THESIS

INVESTIGATING THE RELATIONSHIP BETWEEN HOOF, LIVER, AND HEART ABNORMALITIES IN GRAIN-FED BEEF CATTLE (*BOS TAURUS*) <30 MOS AT SLAUGHTER

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ABSTRACT

INVESTIGATING THE RELATIONSHIP BETWEEN HOOF, LIVER, AND HEART ABNORMALITIES IN GRAIN-FED BEEF CATTLE (*BOS TAURUS*) <30 MOS AT SLAUGHTER

Hoof abnormalities, liver abscesses, and congestive heart failure (CHF) are animal welfare concerns that have increased in fed cattle. These production diseases are costly to producers and have a negative impact on animal welfare during the feeding phase and upon arrival to slaughter. Our primary objective was to determine whether relationships between these production diseases existed in fed cattle at slaughter. The secondary objective was to determine if relationships exist between each production disease and carcass characteristics. Each condition was evaluated at a slaughter establishment in the Great Plains region of the United States (1,417 m elevation) on cattle (*Bos taurus* beef-type only) < 30 mos of age (N = 398). Statistical analyses were performed to determine relationships between the prevalence of hoof abnormalities, liver abscesses, and CHF between each other and selected carcass characteristics: (USDA quality grade (QG), USDA yield grade (YG), hot carcass weight (HCW), ribeye area (REA), and fat thickness (FT)). Eighty five percent of cattle had at least one hoof abnormality, 13% had a liver abscess, 52% had CHF, and 5% had all three disorders. There were no differences ($P > 0.4955$) within the proportion of CHF, liver abscess, and hoof abnormality scores. Cattle with both a wide toe and inward curve (421.62 ± 10.45 kg) had lighter carcasses ($P < 0.034$) than cattle with only an inward curve (460.95 ± 2.72 kg) or cattle with a shovel hoof (470.16 ± 6.79 kg). Hot carcass weight was heavier ($P = 0.0295$) for cattle with mild CHF (463.60 ± 3.24 kg) than no CHF

(451.51 ± 3.22 kg). Ribeye area for cattle with no CHF was 103.17 ± 0.93 cm^2, mild CHF was 104.51 ± 0.88 cm^2, and severe CHF was 98.63 ± 2.46 cm^2 ($P = 0.0711$). There was a greater proportion ($P = 0.0099$) of heifers with no CHF (70.97 ± 8.17%) than steers (45.78 ± 2.61%). There were no differences ($P > 0.1025$) in REA, FT, and QG, across hoof, liver, and CHF scores. Differences were present ($P < 0.034$) in HCW between hoof and CHF scores. Further research is required to guide actions to address the animal welfare and productivity concerns associated with these issues.

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CHAPTER 1

INTRODUCTION

There are several critical components to animal welfare. Each day, producers make management decisions regarding genetics, nutrition, and environment which can positively or negatively impact animal welfare. To meet the global demand for food, cattle size and efficiency has increased. Today, the same amount of beef product is produced with a smaller number of cattle. Despite improving the efficiency of feedlot systems, there are trade-offs that come with this change which are called production diseases. Production diseases, according to Dr. Bernie Rollin, are diseases which would not arise, if it were not for our increased production and demand for animals. Three production diseases that are present in cattle today include hoof abnormalities, liver abscesses, and congestive heart failure.

Hoof abnormalities are contributing to the increased lameness which has been recorded in cattle upon arrival to slaughter establishments. Cattle that are lame have difficulty competing with other cattle at the feed bunk and move slower through handling systems during transport and slaughter. This causes losses in potential average daily gain and delays in efficiency at slaughter. Liver abscesses are present in all classes of cattle and have existed for several years. Cattle that are fed high-concentrate diets are more prone to developing liver abscesses. Preventative measures exist in the form of antibiotics and vaccines to prevent the development of liver abscesses, but no method is completely effective. Cattle with liver abscesses do not show clinical signs, but can have a lower average daily gain than cattle without liver abscesses. Any abscess on the liver renders it inedible and causes a full loss of that product at slaughter. Congestive heart failure (CHF) used to be called “high mountain disease” and only exist at elevations greater than 1,600 m. Now, cattle in the Great Plains region of the United States have developed CHF resulting in death on the feedlot and heart swelling at slaughter. Cattle with CHF can develop swollen briskets, exercise intolerance, and cough or respiratory symptoms. Losses occur in both dead animals on feed and decreased efficiency at a slaughter establishment due to affected cattle being unable to keep up with the group.

All three of these production diseases have been linked to genetic differences in breed and sometimes sire. There are also nutrition and management components which can contribute to these diseases. Because of potential shared etiologies, and the high prevalence of all three production diseases in today’s fed beef industry, it was not clear if there were existing relationships between the presence of each disease, or if they were three separate issues. This preliminary work investigated hoof abnormalities, liver abscesses, and congestive heart failure in a group of cattle from one feedyard. The objective of this study was to determine if there was a relationship between each disease. The secondary objective was to determine if there was a relationship between the presence of each disease and the following carcass characteristics: hot carcass weight (HCW), ribeye area (REA), fat thickness (FT), USDA Quality Grade (QG), USDA Yield Grade (YG), hide color, and sex.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Animal welfare is defined by the World Organization for Animal Health as "the physical and mental state of an animal in relation to the conditions in which it lives and dies" (WOAH, 2025). Animal welfare benefits from a positive human-animal bond (Rault et al., 2020). Consumers want to purchase products that come from animals who are raised with positive animal welfare and will pay more for products with animal welfare related certifications (Spain et al., 2018). Cattle transporters have a sense of pride in caring for animals and knowing that they have a role in feeding the world (Sullivan et al., 2025). Experiences such as how cattle are handled, where they are raised, and what diet they are provided can have a significant impact on their welfare, as expressed by the Five Domains model of nutrition, physical environment, health, behavioral interactions, and mental state (Mellor et al., 2020). Animal caretakers can control these experiences and create a positive living environment for animals to experience positive affective states, normal biological functioning, and fulfill natural behaviors (Fraser, 1997). These are the components of the Fraser 3 Circles model of animal welfare (Fraser, 1997).

Dr. Bernie Rollin first introduced the concept of production diseases and their impact on animal welfare (Rollin, 2005). He defined production diseases as "diseases that would not arise, or not be of significance, were it not for the means of production used to create the animal" (Rollin, 2005). At the time that Rollin (2005) first discussed production diseases in 2005, he described liver abscesses in cattle as an example within the livestock industry (Rollin, 2005). Liver abscesses are still a problem, but we have also seen lameness and congestive heart failure (CHF) become problems that could be categorized as production diseases (Baier et al., 2020; Grandin, 2024) and replaced or added to Rollin's previously described production diseases.

Production diseases such as hoof abnormalities, liver abscesses, and CHF are prevalent in the fed beef industry and can cause pain or lead to painful disorders (Nagaraja and Chengappa, 1998; Whay et al., 1998; Bexiga et al., 2008). When production diseases cause pain, they inhibit animals from performing essential natural behaviors and may limit their mobility (Flower et al., 2008; Fraser, 2008). The consequence of this can be frustration and pessimism, both of which are emotions that have been recorded in livestock animals (Lv et al., 2018; Neave et al., 2024). Consumers are mindful of animal welfare and trending perceptions exist based on current management practices (McKendree et al., 2018). Recent studies have indicated that consumers desire management practices such as pain control in castration and dehorning for cattle (Wolf et al., 2016; McKendree et al., 2018). A study by Prickett et al. (2023) indicated that consumers value the ability for animals to exhibit natural behaviors and exercise outdoors over other components of animal welfare. Thus, consumer-producer trust would be negatively impacted if production diseases continued to worsen in severity.

Production diseases have resulted from an industry drive to push cattle to a larger size by over-selecting for carcass traits (Grandin, 2024). In 1991, the average hot carcass weight (HCW) was 344 kg. (NBQA, 1992), this fluctuated since 1991 but landed at 401.90 kg. in 2022 (Mayer et al., 2024). Desirable outcomes such as ribeye area and the proportion of cattle grading Prime and Choice have also increased since 1991 (NBQA, 1992; Mayer et al., 2024). In 1991, 2.3% of cattle graded Prime and 52.7% graded Choice (NBQA, 1992). In 2022, 7.5% of cattle graded

Prime and 69.2% graded choice, increasing the number of cattle which now qualify for branded beef programs (NBQA, 1992; Mayer et al., 2024; Smith et al., 2024). Ribeye area (REA) was 83.22 cm^2 in 1991 and has grown to an average of 91 cm^2 in 2022 (NBQA, 1992; Mayer et al., 2024). With the increase in cattle size, the fed beef industry has observed mobility issues such as lameness arise due to poor hoof quality (Grandin, 2024). Cattle with lameness issues experience reduced dry matter intake (Margerison et al., 2002). Anecdotal reports from slaughter establishment employees have stated that lame cattle are slower to move and have difficulty walking up a ramp at a slaughter establishment.

There are genetic components that have driven a desirable change in cattle meat quality, but over-selection for one trait has yielded consequences which are now seen as production diseases (Grandin, 2022; Pauling et al., 2023). Breeding for hide color to meet a standard for boxed beef programs and achieve carcass characteristics associated with breed-types is a popular decision among ranchers (Eastwood et al., 2017). Weaning weight is a desirable genetic component (Bullock, 2018) which measures the total weight of the calf at its estimated weaning (Schalles and Zoellner, 1993). Heavier weaning weights are desirable because cow-calf producers are paid on that marketed weaning weight, so a heavier weight will yield a higher price for that animal (Schalles and Zoellner, 1993).

Selection for high weaning weight, larger ribeye area, and rapid growth has been linked to an unfavorable PAP (Pulmonary Arterial Pressure) score, which can lead to CHF (Shirley et al., 2008; Pauling et al., 2023). In beef cattle, this has led to the consequence of the cow-calf producer being disconnected from observing the production diseases that may develop during later stages of the production lifecycle. Therefore, they cannot use those observations to make different breeding decisions to attempt to reduce those production diseases. Genetic traits may be related to each other in ways that do not become apparent until the negative impact of over-selection shows phenotypically. For example, several swine producers struggled with managing sow aggression when California Proposition 12 caused multiple swine operations to change from single-housed gestating sows to group housing during gestation (Verdon et al., 2016; CDFA, 2023; Horback, 2021; Romoser et al., 2023). In this case, dominant sows were more aggressive and had a higher average daily gain (ADG) than submissive sows (Verdon et al., 2016). Now, producers must consider docility in breeding so that group housing adjustments can be made to comply with new regulations without aggression issues (Johnson, 2007; CDFA, 2023).

Another contributing factor to production diseases in cattle today is nutrition (Boettcher et al., 1998; LokeshBabu et al., 2018; Losada-Espinosa et al., 2021). Beef cattle are selected for faster growth and a greater ability to gain weight, which is desirable from a meat quality and economic perspective (Coleman et al., 2023). However, high concentrate diets with ingredients such as steam-flaked corn paired with low levels of roughage can have a negative impact on the microbiome of cattle (Galyean and Rivera, 2003).

Pushing cattle growth, feeding high-concentrate diets, and successfully yielding larger cattle have resulted in the increased prevalences of hoof conformation issues, liver abscesses, and congestive heart failure (Galyean and Rivera, 2003; Buchanan et al., 2023; Grandin, 2024). All three of these issues impact animal welfare and the profitability of the feeding phase (Edwards-Callaway et al., 2017; Losada-Espinosa et al., 2021; Johnson et al., 2021). Further investigation is needed to determine the root cause of these problems and how the fed beef industry can work to make genetic changes, adjust the metabolic demand of cattle, and make purchasing decisions at slaughter to promote reductions in the occurrence of production diseases.

2.2 Hoof Conformation Issues

Lameness is a painful clinical sign indicative of multiple diseases or resulting from conformation issues that affect gait of cattle (Flower et al., 2008; Cortes et al., 2021). Lameness affects both dairy and beef cattle across various life stages (Juarez et al., 2003; LokeshBabu et al., 2018). Lameness is painful and prevents cattle from moving in their normal times or patterns (Juarez et al., 2003; Laven et al., 2008). Research on lameness in cattle began in the 1980s and was initially focused on dairy cattle (Manson and Leaver, 1988). Lactating dairy cows are observed more frequently and fed a higher energy maintenance diet than that of grazing beef cows. However, beef cattle still experience lameness and abnormal mobility scores (NBQA, 2022). The prevalence of lame cattle has fluctuated, but it currently stands as an issue that is present in cattle arriving at slaughter establishments (Edwards-Callaway et al., 2017; Schwartz et al., 2025). The purpose of this literature review will focus on hoof abnormalities and hoof-related lameness.

Hoof-related lameness stems from nutrition-related disorders (LokeshBabu et al., 2018), management issues (Huang et al., 1995; Cortes et al., 2021), and hoof and leg conformation issues (Franks and Grandin, 2015). The normal hoof is a split, cloven-shaped toe with a level medial aspect to each side which are even in size and with a normal small gap between (American Angus Association (AAA), 2017). Hoof abnormalities can be any deviation from this cloven hoof (AAA, 2017). Proper hoof conformation is important for producers to sustain an animal for the duration of their life (AAA, 2017)

The American Angus Association (AAA) released a nine-point scale showing a range from a wide toe to a normal hoof, then a hoof with an inward curve, and finally a hoof with a full corkscrew (AAA, 2017) shown in Fig 1. A wide toe features a hoof where the claws are each normal in shape, but there is a large gap between them causing each claw to splay outward (AAA, 2017). There currently doesn't appear to be any peer-reviewed literature evaluating the presence and/or implications of a wide toe in cattle.

Figure 1. American Angus Association (AAA) 9-pt claw-set scoring system.

A hoof with an inward curve could be considered the beginning of a corkscrew, a conformation type described by Capion et al. (2024). Each claw begins to curve inward at the tip, displaying what is also known as a "scissor" claw (AAA, 2017). As this condition worsens, the hoof wall begins to have a permanent curvature or "screw" shape, thus naming this condition "corkscrew" claw (AAA, 2017; van Amstel et al., 2017; Capion et al., 2024). Once a corkscrew claw begins, there is no remission (Capion et al., 2024). Although management options such as hoof trimming can improve the shape of the foot, genetic changes are needed to reverse the regression of the hoof quality (Odegard et al., 2014). Odegard et al. (2014) defines corkscrew claw as "small to large twist in the abaxial wall on the lateral hind claw". Corkscrew claw can develop as a result of both genetics and nutrition (Huang et al., 1995; Fjeldaas et al., 2010; van Amstel et al., 2017; Capion et al., 2024). These include linkages to breed, presence of laminitis, and management factors related to housing (Huang et al.,1995; Fjeldaas et al., 2010; van Amstel et al., 2017; Capion et al, 2024). Animals that are clinically affected by corkscrew claw have the potential to show signs of lameness, reluctance to move, and weight loss (van Amstel et al., 2017).

"Shovel" claw results from metabolic consequences which cause inflammation of the laminae in the hoof (Manson and Leaver; 1988). Clinical signs of laminitis, or "shovel" claw include a lengthened and flat toe or claw (Thoefner et al., 2005; Lean et al., 2013), anecdotally referred to as having a "ski-like" appearance. Laminitis can be painful and cause severe lameness or difficulty walking (Lean et al., 2013; Freitas et al., 2023). Odegard et al. (2014) recorded nine different claw disorders, three of which were identified as laminitis-related lesions: sole ulcer, white line disorder, and hemorrhage of the sole and white line. Of the N = 18, 895 animals evaluated in that study a final heritability estimate of 0.10 was detected for laminitis-related claw disorders (Odegard et al., 2014). Thus, there is a small potential for genetic predisposition for the development of laminitis. Some clinical signs of lameness, a secondary condition to hoof conformation issues, include arched back, shorter strides, unwillingness to move or "statue-like" behavior, and moving slower (Fjeldaas et al., 2010; Edwards-Callaway et al., 2017). These symptoms have also been reported to cause pain to cattle (Juarez et al., 2003; Flower et al., 2008) and affect their locomotion scores and ability to keep up with other cattle during handling events (Manson and Leaver, 1998; Juarez et al., 2003; Fjeldaas et al., 2010). This has been identified as a welfare concern by numerous scientists (Laven et al., 2008; LokeshBabu et al., 2018; Grandin, 2024).

Lameness has been reported and researched in cattle since the 1980's, starting with a concern for acidosis in dairy cattle (Manson and Leaver, 1988) and slowly shifting toward the impact on beef cattle, but most studied in fed cattle at the slaughter establishment (Edwards-Callaway, 2017). The first broad-scale observation of lameness in fed cattle was reported in the

NBQA report from 2016 with 3.1% of fed cattle having mobility scores of 2-3 in a 4-point mobility scoring system (ranging from slight lameness to extreme stiffness or obvious discomfort) (NBQA, 2016). Mijares et al. (2021) used the same 4-point mobility scoring system (NAMI, 2016) on N = 15,388 animals from one slaughter facility and reported that 25.45% of full fed steers and heifers showed signs and symptoms of lameness upon arrival to a slaughter facility. The most recent NBQA report from 2022 reported that 8% of fed steers and heifers showed signs and symptoms of lameness upon arrival to slaughter facilities on a 4-pt scale (NBQA, 2022; Schwartz et al., 2025). This number, while smaller than the proportion observed by Mijares et al., 2021, is still greater than what was reported in 2016 and a large proportion of animals experiencing behavioral alterations due to mobility issues.

There are multiple contributing factors to lameness in feedlot cattle: genetics, nutrition, and management are three that have been prevalent in literature. Grandin (2001) suggested that an increase in lameness could be indicative of selection pressure for carcass characteristics, without enough consideration for sound feet and limbs. Pauler et al. (2020) supports this claim and reported that cattle claw base, which supports animal mass and weight distribution, was not considered in breeding decisions and has thus become underdeveloped in today's cattle population. The genetic choices of producers either selecting traits that could be linked to poor hoof conformation, or simply putting less selection pressure on choosing cows with appropriate hoof conformation could lead to lameness (Grandin, 2001; Pauler et al., 2020).

