Marbling Score[2]	RATIO, cm^2/kg
Normal	288,798	396.6^{a}	1.38^{b}	93.3^{a}	2.08^{b}	2.90^{b}	44.1^{bc}	0.2424
A-[3]	26,888	394.7^{b}	1.35^{c}	91.8^{b}	2.09^{b}	2.90^{b}	45.0^{ab}	0.2410
A[3]	9,855	394.3^{b}	1.34^{cd}	91.6^{bc}	2.09^{b}	2.90^{b}	45.0^{ab}	0.2411
A+[3]	8,581	388.8^{d}	1.30^{d}	90.9^{c}	2.09^{b}	2.90^{b}	44.6^{b}	0.2401
A+AD[3]	13,724	382.4^{e}	1.20^{e}	88.4^{d}	2.07^{b}	2.79^{c}	43.8^{c}	0.2411
A+OP[3]	5,071	381.8^{e}	1.35^{bc}	89.6^{cd}	2.10^{b}	2.90^{b}	45.8^{a}	0.2441
A+AD/OP[3]	2,832	375.9^{f}	1.36^{bc}	87.6^{d}	2.08^{bc}	3.00^{ab}	45.2^{ab}	0.2408
Cirrhosis/CHF	552	354.1^{g}	1.17^{e}	83.1^{e}	1.95^{c}	2.77^{c}	42.9^{c}	0.2447
Liver Flukes	12,966	392.2^{c}	1.38^{bc}	92.3^{b}	2.03^{c}	2.91^{b}	43.8^{c}	0.2409
Telangiectasis	2,209	393.4^{b}	1.51^{a}	93.8^{a}	2.18^{a}	3.02^{a}	45.5^{ab}	0.2415
SEM	-	0.17	0.004	0.08	0.003	0.006	0.06	0.0002
P-value	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

$^{a-g}$Means within a column that do not have a common superscript differ ($P < 0.05$).

[1]HCW, kg = hot carcass weight, kg; LM area, cm^2 = longissimus muscle area, cm^2; KPH% = percentage of kidney, pelvic, and heart fat; RATIO cm^2/kg = ratio of longissimus muscle area, cm^2 per kg of hot carcass weight.

[2]Scores: 30-39 =Slight; 40 to 49 = Small; 50 to 59 = Modest.

[3]A- = 1 or 2 small abscesses or inactive scars; A = 1 to 2 large abscesses or multiple small abscesses; A+ = multiple large abscesses; A+AD = liver adhered to part of the gastrointestinal tract or diaphragm or both; A+OP = ruptured abscess; A+AD/OP = Combination of A+AD or A+OP score.

Table 4.2. Frequency of carcasses by individual feedyard lots (n = 7,196), representing 1,171,057 head of cattle by liver abnormality in database 2.

Item	Mean	Std. Dev	Min	Max
Normal, %	67.0	0.17	0.0	100.0
Total liver abscess[1], %	26.6	0.16	0.0	95.5
Minor liver abscess[2], %	12.6	0.07	0.0	71.9
A- liver abscess, %	7.2	0.06	0.0	65.2
A liver abscess, %	5.3	0.05	0.0	49.5
Major liver abscess[3], %	14.0	0.12	0.0	89.1
A+ liver abscess, %	4.8	0.05	0.0	87.3
A+Adhesion liver abscess, %	6.2	0.08	0.0	70.4
A+Open liver abscess, %	1.7	0.02	0.0	20.4
A+Adhesion/Open liver abscess, %	1.3	0.02	0.0	23.3
Cirrhosis/CHF liver, %	0.1	0.00	0.0	9.7
Liver flukes, %	1.3	0.03	0.0	80.3
Telangiectasis liver, %	0.6	0.01	0.0	20.6

[1]Total liver abscess = sum of all liver abscess scores.

[2]Minor liver abscess = sum of A- and A liver abscess scores.

[3]Major liver abscess = sum of A+, A+Adhesion, A+Open, and A+Adhesion/Open liver abscess scores.

Table 4.3. Frequency of liver abscess outcomes by cattle type.

Liver score	Native (n = 990,648)[1]	Beef x Dairy (n = 36,972)[1]	Holstein (n = 129,164)[1]	Mexican (n = 9,272)[1]	SEM	*P*-value
	Cattle Type					
Normal, %	70.24^{a}	45.42^{c}	55.57^{b}	74.31^{a}	0.0028	<0.01
Total liver abscess[2], %	23.02^{c}	50.18^{a}	39.24^{c}	16.81^{b}	0.0027	<0.01
Minor liver abscess[3], %	11.96^{c}	22.17^{a}	14.10^{b}	6.09^{d}	0.0013	<0.01
A- liver abscess, %	6.99^{b}	14.21^{a}	7.40^{b}	3.83^{c}	0.0011	<0.01
A liver abscess, %	4.98^{c}	7.94^{a}	6.67^{b}	2.26^{d}	0.0009	<0.01
Major liver abscess[4], %	11.08^{c}	28.04^{a}	25.16^{b}	10.83^{c}	0.0020	<0.01
A+ liver abscess, %	4.39^{c}	8.29^{a}	6.20^{b}	1.85^{d}	0.0010	<0.01
A+Adhesion liver abscess, %	4.36^{c}	12.38^{a}	13.58^{a}	7.96^{b}	0.0012	<0.01
A+Open liver abscess, %	1.48^{c}	4.00^{a}	2.37^{b}	0.52^{d}	0.0004	<0.01
A+Adhesion/Open liver abscess, %	0.86^{b}	3.43^{a}	3.02^{a}	0.41^{b}	0.0004	<0.01

$^{a\text{-}d}$Frequencies within a row that do not have a common superscript differ ($P < 0.05$).

[1]Total head count; representing 7,165 pens of cattle.

[2]Total liver abscess = sum of all liver abscess scores.

[3]Minor liver abscess = sum of A- and A liver abscess scores.

[4]Major liver abscess = sum of A+, A+Adhesion, A+Open, and A+Adhesion/Open liver abscess scores.

