

From calf ranch to harvest: health outcomes, management practices, and performance of beef-on-dairy cattle

by

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AN ABSTRACT OF A DISSERTATION

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DOCTOR OF PHILOSOPHY

Department of Diagnostic Medicine/ Pathobiology
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Abstract

Breeding practices within the dairy industry have shifted to using beef semen to breed cows and have led to the increased production of crossbred beef-on-dairy calves that enter the beef supply chain. Similar to dairy replacement heifers, beef-on-dairy calves are separated from their dams shortly after birth and transported to calf ranches. A calf ranch is an off-site operation that raises calves from birth to a targeted weight or age depending on the marketing plans for that animal. The objective of this dissertation was to evaluate management practices, welfare, health, and performance of beef-on-dairy cattle from calf ranch through harvest.

First, a survey of 15 commercial calf ranches was conducted. The survey focused on management of beef-on-dairy calves and consisted of 10 sections related to ranch demographics, calf arrival protocols, pre-weaning housing, starter feed, and milk offering, post-weaning housing and feed management, and health challenges and protocols. Results were descriptive, reported as frequencies of participants' answers calculated as percentage of operations for each question. This survey revealed substantial variability in management practices across operations, highlighting a lack of standardized protocols for raising beef-on-dairy calves.

Next, two cross-sectional observational studies were conducted focused on mortalities within commercial calf ranches. The first was conducted during the summer of 2023 at 2 calf ranches to report the frequency of causes of mortality and determine associations of breed (dairy vs. beef-on-dairy), sex (female vs. male), and days of age (< 30, 30 to 59, 60 to 89, > 90 days) with mortality diagnosis as determined via gross necropsy. Gastrointestinal (GI) and respiratory diagnoses were identified in high frequencies in young calves (18.5% and 71.1%, respectively), and the probability of GI and respiratory diagnoses were associated with days of age but not breed nor sex. Calves > 60 days of age were at greater risk for respiratory diagnoses compared to

calves < 30 days of age, 88% vs 37%, respectively. In contrast, probability of a GI mortality diagnosis was greater for calves < 30 days of age compared to calves between 60 and 89 days of age, 46% vs 5%.

The second cross-sectional observational necropsy study was conducted over 12 months to identify primary and co-morbidities in mortalities at commercial calf ranches and determine whether relative risk of RESP or GI diagnoses in mortalities varied by season (Period 1: Feb, Mar, Apr, May; Period 2: June, July; Aug, Sept; Period 3: Oct, Nov, Dec, Jan), sex (female vs. male), breed (dairy vs. beef-on-dairy), or ranch. Respiratory diagnoses were the most common (67.5%; 164/243) followed by GI (11.5%; 28/243). The location of GI lesions (none, upper GIT, lower GIT, or both upper and lower GIT) was also analyzed for associations with season, sex, breed, or ranch. Risk of diagnosing a calf with respiratory at time of necropsy or finding at least 1 GI lesion did not differ between season, sex, breed, or calf ranch. Location of GI lesion was also not significantly associated with season, sex, breed, or calf ranch.

Next, a complete randomized block design was used (n = 26 male beef-on-dairy calves) to determine if a single topical dose of maternal bovine appeasing substance (MBAS) would decrease cortisol concentrations in blood, produce changes in behavior, and improve performance outcomes during and following weaning. Calves were randomly allocated to receiving a dose of MBAS or saline (CONT). Calves were housed individually in pens and stepped down from 2 bottles of milk to none over 3 days. Blood was collected to determine cortisol concentration. Accelerometers and cameras were used to assess behavior. Feed offerings and refusals were measured, and body weights were collected to assess performance. Cortisol concentrations were lower for CONT vs MBAS calves. No treatment effects were identified for performance metrics. Several treatment by time interactions were found for behaviors with

CONT having more lying bouts than MBAS calves on day 0, the first day of step-down weaning, and day 2. This study demonstrated that MBAS altered behavior during weaning, but it did not improve performance or reduce stress, as indicated by blood cortisol compared to CONT.

The fifth study was a prospective, observational study designed to determine the probability of treating a calf within 12 days of an adjacent calf being treated for diarrhea or respiratory disease. Hutch location and daily health records were collected for 9,756 calves. Calves treated for diarrhea or respiratory disease without an adjacent calf treated in the previous 12 days were classified as “noncontact”, whereas calves with an adjacent calf treated were classified as “contact”. The probability of treatment for both diseases was estimated based on contact status, age category, and their interaction. Daily probability of treatment for both diseases was significantly affected by the interaction between contact status and age. Calves < 30 days old (vs > 30 days) had higher probability of diarrhea treatment. For respiratory disease, contact calves had a higher probability of treatment within each age group; although magnitude of difference varied by age. These findings indicate proximity between hutches may influence disease and should be considered when managing the health of calves within a calf ranch.