An increase in structural conformation issues could be one reason for an increase in lameness (Franks and Grandin, 2015). Boettcher et al. (1998) linked poor leg conformation to a decreased foot angle and sickle-hocked cattle, predisposing them to the development of clinical lameness down the line. Odegard et al. (2014) observed hoof and leg conformation on N = 18,895 Norwegian Red cows and concluded that conformation can be a direct cause of lameness.

Certain nutrition programs can lead to lameness in cattle (Boelling and Pollott, 1998; LokeshBabu et al., 2018). When cattle are fed a diet with large volumes of carbohydrates, an accumulation of volatile fatty acids (VFA's) can occur in the rumen (Kleen et al., 2003; Krause and Oetzel, 2006). During this process, lactic energy substances cannot be absorbed by the rumen wall, saliva production is reduced, and the pH of the rumen decreases (Fu et al., 2022). Subacute ruminal acidosis (SARA) can occur when the pH of the rumen drops below 5-5.5 (Garrett et al., 1999; Plaizier, 2004; Passos et al., 2023). The development of SARA activates vascular activity and increases blood pressure in the hoof (Fu et al., 2022). In conjunction, rumen endotoxins and histamine are released into the bloodstream, which increases vasoconstriction and dilation in the hoof (Guo et al., 2021). These pathways ultimately cause a lengthening of the horn of the hoof wall and pain for the animal (Freitas et al., 2023; Passos et al., 2023). Other dietary changes which have led to this disorder include a rapid change from grass to a high-concentrate diet, increase in feed volume, and an increase in oligofructose or starch in the diet (Lean et al., 2013; Estima-Silva et al., 2020).

As cattle size increases, there is more weight put on the claw base of the animal (Pauler et al., 2020; Grandin, 2022). In horses, larger- and heavier- boned breeds have larger and wider hoof sizes. Additionally, obesity can have negative metabolic effects leading to laminitis (Sanderska-Plonowska et al., 2022). Pauler et al. (2020) measured hoof size relative to animal weight and reported that highland cattle had the greatest claw base relative to their body weight, in comparison to Original Braunvieh and Angus x Holstein cattle (Pauler et al., 2020). This study concluded that the static pressure on each claw was less for Highland cattle than for other breeds

(Pauler et al., 2020). This is something to consider when breeding cattle, to potentially decrease prevalences of lameness associated with cattle size.

Lameness is a painful condition and can cause financial losses through treatment costs, animal loss, and performance losses (Whay et al., 1998; Tibbetts et al., 2006; Edwards-Callaway et al., 2017). Hoof disorders can reduce animal performance (i.e. eating) for up to five months after the initial presentation (LokeshBabu et al., 2018). Cortes et al. (2021) reported that cattle diagnosed with digital dermatitis had a lower ADG and HCW in comparison to healthy cattle. Juarez et al. (2003) reported that lame dairy cows spend less time eating, which is a behavior of significant value to the fed beef industry (Galyean and Rivera, 2003; Juarez et al., 2003). To protect the welfare of cattle and to improve economic and genetic opportunity in the fed beef industry, producers should be cautious when making genetic and nutrition-related decisions to create a healthier hoof conformation. This will benefit fed cattle going into slaughter establishments and retained heifers and bulls.

2.3 Liver Abscesses

Liver abscesses can occur as a result of subacute ruminal acidosis (SARA) (Nagaraja and Chengappa, 1998; Kleen et al., 2003; Rezac et al., 2014). This acidic condition causes epithelial damage to the rumen, allowing pathogenic bacteria to enter the bloodstream and circulate into liver tissue (Kleen et al., 2003; Rezac et al., 2014). These bacteria colonize and cause liver abscesses (Kleen et al., 2003). Severe liver abscesses can adhere to the diaphragm and other organs of the abdominal cavity, which require trimming from the carcass (Fox et al., 2009; Rezac et al., 2014; Amachawadi and Nagaraja, 2022). The USDA mandates that all livers with an abscess present are condemned, totaling a value of $61.2 million per year, reported in 2023 (USDA-FSIS, 2015; Jaborek, 2023).

Ruminal acidosis occurs when an animal is fed heavily processed grains such as steam-flaked corn or other readily fermented carbohydrates with low levels of roughages in finishing diets (Galyean and Rivera, 2003). Although cattle in modern feedyards handle these diets, not every animal can do so without a stepwise transition diet (Galyean and Rivera, 2003). A transition diet is used to prepare the rumen mucosa to digest high-concentrate, low forage diets (Galyean and Rivera, 2003; Islam et al., 2021). The reason that high concentrate diets are preferred is because the animal yields increased growth rates, which are economically favorable (Bures and Barton, 2012; Pauling et al., 2023). Upon arrival at a feedyard, cattle are fed a transition diet starting with a high roughage backgrounding diet and then shifting to a high concentrate finishing diet (Holthausen et al., 2013). This diet is typically shifted over a twenty-one-day period, however, some cattle can go up to twenty-one days without consuming a normal volume of feed (Felix, 2023). Therefore, the twenty-one-day transition phase does not fully account for these animals who did not slowly adapt to the change in diet.

Cattle with liver abscesses have been associated with a reduced average daily gain and total carcass value, as abscessed livers and surrounding adhered organs cannot be marketed (Fox et al., 2009; USDA-FSIS, 2015). Fox et al. (2009) evaluated N = 1,307 steers and heifers raised under natural conditions (receiving no growth hormones) across three treatments: control, Fusobacterium necrophorum vaccine (Fusogard, FNB), and Arcanobacterium pyogenes-Fusobacterium necrophorum toxoid vaccine (Centurion, APFNT). The authors reported that in general, presence of severe liver abscesses reduced (P = 0.01) HCW. Brink and Stock (1990) reported that cattle with abscessed livers had reduced feeding performance. When compared to animals with a common physiological endpoint, cattle with liver abscesses required more days on feed to reach the same finishing weight as cattle without abscesses (Brink and Stock, 1990). Physiologically, liver abscesses impact feeding behavior or feed efficiency.

In 1991, 19.24% of carcasses from beef steers and heifers had their livers condemned, resulting in a $14 million economic loss to the fed beef industry (NBQA, 1992). Of those condemnations, 72.7% were attributed to liver abscesses (Lorenzen et al., 1993). The NBQA report from 2016 collected data across 17 slaughter establishments on n = 24,940 carcasses (for offal assessments) (Eastwood et al., 2017). Of those, 11.8% of cattle had minor abscesses and 6.0% had major abscesses, totaling 17.8% of cattle having a liver abscess present (Eastwood et al., 2017). In 2020, Baier et al. (2020) measured liver abscesses on 363 feedlot steers and reported a total abscess prevalence of 12.4%. That 12.4% is composed of 5.79% of cattle with mild liver abscesses and 6.61% with severe liver abscesses. More recently, Herrick et al. (2024) measured liver abscesses on n = 2,143 fed Holsteins in Texas and Kansas. Of the Holsteins measured by Herrick et al. (2024), 44.38% of animals had liver abscesses present- 11.01% had minor abscesses and 33.36% had major abscesses. This prevalence could be attributed to the Holstein breed-type, due to their increased days on feed (Reinhardt and Hubbert, 2015; Fox et al., 2009). Borders et al. (2024) quantified the proportion of condemned livers in cows and bulls in 2022. They reported that 16.5% of condemnations were due to liver abscesses (Borders et al., 2024).

Multiple studies have evaluated the microbial composition of liver abscesses and reported that Fusobacterium necrophorum and Arcanobacterium pyogenes are two gram-negative anaerobic bacteria that are present in liver abscesses (Nagaraja and Chengappa, 1988; Fox et al., 2009). Studies have suggested that the administration of vaccines that stimulate an immune response to Fusobacterium necrophorum (Rezac et al., 2014) may be a beneficial method to reducing liver abscesses. However, in the study by Fox et al. (2009) vaccine status had no effect of incidence of liver abscesses. Another method is the administration of antibiotics such as Tylosin to the diet, which is effective against gram-positive bacteria and fusobacterium necrophorum (Lecthenberg et al., 1998; Nagaraja et al., 1999; Fuerniss et al., 2022). This impact equates to the overall reduction of liver abscesses in cattle (Meyer et al., 2013). This has been reported as the most economical method to reducing abscesses (Brown et al., 1975; Nagaraja and Lecthenberg, 2007; Fuerniss et al., 2022).

Although these methods have reduced the prevalence of liver abscesses significantly, neither has been 100% effective in reducing their prevalence (Theurer and Amachawadi, 2022). There is also a consumer drive for "natural" products, which eliminate the use of antibiotics and growth-promoting hormones in their programs (Fox et al., 2009). Thus, a need for further research exists to potentially reduce the prevalence of liver abscesses via dietary or genetic components, while retaining the same efficiency of the cattle industry that stands today.

Liver abscesses are evaluated at the carcass level (USDA-FSIS, 2015). Ultrasound technologies do exist to evaluate liver abscesses in cattle (Braun, 2009) but evaluation in finished cattle proves difficult (Thompson et al., 2025). Most visual liver evaluations occur once the viscera are removed from the carcass at slaughter or during necropsy post-mortem (Amachawadi and Nagaraja, 2022).

Liver abscesses have traditionally been scored on a 4-pt scale referred to as the Elanco Liver Scoring System (Fox et al., 2009). This scale includes a 0: no liver abscess present, A-: minor liver abscess present, A: moderate liver abscess presence, and A+: severe liver abscess presence (Fox et al., 2009). A fifth component to the scale has been recognized in some studies and is referred to as a body wall adhesion (B) (Rezac et al., 2014; Baier et al., 2020). Body wall adhesions occur when the liver abscess adheres to the diaphragm or adjacent organs, resulting in additional trimming to the carcass as the affected areas cannot be marketed (Rezac et al., 2014).

Liver evaluation is most realistic for producers post-mortem and at slaughter, therefore, prevention is the best method of reducing liver abscess prevalence (Galyean and Rivera, 2003), and reporting data from the slaughter establishment would allow producers to understand how their inputs are affecting carcass quality post-mortem. It is essential to make genetic, nutrition, and other management changes quickly and to continue monitoring the presence of abscesses (Galyean and Rivera, 2003; Rezac et al., 2014).

2.4 Congestive Heart Failure

Congestive heart failure (CHF) includes many pathologies: cardiomyopathy and pulmonary hepatic lesions (Bastianello et al., 1996), left heart dysfunction (Heaton et al., 2019), cardiovascular remodeling associated with pulmonary hypertension (Kukor et al., 2021), ventricular fibrosis, stiffening of the myocardium, and severe ventricular remodeling (Buchanan et al., 2023).

Throughout this literature review, the term CHF is equivalent to brisket disease or high-altitude disease. The term “brisket disease” was coined in the Rocky Mountain Region over 100 years ago (Heaton et al., 2019). Brisket disease is caused by the reduced partial pressure of oxygen at high altitudes causing pulmonary hypoxia, vascular resistance, arterial remodeling, and pulmonary hypertension (Heaton et al., 2019). The actual development of CHF from brisket disease results from chronic or long-term exposure to high altitude, which was defined in 1963 as cattle grazing higher than 2,100 m but has transitioned to elevations greater than 1,600 m in the past ten years (Neary et al., 2016; Heaton et al., 2019; Heffernan et al., 2020; Buchanan et al., 2023).

Brisket disease has made its way down the mountains and onto feedyards. Feedlot Heart Disease is a condition that has been observed in fed cattle at elevations between 800 and 1600 m (Neary et al., 2016; Heffernan et al., 2020). Cattle with Feedlot Heart Disease experience pulmonary hypertension, leading to right-sided heart failure which ultimately ends in mortality (Krafsur et al., 2019; Heffernan et al., 2020). When pulmonary hypertension occurs, the left ventricle remodels and can cause the heart wall to thin, fluid to build-up in the heart and swell, and the sides of the heart to stretch out (Hecht et al., 1962; Heffernan et al., 2020). Ultimately, cattle can live with Feedlot Heart Disease to a certain degree, but severe heart disease results in hypoxia because the fluid buildup engorges the lungs, ulitmately resulting in death (Hecht et al., 1962; Shirley; et al., 2008; Neary et al., 2013; Buchanan et al., 2023).

Pulmonary Arterial Pressure (PAP) contributes to the development of CHF. Pulmonary arterial pressure is a measurement of the pressure in the pulmonary artery (Heffernan et al., 2020). A greater PAP score leads to cor pulmonale, where the right ventricle becomes enlarged and struggles to move a volume of blood from low to high pressure (Enns et al., 1992). This results in excessive muscle contraction and can lead to right sided heart failure (Heffernan et al., 2020). Pulmonary Arterial Pressure is moderately heritable (0.20 to 0.46) (Enns et al., 1992) and is commonly used as a breeding objective in high altitudes to decrease the incidence of right-sided CHF (Pauling et al., 2023). Cattle with a score of 34-39 mm HG are at low risk, 40-45 mm HG are at moderate risk, and 46 mmHG or greater are at high risk (Holt and Callan, 2007). There are rewards to breeding for a lower PAP score, with low PAP steers having a better ADG and feed to gain ratios than high PAP steers (Heffernan et al., 2020). However, the producer drive to increase muscle mass is correlated with a higher PAP score (Pauling et al., 2023), suggesting the potential indicator for how heart disease made its way to lower altitudes.

Cattle with CHF show signs of tachypnoea, tachycardia, dyspnea, and exercise intolerance (Bastianello et al., 1996). Cattle with CHF are often diagnosed with respiratory diseases that show similar signs (Kukor et al., 2021). These shared characteristics make management of cattle with CHF difficult. Exercise intolerance can have an impact on the animal as it could limit their ability to walk to the feed bunk, keep up with other cattle, and walk up a ramp at slaughter, thus reducing efficiency at all stages of the feeding cycle. Because CHF takes on the clinical symptoms of some other respiratory illnesses (Nart et al., 2004; Neary et al., 2013; Hussein and Staufenbiel, 2014), misdiagnoses are possible (Kukor et al., 2021). Moxley et al. (2019) reported that in several post-mortem examinations of cattle with lesions indicative of congestive heart failure, mild acute or chronic bronchointerstitial pneumonia was also present. Hussein and Staufenbiel. (2014) found that female water buffaloes aged 3 to 8 years who were diagnosed with CHF had a history of previous antibiotic injections but did not show obvious improvement to their condition. With the use of antibiotics, there is also a withdrawal time which delays the date from when that animal can be slaughtered for food consumption (BQA, 2025). This could be impactful to animal welfare if producers are holding the animal for a withdrawal period before slaughter rather than performing an appropriately timed euthanasia when signs of CHF are present.

Neary et al. (2016) reported that the risk of CHF doubled from 2000-2012 from 0.21 to 0.40 per 1,000 head placed on the feedlot. From there, death loss because of CHF was 0.04% in 2016, 0.078% in 2017, and 0.08% in 2018, showing an increase just across three years (Johnson et al., 2021). Kukor et al. (2021) evaluated cardiac remodeling indicative of congestive heart failure in cattle at slaughter; this study reported that 34% of beef cattle (elevation: 1,062 m) had mild or severe changes or a flaccid heart at slaughter. Most recently, Kukor et al. (2023) reported that moderate to severe heart swelling was observed in 26.87% of Angus influenced cattle in the panhandle of Texas (elevation: 1,103 m) and 10.87% of beef-on-dairy cattle in western Kansas (elevation: 846 m).

Congestive heart failure may have genetic linkages resulting from intensive selection of carcass traits in beef cattle (Kukor et al., 2021). Kukor et al. (2021) reported that sire had a significant effect on heart score, indicating that there could be a genetic role in the remodeling of heart structure leading to failure. Moderate genetic correlations have been reported between PAP score and weaning weight (Pauling et al., 2023). Weaning weight is a desirable genetic and growth component to cow-calf operations as their economic return from the animal is based on a price by pound basis at weaning (Bullock, 2020; Lalman et al., 2019; Miller et al., 2001). Thus, a larger weaning weight is more desirable than a lower weaning weight for an animal raised on pasture. Previous literature has hypothesized that the changes leading to pulmonary hypertension (leading to CHF) are a result of increased growth rates (Buchanan et al., 2023). Newman et al. (2015) evaluated the EPAS1 gene and it's prevalence in *Bos taurus* Angus cattle in the Rocky Mountain region of the United States with pulmonary hypertension. They concluded that the EPAS1 double variant was highly associated with the presence high altitude pulmonary hypertension in the sample group of cattle.

In addition to management factors linked to CHF, there are carcass characteristics that are linked to the disorder as well. Buchanan et al. (2023) reported that cattle with severe CHF at harvest had significantly lighter HCW than animals with any other heart score. Heffernan et al. (2020) reported that as CHF score increased in severity, REA decreased in size, which is an undesirable characteristic for a carcass. Cattle with severe CHF at slaughter have also been linked to a smaller average daily gain (ADG), indicating that severe cardiac insufficiency impairs growth (Heffernan et al., 2020; Buchanan et al., 2023).

Congestive heart failure can be evaluated on a live animal via ultrasound technologies (Hussein and Staufenbiel, 2014; El Raouf et al., 2020) but requires a trained individual or veterinarian and optimal restraint of the animal to do so (Crestani, 2016; Buchanan et al., 2023). Therefore, most industry evaluations occur post-mortem either via necropsies on the feedlot or scoring at the slaughter establishment (Bexiga et al., 2008; Kukor et al., 2021; Buchanan et al., 2023). Kukor et al. (2017) used a 5-point heart scoring system ranging from a score of 1: normal heart, 2: mild changes, 3: moderate changes, 4: severe changes, and 5: severe changes with flaccid heart.

Congestive heart failure has crucial consequences for animal welfare. Evidence demonstrates that animals with severe CHF have difficulty maintaining weight in comparison to other cattle in their cohort who do not have severe CHF (Heffernan et al., 2020; Buchanan et al., 2023). When the result of CHF is death, the pericardium fills with fluid and the animal ultimately dies of hypoxia (Kumari et al., 2023).