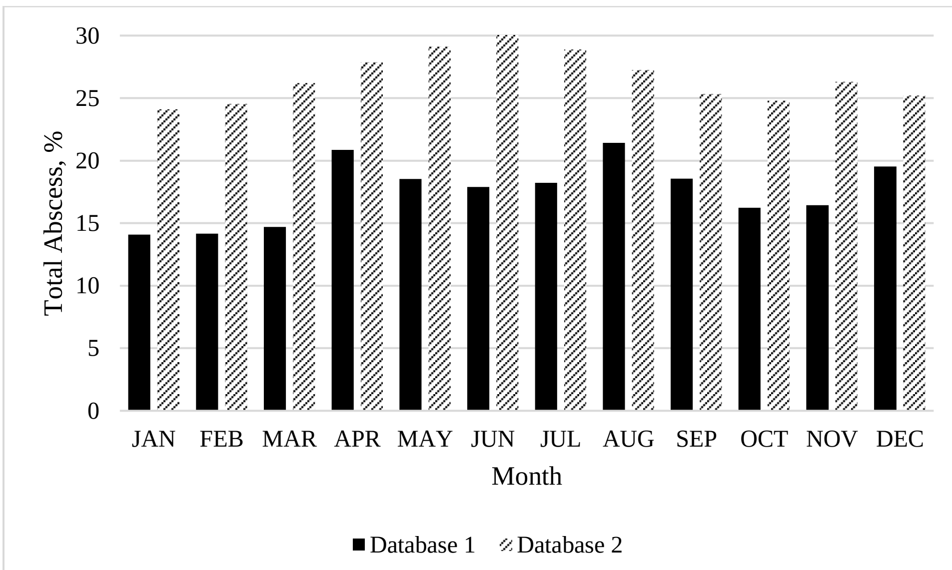

Figure 4.1. Percentage of abscess rate in database 1 and 2 by month.

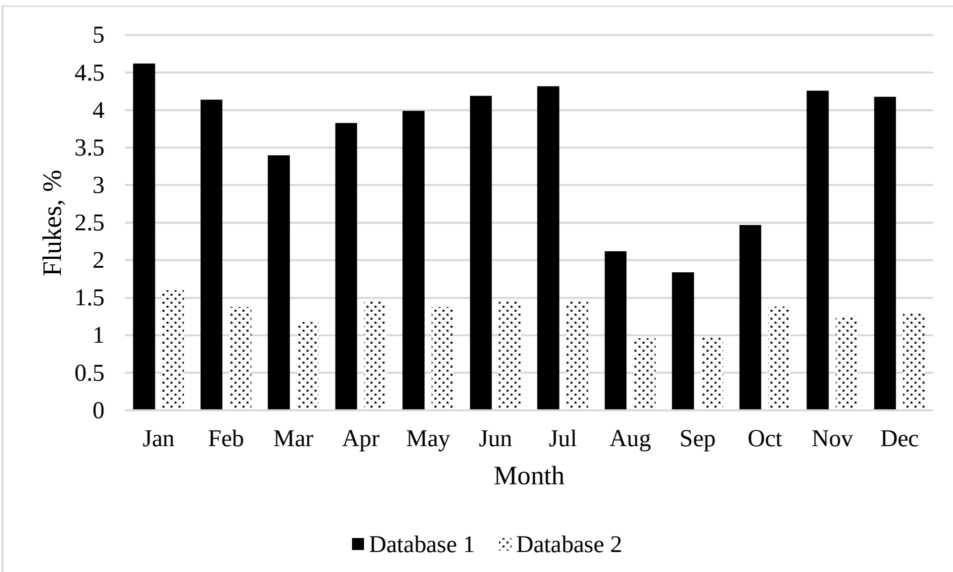

Figure 4.2. Percentage of beef livers condemned for flukes in database 1 and 2 by month.

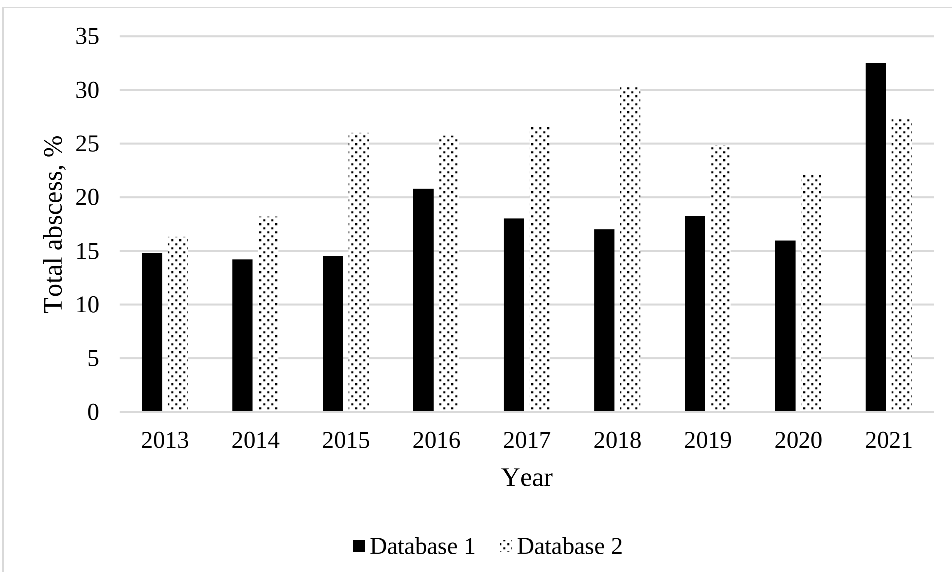

Figure 4.3. Percentage of abscess rate in database 1 and 2 by year.