The final two studies investigated associations between various predictor variables and liver abscess (LA) prevalence at harvest in beef-on-dairy cattle during the finishing phase. The first study evaluated associations between origin, feedyard performance, and health metrics with LA at harvest in beef-on-dairy cattle. Feedyard data and liver scores were collected from two sources (Dataset 1 (D1) = 330 cohorts; Dataset 2 (D2) = 386 cohorts). For D1, a modified version of Elanco’s scoring system was used and 4 outcomes of interest were created (Total LA = all scores (D1TA), Severe LA = scores A+, A+Adhered (A+Ad), A+Open (A+Op) (D1SA), Severe+ LA = scores A+Ad, A+Op (D1S+A), and Severe LA as proportion of Total LA (D1ST)).

Dataset 2 used an in-house scoring system with non-mutually exclusive categories: Abscessed which consisted of livers with any abscess present (D2TA), Adhered which included livers with any adhesion present (D2AdL), and Condemned which consisted of livers deemed unfit to enter production chain and were condemned (D2CL). Multiple risk factors such as sex, days on feed (DOF), average shipping weight, percentage of cohort railed, and origin were associated with D1TA, D1SA, D1S+A, and D1ST. Average daily gain and quarter harvested were associated with D2TA and D2CL. Average shipping weight and origin were also associated with D2TA. The only risk factor associated with D2AdL was sex. Steer cohorts had higher probability ($P \leq 0.05$) of D1TA, D1SA, D1S+A, D1ST, and D2AdL than heifer cohorts. Cohorts on feed > 300 days had higher probability ($P \leq 0.05$) of D1TA, D1SA, and D1S+A than cohorts with fewer DOF. Cohorts with shipping weights of 680 to 725 kg had higher risk ($P = 0.03$) of D1SA than those > 726 kg. Cohorts with < 0.5% railed had lower probability ($P \leq 0.04$) of LA outcomes than those with > 0.5% railed. Cattle harvested in quarter 3 had lower risk ($P \leq 0.03$) of D2TA compared to quarter 4 and D2CL compared to all other quarters. Cohorts originating from region 3 had lower risk ($P \leq 0.05$) of D1TA, D1SA, D1S+A, and D1ST than those from regions 1 and 4. These results identify factors associated with LA in beef-on-dairy cattle; further research is needed to determine management strategies to mitigate LA occurrence.

The second LA study used feed intake data to determine the association of LA prevalence at harvest with feeding patterns in beef-on-dairy cattle during the finishing phase. Cohort-level closeout and daily feed delivery records were collected from 5 feedyards ($n = 378$ cohorts). Livers were scored using a modified version of Elanco's scoring system, and the same categories were used from the previous study: Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe LA as proportion of Total LA (ST). Feeding patterns were described using several

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In conclusion, this body of work advances understanding of beef-on-dairy calf management, health, and performance across the production system, from calf ranch to harvest. These findings demonstrate that factors such as calf age and proximity to calves previously treated may affect morbidity and mortality outcomes within the calf ranch. Additionally, origin, demographics, and feeding behaviors were associated with liver abscess outcomes identified at harvest, highlighting critical opportunities for intervention in the calf ranch and finishing phases.

Together, these results highlight the need for more standardized, data-driven management strategies to improve animal health, welfare, and performance in the growing beef-on-dairy production system.

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Chapter 1 - Beef-on-dairy calf management practices in commercial calf ranches

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Abstract

The number of beef-on-dairy calves being produced has been steadily increasing. Many calves are sent off-site to calf ranches for raising after birth. The objective of this survey was to describe management practices of beef-on-dairy calves in commercial calf ranches. A total of 15 calf ranches were surveyed in 3 regions: the High Plains (n = 7), Midwest (n = 6), and West (n = 2). Operation capacities were categorized as less than 1,000, between 1,000 and 20,000, 20,000 to 50,000, and greater than 50,000 calves. All operations received calves less than 4 days of age. There was a variety of types of pre-weaning housing. Almost all operations fed milk replacer with one operation feeding saleable milk; feeding protocols (timing and quantity) varied among operations. Every operation offered calf starter upon arrival, but formulation of starter differed among ranches. Weaning age ranged between 42 and 72 days with about 53% of operations weaning calves at 60 days or greater. Calves spent anywhere between 0 and 180 days in a group pen setting. Thirty-three percent of operations moved calves through multiple group pens post-weaning. Similarly, 33% of operations transitioned calves through multiple diets once they were

in group pens. Most operations fed the transition/grower diet ad libitum, however the ingredients used were variable among operations. All operations administered at least 2 health products such as vaccines, antimicrobials, etc. while the calf was on the property. These results provide important information regarding the management of beef-on-dairy calves at commercial calf ranches.