Buchanan et al. (2023) reported that 29.61% of cattle harvested under emergency harvest had severe CHF and were transported to slaughter early due to suspected cardiac morbidities. In 2019, some producers reported an estimated loss of $250,000 (Heaton et al., 2019). This is a serious concern for the economic health of the fed beef industry, with no data supporting a current reduction in CHF (Neary et al., 2016; Kukor et al., 2021; Kukor et al., 2023). Bexiga et al. (2008) stated that animals with signs of cardiac failure should not be transported, according to the European Commission.

2.5 Natural Fed Cattle Programs

There are two popular modes of raising cattle: Conventional and Natural. Conventional-fed cattle do not have restrictions on what they receive in their diet regarding antibiotics, growth promotants, implants, ionophores, or beta-adrenergic agonists (Vanderhoff, 2020). They are often given vaccines, antibiotics, and growth-promotants to increase their carcass quality and average daily gain (Heinemann et al., 1978; Pendlum et al., 1978). Natural-fed cattle come with their own restrictions depending on their specific program but are typically designated as cattle that have never been fed animal by-products and have not been given antibiotics or growth-promotants (Capper, 2012; USDA: USDA-AMS, 2026).

Consumers have a desire to purchase products from cattle who they perceive as being raised more “natural”, thus the name for natural-fed cattle began (Fallon et al., 1998; Grunert et al., 2015). Some factors to cattle production including those mentioned above, animal by-product feed additives, antibiotics for preventative medicine, and growth promotants, are concerning for consumers, thus creating a market for these natural cattle to be raised and marketed separately (MacArthur et al., 2006; Fraser, 2008). Consumers desire these natural-fed animals for a variety of reasons, ranging from concerns with animal welfare, human health, and environmental sustainability (Anderson et al., 2001; Harrington and Lu, 2002). In a 2017 survey, consumers were willing to pay $1.22 per pound for steak that was labeled natural (Syrengeles et al., 2017).

In general, production of conventional cattle is considered more sustainable and efficient (Capper, 2012). Conventional cattle have higher slaughter weights, yielding more product from one carcass, have a lower environmental impact, require less land to feed one animal, and reduce water consumption during production (Capper, 2012).

There is currently no research that exists evaluating hoof abnormalities, liver abscesses, or CHF for natural fed cattle. Natural cattle and conventional cattle have different nutrition, but could be of any genetic background, so certain hoof abnormalities likely exist in some cattle in both populations (Vanderhoff et al., 2020; Grandin, 2024). One factor that might contribute to hoof abnormalities or lameness however is hot carcass weight, which was reported to be greater in conventional cattle than natural cattle, so there might be fewer hoof abnormalities observed in the natural cattle population (Capper, 2012).

Natural cattle cannot be administered antimicrobials which are utilized in the conventional cattle industry to prevent liver abscesses (Heinemann et al., 1978; Pendlum et al., 1978; USDA-AMS, 2026). Therefore, a higher prevalence of liver abscesses might be observed. Reinhardt and Hubbert (2015) also reported that liver abscess prevalence increases with greater days on feed, this might also be a factor contributing to the increased prevalence in natural fed cattle. One option for reducing or preventing liver abscesses in natural cattle might be the administration of a vaccine, which would be allowed in natural programs (USDA-AMS, 2026), however, its efficacy requires further development (Fox et al., 2009).

The presence of CHF at elevations < 1,600 m is an emerging issue to the fed beef industry (Heffernan et al., 2020; Neary et al., 2016). There is currently no research that exists regarding the prevalence of this issue in natural-fed cattle. A majority of research exists regarding conventional beef cattle or beef-on-dairy crossbred cattle (Heffernan et al., 2020; Kukor et al., 2023). Further research would benefit the natural-fed industry to understand if some of the differences between natural and fed cattle contribute to the presence of CHF.

2.6 Connecting Production Diseases

Hoof abnormalities, liver abscesses, and CHF have all been attributed to genetic factors. With the potential for shared etiologies it is possible that one disorder could be linked to another. Dr. Temple Grandin reported that a four-month-old *Bos taurus* beef type heifer had a corkscrew claw (personal communication, Temple Grandin). Because this animal was not yet on an intensive feeding system which would typically yield hoof abnormalities, it is likely that there is a genetic basis for this animal's claw disorder. It has also been reported that liver abscesses are more prevalent in cattle of certain breed compositions and hide colors (Fox et al., 2009; Losada-Espinosa et al., 2021). Current research suggests some potential linkages between CHF and carcass quality (Heffernan et al., 2020; Buchanan et al., 2023), likely as a result of breeding objectives (Kukor et al., 2021; Grandin, 2022; Pauling et al., 2023). For example, Pauling et al. (2023) reported a moderate genetic correlation (0.51 +- 0.18) between PAP score and weight at weaning.

Hoof abnormalities and liver abscesses have also been attributed to nutritional factors. An association has been reported between hoof conformation issues such as laminitis and corkscrew claw and nutritional components such as ruminal acidosis (Nagaraja and Lechtenberg, 2007; Freitas et al., 2023). Similarly, more days on feed can increase the prevalence of liver abscesses (Fox et al., 2009) thus, a relationship could exist between hoof conformation issues and liver abscesses with a shared contribution of nutrition.

It is critical to explore relationships between production diseases so that ranchers can recognize phenotypic characteristics and make genetic and management decisions to ultimately reduce their prevalence. In addition to exploring relationships between these disorders, identifying the contributing factors to hoof abnormalities, liver abscesses, and CHF could change the trajectory of the future of cattle breeding. These changes would not only improve the welfare of these animals but could have a positive contribution to reducing financial losses in the fed beef industry. Cattle with hoof abnormalities are at an increased risk of experiencing lameness (Rousing et al., 2004; Flower et al., 2008), liver abscesses can cause product loss and reduce carcass value (NBQA, 2022; Herrick et al., 2024), and CHF is a serious welfare concern that also impacts overall value of the animal on the feedlot (Heaton et al., 2019; Johnson et al., 2021; Buchanan et al., 2023). Solutions such as breeding for normal hoof conformation and cattle that do not develop congestive heart failure, and monitoring the prevalence of liver abscesses at slaughter could contribute to a reduction of these production diseases.

CHAPTER III.

INVESTIGATING THE RELATIONSHIP BETWEEN HOOF, LIVER, AND HEART ABNORMALITIES IN GRAIN-FED BEEF CATTLE (*BOS TAURUS*) <30 MOS AT SLAUGHTER

ABSTRACT

Hoof abnormalities, liver abscesses, and congestive heart failure (CHF) are animal welfare concerns that have increased in fed cattle. Our objective was to determine whether relationships between these issues existed in fed cattle at slaughter. Each condition was evaluated at a slaughter establishment in the great plains region of the United States (1,417 m elevation) on cattle (*Bos taurus* beef-type only) < 30 mos of age (N = 398). Statistical analysis was performed to determine relationships between the prevalence of hoof abnormalities, liver abscesses, and CHF between each other and selected carcass characteristics: (USDA quality grade (QG), USDA yield grade (YG), hot carcass weight (HCW), ribeye area (REA), and fat thickness (FT)). Eighty five percent of cattle had at least one hoof abnormality, 13% had a liver abscess, 52% had CHF, and 5% had all three disorders. There were no differences ($P > 0.4955$) within the proportion of CHF, liver abscess, and hoof abnormality scores. Cattle with both a wide toe and inward curve (421.62 ± 10.45 kg) had lighter carcasses ($P < 0.034$) than cattle with only an inward curve (460.95 ± 2.72 kg) or cattle with a shovel hoof (470.16 ± 6.79 kg). Hot carcass weight was heavier ($P = 0.0295$) for cattle with mild CHF (463.60 ± 3.24 kg) than no CHF (451.51 ± 3.22 kg). Ribeye area for cattle with no CHF was 103.17 ± 0.93 cm^2, mild CHF was 104.51 ± 0.88 cm^2, and severe CHF was 98.63 ± 2.46 cm^2 ($P = 0.0711$). There was a greater proportion ($P = 0.0099$) of heifers with no CHF (70.97 ± 8.17%) than steers (45.78 ± 2.61%). There were no

differences ($P > 0.1025$) in REA, FT, and QG, across hoof, liver, and CHF scores. Differences were present ($P < 0.034$) in HCW between hoof and CHF scores. Further research is required to guide actions to address the animal welfare and productivity concerns associated with these issues.

INTRODUCTION

In 2023 there were more than 25 million steers and heifers slaughtered in federally inspected establishments (USDA-NASS, 2024). Cattle and carcass sizes have increased over the past 40 years (Vogel et al., 2015; Eastwood et al., 2017; Grandin, 2022, 2024). By producing larger cattle, more meat can be produced from fewer cattle and less feed (Eastwood et al., 2017; Coleman et al., 2023). There has been a consumer demand for increased meat quality. One factor influencing meat quality is intramuscular fat, or "marbling", which is located within the cross-section of the muscle and gives the meat enhanced flavor (Chambaz et al., 2002; Bures and Barton, 2012; Eastwood et al., 2017). The move towards heavier carcasses and increased intramuscular fat is accomplished by higher energy diets (Irshad et al., 2012; Pauling et al., 2023) and selection for such traits (American Angus Association, 2021; Pauling et al., 2023).

In the past ten years there has been an increase in the occurrence of health and conformation disorders in fed cattle (Vogel et al., 2015; Edwards-Callaway et al., 2017; Losada-Espinosa et al., 2018; Grandin, 2022, 2024; Pauling et al., 2023). These issues include an increase in hoof abnormalities and lameness (Grandin, 2001; Franks and Grandin, 2015; Edwards-Callaway, 2017; NBQA, 2022), an increase in liver abscesses and subsequent condemnations (Fox et al., 2009; Eastwood et al., 2017; Losada-Espinosa et al., 2021), and an increase in the presence of congestive heart failure (CHF) (Neary et al., 2016; Heaton et al., 2019; Johnson et al., 2021; Grandin, 2022, 2024). All three of these issues compromise animal welfare and have significant financial impacts on the fed beef industry (Laven et al., 2008; Edwards-Callaway et al., 2017; Losada-Espinosa et al., 2018; Buchanan et al., 2023; Grandin, 2024).

Compared to 20 years ago, more cattle have been reported to have inhibited mobility and apparent lameness upon arrival at slaughter establishments (Grandin, 2001; Franks and Grandin, 2015; Edwards-Callaway et al., 2017; Grandin, 2022; NBQA, 2022). Lameness may be a result of increased cattle size and genetic components (Grandin, 2001; Thomson et al., 2015; Frese et al., 2015; Pauler et al., 2020) or various metabolic and dietary disorders (e.g. ruminal acidosis, vitamin and mineral toxicities and/or deficiencies, nutrient deficiencies) which decrease the positive gains from feed efficiency to the carcass (Boettcher et al., 1998; Lean et al., 2013; Freitas et al., 2023). Lameness is an animal welfare concern as it can be painful and may inhibit an animal's ability to walk normally and keep up with the pace and flow of other cattle during handling events (Laven et al., 2008; Franks and Grandin, 2015; Edwards-Callaway et al., 2017).

The American Angus Association (AAA) developed a 9-pt scale to assess lameness at the claw level (AAA, 2017). On this scale a score of 5 is ideal, which features a hoof with two evenly shaped and distributed claws, neither one featuring any excessive curve, and a normal gap between the two (AAA, 2017). As the scale deviates from a 5 to a 9, the hoof presents the beginning of a corkscrew where each claw is curving inward, and then finally deviates to a complete corkscrew claw with pronounced curling of one or both of the claws (AAA, 2017). The opposite end of the scale is a score of 1: a hoof where each claw is splayed outward and there is a large gap between the two claws at the interdigital cleft. There is another hoof conformation concern in feedlot cattle: "shovel" foot. Shovel foot, also referred to as laminitic hooves, refers to hooves that are extremely long, and are often thickened at the base, with a bend at the corium to curve upward (Ossent and Lischer, 1998; Thoefner et al., 2005; Lean et al., 2013). Shovel foot may be linked to ruminal acidosis, as the physiological outcome of acidosis can cause damage to the hoof (Thoefner et al., 2005; Nagaraja and Lechtenberg, 2007). Several studies have observed hoof conformation issues in dairy cattle (e.g., Fjeldaas et al., 2011; LokeshBabu et al., 2018), but there did not appear to be any peer-reviewed literature identifying and describing hoof conformation issues in beef steers and heifers at the time of this study.

The first National Beef Quality Audit (NBQA) in 1991 reported that 19.2% of fed cattle had their livers condemned and 72.7% of those condemnations resulted from liver abscesses (Lorenzen et al., 1993). Since then, liver condemnations have increased over 10% and were most recently reported at a prevalence of 30.8% for steers and heifers in 2016 (Eastwood et al., 2017). Liver abscesses are costly to the fed beef industry, as they result in organ condemnations and a resultant loss of marketable product (NBQA, 2022). As liver abscesses increase in severity they can adhere to the body wall, diaphragm, and other organs (Rezac et al., 2014) and must be trimmed and removed from the carcass and condemned (Herrick et al., 2024). The presence of liver abscesses has been linked to changes in operations and management at feedlots that have happened over time including feeding increased concentrate diets, greater feed intake, and more days on feed (Fox et al., 2009). In a physiological sense, the presence of liver abscesses has been strongly associated to ruminal acidosis (Losada-Espinosa et al., 2021). Fox et al. (2009) observed that cattle with abscessed livers had reduced average daily gain (ADG) and HCW and a greater proportion of carcasses grading Select as compared to Choice. It has also been reported that cattle with liver abscesses may be more prone to lesions and bruising, reducing meat yield (Losada-Espinosa et al., 2021). In 1991, an annual loss greater than $14 million was reported due to liver abscesses (NBQA, 1992). Recently, an estimated $400 million loss was attributed to liver abscesses annually (Broadway et al., 2024); this is a great concern for feedlot economic health.

Congestive heart failure (CHF) has been reported at high altitudes in feedlot cattle since the 1970s (Heaton et al., 2019), but frequent investigations began picking up in the last 10 years and have observed that the disorder was prevalent at lower altitudes as well (Neary et al., 2016; Moxley et al., 2019; Kukor et al., 2021). Congestive heart failure is a costly problem that contributes to feedlot morbidity and mortality rates (Buchanan et al., 2023; USDA Agriculture Research Service (ARS), 2024). Neary et al. (2016) reported that CHF increased from 2.10 to 4.0 animals per 10,000 head placed on the feedlot between 2000 and 2012. More recently, Buchanan et al. (2023) observed that 4.14% of cattle that died at the feedlot had a heart score of 4 or 5 (severe CHF) on a 5 pt scoring system. Exercise intolerance is a clinical symptom of CHF, which may make it difficult for animals to walk through lairage and up a ramp or into a restrainer at the slaughter establishment (Bastianello et al., 1996). Some potential causes of CHF at lower altitudes include genetic results of intensive selection for traits such as birth and weaning weight (Shirley et al., 2008; Heaton et al., 2019; Kukor et al., 2021), increased size and growth rate (Neary et al., 2016; Kukor et al., 2021; Johnson et al., 2021), and heat stress (NBQA, 2022). Heaton et al. (2019) reported that some producers estimated an annual loss exceeding $250,000 attributable to CHF. This cost may not include all externalities associated with CHF and is something that warrants further research to attempt to fully understand the costs and reduce them.

There has been an increase in public interest in the welfare of animals raised for food (Ventura et al., 2013; Schütz et al., 2023). One common framework for assessing animal welfare is the Three Circles Model, developed by Fraser et al. (1997); this framework includes affective states, natural living, and biological functioning (Fraser et al., 1997; Fraser, 2008). When assessing the welfare of fed cattle, it is important to consider each of these areas. Increases in mobility issues, liver abscesses, and CHF indicate that biological functioning is compromised, and cattle may experience negative affective states and limited ability to engage in behaviors that have evolutionary value (natural living). Additionally, the clinical symptoms of the aforementioned issues result in pain experienced by the animal, which causes suffering in the feedlot, during transport, and in lairage (Laven et al., 2008; Franks and Grandin, 2015; Kukor et al., 2021). To maintain consumer trust, and work toward minimizing pain and distress during animal production, it is important to continue to investigate and understand the causative factors of these diseases and modes of prevention.

Rollin (2005) defined production diseases as, "… diseases that would not arise, or not be of significance, were it not for the means of production used to create the animal." Hoof conformation issues, liver abscesses, and CHF may be considered production diseases because all have been linked to increased growth rates with the potential for genetic contributions as well. Lameness in feedlot cattle has been linked to increased muscling (Boettcher et al., 1998) and body mass (Radišić et al., 2012). Liver abscesses have been linked to animals with a lighter hot carcass weight (HCW) (Fox et al., 2009). Congestive heart failure has been linked to animals with a lower HCW, a less efficient feed to gain ratio and ADG, and breed type (*Bos taurus*, *Bos indicus*, beef-type, dairy-type) (Heffernan et al., 2020; Buchanan et al., 2023). With each of these issues having relationships to carcass characteristics and being traced back to similar causes, exploration of the potential for shared etiologies is warranted and necessary. The objective of this preliminary study was to explore the relationships between hoof conformation issues, liver abscesses, and congestive heart failure in a sample of conventionally-fed cattle from one feedlot.

A secondary objective was to evaluate the differences in the presence of carcass characteristics for each hoof, liver, and CHF score.

MATERIALS AND METHODS

Ethical Statement

The cattle observed in this study were slaughtered at a commercial slaughter establishment in accordance with the Humane Methods of Slaughter Act (7 USC 1901) (United States Electronic Code of Federal Regulations, 2025) and the regulations that enforce it (9 CFR 313) (United States House of Representatives Office of the Law Revision Counsel, 2025) under inspection by the United States Department of Agriculture Food Safety and Inspection Service (USDA FSIS). All cattle were rendered insensible with a penetrating captive bolt and then exsanguinated before data collection procedures began, so a waiver was submitted to the Colorado State University Institutional Animal Care and Use Committee (CSU IACUC). The IACUC waiver for this study (6089) was approved by the CSU IACUC on 26 August 2024.