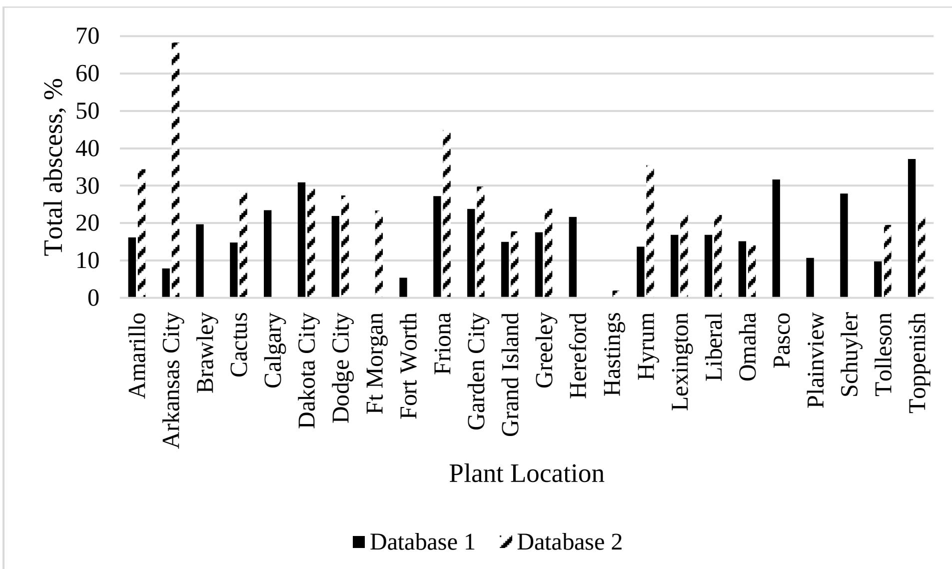

Figure 4.4. Percentage of abscess rate in database 1 and 2 by beef processor location.

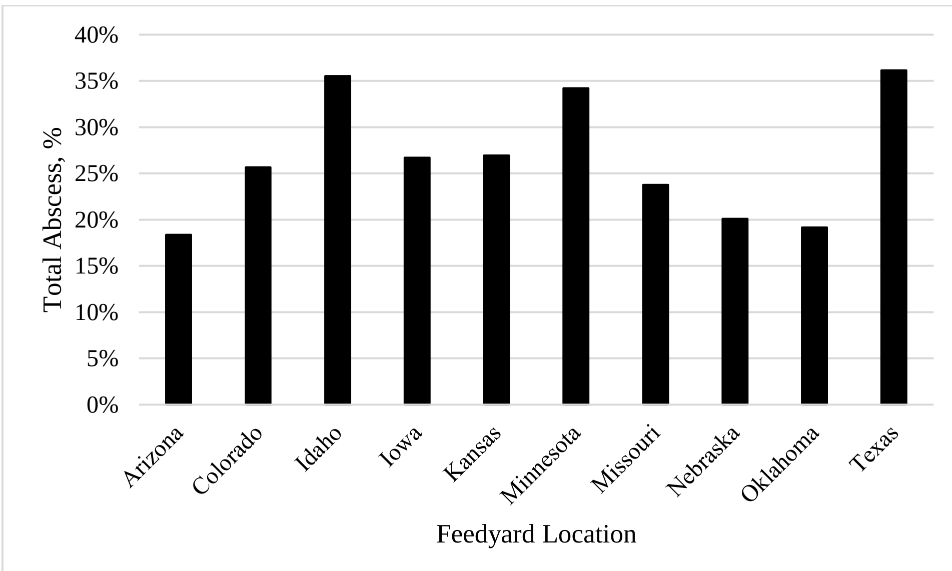

Figure 4.5. Percentage of abscess rate in database 2 by feedyard location.

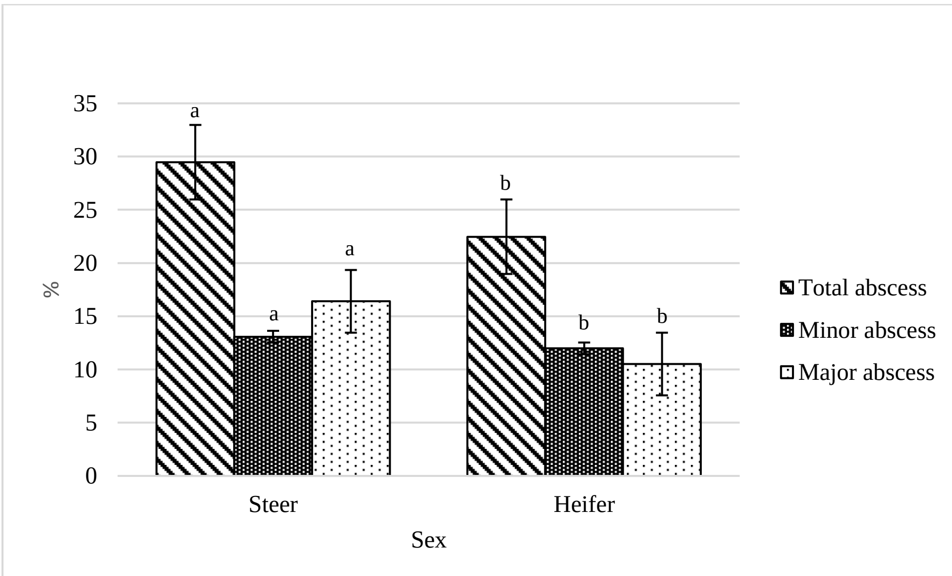

Figure 4.6. Percentage of total, minor, and major abscess rate in database 2 by sex class.
[a, b]Differing superscripts indicates statistical difference (P < 0.05)