Introduction

In recent years, the use of semen from beef sires has become increasingly common within the dairy industry to produce beef-on-dairy calves. From 2022 to 2023, the National Association of American Breeders reported a shift in semen sales to an increased number of units of beef semen, 1.5 million units, sold while dairy semen sales decreased by 2.5 million units, indicating a shift in breeding practices within the dairy industry (Weiker, 2024a). Separating calves from their dams as young as one day of age is a common practice within the dairy industry. In 2007, the USDA National Animal Health Monitoring System (NAHMS) survey reported that about 1 in 10 operations raised some dairy heifers off the operation, and by 2014, approximately one-fourth of all heifer calves were raised off-site (USDA, 2010a; USDA, 2021a). These off-site operations are often termed calf ranches or calf raising facilities. A calf ranch can be defined as an operation that raises calves from a young age to a specific weight or age dependent on the production plan for those animals.

Previous literature has reported management practices that are implemented at preweaned replacement heifer raising facilities (USDA, 2010a; USDA, 2012; Urie et al., 2018a; USDA, 2021a). Additionally, there have been surveys conducted with beef cow-calf producers to record herd management practices in the U.S. and Canada (USDA, 1997a; Hanzlicek et al., 2013; Woolums et al., 2013; Murray et al., 2016). However, little to no information is published

regarding the management of beef-on-dairy cross calves in commercial calf ranches. In 2007, Walker et al. (2012) conducted a cross-sectional study with calf ranches that exclusively reared heifers and operations that raised a mix of heifer and bull calves. Of all the preweaned calves raised on the mixed operations, a median of 73% were heifers and 23% were bulls (Walker et al., 2012). However, there was no specification as to the breed of the bull calves being raised. Machado and Ballou (2022) completed a literature review to summarize the common management practices associated with calf raising facilities in the U.S.; however, the authors highlighted the lack of knowledge surrounding management of beef-on-dairy calves and advocated for more research to be completed in this area. There have been surveys conducted with replacement heifer raising facilities, however, there has only been speculation that beef-on-dairy calves on the same operations may be managed differently. Therefore, the objective of this study was to describe common management practices of beef-on-dairy calves implemented on commercial calf ranches.

Materials and Methods

This survey (#IRB-11903) was reviewed by the Institutional Review Board (IRB) for Kansas State University and deemed exempt from further review. The survey was designed by the authors in discussion with commercial calf ranch owners, managers, and consulting veterinarians. Participants were identified through personal communication with consulting veterinarians. Due to this approach, the sampling can be described as a convenience sample. This resulted in a small sample size of 15 calf ranches. A comprehensive survey was developed to collect information regarding the management practices implemented at commercial calf ranches feeding beef-on-dairy calves. The survey was focused on management of beef-on-dairy calves and consisted of 74 questions. To be included in the research, the operation had to raise beef-on-

dairy calves in some proportion. For operations that raised both dairy and beef-on-dairy calves, data was not collected on management of the dairy animals. There were 10 sections of the survey including general information/ranch demographics, calf arrival processing procedures, pre-weaning housing, milk feeding protocol, starter feed formulation and feeding protocol, water offerings, weaning protocol, movement/management of group pens, transition/grower diet formulation and feeding protocol, and health challenges and vaccine/treatment protocols. The participants were not required to answer any questions that they were not comfortable with or if they had proprietary information/protocols that could not be shared.

For general information/ranch demographics, there were 8 questions. One multiple-choice question pertained to whether the calf ranch, dairy, or a combination of the two owned the calves being raised. This section also included questions about the participant interviewed, the capacity of the ranch, and population demographics related to the proportion of beef-on-dairy and dairy replacement heifers raised. The section about calf arrival processing consisted of 11 questions. Six of the questions were about the age of the calves, number received, frequency of receipt, and regions from which the operations received calves. When asked about where they receive calves from, each operation was provided with a map that was used in the “Health Management on U.S. Feedlots 2021 Phase 1 Questionnaire” (USDA-APHIS, 2020a). The remaining 5 questions asked about the specific practices performed on all calves upon arrival at the ranch including tagging, castration, metaphylaxis, etc. The section for pre-weaning phase housing consisted of 8 questions, 6 of which were multipart. First, the participants were asked if they housed preweaned calves in group pens or individually. Then, depending on that answer, they were directed to multipart questions describing the housing. The participants were asked about housing calves indoors/outdoors, in hutches or individual pens, specific characteristics

about the housing such as if hutches/pens were elevated, total square footage, distance between hutches/pens, and whether the ranch provided bedding or not.