Source Animals

All animals were sourced from a convenience sample within a single large feedlot in the great plains region of the United States (1,417 m elevation, FAA, Washington, D.C.). Source animals entered the feedlot at varying weights and total days on feed was not made available to the researchers. A total of 398 (31 heifers, 367 steers) *Bos taurus* beef animals < 30 mos of age were evaluated in this study (HCW = 457.36 ± 44.32 kg (mean ± SD)). The information on which cattle were penned together at the feedlot was not made available to the authors, because data collection took place only at the slaughter establishment. Additionally, the data collection team did not have control over the proportion of heifers and steers in this study. The animals were observed at the slaughter establishment and carcass data was received post-data collection. Cattle with dairy or *Bos indicus* phenotypes were excluded from this study. The specific breed of each animal was not known, but 64.57% of animals were black-hided (no white present). All animals received a viral vaccine (Infectious Bovine Rhinotracheitis/Bovine Viral Diarrhea (IBR/BVD) Types 1 +2) and 7-way clostridial vaccine at the feedlot. The supplier feedlot indicated that the cattle were also administered an implant (either Synovex (Zoetis, Troy Hills, New Jersey, USA) or Revalor (Merck Animal Health, Rahway, New Jersey, USA) products) according to label instructions. The timing of vaccine and implant administration was not available. When the animals reached finishing weight, they were shipped < 32.2 km on double deck livestock trailers to a USDA inspected commercial beef slaughter establishment in the great plains region of the United States (1,416 m elevation, FAA, Washington, D.C.). Upon arrival to the slaughter establishment, all cattle from the single feedlot were unloaded into lairage pens and further identified as one lot. All data collection occurred on a single day in August 2024 with animals who reached finishing weight during the summer season.

Study Design

A convenience sample was used similar to methods described by Van Os et al. (2018) and Huser et al. (2023) from a single feedlot. Sample size was determined using WinEpi (Working in Epidemiology, 2010) with the ‘Estimate Percentage’ option within the ‘Sample Size’ program. A confidence level of 95%, accepted error of 5%, an expected proportion of 30.8%, and a known population of 98,000 were utilized. The expected proportion was based on the prevalence of liver abscesses from the 2016 National Beef Quality Audit (NBQA) for Fed Cattle (Eastwood et al., 2017) and the population size was based upon the capacity of the feedlot where the source animals were finished. This sample size calculation yielded N = 328 animals. Due to rapid line speed at the slaughter establishment, every other animal was evaluated. The data collection team evaluated the full lot of cattle from the source feedlot until a total of 425 scores were collected; this was to reach the target sample size with consideration for potential lost scores (i.e. lost identification tags, railed-out carcasses, and condemnations, for example).

Scorecard Development

Three scorecards were developed for data collection: hoof conformation, liver abscesses, and CHF. All images for scorecards were collected using one of two cameras (Camera 1: Olympus Tough TG-6 Waterproof Camera, OM Digital Solutions Corp., Tokyo, Japan; Camera 2: GoPro HERO 10, GoPro, Inc., San Mateo, CA, USA) and all images were taken of a group of cattle similar to the sample population of those in the study. The lead investigator (EMH) developed each scorecard (Fig 2, Fig 3, Fig 4), and the group of coauthors agreed on each reference image. Irrelevant parts of the background in each image were cropped. No further editing software was utilized during scorecard development.

To determine inter-observer reliability, a series of images for each score was compiled and a group of co-authors (EMH, KNA, AAK, KDV) met to reach an agreed score for each sample image. The individual tasked with each scoring role was trained with sample images by the lead investigator. Each observer completed a randomized survey with at least 25 images each and scored 80% accuracy on two different randomized tests (McHugh, 2012). Scorecards were available during the randomized survey and data collection.

Hoof Scoring

The hoof scorecard consisted of a 5-pt categorical scale where each of the front two hooves of each animal were scored. The scorecard included the name of the conformation presentation (Normal, Corkscrew, Inward Curve, Shovel, Wide), a written description, and a visual reference image. The five conformation types evaluated were based on the prevalence observed by coauthors and previously reported concerns (Fjeldaas et al., 2011; AAA, 2017; Freitas et al., 2023). All reference photos were taken in the same slaughter establishment as data collection, except for the example of the “corkscrew” hoof, which was taken from a live animal that was on their side on a tilt table. The scorecard can be referenced in Fig 2. For each animal, all of the scores that were visually present on either of the front two hooves were assigned, including if one hoof displayed more than one conformation type. A study by Enevoldsen et al. (1991) described that dairy cows with one foot disorder can suffer from others as well. Therefore, it was important for the observers to fully describe the anatomy of each animal.

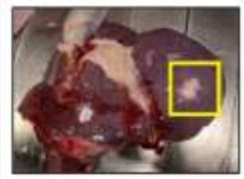
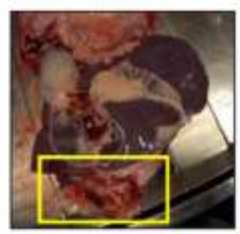
SCORE	DEFECT	DESCRIPTION	IMAGE
S	SHOVEL	There is a clear deviation from the predominant angle of the hoof and the hoof becomes more obtuse (flattened). The claw may also be thickened at the base where it meets the ground.	
W	WIDE	The hoof has a large gap (about 1 finger width or 0.75 inches) between the two front claws at the cornual line.	
C	CORKSCREW	There is an evident twisting in the horn of the hoof/the hoof capsule by the toe.[2]	
I	INWARD CURVE	Either one or both front claws have an evident turn/angle inward at the toe.	
N	NORMAL	Hoof deformities are absent: The two front claws are even in shape, with a small gap between them. The medial side of each claw is straight and not curved.	

[1] When scoring hooves, each defect that is present in any of the front 4 claws will be noted. Multiple scores can be assigned to each animal.
[2] NOTE: Animal in the image is laying on its side, not hanging

Figure 2. Bovine hoof conformation scorecard: front hooves with animal shackled

Liver Scoring

Livers were scored with the 4-pt Elanco liver scoring system as a reference (0 = no abscess, A- = one or two small abscesses, A = 2 to 4 well-organized abscesses less than 1 in (2.54 cm) in diameter, and A+ = one or more large, active abscesses greater than 1 in (2.54 cm) in diameter with inflammation into hepatic parenchyma) (Fox et al., 2009). In addition to the Elanco liver score, a score of “B” was added to the final 5-pt scale for livers and referred to body wall adhesions (Rezac et al., 2014). A body wall adhesion was classified as a liver that was adhered to the diaphragm, other organs, or abdominal cavity (Rezac et al., 2014). If an adhesion was present on the liver, this was the final score given. Only one score could be assigned per liver. The liver scorecard was developed with photos taken in previous visits to the slaughter establishment and can be observed in Fig. 3 Information was added to the description to include further instruction on how to score a liver with a combination of small and large abscesses.

SCORE	DESCRIPTION	IMAGE
0	No abscesses present, healthy liver.	
A-	1-2 small abscesses[1] present	
A	3 or more small abscesses[1] **or** 1-2 large abscesses[2] present	
A+	3 or more large abscesses[2] present **or** 1 or more large abscesses[2] and 3 or more small abscesses[1] present	 Photo courtesy of Elanco Liver Check Service (Jaborek, 2023).
B	Body Wall Adhesion: An attachment of abdominal lining and muscle tissue to the liver is present. If a body wall adhesion is present, the liver will be given this score and the presence of other abscesses will be ignored.	 

*A defect will be considered an abscess if it appears to be a raised bump that is visually detectable on the surface of the liver. The portion of the abscess that is raised and any discolored or pus-filled areas surrounding it will be scored to determine severity.
[1]Small Abscess: less than 1 inch (quarter size) in diameter
[2]Large Abscess: greater than or equal to 1 inch (quarter size) in diameter

Figure 3. Bovine liver abscess scorecard

CHF Scoring

Hearts were scored for CHF using a 3-pt scale adapted from the 5-pt scale used by Kukor et al. (2023) and Buchanan et al. (2023). A 3-pt scoring system was used due to line speed and slaughter establishment configuration. The scorecard depicted the changes from a normal heart to a heart displaying mild changes, and finally a heart displaying extreme changes. Because heart swelling due to CHF is a continuous trait that develops and worsens, the authors considered any deviation from a normal heart as potential development of CHF in this study. The heart scorecard that was used can be visualized in Fig 4. Each heart could only receive one score. All images used in the heart scorecard were collected during previous visits to the slaughter establishment.

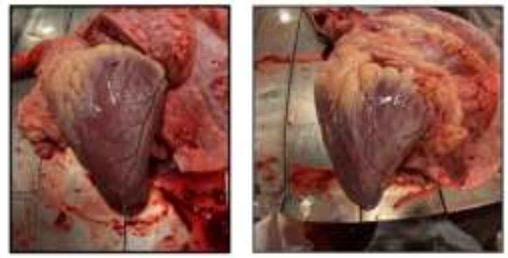
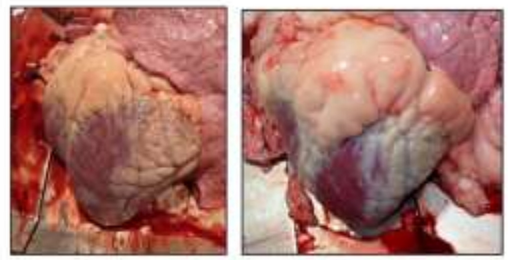
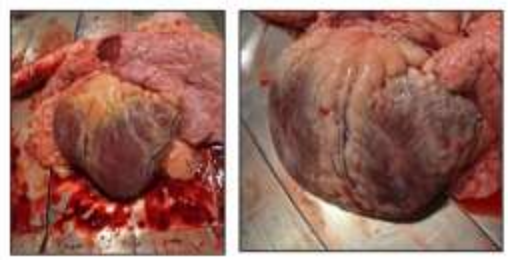
SCORE	DESCRIPTION	IMAGE
0	NORMAL The heart is normal in shape, does not appear fluid filled or stretched beyond normal capacity.	
1	MILD/MODERATE CHANGES The capacity of the heart overall has expanded beyond its regular shape. Either of the sides of the heart have stretched beyond its normal shape.	
2	SEVERE CHANGES The capacity of the heart overall has expanded significantly to take a rounded shape. Both sides of the heart have stretched beyond their normal shape. The heart begins to take a rounded-like appearance, becoming flaccid.	

Figure 4. Bovine congestive heart failure scorecard

Slaughter Facility Data Collection

Hoof conformation was scored directly after exsanguination and before the individual slaughter establishment carcass identification sticker was placed. Line speed was 390 animals per hour. The first observer (EMH) at the hoof score station scored all hooves and wrote the score on the right shoulder of the animal with either fluorescent pink or orange livestock chalk (SyrVet Livestock Marker, Item No. LMFLPK-F, SyrVet, Inc. Waukee, IA, USA). A singular line was made with chalk on the left shoulder of the animal and was used as an aide in the tracking of every other animal that was scored for the study. At this time all animals had their hides and heads attached. A second observer (OB) at this station recorded the hoof score identified by the first observer and hide color (predominant color and whether white was present).

A third observer (AAK) was located behind the slaughter establishment employee who was responsible for placing carcass identification tags. This individual recorded the hoof score that was visible on each animal's hide and the carcass identification number. A food grade metal pin with two food grade strings was attached to the exposed brisket of the animal so that the final two observers could identify the carcass at the viscera conveyer. The carcasses underwent hide removal, cleaning, and evisceration according to normal slaughter establishment procedures before livers and hearts were evaluated. The individual (AM) scoring liver abscesses stood on the side of the viscera conveyer prior to USDA inspection; USDA liver condemnations did not impact liver score in this study. Each liver was placed directly in front of the ventral side of each carcass. Each liver associated with a carcass that had strings was scored and the corresponding carcass identification number was noted.

Slaughter establishment employees removed the heart from the pericardial sac and turned it so that the right atrium was visually to the left of the observer's line of sight. The final observer (KNA) was located on the side of the conveyer where hearts were placed prior to USDA inspection. One employee at the liver station vocalized each carcass identification number and the heart observer used that indication to identify which carcass to score. The liver and heart observers each recorded their own score along with the corresponding carcass identification number. The observers at the liver and heart station were completely blinded to hide color and hoof score for each carcass.

The collaborating slaughter establishment provided carcass data for all animals enrolled in the study. Hot carcass weight was collected from a digital scale and QG, YG, REA, and FT were recorded from an imaging device used as a standard part of operating procedures (e+v Standard Grading Camera, e+v Technology GmbH & Co. KG, Brandenburg, Germany). Final USDA QG and YG were confirmed in-person for grading.

Statistical Analyses

A convenience sample of cattle from one feedlot were evaluated for this observational study. Hand-written scores were scanned and saved to Microsoft OneDrive (Microsoft, Redmond, Washington, United States) and each carcass ID was matched across each hide color and score observation. There were some carcasses where either CHF or liver scores were missed due to the high speed of the establishment and the placement of observers relative to USDA FSIS employees. Carcasses which did not have all three (hoof, liver, CHF) scores present were removed from the study. Additional exclusion criteria for this study included the removal of cattle > 30 mos (n = 3) and carcasses with a QG of Cutter (n = 3). This yielded a total of 398 carcasses which were included in the statistical analyses.

Prior to statistical analysis, all measurements were converted into metric units. Animals were put into a HCW, REA, and FT category using increments of 100 lbs., 1 in^2, and 0.1 in, respectively. These categories were then converted to kg, cm^2, and cm. Pivot tables within Excel (Microsoft) were used to determine the proportion of animals within each HCW, REA, FT category as well as hide color, QG, and YG. Pivot tables were also used to determine the proportion of animals with the presence of liver abscesses, CHF, and hoof abnormalities within each category. Microsoft Excel (Microsoft) was used to calculate a percentage for each group.

The *binom* package in R version 4.4.1 and R Studio version 2024.04.2+764 (R Core Team, 2024), was used for descriptive statistics to report 95% confidence intervals (CI) of hoof, liver, and CHF score within hide color, as well as the overall presence of each hide color, hoof score, liver score, and CHF score. For all further statistical analyses, liver scores A+ and B were combined because only one liver was classified as B.

SAS Enterprise Guide 7.1 (Statistical Analysis System Institute, Inc., Cary, NC) was used with the UNIVARIATE procedure and the histogram statement to assess normality for all continuous outcomes within categories. A variable was considered normal if two out of the three following criteria were met: histogram was normally distributed, Cramer-von Mises *P*-Value > 0.05, and QQ-plot appeared normal. The following results were not identified as normally distributed: HCW for hoof score SW, FT for hoof scores SW and WI; REA for liver scores A+/B. For all non-normal data, R version 4.4.1 and R Studio version 2024.04.2+764 (R Core Team, 2024) were used to perform a Kruskal Wallis test to determine significant differences in outcome variables (HCW, REA) between their corresponding scores (hoof score, liver score) for all scores within those categories. If this overall difference was significant, a Dunn's test was used to determine differences between specific scores (Dinno, 2015).

SAS Enterprise Guide 7.1 (Statistical Analysis System Institute, Inc.) was used to apply student's t-tests with the Bonferroni-Holm adjustment for multiple comparisons for normally distributed levels of hoof, liver, and heart conditions with continuous variables (HCW, REA, FT). Interactions between sex were checked and considered present if $P < 0.05$ for each continuous outcome variable. No interactions were present, so the interaction term was not included in the model (Engle et al., 2024; Loh et al., 2025). During data collection, an equipment malfunction yielded 147 animals where the REA and FT were not recorded, so comparisons between scores for those outcomes only include a portion of the sample (n = 181). For this analysis, scores that did not meet a criteria of ≥ 5 animals per group were also excluded from comparisons between means. Exclusions are reported in each corresponding table.

Comparisons between the proportion of animals with each score present (hoof, liver, CHF) among categorical carcass variables (QG and YG), animal characteristics (sex, hide color category), and other scores (hoof, liver, heart) were completed using SAS Enterprise Guide 7.1 (Statistical Analysis System Institute, Inc.) in the GLIMMIX procedure as a binomial distribution with the Satterthwaite adjustment and the random statement with residual. Sex was tested as an interaction and considered present if the interaction $P < 0.05$. No interactions were present, so means were reported from a statement without the interaction term (Engle et al., 2024; Loh et al., 2025). Categories that did not meet a criteria of ≥ 5 animals per group were excluded from comparisons between means and are identified in their corresponding tables. For analyses including hide color, animals were grouped into two categories: black (included animals that were black, or black and white) and not black (included animals that were red, red and white, gray, gray and white, tan, and tan and white). For all comparisons between means, statistical significance was defined as $P \leq 0.05$. Trends were defined as $P < 0.10$ and warrant further investigation.

RESULTS

Feedlot Cattle Sample

Descriptive statistics for source animals can be observed in Table 1 and are reported as means ± SD. The average hot carcass weight (HCW) for the entire sample of animals (N = 398) was 457.36 ± 44.32 kg. The average HCW for steers (n = 367) was 462.95 ± 40.64 kg and the average HCW for heifers (n = 31) was 392.22 ± 31.97 kg. Average ribeye area (REA) for the sample of animals was 103.54 ± 0.89 cm^2. Average fat thickness (FT) for the sample of animals was 1.79 ± 0.25 cm. The presence of hide color is reported in Table 2 (proportion, %, 95% CI).

Table S1 reports HCW, REA, and FT categories, with the presence of each condition (hoof abnormality, liver abscess, CHF) reported as %, proportion on a yes/no basis. Table S1 also includes the presence of each condition within each QG, YG, and hide color.

Table 1. Descriptive statistics for hot carcass weight (HCW), ribeye area (REA), and fat thickness (FT) for the sample population of fed cattle (N = 398).

Carcass Characteristic	n	Mean	SD	Median	Minimum	Maximum
HCW (kg)	398	457.36	44.32	459.18	276.19	570.52
REA (cm^2)	181	103.54	9.89	101.94	70.33	132.91
FT (cm)	181	1.79	0.25	1.78	1.07	2.64

Table 2. Proportion and 95% confidence intervals for the prevalence of hide color, hoof score, liver score, and congestive heart failure (CHF) score observed in fed cattle (N = 398).