CHAPTER V

RELATIONSHIP OF LUNG HEALTH OUTCOMES WITH CARCASS PERFORMANCE

5.1. Abstract

The association of lung abnormalities with carcass performance was evaluated on data from 60,843 carcasses housed in the West Texas A&M University Beef Carcass Research Center database and collected from 2010 to 2021 to quantify the relationship of lung health and carcass performance. Lung outcomes were scored for severity of consolidation (N = Normal and < 5% consolidation, 1 = 5 to 15% consolidation, 2 = 15 to 50% consolidation, 3 = >50% consolidation) and presence of fibrin tags (N = None, M = Minor fibrin, E = Extensive fibrin). Lung consolidation had a strong and detrimental effect ($P < 0.01$) on hot carcass weight, with lung scores of 1, 2, and 3 resulting in 4.2, 13.3, and 29.9 kg less carcass weight compared to carcasses with normal lungs. Minor and extensive fibrin tags (3.5 kg and 7.1 kg, respectively), independent of consolidation, resulted in lighter carcasses ($P < 0.01$) compared to those with normal lungs. Lung score did not have an effect on marbling score. Both lung tissue consolidation and presence of fibrin tags affected 12th rib fat thickness; lung consolidation scores of 1, 2, and 3 (-0.09, -0.21 and -0.09 cm, respectively) and fibrin tag prevalence of minor and extensive (-0.14 and -0.19 cm) resulted in and less ($P < 0.01$) 12th rib fat thickness compared to carcasses

with normal lungs. Similarly, LM area was reduced ($P < 0.01$) in carcasses with lung consolidation (-1.5, -3.8, and -5.5 cm^2) or presence of fibrin tags (-2.3 and -2.7 cm^2) compared to carcasses with normal lungs. Additionally, severity of lung consolidation and presence of fibrin tags reduced ($P < 0.01$) calculated yield grade; lung consolidation and fibrin tags resulted in a 0.08 to 0.20 and 0.09 to 0.13 reduction in overall yield grade. In addition to lung outcomes, liver abscess outcomes were also collected and analyzed for synergistic effect on carcass outcomes with severity of lung scores. The greatest proportion of carcasses within lung consolidation and presence of fibrin tags (47.67 and 48.88%) exhibited edible livers with a normal lung. Whereas the lowest proportion of carcasses (1.12 and 1.89%) exhibited a 3 lung consolidation score and extensive prevalence of fibrin tags with a major abscess outcome. Severity of lung consolidation was determined to have a more dramatic effect on carcass weight than presence of fibrin tags within liver abscess categories. Within the edible, minor and major abscess category, as lung consolidation increased from normal to 3 and presence of fibrin tags increased from normal to extensive, a decrease in carcass weight (21.4, 30.9, and 50.1 kg; 5.5, 7.4, and 5.4 kg), LM area (4.7, 3.9, and 6.3 cm^2; 2.0, 3.1, and 1.6 cm^2), and AFT (0.02, 0.18, and 0.13 cm; 0.12, 0.30, and 0.24 cm) was observed. These data indicate that lung health is an important factor that impacts carcass performance, particularly carcass weight, muscling, and yield grade outcomes.

5.2. Introduction

Bovine respiratory disease (BRD) has continually been proven to be the most economically devastating disease in the beef cattle industry (Richer et al., 1988; Perino, 1992; Chirase and Greene, 2001; Snowder et al., 2006; Blakebrough-Hall et al., 2020).

Clinical signs of BRD can be identified in live cattle and the “pull and treat” method for treating BRD has shown to be effective, but there is a large population of cattle that are undiagnosed and effects of BRD are not apparent until slaughter (Wittum et al., 1996). The ability to score lungs and understand disease development assists the industry with identifying trends in cattle type, management, and the total economic loss of cattle affected by lung lesions at slaughter. Lung scoring has indicated that cattle with lung lesions present at slaughter result in decreased live weight in addition to declined carcass performance compared to carcass with healthy, normal lungs (Wittum et al., 1996; Bryant et al., 1999; Gardner et al., 1999; Tennant et al., 2014).

Liver scoring in beef cattle at slaughter has been utilized for decades and assisted the industry in understanding causations and trends for liver abscess development and potential effects on cattle and carcass performance (White and Montgomery, 1985; Brown and Lawrence, 2010). The effects of lung health on beef cattle performance has shown to be detrimental in live cattle, the objective of this study was to provide the analysis of a large quantity of lung outcomes in relation to carcass performance as there is limited data supporting the effects of adverse lung health on carcass performance.

5.3. Materials & Methods

No Institutional Animal Care and Use Committee was necessary due to no live animals being involved in this study.

5.3.1. Data collection procedures

Data (n = 60,843) were collected by the Beef Carcass Research Center at West Texas A&M University from 2010 to 2021. Qualification for entry into database included presence of lung health and liver abscess outcomes in addition to carcass outcomes including carcass weight (HCW), calculated yield grade (YG), longissimus muscle area (LM area), 12th rib fat thickness (AFT), kidney, pelvic, and heart fat percentage (KPH), and marbling score. Lungs were visually evaluated and scored on an individual animal basis following the procedures of Tennant et al. (2014) as follows: Normal (healthy lungs, <5% consolidation and without fibrin tags), Minor (presence of minor fibrin tags), Extensive (presence of extensive fibrin tags), 1 (5-15% consolidated lung tissue), 2 (15-50% consolidated lung tissue), 3 (>50% consolidated lung tissue). Lung classification (consolidation severity and presence of fibrin tags) were analyzed as independent outcomes. Liver abnormalities were observed during harvest and scored as: edible liver; A- = 1 to 2 small abscesses or inactive scars; A = 1 to 2 large abscesses or multiple small abscesses; A+ = multiple large abscesses; A+AD = liver adhered to diaphragm; A+OP = open liver abscess; A+AD/OP = adhered to diaphragm with an open liver abscess. Liver outcomes were categorized as minor (A- and A) and major abscesses (A+, A+AD, A+OP, A+AD/OP)

5.3.2. Statistical Analysis

All analyses were performed using SAS (SAS Inc., NC). Individual animal (n = 60,843) served as the experimental unit. Frequency of lung consolidation and presence of fibrin tags within liver abscess class was determined via the frequency procedure of SAS. The GLIMMIX procedure of SAS was used to determine differences in carcass outcomes within lung consolidation and fibrin tag scores in addition to differences in HCW, LM AREA, and AFT outcomes within lung outcomes and liver abscess outcomes with Kenwood-Rogers degrees of freedom approximation. Least squares means were generated and separated using the PDIFF option with a Bonferroni adjustment to control for type I error across multiple comparisons.