The milk feeding portion had 14 questions. When asked about type of milk fed, the participants could choose up to 3 choices: milk replacer, nonsaleable/discount milk, saleable milk. If they chose more than one type, they were asked to report the percentage of each type they fed. They were also asked about formulation of milk replacers, pasteurization protocols, target percent protein and fat, the addition of anything to the milk such as vitamins, minerals or antibiotics, their milk feeding protocol and the method of feeding. Questions about milk feeding protocol were structured into a table where the participants were asked how many times calves were fed per day, quantity fed, and how those might change as the calf aged. Similarly, there was a table for starter feed for the surveyor (RB) to record the ration type (pelletized, total mixed ration (TMR), texturized feed), the times fed per day, the quantity fed and how that may change as the calf aged. This section also consisted of close-ended questions regarding the formulation of the starter diet. These included whether the starter feed included roughages, grains, liquids, and/or feed additives, and if so, what kind. The section about water consisted of 5 questions about when water was first offered, how it was offered, how often it was changed out, frequency of thawing ice in the winter, and frequency of cleaning the buckets/troughs/drinkers.

The weaning section consisted of 7 questions related to weaning age of calves, reasons calves may be weaned earlier/later, criteria used to make weaning decisions, age calves are moved to group pens, and reasons calves may be moved earlier or later to group pens. The first question of the group pen section was structured into a table where the surveyor (RB) recorded the number of different group pens that calves were moved through, the number of head per pen, the size/dimensions of the pen, and the linear bunk space. The remaining 7 questions were

related to pen environment such as bedding, enrichment, cleaning of the pens, and cleaning of the bunks and waterers. For the transition/grower feed, there was another table to record the ration type, number of times fed per day, and quantity fed in relation to age of the calf. Similar to the starter feed section, the participants were asked about the formulation of the diet and what ingredients were used.

For health, participants were first asked about measuring serum total protein. Next, they were asked about their vaccine/health protocol. The 6 calf ranches from the Midwest all used the same consulting veterinarian, so for the health section, those participants' answers were counted as 1 observation due to the fact they had the same health protocol. The participants were not required to give the specific vaccines used, only the type of vaccines and at what age the vaccines were given. For example, the surveyor (RB) listed off the different kinds such as viral respiratory, bacterial respiratory, autogenous, clostridial, scours, or other. Next, questions were asked about respiratory and digestive diseases. Participants were asked about treatment protocols for each disease listing only the type of product such as an antimicrobial, anti-inflammatory, electrolytes, or other products. They were then asked about precautions taken in adverse weather events such as winter storms or heat waves. Finally, they were asked about whether they kept individual treatment records.

Between November 2023 and June 2024, surveys were conducted in-person ($n = 13$) or face-to-face via video call on Microsoft Teams ($n = 2$). For the in-person visits, the participant would give the surveyor (RB) a tour of the facility while answering questions followed by sitting down to verify that all questions were answered. The survey answers were then entered into a Microsoft Form upon return to Kansas State University. Data cleaning and summarization was performed using Microsoft Excel and pivot tables. All questions were answered by every

operation unless the question was not applicable (N/A). For example, one operation shipped calves to a different location immediately following weaning, so any questions about post-weaning housing and feed were N/A. Categorization of answers was completed post hoc. The surveyor examined every question and the answers to determine whether answers could be summarized when appropriate. For example, total capacities were summarized as less than 1,000, 1,000 to 50,000, and greater than 50,000. Frequencies of participants' answers were calculated as a percentage of operations for each question to describe the management practices used at calf ranches.

Results

General Information/Ranch Demographics

The calf ranches were located in Kansas (n = 4), Texas (n = 2), New Mexico (n = 1), Indiana (n = 4), Ohio (n = 2), and California (n = 2). The ranches from Kansas, Texas and New Mexico were categorized as the High Plains region. The ranches from Indiana and Ohio were grouped into the Midwest region, and the California ranches were classified as the West region. In total, 15 calf ranches were surveyed with 47% (7/15) residing in the High Plains region, 40% (6/15) from the Midwest, and 13% (2/15) from the West. Of the surveys, 2 were conducted with the operation's veterinarian, 4 were with the general manager, and 9 were conducted with the owner of the operation. The operations were classified as either a calf ranch only (12/15; 80%) or a combination of a calf ranch and dairy (3/15; 20%). None of the calf ranches had sole ownership of the calves, as 60% of the operations reported the dairies where calves were born/received from retained ownership and 40% reported a combination of the dairies and calf ranch owning the calves. Size of operation was categorized with 40% (6/15) of ranches having a capacity of less than 1,000 calves, 13% (2/15) between 1,000 and 20,000, 20% (3/15) between 20,000 to 50,000,

and 27% (4/15) having a capacity greater than 50,000 calves. All ranches that had a capacity of 1,000 calves or less exclusively raised beef-on-dairy calves. Operations between 1,000 to 20,000 calves raised a proportion of beef-on-dairy calves between 50 and 70% of their total capacity, and those that had a capacity between 20,000 and 50,000 raised between 14 and 100% beef-on-dairy. Operations that were greater than 50,000 head raised a proportion of beef-on-dairy calves between 35 and 70% of their total capacity.