Attribute		% (Proportion)	95% CI
Hide Color			
	Black	64.57 (257/398)	59.65 to 69.27
	Black and White	12.56 (50/398)	9.47 to 16.23
	Red	4.77 (19/398)	2.90 to 7.35
	Red and White	5.78 (23/398)	3.70 to 8.55
	Gray	6.78 (27/398)	4.52 to 9.72
	Gray and White	1.51 (6/398)	0.56 to 3.25
	Tan	3.77 (15/398)	2.12 to 6.14
	Tan and White	0.25 (1/398)	0.00 to 1.39
Hoof Score			
	Normal	15.33 (61/398)	11.93 to 19.25
	Corkscrew	6.28 (25/398)	4.11 to 9.13
	Inward Curve	56.78 (226/398)	51.76 to 61.71
	Shovel	4.27 (17/398)	2.51 to 6.75
	Shovel and Corkscrew	0.25 (1/398)	0.00 to 1.39
	Shovel and Inward Curve	5.28 (21/398)	3.30 to 7.95
	Shovel and Wide	3.02 (12/398)	1.57 to 5.21
	Shovel, Wide, and Inward Curve	0.25 (1/398)	0.00 to 1.39

	Wide	4.77 (19/398)	2.90 to 7.35
	Wide and Inward Curve	3.77 (15/398)	2.12 to 6.14
Liver Abscess Score			
	0 (Normal)	86.93 (346/398)	83.22 to 90.09
	A-	4.02 (16/398)	2.32 to 6.45
	A	5.53 (22/398)	3.50 to 8.25
	A+	3.27 (13/398)	1.75 to 5.52
	B	0.25 (1/398)	0.00 to 1.39
CHF Score			
	0 (No CHF)	47.74 (190/398)	42.74 to 52.78
	1 (Mild CHF)	46.98 (187/398)	41.99 to 52.02
	2 (Severe CHF)	5.28 (21/398)	3.30 to 7.95

Hoof Abnormalities

Eighty-five percent of cattle in this study had at least one hoof abnormality (inward curve, wide toe, shovel, or corkscrew present). Hoof conformation scores can be observed in Table 2 (proportion, %, 95% CI). Proportions are reported as the number of cattle with each condition out of all cattle (or carcasses) observed. The total proportion of animals in this study with no hoof abnormalities (N) was 15.33% (61/398, 95% CI: 11.93 to 19.25%). The total proportion of animals with a corkscrew (C) hoof was 6.28% (25/398, 95% CI: 4.11 to 9.13%). The total proportion of cattle with an inward curve (I) was 56.78% (226/398, 95% CI: 51.76 to 61.71%). The total proportion of cattle in the study with a shovel (S) hoof was 4.27% (17/398, 95% CI: 2.51 to 6.75%). Cattle with a wide toe (W) represented 4.77% (19/398, 95% CI: 2.90 to 7.35%) of animals enrolled in this study. Cattle that had a shovel and corkscrew (SC) hoof represented 0.25% (1/398, 95% CI: 0.00 to 1.39%) of the proportion of animals in this study. The proportion of cattle with a shovel and inward curve (SI) was 5.28% (21/398, 95% CI: 3.30 to 7.95%). The proportion of cattle with a wide toe and inward curve (WI) was 3.77% (15/398, 95% CI: 2.12 to 6.09%). The proportion of cattle with a shovel and wide toe (SW) was 3.74% (12/398, 95% CI: to 1.57-5.21%). One animal had three hoof abnormalities which included a shovel, wide toe, and inward curve (SWI); this represented 0.25% (1/398, 95% CI: 0.00 to 1.39%) of animals in this study.

Liver Abscesses

Thirteen percent of cattle in this study had one or more liver abscesses. The prevalence of liver abscesses reported in this study can be observed in Table 2. Animals with no liver abscesses represented 86.93% (346/398, 95% CI: 83.22 to 90.09%), animals with a liver score of A- represented 4.02% (16/398, 95% CI: 2.32 to 6.45%), animals with a liver score of A represented 5.53% (22/398, 95% CI: 3.50 to 8.25%), and animals with a liver score of A+ represented 3.27% (13/398, 95% CI: 1.75 to 5.52%) of this group of cattle. Only one animal had a body-wall adhesion representing 0.25% (1/398, 95% CI: 0.00 to 1.39%) of cattle evaluated.

Congestive Heart Failure

Fifty-two percent of cattle in this study had heart scores of 1 and 2, indicating potential development of CHF. The prevalence of CHF reported in this study is reported in Table 2. Cattle with no signs of CHF represented 47.74% (190/398, 95% CI: 42.74 to 52.78%) of animals in this study. The total proportion of animals in this study (elevation: 1,417 m) scoring CHF 1 (mild development of CHF) was 46.98% (187/398, 95% CI: 41.99 to 52.02%). The total proportion of cattle in this study (elevation: 1,417 m) that scored CHF 2 (severe presence of CHF) was 5.28% (21/398; 95% CI: 3.30 to 7.95%).

Relationships between hoof conformation, carcass characteristics, and hide color

Sample values for HCW, REA, and FT for hoof scores can be observed in Table 3 and are reported as means ± SE. Cattle with HOOF WI (n = 15) (HCW = 421.62 ± 10.45 kg) were lighter ($P \leq 0.0393$) than cattle with HOOF I (n = 224) (HCW = 460.95 ± 2.72 kg), cattle with HOOF C (n = 23) (HCW = 465.40 ± 13.30 kg), and cattle with HOOF S (n = 17) (HCW = 470.16 ± 6.79

kg). Mean HCW for HOOF SWI (n = 1) was 452.15 kg and SC (n = 1) was 425.85 kg: SE was not available for HOOF SWI and HOOF SC because they were only observed for one animal. Individual p-values those groups were not reported because they did not meet the requirement of ≥ 5 animals. There was no evidence ($P > 0.218$) to support a difference between HOOF S and HOOF I (n = 223) (HCW = 460.95 ± 2.72 kg), HOOF C (n = 23) (HCW = 465.40 ± 13.30 kg), HOOF SW (n = 12) (HCW = 454.08 ± 9.42 kg), HOOF N (n = 61) (HCW = 452.31 ± 5.95 kg), HOOF W (n = 19) (HCW = 434.92 ± 13.69 kg), or HOOF SI (n = 20) (HCW = 464.44 ± 9.03 kg).

Table 3. Mean hot carcass weight (HCW) ribeye area (REA), and fat thickness (FT) for each hoof score for fed cattle (N = 398).

	Independent Variable								
	HCW (kg)[1]			REA (cm^2)[2]			FT (cm)[3]		
Hoof Score	n	LS Means	SE	n	LS Means	SE	n	LS Means	SE
Normal (N)	61	452.31[ab]	5.95	38	104.78	1.60	38	1.70	0.04
Corkscrew (C)	23	465.40[a]	13.30	16	98.59	2.47	16	1.85	0.07
Inward Curve (I)	223	460.95[a]	2.72	143	103.96	0.82	143	1.80	0.02
Shovel (S)	17	470.16[a]	6.79	10	107.88	3.12	10	1.78	0.08
Shovel and Corkscrew (SC)[4]	1	425.85[ab]	-	0	-	-	0	-	-
Shovel and Inward Curve (SI)	20	464.44[ab]	9.03	19	100.85	2.26	18	1.86	0.06
Shovel and Wide (SW)	12	454.08[ab]	9.42	7	103.79	3.73	7	1.84	0.07
Shovel, Wide, and Inward Curve (SWI)[4]	1	452.15[ab]	-	0	-	-	0	-	-
Wide (W)	19	434.92[ab]	13.69	13	102.29	2.73	7	1.74	0.06
Wide and Inward Curve (WI)	15	421.62[b]	10.45	6	102.59	4.03	6	1.72	0.06
Overall P-Value	0.0131			0.2955			0.1356		

[1]P-Values are not reported for comparisons of HOOF SC and HOOF SWI within HCW as each category did not meet a criteria of ≥ 5 animals per group.
[2]P-Values are not reported for comparisons of HOOF SWI and HOOF SC within REA as each category did not meet a criteria of ≥ 5 animals per group.
[3]P-Values are not reported for comparisons of HOOF SWI and HOOF SC within FT as each category did not meet a criteria of ≥ 5 animals per group.

[4]Values for SE are not reported for HOOF SC and HOOF SWI because they were observed in only one animal.
[a,b]Superscripts that differ within a column identify significant differences between carcass characteristics within CHF scoress across placements ($P \leq 0.05$).

Ribeye area and FT were only available for a portion of cattle included in this study (N = 181) due to an electronic grading malfunction. Ribeye area was not available for animals with HOOF SC and HOOF SWI. For the remaining animals, there was no evidence ($P = 0.2955$) to support a difference in average REA between hoof scores. Average REA for HOOF S (n = 10) was 107.88 ± 3.12 cm^2, HOOF N (n = 38) was 104.78 ± 1.6 cm^2, HOOF I (n = 143) was 103.96 ± 0.82 cm^2, HOOF SW (n = 7) was 103.79 ± 3.73 cm^2, HOOF W (n = 13) was 102.29 ± 2.73 cm^2, HOOF SI (n = 19) was 100.85 ± 2.26 cm^2, and HOOF C (n = 16) was 98.59 ± 2.47 cm^2.

There was no FT data for animals with HOOF SC and HOOF SWI. For the remaining animals, there was no evidence ($P = 0.1356$) to support significant differences for FT between hoof scores. Average FT for HOOF SI (n = 18) was 1.86 ± 0.06 cm, HOOF C (n = 16) was 1.85 ± 0.06 cm, HOOF SW (n = 7) was 1.84 ± 0.07 cm, HOOF I (n = 144) was 1.79 ± 0.02 cm, HOOF S (n = 10) was 1.78 ± 0.08 cm, HOOF W (n = 13) was 1.74 ± 0.07 cm, HOOF WI (n = 6) was 1.72 ± 0.06 cm, and HOOF N (n = 38) was 1.70 ± 0.04 cm.

The mean proportion and SEM for each hoof score within each QG can be observed in Table 4. There was no evidence ($P > 0.8228$) to support differences in the proportion of cattle with each hoof score within each QG. The mean proportion of each hoof score within YG 1-5 is reported in Table 5. There was no evidence ($P > 0.6713$) to support differences in the proportion of cattle with each hoof score within each YG.

Table 4. Mean and SEM for the proportion of each hoof, liver, and CHF score present within each reported quality grade (QG) for fed cattle (N = 398).

		Quality Grade						Overall *P*-value
	n	Prime		Choice		Select		
Hoof Score[1]		Mean (%)	SEM	Mean (%)	SEM	Mean (%)	SEM	
Normal (N)[3]	61	0.00	0.00	16.40	2.00	20.00	5.75	0.8228
Corkscrew (C)	25	9.68	5.33	5.99	1.34	4.44	3.08	-
Inward Curve (I)	226	54.84	8.97	57.41	2.79	53.33	7.47	0.8547
Shovel (S)	17	12.90	6.04	3.79	1.08	2.22	2.21	-
Shovel and Corkscrew (SC)	1	0.00	0.00	0.32	0.28	0.00	0.00	-
Shovel and Inward Curve (SI)	21	9.68	5.33	4.73	1.20	4.44	3.08	-
Shovel and Wide (SW)	12	6.45	4.43	2.21	0.83	6.67	3.73	-
Shovel, Wide, and Inward Curve (SWI)	1	3.23	0.89	0.00	0.00	0.00	0.00	-
Wide (W)	19	3.23	3.19	5.05	1.23	4.44	3.08	-
Wide and Inward Curve (WI)	15	0.00	0.00	4.10	1.07	4.44	2.96	-
Liver Score[2]								
0 (No Abscess)	346	90.32	5.33	87.07	1.89	84.44	5.42	0.7577
A-	16	6.45	4.43	3.47	1.03	6.67	3.73	-
A	22	3.23	3.19	5.68	1.31	4.44	3.08	-
A+/B	14	0.00	0.00	3.79	1.03	4.44	2.96	-
CHF Score								
0 (No CHF)	190	36.56	8.80	48.93	2.85	46.49	7.55	0.4326
1 (Mild CHF)	187	63.50	8.79	45.63	2.84	46.73	7.54	0.1846
2 (Severe CHF)[4]	21	0.00	0.00	5.36	1.22	6.67	3.58	-

[1]P-Values are not reported for comparisons of HOOF C, HOOF S, HOOF SC, HOOF SI, HOOF SW, HOOF SWI, HOOF W, and HOOF WI within QG as each category did not meet a criteria of ≥ 5 animals per group.

[2]P-Values are not reported for comparisons of LIVER A-, LIVER A, and LIVER A+/B as each category did not meet a criteria of ≥ 5 animals per group.

[3]P-Values are not reported for comparisons of HOOF N within QG prime as this category did not meet a criteria of ≥ 5 animals per group.

[4] P-Values are not reported for comparisons of CHF 2 between QG as each category did not meet a criteria of ≥ 5 animals per group.

Table 5. Mean and SEM for the proportion of each hoof, liver, and CHF score present within each USDA yield grade (YG) for fed cattle (N = 398).

		Yield Grade										Overall *P*-Value
	n	1		2		3		4		5		
Hoof Score[1]		Mean (%)	SEM	Mean (%)	SEM	Mean (%)	SEM	Mean (%)	SEM	Mean (%)	SEM	
Normal (N)[2]	61	0.00	0.00	15.79	4.78	17.15	2.25	9.26	3.90	0.00	0.00	0.7209
Corkscrew (C)	25	33.33	27.39	3.51	2.45	6.20	1.47	7.41	3.59	10.00	9.55	-
Inward Curve (I)[3]	226	33.33	27.39	54.39	6.64	55.84	3.02	62.96	6.61	70.00	14.58	0.6713
Shovel (S)	17	0.00	0.00	5.26	2.97	3.65	1.14	5.56	3.13	10.00	9.51	-
Shovel and Corkscrew (SC)	1	0.00	0.00	0.00	0.00	0.37	0.30	0.00	0.00	0.00	0.00	-
Shovel and Inward Curve (SI)	21	0.00	0.00	5.26	2.97	5.11	1.33	5.56	3.13	10.00	9.51	-
Shovel and Wide (SW)	12	0.00	0.00	3.51	2.41	2.56	0.94	5.56	3.09	0.00	0.00	-
Shovel, Wide, and Inward Curve (SWI)	1	0.00	0.00	0.00	0.00	0.00	0.00	1.85	0.68	0.00	0.00	-
Wide (W)	19	33.33	27.04	7.02	3.36	4.75	1.28	1.85	1.82	0.00	0.00	-
Wide and Inward Curve (WI)	15	0.00	0.00	5.26	2.71	4.38	1.13	0.00	0.00	0.00	0.00	-
Liver Score[4]												

0 (No Abscess)[5]	346	100.00	0.00	87.72	4.36	85.40	2.14	92.59	3.57	90.00	9.51	0.7174
A-	16	0.00	0.00	1.75	1.72	4.75	1.27	3.70	2.54	0.00	0.00	-
A	22	0.00	0.00	5.26	2.97	6.20	1.46	1.85	1.84	10.00	9.51	-
A+/B	14	0.00	0.00	5.26	2.93	3.65	1.12	1.85	1.82	0.00	0.00	-
CHF Score												
0 (No CHF)[6]	190	68.38	26.70	35.14	6.43	51.94	3.07	44.06	6.88	21.28	13.36	0.0808
1 (Mild CHF)[7]	187	31.73	26.77	59.52	6.61	42.49	3.04	52.30	6.91	68.44	15.05	0.0922
2 (Severe CHF)[8]	21	0.00	0.00	5.26	2.97	5.47	1.38	3.70	2.58	10.00	9.51	-

[1]P-Values are not reported for comparisons of HOOF C, HOOF S, HOOF SC, HOOF SI, HOOF SW, HOOF SWI, HOOF W, and HOOF WI within YG as each category did not meet a criteria of ≥ 5 animals per group.
[2]P-Values are not reported for comparisons of HOOF N within YG 1 and YG 5 as this category did not meet a criteria of ≥ 5 animals per group.
[3]P-Values are not reported for comparisons of HOOF I within YG 1 as this category did not meet a criteria of ≥ 5 animals per group.
[4]P-Values are not reported for comparisons of LIVER A-, LIVER A, and LIVER A+/B as each category did not meet a criteria of ≥ 5 animals per group.
[5]P-Values are not reported for comparisons of LIVER 0 within YG 1 as this category did not meet a criteria of ≥ 5 animals per group.
[6]P-Values are not reported for comparisons of CHF 0 within YG 1 and YG 5 as each category did not meet a criteria of ≥ 5 animals per group.
[7]P-Values are not reported for comparisons of CHF 1 within YG 1 as this category did not meet a criteria of ≥ 5 animals per group.
[8]P-Values are not reported for comparisons of CHF 2 within YG as each category did not meet a criteria of ≥ 5 animals per group.

The proportion of each hoof score present within sexes (steer and heifer) can be observed in Table 6. There was no evidence ($P > 0.5196$) to support a difference in the proportion of cattle with each hoof score between steers and heifers.

Table 6. Mean and SEM for the proportion of each hoof, liver, and CHF score present within each sex (steer, heifer) for fed cattle (N = 398).