5.4. Results and Discussion

5.4.1 Severity of lung consolidation and presence of fibrin tags

Severity of lung consolidation (Table 5.1) and presence of fibrin tags (Table 5.2) had an effect ($P < 0.01$) on carcass weight. Mean carcass weight decreased as lung consolidation increased. Carcasses with lung consolidation scores of 1, 2, and 3 resulted in decreased carcass weight (-4.2, -13.2, and -29.9 kg) compared to normal lungs. Likewise, presence of minor and extensive fibrin tags also resulted in less carcass weight (-3.5 and 7.1 kg) compared to normal lungs, but did not result in as severe decrease in carcass weight as compared to lung consolidation (Table 5.2). Tennant et al. (2014) also reported a linear decrease in carcass weight as lung consolidation increased in severity, but did not report differences in carcass weight between carcasses with fibrin tags as those with normal lungs. Furthermore, Bryant et al. (1996) and Gardner et al. (1999) reported losses of 27 to 33 kg in carcass weight in cattle exhibiting lung lesions (lung consolidation) compared to none. Additionally, Schneider et al. (2009) reported a difference in carcass weight when comparing lungs with active bronchial lymph nodes to those without.

Longissimus muscle area was determined to be greatly affected ($P < 0.01$) by lung health. Increasing severity of lung consolidation (1, 2 and 3) resulted in 1.5, 3.8, and 5.5 cm^2 smaller LM area compared to normal lungs (Table 5.1). Furthermore, presence of fibrin tags (minor and extensive) resulted in smaller LM area (-2.7 and 2.3 cm^2), but no difference (P = 0.65) in LM area occurred between fibrin tag scores. Tennant et al. (2014) reported less LM area in steers with greater than 50% lung consolidation compared to normal lungs. An indicator of carcass muscling, RATIO, was affected (P < 0.01) by lung health. In contrast to the results of LM area, increasing lung consolidation did not result in a linear decrease in RATIO. Between normal and lung scores of 1 and 2, a 0.0023 and 0.0055 cm^2/kg decrease in RATIO was observed, whereas a lung score of 3 resulted in a numerical increase of 0.0022 cm^2/kg compared to normal lungs with no difference detected (P = 0.52).

Due to the effects of lung health on carcass weight and LM area, it is logical to assume YG was affected in a similar manner. Increasing severity of lung consolidation resulted in a linear decrease in YG (P < 0.01), with YG decreasing by 0.08, 0.16, and 0.21 units as lung consolidation scores increased from 1 to 3. Similarly, presence of fibrin tags (minor and extensive) also affected (P < 0.01) YG in a linear manner, resulting in 0.10 and 0.13 less units of YG compared to carcasses with normal lungs. There was no difference (P = 0.36) detected between minor and extensive lung scores on YG.

Lung consolidation tended to affect (P = 0.07) marbling score. Unexpectedly, presence of fibrin tags was determined to result (P < 0.01) in increased marbling scores, with no difference (P = 1.0) in marbling score occurring between minor and extensive fibrin tags. Presence of minor and extensive fibrin tags resulted in a gain in marbling score of 0.81 and 0.74 units. Reasoning for the resulting increase in marbling score is unknown, and likely a type I error as the difference between Small^{34} and Small^{41} could occur by subjective assessment by a scorer or camera instrument error. Tennant et al. (2014) reported steers with lung consolidation scores of 50% or greater exhibited lower marbling scores (Slight^{74} vs Slight^{98}) than steers with normal lungs. These results were not repeated in the current study. The absent effect of lung consolidation on marbling score may be due to the preexisting genetic potential for an animal to reach USDA Choice prior to entry into a feedyard. Gardner et al. (1999) revealed that carcasses from steers without lesions at harvest had greater HCW, estimated percentage KPH, and marbling score than steers with lung lesions.

5.4.2. Association of liver abscess outcomes and lung health

Overall frequency of carcasses within liver abscess class by lung consolidation and presence of fibrin tags are reported in Table 5.3 and within abscess class by lung consolidation, the greatest percentage of carcasses (47.67%) exhibited edible livers with a normal lung. Likewise, regarding presence of fibrin tags, the greatest percentage of carcasses (48.88%) exhibited edible livers with a normal lung. Schneider et al. (2009) reported that 38% of cattle within their study had no lung lesions present at slaughter. Frequency of carcasses within the edible liver abscess category decreased as both lung consolidation and presence of fibrin tags increased in severity. Based on these outcomes, only 1.12% of carcasses exhibited a major abscess with a lung score consolidation of 3 (the most severe combination of liver abscess and lung consolidation score), whereas 1.89% of carcasses exhibited a major abscess with an extensive fibrin tag score (the most severe combination of liver abscess and fibrin tag prevalence).

5.4.3. Carcass outcomes by lung consolidation and liver abscess class

Mean carcass outcomes were determined by lung health (Table 5.4) and liver abscess (Table 5.5) outcome. The greatest mean HCW (391.0 kg) was observed in carcasses that exhibited an edible liver and no lung consolidation. As lung consolidation increased in severity within the edible liver category from normal to 3, HCW decreased (up to -21.5 kg) and was different ($P < 0.05$) between all lung consolidation scores. Within the minor liver abscess class, HCW decreased numerically from normal to 3 lung consolidation (-30.9 kg), with no difference detected ($P = 1.0$) between normal, 1, and 2 lung consolidation score, however a sharp 17.1 kg decrease in carcass weight was observed between the 2 and 3 lung consolidation score. Furthermore, within the major abscess class, HCW also decreased numerically from normal to 3 (-50.1 kg). When comparing carcasses with an edible liver and normal lung to carcasses with a major abscessed liver and a lung consolidation score of 3 (the most severe combination of both outcomes), a decrease in carcass weight of 60.1 kg was observed. Likewise, within the normal, 1, 2 and 3 lung consolidation scores, carcass weight decreased numerically as liver abscess class increased in severity from edible to major.