Calf Arrival Processing Procedures

Most of the operations (67%) received calves when they were 2 to 4 days of age, and 33% received calves that were 0 to 1 day of age. The number of calves received at one time varied from less than 100 to greater than 250 calves with 33% receiving less than 100, 33% receiving between 100 and 250, and the final 33% receiving greater than 250 calves at one time. For frequency of receiving calves, 47% received new loads of calves daily, 13% received loads once to twice a week, and 40% received loads every 5 weeks or longer. The 40% that received loads every 5 weeks or longer were all located in the Midwest region. When asked if frequency of receiving calves fluctuated based on season, 60% reported “Yes”, and 40% reported “No”. Of the 9 operations that reported changes based on season, 3 reported that fall was their busiest season for receiving calves, 2 winter, 1 spring, and 3 in the summer. Based on the provided map, 20% (3/15) of the operations received calves from a state in region 1, 33% (5/15) received from a state in region 2, 27% (4/15) received from a state in region 3, 60% (9/15) received from a state in region 4, 13% (2/15) received from a state in region 5, and 40% (6/15) received calves from a state in region 6. No operations received calves from region 7 or 8. Eight of the operations (53%) received calves from multiple regions. This is the reason the percentages above are greater than 100% when summed.

For arrival processing of all calves, 40% of operations reported they tag calves with their own form of identification. For castration, 47% of operations used banding as their preferred castration method, and 53% of operations performed surgical castration. Twenty percent of operations castrated calves when they were less than 7 days of age, 33% castrated calves between 7 and 14 days of age, and 47% waited until calves were greater than 14 days of age to castrate. Most operations (87%) reported that they did not feed colostrum to newly received calves. Upon arrival, 33% reported giving an antibiotic metaphylactically to all calves, 53% reported they did not, and 13% reported that they sometimes gave metaphylaxis. One operation gave metaphylaxis in the summer, and the other operation reported they would give metaphylaxis based on the visual assessment of the health of the calves upon arrival.

Pre-weaning Housing

Of all the operations, 6 ranches housed their pre-weaned calves indoors and 9 housed calves outdoors. All operations that housed calves indoors were located in the Midwest. Upon arrival, 60% housed calves individually in hutches, 33% housed calves in individual pens, and 7% housed calves in group pens. For the 9 operations that use hutches, 44% used elevated hutches and 56% did not. As for hutch material, 44% used plastic hutches and 56% used wooden hutches. When asked about total square footage of the hutches/pens, 47% (7/15) reported less than 15 square feet as the dimensions for the hutch/pen, 47% (7/15) reported between 15 and 50 square feet, and 7% (1/15) reported greater than 50 square feet. The operation reporting greater than 50 square feet per calf was the operation that used group pens to house pre-weaned calves. Most calves (80%) were close enough to have nose-to-nose contact with each other. For bedding, 87% reported bedding down hutches/pens. Of those 13 operations, 38% bedded seasonally in the winter and 62% bedded all year round. The material used for bedding consisted of corn stalks,

shavings, or straw. Most operations (62%; 8/13) that provided bedding reported adding new bedding on top of old as needed then cleaning completely between groups of calves. Other operations changed bedding between groups of calves (23%), monthly (7.5%), or weekly (7.5%). When asked about cleaning the hutches/pens, 87% (13/15) reported cleaning them between groups of calves and 13% (2/15) reported never cleaning. Of the 13 operations that do clean their hutches/pens, 23% power-washed them, 15% disinfected them, and 62% power-washed and disinfected them.