	Sex					*P*-Value
	n	Steer		Heifer		
Hoof Score[1]		Mean (%)	SEM	Mean (%)	SEM	
Normal (N)	61	14.99	1.87	19.35	7.11	0.5196
Corkscrew (C)	25	6.00	1.24	9.68	5.32	-
Inward Curve (I)	226	56.68	2.60	58.06	8.89	0.8812
Shovel (S)	17	4.63	1.06	0.00	0.00	-
Shovel and Corkscrew (SC)	1	0.27	0.26	0.00	0.00	-
Shovel and Inward Curve (SI)	21	5.72	1.17	0.00	0.00	-
Shovel and Wide (SW)	12	3.27	0.89	0.00	0.00	-
Shovel, Wide, and Inward Curve (SWI)	1	0.27	0.26	0.00	0.00	-
Wide (W)	19	4.36	1.07	9.68	5.32	-
Wide and Inward Curve (WI)	15	3.82	100	3.23	3.18	-
Liver Score[2]						
0 (No Abscess)	346	86.92	1.76	87.10	6.04	0.9778
A-	16	3.54	0.97	9.68	5.32	-
A	22	5.72	1.22	3.23	3.18	-
A+/B	14	3.82	0.96	0.00	0.00	-
CHF Score[3]						
0 (No CHF)	190	45.78	2.61	70.97	8.17	0.0099
1 (Mild CHF)	187	48.77	2.62	25.81	7.88	0.0182
2 (Severe CHF)	21	5.45	1.19	3.23	3.18	-

[1]P-Values are not reported for comparisons of HOOF C, HOOF S, HOOF SC, HOOF SI, HOOF SW, HOOF SWI, HOOF W, and HOOF WI as each category did not meet a criteria of ≥ 5 animals per group.
[2]P-Values are not reported for comparisons of LIVER A-, LIVER A, and LIVER A+/B as each category did not meet a criteria of ≥ 5 animals per group.
[3]P-Values are not reported for comparisons of CHF 2 within sex as each category did not meet a criteria of ≥ 5 animals per group.

The proportion of cattle with each hoof conformation score present within each hide color recorded is reported in Table S2. Hide colors were sorted into two categories (any black present, no black present) and the proportion with each hoof score within those categories is noted in Table 7. There was no evidence ($P = 0.1463$) to support a difference in the proportion of cattle in the black-hided category versus the non-black hided category within each hoof score.

Table 7. Mean and SEM for the proportion of each hoof, liver, and CHF score within each hide color category for fed cattle (N = 398).

		Hide Color Category[1]				*P*-Value
		Black		No Black		
Hoof Score[2]	n	Mean (%)	SEM	Mean (%)	SEM	
Normal (N)	61	14.66	2.02	17.58	4.00	0.4985
Corkscrew (C)	25	6.52	1.41	5.50	2.40	0.7258
Inward Curve (I)	226	57.33	2.83	54.95	5.23	0.6878
Shovel (S)[2]	17	4.89	1.23	2.20	1.54	-
Shovel and Corkscrew (SC)[2]	1	0.33	0.29	0.00	0.00	-
Shovel and Inward Curve (SI)	21	4.89	1.23	6.60	2.61	0.5252
Shovel and Wide (SW)[2]	12	3.26	1.02	2.20	1.54	-
Shovel, Wide, and Inward Curve (SWI)[2]	1	0.33	0.29	0.00	0.00	-
Wide (W)	19	3.91	1.11	7.69	2.80	0.1463
Wide and Inward Curve (WI)[2]	15	3.91	1.11	3.30	1.88	-
Liver Score[3]						
0 (No Abscess)	346	85.34	2.02	92.31	2.80	0.0906
A-[2]	16	4.56	1.19	2.20	1.54	-
A[2]	22	6.52	1.41	2.20	1.54	-
A+/B[2]	14	3.58	1.06	3.30	1.88	-
CHF Score						
0 (No CHF)	190	49.27	3.01	42.99	5.94	0.3725
1 (Mild CHF)	187	45.27	2.98	52.07	5.98	0.3321
2 (Severe CHF)[4]	21	5.54	1.31	4.40	2.15	-

[1]Hide colors are defined as: Black (includes animals that were black or black and white hided), No Black (includes animals that were red, red and white, gray, gray and white, tan, or tan and white hided).
[2]P-Values are not reported for comparisons of HOOF S, HOOF SC, HOOF SW, HOOF SWI, and HOOF WI as each category did not meet a criteria of ≥ 5 animals per group.
[3]P-Values are not reported for comparisons of LIVER A-, LIVER A, and LIVER A+/B as each category did not meet a criteria of ≥ 5 animals per group.
[4]P-Values are not reported for comparisons of CHF 2 within hide color as each category did not meet a criteria of ≥ 5 animals per group.

Relationships between liver abscesses, carcass characteristics, and hide color

Average HCW, REA, and FT were compared between liver scores for cattle and can be observed in Table 8. They are reported as means ± SE. There was no evidence (P = 0.1032) to support a difference in HCW between liver scores. For cattle with LIVER 0, average HCW was

459.15 ± 2.39 kg. For cattle with LIVER A-, average HCW was 433.11 ± 11.04 kg. For cattle with LIVER A the average HCW was 449.04 ± 9.63 kg. Cattle with LIVER A+/B yielded an average HCW of 453.90 ± 11.80 kg.

Table 8. Mean and SE for hot carcass weight (HCW), ribeye area (REA), and fat thickness (FT) for each liver score for fed cattle (N = 398).

	Independent Variable								
	HCW (kg)			REA (cm)			FT (cm)		
Liver Score	n	LS Means	SE	n	LS Means	SE	n	LS Means	SE
0 (No Abscess)	341	459.15	2.39	218	103.59	0.67	217	1.79	0.02
A-	16	433.11	11.04	8	96.94	3.47	8	1.85	0.09
A	21	449.04	9.63	14	102.73	2.81	14	1.79	0.07
A+/B[1]	14	453.90	11.80	12	108.07	1.75	12	1.71	0.07
Overall P-Value		0.1032			0.1597			0.6052	

[1]Liver scores A+ and B were combined for these analyses.

There was no evidence (P = 0.1597) to support a difference for REA between LIVER 0 (103.59 ± 0.67 cm^2), LIVER A- (96.94 ± 3.47 cm^2), LIVER A (102.73 ± 3.47 cm^2), and LIVER A+/B (108.07 ± 1.75 cm^2). There was no evidence (P = 0.6052) to support a difference for mean FT between liver scores. Average FT for cattle with LIVER 0 was 1.79 ± 0.02 cm, LIVER A- was 1.85 ± 0.09 cm, LIVER A was 1.79 ± 0.07, and Liver A+/B was 1.71 ± 0.07 cm.

Comparisons between the proportion of each liver abscess score across each quality grade observed in this study are reported in Table 4. There was no evidence (P = 0.7577) to support a difference between the proportion of cattle with a LIVER 0 that graded Prime (90.32 ± 5.33%), Choice (87.07 ± 1.89%), or Select (84.44 ± 5.42%). Comparisons between means for cattle with LIVER A-, LIVER A, and LIVER A+/B within each QG were not completed as these groups did not meet the requirement of ≥ 5 animals to complete analyis. Cattle with LIVER A- comprised 6.45 ± 4.43% of those that graded Prime, 3.47 ± 1.03% of those that graded Choice, and 6.67 ± 3.73% of those that graded Select. Cattle with LIVER A comprised 3.23 ± 3.19% of those that graded Prime, 5.68 ± 1.31% of those that graded Choice, and 4.44 ± 3.08% of those that graded Select. Lastly, cattle with LIVER A+ and LIVER B comprised 0.00 ± 0.00% of those that graded Prime, 3.79 ± 1.03% of those that graded Choice, and 0.44 ± 2.96% of those that graded Select.

The proportion of cattle with each liver score distributed across YG is reported in Table 5. There was no evidence (*P* = 0.7174) to support a difference between the proportion of cattle with LIVER 0 within YG 2 (87.72 ± 4.36%), YG 3 (85.40 ± 2.14%), YG 4 (92.59 ± 3.57%), or YG 5 (90.00 ± 9.51%). Cattle that scored LIVER 0 within the YG 1 (100.00 ± 0.00%) category were not included in this comparisons and scores LIVER A-, LIVER A, and LIVER A+/B were not included as those groups did not meet the requirement of ≥ 5 animals to complete analyis.

The proportion of cattle with each liver score within each sex (steer, heifer) is reported in Table 6. There was no evidence (*P* = 0.9778) to support a difference between the proportion of steers within LIVER 0 (86.92 ± 1.76%) and the proportion of heifers within LIVER 0 (87.10 ± 6.04%). Comparisons between the proportion of steers and heifers with each liver score: A-, A, and A+/B were not performed as each of those groups did not meet the requirement of ≥ 5 animals to complete analyis.

The proportion of cattle with each liver score present within each hide color observed is reported in Table S3. Hide colors were broken down into two groups (any black present, no black present) to determine differences between the presence of liver scores. Those results are reported in Table 7. Cattle with LIVER 0 (no abscesses present) with no black on their hides tended (*P* = 0.0906) to have a greater prevalence (92.31 ± 2.80%) than cattle with black present on their hides (85.34 ± 2.02%). Comparisons between mean prevalence of LIVER A-, LIVER A, and LIVER A+/B within hide color are not reported as those groups did not meet the requirement of ≥ 5 animals to complete analyis. The proportion of cattle that had black on their hide within

LIVER A- was 4.56 ± 1.19%, and the proportion of cattle that did not have black on their hide was 2.20 ± 1.54%. Cattle with LIVER A comprised 6.52 ±1.41% of the black hided group, and 2.20 ± 1.54% of the non-black hided group. Lastly, cattle with LIVER A+/B comprised 3.58 ± 1.06% of those with any black on their hide, and 3.30 ± 1.88% of those without black on their hides.

Relationships between congestive heart failure, carcass characteristics, and hide color

Sample values for HCW, REA, and FT between heart scores can be observed in Table 9 and are reported as mean ± SE. Cattle with CHF 1 (463.60 ± 3.24 kg) were heavier (P = 0.0254) than those with no CHF (451.15 ± 3.22 kg). However, there was no evidence (P = 1.000) to support a difference in HCW between CHF scores 0 and 2 (454.26 ± 9.85 kg), or 1 and 2.

Table 9. Mean and SEM for hot carcass weight (HCW), ribeye area (REA), and fat thickness (FT) for each congestive heart failure (CHF) score for fed cattle (N = 398).

	Independent Variable								
	HCW (kg)			REA (cm)			FT (cm)		
CHF Score	n	LS Means	SE	n	LS Means	SE	n	LS Means	SE
0 (No CHF)	187	451.51[b]	3.22	112	103.17	0.93	111	1.79	0.02
1 (Mild CHF)	185	463.60[a]	3.24	124	104.51	0.88	124	1.78	0.02
2 (Severe CHF)	20	454.26[ab]	9.85	16	98.63	2.46	16	1.83	0.06
Overall P-Value		0.0295			0.0711			0.7420	

[a,b,c,d]Superscripts that differ within a column identify significant differences between carcass characteristics within CHF scores across placements ($P \leq 0.05$)

Cattle with CHF 1 (n = 124) tended (P = 0.0711) to have the largest REA (104.51 ± 0.88 cm^2), followed by cattle with CHF 0 (n = 112) (103.17 ± 0.93 cm^2), and cattle with CHF 2 (n = 16) (98.63 ± 2.46 cm^2). There was no evidence (P = 0.7420) to support a difference between the mean FT for each CHF score (0, 1, 2) in this study.

The proportion of cattle with CHF 0, CHF 1, and CHF 2 within each QG is reported in Table 4 as mean ± SE. There was no evidence ($P > 0.1846$) to support a difference between the proportion of animals within each CHF score that graded Prime, Choice, and Select. Comparisons of means between the prevalence of CHF 2 within each QG were not made, due to the requirement of requirement of ≥ 5 animals needed per group to complete analyis.

The proportion of cattle with CHF scores 0, 1, and 2 within each YG is reported in Table 5. Cattle with YG 1 tended ($P = 0.0808$) to have the greatest proportion of cattle with CHF 0 (68.38 ± 26.70%), followed by YG 3 (51.94 ± 3.07%), and YG 2 (35.14 ± 6.43%). For comparisons between means, CHF 0 for YG 1 and 5 were not included as they did not meet the requirement of ≥ 5 animals to complete analysis. The proportion of cattle with CHF 0 within YG 1 was 68.38 ± 26.70% and the proportion within YG 5 was 21.28 ± 13.36%. For comparisons between means, cattle with a CHF 1 within YG 1 (31.73 ± 26.77%) were not included as they did not meet the requirement of ≥ 5 animals to complete analyis. Cattle with CHF 1 tended ($P = 0.0922$) to vary across YG as their presence was 68.44 ± 15.05% of the animals with YG 5, followed by 59.52 ± 6.61% of those with YG 2, then 52.30 ± 6.91% of those with YG 4, and lastly 42.49 ± 3.04% of those with YG 3. For cattle within CHF 2, there were no comparisons between means for their prevalence within each YG, as those groups did not meet the requirement of ≥ 5 animals to complete analyis. The proportion of cattle within CHF 2 comprising the YG 1 group was 0.00 ± 0.00%, the proportion of cattle within YG 2 was 5.26 ± 2.97%, the proportion within YG 3 was 5.47 ± 1.38%, the proportion within YG 4 was 3.70 ±2.58%, and the proportion within YG 5 was 10.00 ± 9.51%.

The proportion of each CHF score represented within sexes (steer, heifer) is reported in Table 6. A greater ($P = 0.0099$) proportion of heifers (70.97 ± 8.17%) had CHF 0 than steers

(45.78 ± 2.61%). Alternatively, more (P = 0.0182) steers (48.77 ±2.62%) had a CHF 1 than heifers (25.81 ± 7.88%). Comparisons between the proportion of steers and heifers within CHF 2 were not completed as those groups did not meet the requirement of ≥ 5 animals to complete analyis. The proportion of steers within CHF 2 was 5.45 ± 1.19%, and the proportion of heifers was 3.23 ± 3.18%.

The proportion of each CHF score present within each hide color observed is reported in Table S4 (%, proportion, 95% CI). Hide color was consolidated into two categories (any black present, no black present) and reported in Table 7. There was no evidence (P > 0.3321) to support a difference between the proportion of cattle with black present versus the proportion without black present for each CHF score. The proportion of cattle within CHF 2 within each hide category was not included in statistical comparisons, as those groups did not meet the requirement of ≥ 5 animals per group to complete analyis.

Cattle with more than one production disease

Table 10 reports the proportion of cattle with multiple disorders present. Cattle with two disorders present comprised 56.03% (223/398) of those in this study. Within that group, 43.22% (172/398) had at least one hoof abnormality and CHF present, 11.81% (47/398) had a hoof abnormality and a liver abscess present, and 6.28% (25/398) had a liver abscess and CHF present. There were 21 animals (5.28%, 21/398) who had all three disorders present: hoof abnormalities, liver abscesses, and congestive heart failure.

Table 10. Proportion of fed cattle (N = 398) with either two or three conditions present (hoof abnormality present, liver abscess present, and/or CHF present).

Conditions Present	% of cattle in subset (proportion)
2 conditions present	56.03% (223/398)
Hoof Abnormality and Liver Abscess Present	11.81% (47/398)
Hoof Abnormality and CHF Present	43.22% (172/398)
Liver Abscess and CHF Present	6.28% (25/398)
3 conditions present (Hoof Abnormality, Liver Abscess, and CHF Present)	5.28% (21/398)

The proportion of cattle with liver abscesses within each hoof score can be observed in Table S5. The prevalence of each liver score within hoof scores is reported in Table 11. There was no evidence (P = 0.7686) to support a difference between the proportion of cattle with LIVER 0 within HOOF N (91.80 ± 3.55%), HOOF C (80.00 ± 8.08%), HOOF I (85.40 ± 2.37%), HOOF S (88.24 ± 7.89%), HOOF SI (100.00 ± 0.00%), HOOF SW (75.00 ± 12.63%), HOOF W (89.47 ± 7.11%), or HOOF WI (93.33 ± 6.51%). HOOF SC (100.00 ± 0.00%) and HOOF SWI (100.00 ± 0.00%) were not included in comparisons between means for presence of CHF 0 as those groups did not meet the requirement of ≥ 5 animals to complete analyis. For the remaining liver scores indicating the presence of abscesses (A-, A, A+/B) comparisons were not made between prevalence within each hoof score as those groups did not meet the requirement of ≥ 5 animals to complete analyis.

Table 11. Mean and SEM for the proportion of each liver score present within each hoof score for fed cattle (N = 398).

	Liver Score							
	0 (No Abscess)[1]		A-[2]		A[2]		A+/B[2]	
Hoof Score	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Normal (N)	91.80	3.55	1.64	1.61	3.28	2.13	3.28	2.16
Corkscrew (C)	80.00	8.08	4.00	3.88	12.00	6.08	4.00	3.71
Inward Curve (I)	85.40	2.37	4.43	1.36	6.20	1.50	3.98	1.23
Shovel (S)	88.24	7.89	5.88	5.66	0.00	0.00	5.88	5.41
Shovel and Corkscrew (SC)	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Shovel and Inward Curve (SI)	95.24	4.70	4.76	4.61	0.00	0.00	0.00	0.00
Shovel and Wide (SW)	75.00	12.63	8.33	7.91	16.67	10.06	0.00	0.00
Shovel, Wide, and Inward Curve (SWI)	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wide (W)	89.47	7.11	5.26	5.08	0.00	0.00	5.26	4.85
Wide and Inward Curve (WI)	93.33	6.51	0.00	0.00	6.67	6.02	0.00	0.00
Overall P-Value	0.7686		-		-		-	

[1]P-Values are not reported for comparisons of LIVER 0 within HOOF SC and HOOF SWI as each category did not meet a criteria of ≥ 5 animals per group.
[2]P-Values are not reported for comparisons of LIVER A-, A, and A+/B within hoof score as each category did not meet a criteria of ≥ 5 animals per group.