Assuming \$5.07/kg for carcass weight, a carcass with a normal and healthy lung/liver combination would be worth \$1,982.37. For carcasses exhibiting an edible liver within lung consolidation scores (1, 2, and 3) carcass weight value decreased by \$13.19, \$55.79, and \$108.53 with increasing severity of lung consolidation compared to normal lungs. For carcasses exhibiting a minor liver abscess and a normal lung or 1, 2, or 3 lung consolidation score, we would expect a decrease in carcass weight value of \$15.21, \$35.50, \$85.20, and \$171.92 with increasing lung consolidation within the minor abscess category. The greatest observed loss in estimated carcass value occurred within the major abscess category. As lung consolidation increased in severity from normal to 3, estimated carcass value losses occurred \$50.72, \$89.77, and \$127.29, with a major abscess and lung consolidation score of a 3 (the most severe combination) resulting in $304.80 of estimated individual carcass value loss compared to a normal lung and edible liver.

The greatest mean LM area (94.3 cm^2) was observed in carcasses that exhibited an edible liver and no presence of lung consolidation. As lung consolidation increased from normal to 3 within the edible liver category, LM area decreased numerically (-4.7 cm^2), with no differences ($P > 0.05$) detected between normal and 1 lung consolidation scores, respectively. Whereas differences were detected ($P < 0.05$) between 1, 2, and 3 lung consolidation scores. Effects of lung consolidation within the minor abscess class were not determined to exhibit as pronounced an effect on LM area as observed within the edible category. Within the minor abscess class, as lung consolidation increased from normal to 3, LM area was not observed to decrease numerically, with the lowest LM area (88.4 cm^2) occurring within the minor abscess class and 2 lung consolidation score. Furthermore, within the major abscess class, as lung consolidation increased from normal to 3, LM area was observed to decrease numerically (-6.3 cm^2), with no differences detected ($P > 0.05$) between normal and 1 and between 2 and 3, however a difference was detected ($P < 0.05$) between 1 and 2 lung consolidation scores, respectively. The lowest mean LM area (84.1 cm^2) observed across all liver and lung outcomes was carcasses with a major liver abscess and a lung consolidation score of 3.

The greatest mean AFT (1.46 cm) was observed in carcasses that exhibited an edible liver and a normal lung. As lung consolidation increased in severity from normal to 3 within the edible liver category, a numerical decrease in AFT was observed from normal to 2 (-0.13 cm), however a lung consolidation score of 3 was determined to be similar ($P > 0.05$) to a normal and 1 lung consolidation score. Within the minor abscess category, AFT was not determined to decrease synergistically with increasing lung consolidation severity. Differences were observed ($P < 0.05$) between normal and 1 (-0.24 cm), however, no differences were detected within 1, 2, and 3 lung consolidation scores. Within the major abscess category, no difference ($P = 1.0$) was observed between normal, 1, and 3 lung consolidation score, whereas a difference across all lung consolidation outcomes and 2 was observed, with a lung score of 2 resulting in the lowest (1.01 cm) mean AFT across all liver and lung outcomes.

5.4.4. Carcass outcomes by prevalence of fibrin tags and liver abscess class

Similar to lung consolidation outcomes, within fibrin tag outcomes, the greatest mean HCW (391.0 kg) was observed in carcasses with an edible liver and normal lung. Within the edible liver abscess class, as prevalence of fibrin tags increased in severity (normal to extensive), HCW decreased (-5.5 kg) in a linear manner. Within the minor abscess class, as prevalence of fibrin tags increased, HCW decreased (-7.4 kg). Furthermore, within the major abscess class, as prevalence of fibrin tags increased in severity, a similar decrease in carcass weight (-5.4 kg) was observed compared to edible livers. The lowest mean carcass weight (375.6 kg) was observed in the most severe liver abscess class (major) and fibrin tag outcome (extensive). Therefore, between carcasses with an edible liver and normal lung and carcasses with a major abscess outcome and most severe prevalence of fibrin tags, a reduction of 15.4 kg in carcass weight was observed. These outcomes indicate that severity of lung consolidation has a much greater detrimental effect (-60.12 kg) on carcass weight than presence of fibrin tags (-15.4 kg).

The greatest mean LM area (94.3 cm^2) was observed in carcasses that exhibited an edible liver and normal lung. Within the edible liver class, as prevalence of fibrin tags increased from normal to minor, LM area decreased ($P < 0.05$; -2.6 cm^2), whereas no difference ($P > 0.05$) was detected between minor and extensive fibrin tags within the edible liver class. Similar to the edible class, within the minor abscess category, a decrease in LM area ($P < 0.01$; -5.4 cm^2) from normal to minor was observed. The extensive lung score was determined to be intermediate to normal and minor, with no differences ($P = 0.07$) between normal and extensive and no differences ($P = 1.0$) between minor and extensive fibrin tags were observed within the minor abscess category. Furthermore, within the major abscess class, as presence of fibrin tags increased in severity (normal to extensive), no difference ($P > 0.05$) was detected within fibrin tag outcomes. These results indicate that presence of fibrin tags does not greatly influence LM area as compared to carcass weight.

The greatest mean AFT (1.46 cm) was observed in the carcasses that exhibited an edible liver and no presence of fibrin tags. Similar to LM area, as prevalence of fibrin tags increased in severity from normal to minor within the edible liver category, a decrease ($P < 0.05$) in AFT was observed (-0.16 cm), but AFT did not differ ($P > 0.05$) between minor and extensive fibrin tag scores. A similar outcome was observed in the minor and major liver abscess classes, where a difference ($P < 0.05$) in AFT was observed between normal lungs and lungs with fibrin tags, but no difference ($P = 1.0$) was observed between minor and extensive fibrin tag scores. These data indicate that overall presence of fibrin tags influence LM area, but no effect of increasing fibrin tag prevalence was observed.