Milk Feeding

For the first milk offering, 6 of participants offered milk upon arrival, 3 offered milk within a few hours of arrival, 2 offered milk at the first feeding following arrival, and 4 waited until the second feeding following arrival to offer milk. All participants reported that they assisted the calves with the first feeding, regardless of when the feeding took place, and 73% reported offering milk for the first feeding and the remaining 27% offered electrolytes as the first feeding. Milk feeding protocols varied based on the quantity fed to calves over time (Figure 1). The choices for type of milk fed consisted of milk replacer, nonsaleable milk, saleable milk, or a combination of these types of milk. Nonsaleable milk was defined as milk that was unable to enter the market for human consumption, sometimes described as discounted milk. Saleable milk was defined as milk safe for human consumption but did not enter the market. Of the 15 calf ranches, 47% fed milk replacer only, 27% fed nonsaleable milk in addition to milk replacer, 7% fed saleable milk in addition to milk replacer, 13% fed all three types of milk, and 7% fed only saleable milk. The operations that exclusively fed milk replacer were located in the Midwest. Of those 14 operations that fed milk replacer, 79% fed a commercial brand of milk replacer and 21% made their own milk replacer on site. For feeding nonsaleable milk, 13% (2/15) fed it to all

calves, 27% (4/15) fed it exclusively to calves older than 14 days of age, and the remaining 60% (9/15) of operations did not feed nonsaleable milk. All operations that fed any proportion of nonsaleable or saleable milk pasteurized the milk prior to feeding.

Average target percent protein in the milk replacer for operations consisted of 20 (7%; 1/15), 22 (33%; 5/15), 24 (13%; 2/15), 26 (27%; 4/15), 27 (13%; 2/15) and 36 (7%; 1/15). For average target percent fat in the milk replacer, values ranged from 18 (13%; 2/15), 20 (53%; 8/15), 22 (13%; 2/15), 24 (13%; 2/15), and 30 (7%; 1/15). Of the total participating operations, 7% reported adding antibiotics to the milk, 33% added vitamins and minerals, 53% added vitamins, minerals, and antibiotics, and 7% reported no inclusion of additives to the milk. The types of milk feeders used varied among operations with 73% using bottles, 7% using buckets with a nipple on them, 7% using a milk trough, and 13% using bottles first then switching to open buckets later in the feeding period. For cleaning of bottles, 1 ranch washed the bottles with detergent between each calf and filled with disinfectant overnight, 6 rinsed the bottles with water between each calf and disinfected between each feeding period (after morning feeding and after evening feeding), 5 rinsed and disinfected bottles between each feeding period, 1 rinsed and disinfected between each calf, and 2 did not feed with bottles and therefore did not answer this question. For nipples, 1 operation washed them between calves and washed them twice before each feeding for calves under 20 days of age, 1 disinfected nipples between each calf, 2 rinsed them between each calf and disinfected them between morning and evening feedings, 4 rinsed and disinfected them between each calf, 6 rinsed and disinfected between each feeding, and 1 did not answer as they did not use nipples for feeding as they fed milk in a milk bar/trough. Examples of disinfectants used include acid rinses, iodine soaks, and chlorinated detergents.

Calf Starter Feed

The types of calf starter fed at these operations consisted of pelletized feed (40%), texturized feed (47%), or a TMR (13%). Pelletized feed was defined as feed where all ingredients were combined into a pelleted form. Texturized feed consisted of feed that included a pellet plus roughage. A TMR was a blend of grain, roughage, liquid, feed additive, etc. Most operations (60%) reported the number of times starter was fed changes over time, ranging between 1 to 5 times a day. All but one operation fed starter to calves *ad libitum*, and the remaining operation increased the amount of starter fed from 0.5 pounds to 14 pounds over 14 weeks. Most operations (93%) reported dumping old feed from buckets. Of the 14 operations dumping old feed, 29% would dump feed as needed, 29% did so twice per week, 7% daily, 7% every 2 weeks, 14% based on the weather, 7% based on illness, and 7% reported that whether they dumped feed changed seasonally. For diet formulation, the specific ingredients included can be seen in Table 1. For pelleted feeds, if the presence of roughage and liquids were reported, they were included within the actual pellet. For cleaning of feed buckets in the hutches/pens, 1 ranch cleaned buckets as needed, 10 cleaned buckets between groups of calves, and 4 cleaned buckets every 2 or 3 days.

Water Offerings

Water was first offered to calves upon arrival at 73% of the operations, 1 day following arrival at 20%, and 2 days following arrival at 7%. In operations housing pre-weaned calves individually ($n = 14$), water was offered in buckets at most operations (86%), in automatic drinkers at 7%, and through water lines to each pen with nipples in 7% of operations. The operation that housed pre-weaned calves in group pens provided water in an open trough. The waterers in the pre-weaning phase were cleaned daily in 2 of the operations, twice per week in 4,

weekly in 2, and between groups of calves in 7 of the operations. For post-weaning group housing, 36% (6/14) offered water in big open troughs and 64% (9/14) used automatic drinkers. In the group pens, waterers were cleaned daily in 2 of the operations, twice per week in 1, weekly in 7, between groups of calves in 3, and seasonally-dependent where they were washed twice per week in the summer and weekly in the winter at 1 of the operations. There is one operation that does not house calves post-weaning thus this question was N/A.