The proportion of cattle with CHF present for each hoof score can be observed in Table S5. The proportion of cattle with CHF scores 0, 1, and 2 within each hoof score is reported in Table 12. There was no evidence (P = 0.7446) to support a difference between the prevalence of cattle with score CHF 0 within HOOF N (40.38 ± 6.44%), HOOF C (42.85 ± 10.17%), HOOF I (50.30 ± 3.41%), HOOF S (37.35 ± 12.05%), HOOF SI (54.60 ±11.00%), W (34.45 ± 11.16%), or HOOF WI (60.61 ± 12.84%). Means for HOOF SC (100.00 ± 0.00%), HOOF SW (60.48 ± 14.20%), and HOOF SWI (0.00 ± 0.00%) were not included in comparisons for CHF 0 as those groups did not meet the requirement of ≥ 5 animals to complete analyis. There was no evidence (P = 0.5761) to support a difference for the proportion of cattle that scored CHF 1 within HOOF

N (54.57 ± 6.53%), HOOF C (44.77 ± 10.22%), HOOF I (44.95 ± 3.39%), HOOF S (62.77 ± 12.04%), HOOF SI (40.82 ± 10.82%), HOOF W (60.05 ± 11.54%), and HOOF WI (39.45 ± 12.84%). Cattle with HOOF SC (0.00 ± 0.00%), HOOF SW (23.46 ± 12.14%), and HOOF SWI (100.00 ± 0.00%) were not included in this comparison as those groups did not meet the requirement of ≥ 5 animals to complete analyis. There was no evidence (P = 0.8603) to support a difference between the prevalence of CHF 2 within HOOF I (4.87 ± 1.39%) and HOOF SI (4.76 ± 4.50%). Comparisons between means for HOOF C (12.00 ± 6.30%), HOOF N (4.92 ± 2.68%), HOOF S (0.00 ± 0.00%), HOOF SC (0.00 ± 0.00%), HOOF SW (16.67 ± 10.42%), HOOF SWI (0.00 ± 0.00%), HOOF W (5.26 ± 4.96%), and HOOF WI (0.00 ± 0.00%) were not reported as those groups did not meet the requirement of ≥ 5 animals to complete analyis.

Table 12. Mean and SEM for the proportion of each congestive heart failure (CHF) score present within each hoof score for fed cattle (N = 398).

	CHF Score					
	0 (No CHF)		1 (Mild CHF)		2 (Severe CHF)[2]	
Hoof Score	Mean	SEM	Mean	SEM	Mean	SEM
Normal (N)	40.38	6.44	54.57	6.53	4.92	2.68
Corkscrew (C)	42.85	10.17	44.77	10.22	12.00	6.30
Inward Curve (I)	50.30	3.41	44.95	3.39	4.87	1.39
Shovel (S)	37.35	12.05	62.77	12.04	0.00	0.00
Shovel and Corkscrew (SC)[1]	100.00	0.00	0.00	0.00	0.00	0.00
Shovel and Inward Curve (SI)	54.60	11.00	40.82	10.82	4.76	4.50
Shovel and Wide (SW)[1]	60.48	14.20	23.46	12.14	16.67	10.42
Shovel, Wide, and Inward Curve (SWI)[1]	0.00	0.00	100.00	0.00	0.00	0.00
Wide (W)	34.45	11.16	60.05	11.54	5.26	4.96
Wide and Inward Curve (WI)	60.61	12.84	39.45	12.84	0.00	0.00
Overall P-Value	0.7446		0.5761		0.8603	

[1]P-Values are not reported for comparisons of HOOF SC, HOOF SW, and HOOF SWI between CHF score as each category did not meet a criteria of ≥ 5 animals per group.
[2]P-Values are not reported for CHF 2 within HOOF C, HOOF N, HOOF S, HOOF SC, HOOF SW, HOOF SWI, HOOF W, and HOOF WI as each category did not meet a criteria of ≥ 5 animals per group.

The proportion of animals with each liver score within CHF categories is reported in Table 13. There was no evidence to support differences (*P* = 0.4955) in the proportion of cattle with LIVER 0 within CHF 0 (85.79 ± 2.54%), CHF 1 (88.77 ± 2.32%), and CHF 2 (80.95 ± 8.60%). For the remaining liver scores (A-, A, and A+/B) comparisons between means were only completed between CHF 0 and CHF 1, as the categories within CHF 2 did not meet the requirement as those groups did not meet the requirement of ≥ 5 animals to complete analyis.

Table 13. Mean and SEM for the proportion of each liver score present within each congestive heart failure (CHF) score for fed cattle (N = 398).

	CHF Score						Overall *P*-Value
	0 (No CHF)		1 (Mild CHF)		2 (Severe CHF)		
Liver Score[1]	Mean (%)	SEM	Mean (%)	SEM	Mean (%)	SEM	
0 (No Abscess)	85.79	2.54	88.77	2.32	80.95	8.60	0.4955
A-	4.21	1.46	3.74	1.39	4.76	4.67	-
A	5.79	1.70	4.28	1.49	14.29	7.67	-
A+/B	4.21	1.42	3.21	1.26	0.00	0.00	-

[1]P-Values are not reported for LIVER A-, LIVER A, and LIVER A+/B within CHF 2 as each category did not meet a criteria of ≥ 5 animals per group.

DISCUSSION

Hoof Abnormalities

Eighty-five percent of cattle in this study had at least one hoof abnormality. Most studies that exist evaluating hoof abnormalities focus on dairy cattle. Fjeldaas et al. (2011) assessed several dairy herds and reported a 24.2% prevalence of corkscrew claw. Fjeldaas et al. (2011) did not report whether cattle had twisting in the horn of the hoof or just an inward curve. In our study, a total of 6.48% had a corkscrew claw, which is less than Fjeldaas et al. (2011) and 56.61% had an inward curve, which is greater than Fjeldaas et al. (2011). It is possible that the proportion of cattle experiencing any level of twisting in the horn capsule has increased since the proportion reported as corkscrew claw in 2010. At the time of our study, there were no published data evaluating the presence of corkscrew hooves in beef cattle; however, Fjeldaas et al. (2011) accounted for a variety of laminitis-related lesions and reported a prevalence of 25.9%. Freitas et al. (2023) reported that 8.75% of 24 mo. old Nellore bulls had clinical laminitis. These bulls were confined to stalls for 20 d and then measured for evidence of clinical laminitis. This was closer to what we observed for *Bos taurus* fed beef cattle. One animal in our study had a shovel claw and a corkscrew present. Huang et al. (1995) evaluated hoof characteristics in five different breeds of lactating and dry dairy cows and reported that corkscrew claw was highly correlated with laminitis (represented in this study as shovel claw). Although we observed only one animal with corkscrew and shovel hoof, it is possible that more animals could develop this disorder based on the findings of Huang et al. (1995). Odegard et al. (2014) studied both corkscrew claw and laminitis-related lesions, concluding that there is a small potential for genetic predisposition to laminitis, and management of conformation issues such as corkscrew claw must be done with genetic changes for future generations of cattle.

Liver Abscesses

Thirteen percent of cattle in this study had one or more liver abscesses. A total of 86.78% of cattle in this study had normal livers, which is consistent with the findings of Baier et al. (2020) who reported that 87.05% of crossbred beef steers (N = 363) had no liver abscess. The cattle in the Baier et al. (2020) were fed a diet including steam-flaked corn and silage, similar to the cattle in this study. Losada-Espinosa et al. (2021) scored livers in feedlot cattle, free-range cattle, and dairy cattle and reported a total proportion of 3.17% from those combined populations having liver condemnations, which aligns with the 3.49% of cattle with liver scores A+ and B in this study. Baier et al. (2020) scored liver abscesses in categories of mild liver abscess presence (MLA) (equivalent to LIVER A) and severe liver abscess presence (equivalent to LIVER A+) (SLA) in *Bos taurus,* beef-type cattle. Baier et al. (2020) also reported 5.79% of livers to be MLA and 6.61% being SLA, which yields a smaller proportion of more severe liver abscesses than this study indicating an overall increase in severe liver abscesses in a similar group of cattle since 2020. The most recent NBQA reported that 45% of livers were condemned in 2022, with the leading cause being liver abscesses (NBQA, 2022). This is greater than what was observed in this study, but represents a broader group of cattle types, breeds, and feeding regions.

Congestive Heart Failure

Fifty-two percent of cattle in this study had heart scores of 1 and 2, indicating the development of CHF. Forty-eight percent of cattle had no signs of CHF. Kukor et al. (2023) measured CHF in beef-on-dairy (breed composition including Angus, Simmental, Jersey, and Holstein) fed cattle in Texas (1,103 m elevation) and reported 73.13% had heart scores which indicate no presence of CHF, which is greater than what was observed in this study, but was with dairy-influence cattle. The same study measured beef-on-dairy (breed composition including Angus, Simmental, Jersey, and Holstein) fed cattle in western Kansas (elevation: 846 m) and reported 89.13% had heart scores indicative of no presence of CHF, which is greater than what was observed for the same type of cattle in Texas (elevation: 1,417 m) (Kukor et al., 2023). Heffernan et al. (2020) measured CHF scores for Black Angus cattle fed in Wyoming (elevation: 2,165 m) and reported 78.65% had heart scores indicating no presence of CHF. Among the previously completed studies, our study had the greatest proportion of cattle with no presence of heart changes indicating CHF. Buchanan et al. (2023) reported the CHF score of fed cattle at an elevation of 756 m. Culminating all of the beef-breed types, 87.65% of cattle in that observational study had heart scores indicating no presence of CHF. Kukor et al. (2021) also reported the proportion of fed cattle (elevation: 1,062 m) harvested in the winter months in the southern region of the United States with no presence of CHF at 66%. Forty-seven percent of cattle in this study scored CHF 1, indicating mild changes leading to CHF. For the Kukor et al. (2023) beef-on-dairy cattle, 22.71% had mild heart changes indicating CHF in Texas (elevation: 1,103 m) and 9.66% in Kansas (elevation: 846 m). Heffernan et al. (2020) measured CHF in black angus cattle in Wyoming (elevation: 2,165 m) and reported 15.73% had mild presence of CHF. Approximately 5% of cattle in this study scored CHF 2, indicating severe changes suggestive of CHF. Heffernan et al. (2020) observed a greater proportion of cattle (5.62%) at a higher elevation (elevation: 2,165 m) with severe CHF. Buchanan et al. (2023) reported that 2.84% of cattle (elevation: 756 m) had severe CHF present. Kukor et al. (2023) reported that 4.16% of cattle had severe CHF in Texas (elevation: 1,103) and 1.2% in western Kansas (elevation: 846 m). There are genetic factors which contribute to congestive heart failure; Grandin (2024) noted that deaths associated with congestive heart failure were traced back to one single Angus sire. These genetic differences are supported by the reduced prevalence of signs of congestive heart failure in cattle with dairy-influence. Other contributing factors to the development of CHF include elevation (Heaton et al., 2019), muscle mass (Pauling et al., 2023), and previous respiratory illnesses (Hussein and Staufenbiel, 2014). The use of ionophores in cattle production poses a risk to cattle if a toxic dose were consumed. However, this is rare in production settings. For example, the lethal dose of monensin for a 600 kg steer would be 15,000 mg (Galitzer et al., 1986), whereas the approved range is 50-360 mg per day for that animal (Elanco, 2019).

4.4 Relationships between hoof conformation, carcass characteristics, and hide color

Cattle with a wide-toe and inward curve were lighter than cattle with only an inward curve, cattle with a corkscrew hoof, or cattle with a shovel hoof. In this study, all cattle were <30 mos. of age which is generally younger than lactating dairy cows. Boettcher et al. (1998) postulated that body weight relative to frame size might be a more important contributing factor than overall carcass weight. Additionally it may be important to identify breed differences in overall capacity for weight gain and how those factors impact lameness in a feedlot setting.

There was no evidence to support a difference in average REA between assessed hoof scores. Boettcher et al. (1998) reported that clinical lameness is more commmon among the daughters of bulls breeding for wider rumps, which is a muscling trait that could be represented by REA size. Further investigation of the relationship between muscling and lameness in feedlot cattle is needed.

There was no evidence to support a difference in QG or YG between hoof scores. Despite this, several other papers have noted that decreased body condition is associated with clinical lameness (Boettcher et al., 1998; Manson and Leaver, 1988). While this study did not evaluate lameness, it did report hoof conformation scores deviating from normal, which is an issue that has been discussed throughout literature as a linkage (Murray et al., 1996; Odegard et al., 2014; Franks and Grandin, 2015; Cortes et al., 2021) to lameness. Potential causes of the association between lameness and decreased body condition include thinning of the fat pad at the sole of the foot compounded by the assumption that lameness causes pain, making cattle less likely to walk to the feed-bunk and stand or compete with other cattle for space to eat, resulting in reduced feed intake (Manson and Leaver, 1988).

There was no evidence to support a difference within each hoof score for hide color category (black, not black). The results suggest that the disorder may have shared etiology across breed-types, rather than just a condition of one breed-type.

Relationships between liver abscesses, carcass characteristics, and hide color

There was no evidence to support a difference in HCW between liver scores. Fox et al. (2009) scored livers on beef cattle that were either in a control group (natural), or administered one of two vaccines: Fusobacterium necrophorum (FNB) or Arcanobacterium pyogenes-Fusobacterium necrophorum toxoid (APFNT) and observed that in all groups, cattle with severe liver abscesses at slaughter had a lighter HCW than cattle without severe liver abscesses. A potential reason for consistent HCW across liver abscess scores in this study could be contributed to the low proportion of cattle with severe liver abscesses (3.52%).

There was no evidence to support a difference between the proportion of cattle with each liver score between QG or YG. Fox et al. (2009) evaluated cattle fed under natural conditions (cattle could not receive antibiotics or growth-promoting hormones) and reported a decrease in the proportion of cattle with liver abscesses grading Choice as compared to Select (Fox et al., 2009). This difference may not have been seen in our sample due to the conventional-based feeding program these animals were sourced from. Regarding YG, our findings are consistent with those of Fox et al. (2009) who reported that liver abscesses had no effect on YG.

Of the cattle with no liver abscesses (LIVER 0) there was a greater proportion of animals without black on their hides (92.31 ± 2.80%) than animals with black present on their hides (85.34 ± 2.02%). These proportions are consistent with observations by Baier et al. (2020) on *Bos taurus* beef cattle who reported that 87.2% of black hided cattle had no liver abscesses and

90.91% of non-black hided cattle had no liver abscesses. This warrants further investigation to determine the true genetic impact of hide color on the potential to develop liver abscesses.

Relationships between congestive heart failure (CHF), carcass characteristics, and hide color

Cattle with CHF 1 were heavier than cattle with CHF 0. Buchanan et al. (2023) observed that cattle with severe CHF had significantly lighter HCW than cattle with mild CHF or no CHF. Heffernan et al. (2020) also reported that as CHF score increased, HCW decreased. Based on the findings of this study, it is possible that a heavy HCW is associated with the early stages of CHF. Further investistigation is warranted to address these concerns.

Cattle with CHF 1 tended to have the largest REA, followed by cattle with no CHF, and then lastly cattle with severe CHF. The REA size difference between cattle with CHF 0 and CHF 2 is corroborated by the findings of Heffernan et al. (2020) who observed that as the severity of CHF increased, REA decreased. Pauling et al. (2023) supported this finding as they reported a positive genetic correlation (0.25 ± 0.12) between PAP score and REA. Pulmonary Arterial Pressure score indicates the presence and severity of pulmonary hypertension, which can cause right sided heart failure. In this case, a positive correlation (an increase in PAP score that indicated an increase in REA size) is undesirable, as it indicates that breeding for REA size can also lead to a greater (i.e. less favorable) PAP score (Pauling et al., 2023). This is especially concerning because producers have been working toward an overall increase in REA, which is economically favorable to the fed beef industry (Woerner, 2025).

There was no evidence to support a difference between the proportion of animals within each CHF score that graded Prime, Choice, and Select. These findings are consistent with those of Buchanan et al. (2023) who reported that marbling scores - a similar measurement to QG - did not differ between heart score categories for a variety of fed cattle (cow-calf, beef-on dairy, and dairy bred). The findings of Buchanan et al. (2023) and the present study differ from those of Heffernan et al. (2020), who observed that marbling appeared to increase from cattle with no presence of CHF to a mild presence of CHF, but then decreased as CHF became more severe.

Cattle with no CHF tended to compose the greatest proportion of those with YG 1, followed by YG 3, and then YG 2. Cattle with mild signs of CHF tended to compose the greatest proportion of those with YG 5, followed by YG 2, then YG 4, and lastly YG 3. Again, further investigation is warranted to determine if there is a true relationship between the presence of mild CHF and each specific YG. Buchanan et al. (2023) observed that cattle with severe CHF had a significantly higher YG than cattle with no CHF, indicating that the presence or increase in severity of CHF has the potential to be linked to fatter carcasses. The tendency for cattle with CHF 0 to have a lower YG and CHF 1 to have a higher YG supports this finding as well.

A greater proportion of heifers had normal hearts than steers. Alternatively, more steers had mild CHF than heifers. This could be explained by the findings of Johnson et al. (2021) that indicated fed steers impacted by CHF died later in the feeding period than heifers, leading to the consideration of survival bias which could not be accounted for in this slaugther establishment data collection. Neary et al. (2016) obtained data from five feedlots in the U.S. and reported that steers had 39% greater odds of having CHF than heifers. Additionally, there was an observed variation in HCW in this study, where steers had an average HCW of 462.95 ± 2.14 kg and heifers were 392.22 ± 5.74 kg. This might be a contributing factor to a difference in the presence of CHF as well, based on our findings relative to CHF and HCW.

There was no difference between the proportion of cattle with black present and the proportion of cattle with no black present between CHF score. Buchanan et al. (2023) reported that Angus breed type fed cattle had the greatest percentage of severe CHF in comparison to all other breed types observed, and cattle classified as a crossbreed of Charolais, Angus, or Hereford had the least observed prevalence of severe CHF at 1.42%. Breeding cattle with black on their hide is desirable due to a consumer-driven support of beef marketing programs (USDA-AMS, 2017). Angus cattle can have two hide colors: black, and red, and are a prevalent breed in the fed beef industry; however, our comparison between cattle with black present on their hides and cattle without black present is not in line with the findings of Buchanan et al. (2023) for Angus cattle and cattle of other breeds. This result, as well as industry tendencies to crossbreed animals, suggests that a proportion of cattle in our study categorized as having black present on their hide were likely comprised of multiple breeds. It is important to evaluate genetic factors related to CHF in cattle as hide color and breed are economic drivers of the fed beef industry.