Griffin et al. (2014) reported that lung adhesions were occasionally observed in association with the inflammatory response across the diaphragm due to the effects of a severe (A+AD) liver abscess. Herrick (2018) reported carcasses with major abscesses had greater rates of lung consolidation than carcasses with no abscess or minor abscessed livers. There is minimal data published evaluating the association of liver health and lung health on carcass outcomes. While effects of lung health and liver health on carcass outcomes have been reported separately across the literature, data in the current study indicate that prevalence of liver abscesses with lung consolidation often happens synergistically and effects observed from abscesses or consolidation can greatly enhance the effects of the other regarding carcass performance, especially carcass weight. When an animal is fighting an infection, whether that be in the liver in the form of an abscess, or in the lung as consolidation/fibrin tags, a greater proportion of the animal's energy is put towards fighting the infections rather than growth of the animal (Waggoner et al., 2009). Furthermore, the detrimental effects of severe lung consolidation and major abscesses on carcass weight is likely due to a combination of depressed metabolic processes in addition to increased carcass trimming at the slaughter abattoir to remove lung and/or liver adhesion to the thoracic cavity.

Tryptophan is found in abundance in all living organisms and serves important functions in metabolic, physiological and organ development in ruminants. However, bacterial metabolism of tryptophan produces compounds such as skatole (3-methylindole) that are recognized as possible agents involved in acute bovine pulmonary edema (ABPE) and emphysema (Thornton-Manning et al., 1993). Previous research has indicated that certain *Lactobacillus* strains of bacteria in the rumen are responsible for the production of skatole from tryptophan metabolism (Yokoyama et al., 1977). *Lactobacillus* strains are known for utilizing starch in high-concentrate diets in the rumen to produce lactate, resulting in decreased pH and possible metabolic disorders such as acidosis (Owens et al., 1998). Acidosis has been known as one of the potential causations of liver abscesses in beef cattle (Nagaraja and Chengappa, 1998). Acute bovine pulmonary edema is caused by the absorption and subsequent lung metabolism of 3-methylindole, resulting in lung tissue damage and edema and emphysema in the lungs. The pathological observations of ABPE mirror those found in BRD-affected cattle: presence of acute respiratory distress signs and lung lesions. Acute bovine pulmonary edema is typically found in cattle that are over two years of age, and have experienced an abrupt change in diet, typically from lower quality forage to high quality forage (Deslandes et al., 2001). Therefore, cases in feedlot cattle are minimal, but an abrupt change in diet can occur during the feeding of fed-beef cattle. Ayroud et al. (2000) reported elevated plasma concentrations of 3-methylindole in fed-beef heifers diagnosed with acute interstitial pneumonia, postulating that signs of respiratory illness in fed-beef cattle may not always be caused by infection with BRD-related pathogens, but by 3-methylindole toxicity. While research is limited, the association between lung health and liver outcomes, considering the pathology of ABPE, potentially supports these theories.

5.5. Conclusions

Bovine respiratory disease often goes undiagnosed in cattle due to misdiagnosis and lack of outward clinical symptoms; evidence of BRD-related illness is not detected until death or slaughter. The ability to perform lung scoring in cattle post-mortem has assisted the industry with identifying cattle that were truly affected by BRD-related infections and severity of lung tissue damage, as well as provide information into cattle type, management practices, and overall economic loss. The detrimental effects of BRD on live animal performance has been well-documented, but the results from the current study indicated that loss in carcass performance is equally pertinent to losses in live performance. Carcasses with lungs exhibiting severe consolidation resulted in lighter carcasses (-29.9 kg), less LM area (-5.5 cm^2), AFT (-0.09 cm), KPH (-0.22%), and YG (-0.21) compared to carcasses with normal lungs. Furthermore, presence of extensive fibrin tags also resulted in lighter carcasses (-7.0 kg), LM area (-2.3 cm^2), AFT (-0.14 cm), KPH (-0.18%) and YG (-0.13) compared to carcasses with normal lungs. The association between liver and lung health has been hypothesized to be a synergistic effect, with detriments in lung health influencing effects of adverse liver abscess conditions and vice versa. Data from the current study indicate that as severity of lung abnormalities and liver abscesses intensify synergistically, the effects on carcass outcomes are increasingly worsened. Carcasses with a lung consolidation of 3 and a major abscess resulted in 60.1 kg less carcass weight, 10.2 cm^2 smaller LM area, and 0.25 cm less AFT compared to a healthy animal. Furthermore, carcasses with extensive fibrin tags and a major abscess resulted in 15.4 kg less carcass weight, 5.5 cm^2 smaller LM area, and 0.36 cm less AFT compared to a healthy animal. These outcomes indicate the effects to which compromised liver and lung function have on the metabolic processes within the body. While the results from the combined effects of abscessed livers in conjunction with lung abnormalities have on carcass performance, it is necessary to note that across the entire population of cattle within the database (n = 60,843) the most severe combination of liver and lung score (major abscess with a lung consolidation score 3 or extensive fibrin tags) occurred only in 1.12 and 1.89% of cattle.

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Table 5.1. Beef carcass yield and quality attributes of carcasses with normal lungs and carcass with lung consolidation.

		Yield and quality attributes						
Lung Score	n	HCW, kg	12th-rib subcutaneous fat depth, cm	LM area, cm^2	KPH, %	Yield Grade	Marbling Score[1]	RATIO, cm^2/kg
Normal	26,994	389.8^a	1.44^a	93.1^a	2.24^a	3.00^a	43.4	0.2349^a
1[2]	10,238	385.6^b	1.35^b	91.6^b	2.05^b	2.92^b	43.8	0.2326^b
2[2]	8,744	376.6^c	1.23^c	89.3^c	2.03^b	2.84^c	43.9	0.2294^c
3[2]	3,585	359.9^d	1.35^b	87.6^d	2.02^b	2.79^c	43.9	0.2370^a
SEM	-	0.46	0.01	0.21	0.008	0.01	0.17	0.0007
P-value	-	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01

[a-d]Means within a column that do not have a common superscript differ ($P < 0.05$).
[1]Scores: 30-39 =Slight; 40 to 49 = Small; 50 to 59 = Modest.
[2]1 = 5 to 15% consolidation; 2 = 15 to 50% consolidation; 3 = >50% consolidation.

Table 5.2. Beef carcass yield and quality attributes of carcasses with normal lungs and presence of fibrin tags.