Weaning Protocol

For average age completely weaned off milk, 33% weaned calves between 40 and 49 days of age, 13% weaned between 50 to 59 days, 47% between 60 and 69 days, and 7% weaned calves that were greater than 70 days of age. The distribution of weaning age by calf ranch can be seen in Figure 2. All operations used age as the main criteria for making weaning decisions, however, some operations used other criteria in addition to age. For example, 20% of the operations used feed intake as well, 33% considered size of the calf, and 7% took capacity into consideration when making weaning decisions. Most operations (73%) did not have any reason for weaning calves at an earlier age than their cohort, but those that did reported reasons such as capacity, cattle flow, size of the calf, or a combination of capacity, weight, and body condition score. In contrast, fewer operations (33%) reported they did not have any reason to wean a calf at an older age than its cohort, but those that did reported size of the calf, feed intake, cattle flow, capacity, weight, and/or BCS as reasons to wean calves at an older age.

Movement to and Management of Group Pens Post-Weaning

There was one operation that did not move calves into a group pen post-weaning as they shipped calves immediately following the weaning period, therefore results from this section are in reference to 14 of the operations. When transitioning calves into group pens post-weaning,

29% of operations moved calves into group pens between 40 to 59 days of age, 21% moved calves between 60 to 79 days of age, 43% moved calves between 80 to 99 days, and 7% moved calves at an age greater than 100 days as seen in Figure 3. Of the 14 operations that transitioned calves to group pens post-weaning, common reasons that calves may be moved to group pens at an earlier age included capacity (14%), size of calf (7%), a combination of the two (7%), or no reason would influence the operation to transition calves to a group pen earlier (71%). Common reasons for moving calves to a group pen at a later age included capacity (14%), cattle flow (14%), feed intake (7%), health status (14%), size of the calf (21%), a combination of size of the calf and feed intake (7%), or no reason would persuade the operation to deter from the age they usually transition calves (21%). Figure 4 shows the total number of days calves resided in a group pen setting for each operation.

Most operations (64%) moved their calves into one group pen where they resided until they shipped, and the remainder moved calves through multiple group pens. Of the 5 operations that transitioned their calves through multiple pens, one operation moved calves twice while four of the operations moved calves three times through group pens with various pen dimensions and head counts. For operations that moved calves to one group pen where they stayed until shipping, 1 ranch placed calves in pens with less than 50 animals, 3 placed them in pens of 50 to 100 animals, 2 placed them in pens of 101 to 150 animals, 2 placed them in pens with 151 to 200 animals, and the remaining operation placed them in a pen with greater than 200 head. For operations that moved calves through multiple group pens, all the first group pens were 25 animals or less. For the second group pen, 40% (2/5) moved the calves to pens of 40 to 50 animals, 40% (2/5) moved them to pens of 51 to 100 animals, and 20% (1/5) moved calves to a pen of more than 100 animals. Four operations moved calves to a third group pen, where 1

operation housed 40 calves together, 2 operations housed 75 to 80 calves together, and the final operation moved calves to a pen of 120 animals. Most operations (79%) reported that they did sort calves into group pens based on specific criteria. Of the operations that sorted into group pens, 1 operation sorted based on breed alone, 2 operations sorted based on health status, 1 sorted based on owner of the calves, 1 sorted based on the location of the pre-weaning housing, 1 sorted based on where calves were going to ship to after the calf ranch, and the remaining 5 operations sorted based on different combinations of the following criteria: sex, origin, breed, weight, age, and genetics.

For bedding of group pens, 79% reported they do bed year-round, 14% do not, and 7% bed seasonally. Of the 12 operations that do provide bedding, 8% use corn fodder, 17% use corn stalks, 17% use shavings, and 58% use straw. The flooring of various group pens consisted of compacted dirt/gravel (7%), a concrete pad (21%), dirt (14%), or dirt with concrete aprons around the bunks and water sources (57%). For pen enrichment, 50% (7/14) reported they do offer some type of enrichment within the group pens. Of these 7 operations, 71% provided lick tubs or salt blocks within the pens, 14% provided tubs of sand, and 14% provided scratching posts. The majority of participants (79%) reported that group pens were cleaned between groups of calves, 7% cleaned pens as needed, 7% weekly, and the remaining 7% cleaned group pens every 2 months. Group pens were cleaned through scraping (64%), using pitch forks (7%), scraping followed by disinfection of the pen (14%), or unspecified means of cleaning (14%). For bunk cleanliness, 7% cleaned bunks as needed, 21% cleaned bunks daily, 14% did so twice per week, 21% weekly, 7% monthly, and 29% did so between groups of calves.