Relationships between production diseases

Cattle with two disorders present comprised 56.03% (223/398) of those in this study There were 21 animals (5.28%, 21/398) who had all three disorders present: hoof abnormalities, liver abscesses, and congestive heart failure. There was no evidence to support a difference in the proportion of cattle with each liver absscess score within each hoof score category, or with each CHF score within each hoof score. There was no evidence to support a difference in the proportion of cattle with each liver score within each CHF score. Recent literature has evaluated relationships between production diseases (hoof conformation issues, liver abscesses, and congestive heart failure) and carcass characteristics, hide color, and sex in feedlot cattle (Irshad et al., 2012; Baier et al., 2020; Heffernan et al., 2020). However, to the authors' knowledge, this is the first study directly evaluating the differences in hoof abnormalities between CHF and liver abscess scores, as well as the relationships between liver abscesses and CHF. Although this study reported limited relationships between these production diseases, the presence of differences in common carcass characteristics as identified by hoof, liver, and CHF scores indicates a need to continue research in these areas to inform improvements in breeding, nutrition, and management choices.

CONCLUSION

Eighty-five percent of the *Bos taurus* beef animals (N = 398) in this small sample from a single large feedlot had hoof abnormalities present at slaughter, 52% had signs of CHF, 13% had liver abscesses, and 5% had all three disorders present. There were no differences within the proportion of hoof abnormalities, liver abscesses, and CHF scores in this group of cattle. There are 25 million steers and heifers slaughtered in the U.S. each year, this study represents only a portion of animals from one sample feedlot. Although this was an observational study on a convenience sample of animals, it is important to monitor these production diseases as we make selection and management decisions. Ultimately, all three of these diseases impact animal welfare and cause a financial loss during the feeding period or at slaughter.

In addition to their prevalence, multiple diseases yielded significant differences in HCW and sex. This study consisted of a mixed group of steers (n = 367) and heifers (n = 31) which is not proportional to what is typically seen in the fed beef industry in this region, it is important to be mindful of those differences between sex, which were represented in this paper. Cattle with both a wide toe and inward curve had significantly lighter carcasses than cattle with only an inward curve, and cattle with only a shovel hoof. Cattle with mild CHF had heavier carcasses than cattle with no CHF. It is possible that severe hoof abnormalities can impact an animal's ability to feed and result in lighter HCW. This may be associated with genetic selection for weight gain. There was a greater proportion of steers with heart scores indicative of CHF than heifers. Likely there are genetic linkages to CHF which result from an overall larger animal and carcass size. Further research on the direct cause of these issues would benefit the fed beef industry so that producers can work towards preventing them in the future.

SUPPLEMENTARIES

Table S 1. Proportion of hoof abnormality, liver abscess, and congestive heart failure (CHF) prevalence within categories of hot carcass weight (HCW), hide color, quality grade (QG), yield grade (YG), ribeye area (REA), and fat thickness (FT) for fed cattle (N =398).

Attribute	% of cattle in subset (Proportion)	Hoof Abnormality Present[1], % (Proportion)	Liver Abscess Present[2], % (Proportion)	CHF Present[2], % (Proportion)
Hide Category				
Black	64.57 (257/398)	84.82 (218/257)	13.62 (35/257)	50.97 (131/257)
Black and White	12.56 (50/398)	88.00 (44/40)	20.00 (10/50)	64.00 (32/50)
Smoke	6.78 (19/398)	70.37 (19/27)	11.11 (3/27)	51.85 (14/27)
Gray and White	1.51 (23/398)	10.00 (6/6)	16.67 (1/6)	16.67 (1/6)
Red	4.77 (27/398)	89.47 (17/19)	0.00 (0/19)	63.16 (12/19)
Red and White	5.78 (6/398)	82.61 (19/23)	8.70 (2/23)	43.48 (10/23)
Tan	3.77 (15/398)	86.67 (13/15)	6.67 (1/15)	46.67 (7/15)
Tan and White	0.25 (1/398)	100.00 (1/1)	0.00 (0/1)	100.00 (1/1)
Carcass Size by Weight Category				
272.11 – 317.01 kg	0.51 (2/392)	50.00 (1/2)	0.00 (0/2)	100.00 (2/2)
317.46 – 362.36 kg	1.79 (7/392)	100.00 (7/7)	0.00 (0/7)	42.86 (3/7)
362.81 – 407.71 kg	9.95 (39/392)	79.49 (31/39)	20.51 (8/39)	51.28 (20/39)
400.16 – 453.06 kg	32.40 (127/392)	85.04 (108/127)	17.32 (22/127)	41.73 (53/127)
453.51 – 498.41 kg	39.03 (153/392)	84.31 (129/153)	11.11 (17/153)	54.90 (84/153)
498.87 – 543.76 kg	14.29 (56/392)	85.71 (48/56)	7.14 (4/56)	66.07 (37/56)
544.22 – 589.12 kg	2.04 (8/392)	87.50 (7/8)	0.00 (0/8)	75.00 (6/8)
Actual Fat Thickness				
1.02 – 1.24 cm	1.59 (4/251)	75.00 (3/4)	0.00 (0/4)	75.00 (3/4)
1.27 – 1.50 cm	8.76 (22/251)	72.73 (16/22)	18.18 (4/22)	77.27 (17/22)
1.52 – 1.75 cm	37.06 (94/251)	79.79 (75/94)	13.83 (13/94)	47.87 (45/94)
1.78 – 2.01 cm	35.06 (88/251)	89.77 (79/88)	13.64 (12/88)	55.68 (49/88)
2.03 – 2.26 cm	13.55 (34/251)	94.12 (32/34)	11.76 (4/34)	61.76 (21/34)
2.29 – 2.51 cm	3.18 (8/251)	87.50 (7/8)	12.50 (1/8)	50.00 (4/8)
2.54 – 2.77 cm	0.40 (1/251)	100.00 (1/1)	0.00 (0/1)	100.00 (1/1)
Rounded Scanned REA				
64.52 – 70.33 cm^2	0.40 (1/252)	0.00 (0/1)	0.00 (0/1)	100.00 (1/1)
70.97 – 76.78 cm^2	0.40 (1/252)	100.00 (1/1)	100.00 (1/1)	0.00 (0/1)
77.42 – 83.23 cm^2	2.38 (6/252)	100.00 (6/6)	16.67 (1/6)	83.33 (5/6)
83.88 – 89.68 cm^2	4.37 (11/252)	90.91 (10/11)	0.00 (0/11)	63.64 (7/11)
90.33 – 96.13 cm^2	14.68 (37/252)	91.89 (34/37)	16.22 (6/37)	45.95 (17/37)
96.78 – 102.59 cm^2	30.16 (76/252)	80.26 (61/76)	10.53 (8/76)	55.26 (42/76)
103.23 – 109.04 cm^2	17.46 (44/252)	88.64 (39/44)	18.18 (8/44)	47.27 (21/44)
109.68 – 115.49 cm^2	19.44 (49/252)	87.76 (43/49)	14.29 (7/49)	61.22 (30/49)
116.14 – 121.94 cm^2	7.14 (18/252)	77.78 (14/18)	11.11 (2/18)	55.56 (10/18)
122.59 – 128.39 cm^2	2.78 (7/252)	71.43 (5/7)	14.29 (1/7)	85.71 (6/7)
129.04 – 134.85 cm^2	0.79 (2/252)	50.00 (1/2)	0.00 (0/2)	50.00 (1/2)
USDA Yield Grade				
1	0.75 (3/398)	100.00 (3/3)	0.00 (0/3)	80.00 (12/15)
2	14.32 (57/398)	84.21 (48/57)	12.28 (7/57)	53.85 (49/91)
3	68.84 (274/398)	82.85 (227/274)	14.60 (40.274)	47.37 (45/95)
4	13.57 (54/398)	90.74 (49/54)	7.41 (4/54)	65.85 (27/41)
5	2.51 (10/398)	100.00 (10/10)	10.00 (1/10)	77.78 (7/9)
USDA Quality Grade				
Prime	7.88 (31/393)	100.00 (31/31)	12.93 (41/317)	51.10 (162/317)

Choice	80.66 (317/393)	83.60 (265/317)	9.68 (3/31)	64.52 (162/317)
Select	11.45 (45/393)	80.00 (36/45)	15.56 (7/45)	53.33 (24/45)

*Categories for HCW, REA, and FT were designed by sorting each measurement into categories of 100 lbs., 1 in^2, and 0.1 in, respectively, and then converted into their corresponding metric units.

[1]Hoof Abnormality Present indicates the proportion of cattle that had one or more hoof abnormalities (HOOF C, HOOF I, HOOF S, HOOF SC, HOOF SI, HOOF SW, HOOF SWI, HOOF W, HOOF WI).

[2]Liver Abscess Present indicates the proportion of cattle that had a liver abscess (LIVER A-, LIVER A, LIVER A+, LIVER B).

[3]CHF Present indicates the proportion of cattle that had CHF (CHF 1, CHF 2).

Table S 2. 95% confidence intervals for hoof scores[1] present within each hide color for fed cattle (N = 398).

	Hoof Score																			
	Normal		Corkscrew		Inward Curve		Shovel		Shovel and Corkscrew		Shovel and Inward Curve		Shovel and Wide		Shovel, Wide, and Inward Curve		Wide		Wide and Inward Curve	
Hide Color	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI
Black	15.18 (39/257)	11.02 to 20.16	5.84 (15/257)	3.30 to 9.44	57.20 (147/257)	20.90 to 63.33	5.45 (14/257)	3.01 to 8.97	0.39 (1/27)	0.00 to 2.15	4.67 (12/257)	2.44 to 8.01	3.50 (9/257)	1.61 to 6.54	0.39 (1/257)	0.00 to 2.15	3.50 (9/257)	1.61 to 6.54	3.89 (10/257)	1.88 to 7.04
Black and White	12.00 (6/50)	4.53 to 24.31	10.00 (5/50)	3.33 to 21.81	58.00 (29/50)	43.21 to 71.81	2.00 (1/50)	0.05 to 10.65	0.00 (0/50)	0.00 to 7.11	6.11 (3/50)	1.25 to 16.55	2.00 (1/50)	0.05 to 10.65	0.00 (0/50)	0.00 to 7.11	6.00 (3/50)	1.25 to 16.55	4.00 (2/50)	0.49 to 13.71
Red	10.53 (2/19)	1.30 to 33.14	5.26 (1/19)	0.13 to 26.03	42.11 (8/19)	20.25 to 66.50	10.53 (2/19)	1.30 to 33.14	0.00 (0/19)	0.00 to 17.65	5.26 (1/19)	0.13 to 26.03	10.53 (2/19)	1.30 to 33.14	0.00 (0/19)	0.00 to 17.65	10.53 (2/19)	1.30 to 33.14	5.26 (1/19)	0.13 to 26.03
Red and White	17.39 (4/23)	4.95 to 38.78	4.35 (1/23)	0.11 to 21.95	56.52 (13/23)	34.49 to 76.81	0.00 (0/23)	0.00 to 14.82	0.00 (0/23)	0.00 to 14.82	8.70 (2/23)	1.07 to 28.04	0.00 (0/23)	0.00 to 14.82	0.00 (0/23)	0.00 to 14.82	8.70 (2/23)	1.07 to 28.04	4.35 (1/23)	0.11 to 21.95
Gray	29.63 (8/27)	13.75 to 50.18	7.41 (2/27)	0.91 to 24.29	51.85 (14/27)	31.95 to 71.33	0.00 (0/27)	0.00 to 12.77	0.00 (0/27)	0.00 to 12.77	3.70 (1/27)	0.09 to 18.97	0.00 (0/27)	0.00 to 12.77	0.00 (0/27)	0.00 to 12.77	7.41 (2/27)	0.91 to 24.29	0.00 (0/27)	0.00 to 12.77
Gray and White	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	66.67 (4/6)	22.28 to 95.67	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	16.67 (1/6)	0.42 to 64.12	16.67 (1/6)	0.42 to 64.12
Tan	13.33 (2/15)	1.66 to 40.46	6.67 (1/15)	0.17 to 45.93	66.67 (10/15)	38.38 to 88.18	0.00 (0/15)	0.00 to 21.80	0.00 (0/15)	0.00 to 21.80	13.33 (2/15)	1.66 to 40.46	0.00 (0/15)	0.00 to 21.80	0.00 (0/15)	0.00 to 21.80	0.00 (0/15)	0.00 to 21.80	0.00 (0/15)	0.00 to 21.80
Tan and White	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0.00 to 97.50	100.00 (1/1)	2.50 to 100.00	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50	0.00 (0/1)	0..00 to 97.50

Table S 3. 95% confidence intervals for the proportion of each liver abscess score present within each hide color category for fed cattle (N = 398).

	Liver Score									
	0 (No Abscess)		A-		A		A+		B	
Hide Color	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI
Black	86.38 (222/257)	81.57 to 90.33	5.45 (14/257)	3.01 to 8.97	6.23 (16/257)	3.60 to 9.91	1.95 (5/257)	0.63 to 4.48	0.00 (0/257)	0.00 to 1.43
Black and White	80.00 (40/50)	66.28 to 89.97	0.00 (0/50)	0.00 to 7.11	8.00 (4/50)	2.22 to 19.23	12.00 (6/50)	4.53 to 24.31	0.00 (0/50)	0.00 to 7.11
Red	1.00 (19/19)	82.35 to 1.00	0.00 (0/19)	0.00 to 17.65	0.00 (0/19)	0.00 to 17.65	0.00 (0/19)	0.00 to 17.65	0.00 (0/19)	0.00 to 17.65
Red and White	91.30 (21/23)	71.96 to 98.93	4.34 (1/23)	0.11 to 21.95	0.00 (0/23)	0.00 to 14.82	0.00 (0/23)	0.00 to 14.82	4.35 (1/23)	0.11 to 21.95
Gray	88.89 (24/27)	70.84 to 97.65	0.00 (0/27)	0.00 to 12.77	7.41 (2/27)	0.91 to 24.29	3.70 (1/27)	0.09 to 18.97	0.00 (0/27)	0.00 to 12.77
Gray and White	83.3 (5/6)	35.88 to 99.58	16.67 (1/6)	0.42 to 64.12	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93	0.00 (0/6)	0.00 to 45.93
Tan	93.3 (14/15)	68.05 to 99.83	0.00 (0/15)	0.00 to 21.80	0.00 (0/15)	0.00 to 21.80	6.67 (1/15)	0.17 to 31.95	0.00 (0/15)	0.00 to 21.80
Tan and White	100.00 (1/1)	2.50 to 100.00	0.00 (0/1)	0.00 to 97.50	0.00 (0/1)	0.00 to 97.50	0.00 (0/1)	0.00 to 97.50	0.00 (0/1)	0.00 to 97.50

Table S 4. 95% confidence intervals for congestive heart failure (CHF) score (0, 1, 2) within hide color for fed cattle (N = 398).

	CHF Score					
	0 (No CHF)		1 (Mild CHF)		2 (Severe CHF)	
Hide Color	% (Proportion)	95% CI	% (Proportion)	95% CI	% (Proportion)	95% CI
Black	49.42 (126/257)	43.15 to 55.70	45.53 (117/257)	39.33 to 51.83	5.45 (14/257)	3.01 to 8.97
Black and White	36.00 (18/50)	22.92 to 50.81	58.00 (29/50)	43.21 to 71.81	6.00 (3/50)	1.25 to 16.55
Red	36.84 (7/19)	16.29 to 61.64	57.89 (11/19)	33.50 to 79.75	5.26 (1/19)	0.13 to 26.03
Red and White	56.52 (13/23)	34.49 to 76.81	43.48 (10/23)	23.19 to 65.51	0.00 (0/23)	0.00 to 14.82
Smoke	48.15 (13/27)	28.67 to 68.05	44.44 (12/27)	25.48 to 64.67	7.41 (2/27)	0.91 to 24.29
Gray and White	83.33 (5/6)	35.88 to 99.58	0.00 (0/6)	0.00 to 45.93	16.67 (1/6)	0.42 to 64.12
Tan	53.33 (8/15)	26.59 to 78.73	46.67 (7/15)	21.27 to 73.41	0.00 (0/15)	0.00 to 21.80
Tan and White	0.00 (0/1)	0.00 to 97.50	100.00 (1/1)	2.50 to 100.00	0.00 (0/1)	0.00 to 97.50

Table S 5. Proportion and percent of liver abscess and congestive heart failure (CHF prevalence for each hoof score)1 for fed cattle (N = 398).

Hoof Score	Liver Abscess Present[1], % (Proportion)	CHF Present[2], % (Proportion)
Normal	8.20 (5/61)	59.02 (36/61)
Corkscrew	20.00 (5/25)	56.00 (14/25)
Inward Curve	14.60 (33/226)	50.00 (113/226)
Shovel	11.76 (2/17)	64.71 (11/17)
Shovel and Corkscrew	0.00 (0/1)	0.00 (0/1)
Shovel and Inward Curve	4.76 (1/21)	47.62 (10/21)
Shovel and Wide	25.00 (3/12)	41.67 (5/12)
Shovel, Wide, and Inward Curve	0.00 (0/1)	100.00 (1/1)
Wide	10.53 (2/19)	63.16 (12/19)
Wide and Inward Curve	6.67 (1/15)	40.00 (6/15)

[1]Liver Abscess Present indicates the proportion of cattle that had a liver abscess (LIVER A-, LIVER A, LIVER A+, LIVER B).
[2]CHF Present indicates the proportion of cattle that had CHF (CHF 1, CHF 2).

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LIST OF ABBREVIATIONS

AAA: American Angus Association

ADG: Average Daily Gain

CHF: Congestive Heart Failure

CFR: Code of Federal Regulations

HOOF C: Corkscrew

CI: Confidence Interval

FSIS: Food Safety Inspection Service

FT: Fat Thickness

HCW: Hot Carcass Weight

HOOF I: Inward Curve

IACUC: Institutional Animal Care and Use Committee

HOOF N: Normal

NASS: National Agricultural Statistics Service

BQA: Beef Quality Audit

PAP: Pulse Arterial Pressure

QG: Quality Grade

REA: Ribeye Area

HOOF S: Shovel

HOOF SC: Shovel and Corkscrew

HOOF SI: Shovel and Inward Curve

HOOF SW: Shovel and Wide Toe

HOOF SWI: Shovel, Wide Toe, and Inward Curve

USDA: United States Department of Agriculture

HOOF W: Wide Toe

HOOF WI: Wide Toe and Inward Curve

YG: Yield Grade