		Yield and quality attributes						
Lung Score	n	HCW, kg	12th-rib subcutaneous fat depth, cm	LM area, cm^2	KPH, %	Yield Grade	Marbling Score[1]	RATIO, cm^2/kg
Normal	26,994	389.8^a	1.44^a	93.1^a	2.24^a	3.00^a	43.4^b	0.2349^a
Minor[2]	10,684	386.3^b	1.26^c	90.4^b	2.07^b	2.90^b	44.2^a	0.2282^c
Extensive[2]	10,014	382.8^c	1.30^b	90.8^b	2.06^b	2.87^b	44.1^a	0.2309^b
SEM	-	0.38	0.009	0.18	0.006	0.01	0.14	0.0005
P-value	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

a-cMeans within a column that do not have a common superscript differ ($P < 0.05$).

[1]Scores: 30-39 =Slight; 40 to 49 = Small; 50 to 59 = Modest.

[2]Minor = Minor fibrin; Extensive = Extensive Fibrin.

Table 5.3. Frequency percentage of lung consolidation and presence of fibrin tags by liver abscess class.

Abscess Class[3]	Consolidation, %[1] (n = 43,440)				Fibrin Tags, %[2] (n = 42,373)		
	Normal	1	2	3	Normal	Minor	Extensive
Edible	47.67	16.78	12.27	4.42	48.88	18.39	16.14
Minor	5.01	2.24	2.09	1.03	5.14	2.56	2.53
Major	2.67	1.80	2.92	1.12	2.74	1.74	1.89

[1]Consolidation: 1 = 5 to 15% consolidation; 2 = 15 to 50% consolidation; 3 = >50% consolidation.
[2]Fibrin Tags: M or E = presence of minor (M) or extensive (E) fibrin tag formation or interlobular adhesions between lobes.
[3]Edible = liver did not possess abscess at slaughter; Minor = combination of A- and A liver abscesses (A- = 1 or 2 small abscesses or inactive scars, A = 1 to 2 large abscesses or multiple small abscesses); Major = combination of all other liver abscess outcomes (A+ = multiple small abscesses or 1 or more large active abscesses; A+AD = liver adhered to part of the gastrointestinal tract or diaphragm or both; A+OP = ruptured abscesses; A+AD/OP = liver adhered to part of the gastrointestinal tract or diaphragm or both and ruptured abscess).

Table 5.4. Mean HCW, kg, LMA, cm^2, and AFT, cm by lung consolidation and liver abscess severity.

	HCW, kg			LMA, cm^2			AFT, cm		
				Liver Abscess Class[1]					
Lung Consolidation[2]	Edible	Minor	Major	Edible	Minor	Major	Edible	Minor	Major
Normal	391.0^{a}	388.0^{bc}	381.0^{c}	94.3^{a}	93.1^{ab}	90.4^{bc}	1.46^{a}	1.44^{ab}	1.34^{bc}
1	388.4^{b}	384.0^{bc}	373.3^{cd}	93.4^{a}	89.9^{bc}	89.6^{bc}	1.39^{b}	1.20^{c}	1.28^{bc}
2	380.0^{c}	374.2^{cd}	365.9^{de}	91.7^{b}	88.4^{c}	86.6^{c}	1.33^{bc}	1.13^{cd}	1.01^{d}
3	369.6^{d}	357.1^{e}	330.9^{f}	89.6^{bc}	89.2^{bc}	84.1^{c}	1.44^{ab}	1.26^{bc}	1.21^{bc}
SEM	-	0.74	-	-	0.36	-	-	0.02	-
P-value	-	<0.01	-	-	0.13	-	-	<0.01	-

[a-f]Means within each carcass outcome table that do not have a common superscript differ ($P < 0.05$).
[1]Edible = liver did not possess abscess at slaughter; Minor = combination of A- and A liver abscesses (A- = 1 or 2 small abscesses or inactive scars, A = 1 to 2 large abscesses or multiple small abscesses); Major = combination of all other liver abscess outcomes (A+ = multiple small abscesses or 1 or more large active abscesses; A+AD = liver adhered to part of the gastrointestinal tract or diaphragm or both; A+OP = ruptured abscesses; A+AD/OP = liver adhered to part of the gastrointestinal tract or diaphragm or both and ruptured abscess).
[2]Consolidation: N = <5% or no lung consolidation; 1 = 5 to 15% consolidation; 2 = 15 to 50% consolidation; 3 = >50% consolidation.

Table 5.5. Mean HCW, kg, LMA, cm^2, and AFT, cm by presence of fibrin tags and liver abscess severi

	HCW, kg			LMA, cm^2			AFT, cm		
				Liver Abscess Class[1]					
Fibrin Tags[2]	Edible	Minor	Major	Edible	Minor	Major	Edible	Minor	M
Normal	391.0^{a}	388.0^{ab}	381.0^{c}	94.3^{a}	93.1^{ab}	90.4^{bc}	1.46^{a}	1.44^{ab}	1
Minor	387.9^{b}	385.1^{bc}	379.9^{c}	91.7^{b}	87.7^{c}	88.3^{c}	1.30^{b}	1.09^{c}	1
Extensive	385.5^{bc}	380.6^{c}	375.6^{c}	92.0^{b}	90.0^{bc}	88.8^{c}	1.34^{b}	1.14^{c}	1
SEM	-	0.65	-	-	0.31	-	-	0.04	
P-value	-	0.84	-	-	0.07	-	-	<0.01	

[a-f]Means within each carcass outcome table that do not have a common superscript differ ($P < 0.05$).

[1]Edible = liver did not possess abscess at slaughter; Minor = combination of A- and A liver abscesses (A- = 1 or 2 small absce inactive scars, A = 1 to 2 large abscesses or multiple small abscesses); Major = combination of all other liver abscess outcome = multiple small abscesses or 1 or more large active abscesses; A+AD = liver adhered to part of the gastrointestinal tract or diaphragm or both; A+OP = ruptured abscesses; A+AD/OP = liver adhered to part of the gastrointestinal tract or diaphragm or and ruptured abscess).

[2]Fibrin Tags: N = no presence of fibrin tags; M = presence of minor; E = extensive fibrin tag formation or interlobular adhesio between lobes.