Transition/Grower Feed

There was one operation that shipped calves immediately following weaning, so that operation did not answer the questions for this section. The type of transition feed at these operations were described as a TMR (57%), texturized feed (14%), or a pelletized feed (14%). The remaining 14% consisted of 2 operations that fed starter until they shipped calves. One operation shipped calves at 42 days of age, and the second operation fed calf starter in the individual pens as well as group housing until calves shipped at 98 days of age. Of the 12 operations that fed a transition diet, the majority of operations (58%) fed one transition diet, 25% fed two different transition diets, 8% fed three different transition diets, and 8% fed a diet with the same ingredients but varying levels of protein throughout the post-weaning phase. The ingredients used for the transition diets can be seen in Table 2. Five of the operations (36%) fed the transition feed just once a day, 4 fed twice a day, 1 fed three times a day, 1 fed six times a day, and 1 ranch fed as needed with an automatic feed delivery system. The remaining 2 operations fed starter feed in the group pens where one operation fed it in bulk and the other fed it biweekly. The majority of operations (64%) fed *ad libitum* in group pens, 29% called bunks, and 7% fed an amount between 14 and 16 pounds. A large portion of the participants (79%) reported cleaning old feed from bunks, and 21% did not. Of the 11 operations cleaning feed out of bunks, 35% did so as needed, 18% did so daily, 9% biweekly, 27% weekly, and the remaining 9% did so depending on the weather. Most operations (86%) did not top-dress the feed in group pens. Two operations top-dressed where one operation added antibiotics for the 1st 3 days in the group pen and the other operation fed a coccidiostat for the 1st week within the group pen.

Health Challenges and Vaccine/Treatment Protocol

The majority of operations (67%) reported that they do not measure serum total protein upon arrival, and of the 5 operations that did measure serum total protein, 3 of them reported the total protein measures back to the dairies they received calves from, 1 used the total protein measurement to build a separate health protocol for high-risk dairies, and 1 used the total protein measurement as verification of calves receiving sufficient colostrum before arriving to the calf ranch. For vaccination protocols, 6 of the ranches used the same consulting veterinarian and all use the same protocol. Due to this, the answers from those operations were counted as 1 rather than 6 observations. The count and percentage of operations that administered different types of health products upon arrival and during pre-weaning is shown in Table 3. The ranches that administered a toxoid, antiparasitic and an implant during the pre-weaning period were all located in the Midwest and used the same consulting veterinarian. The number of products given to a calf in the pre-weaning phase ranged from a minimum of 3 products to 15 products among operations. For the post-weaning phase, the number of products administered ranged from 0 to 6 products. Most operations (80%) reported that their use of vaccines does not vary, and for those that do, cost of the products and disease outbreak were the reasons reported for changing their health protocols.

For treatment of respiratory disease, 73% (11/15) of the participants used an antimicrobial, and 27% (4/15) used an antimicrobial and an anti-inflammatory drug. When treating digestive diseases, there was one operation that treated by giving only IV fluids, while one operation treated digestive disease exclusively with electrolytes, and 12 others treated with electrolytes combined with another therapy. Additional therapies and the percentage of operations that use those to treat respiratory and digestive disease can be seen in Tables 4 and 5,

respectively. For example, approximately 46.7% of operations treated digestive disease with an antimicrobial. Most of the operations (80%) reported that they do keep individual treatment records. Two of the operations that did not keep treatment records were located in the High Plains and the third was in the Midwest.

The final questions for the calf health section of the survey related to precautions taken during winter storms or heat events. The majority of operations (7/15) added extra bedding for winter storms, 1 added an antimicrobial to the water, 1 closed hutches, 1 built windbreaks, 2 built windbreaks and provided extra bedding, 1 provided heaters, extra bedding, and extra feed, and the remaining 2 ranches did not take any precautions for winter weather events. During heat events, most (8/15) operations took no precautions while the remainder (7/15) took precautions such as adding an antimicrobial to the water, closing hutches, turning on fans, spraying cattle with water, providing shade and/or ensuring waterers stay full.

Discussion

The results from this survey were recorded from a population selected by convenience sampling. Therefore, the findings should be interpreted with care and may not be representative of all calf raising facilities within the U.S.

The authors' goal was to describe the management of beef-on-dairy calves at commercial calf ranches since little information has been published in this area. Because of this, broad questions were asked to assess how practices may vary among operations. There have been several national surveys conducted to collect information about replacement dairy heifer calves (Wolf, 2003; USDA, 2010a; USDA, 2012; Walker et al., 2012; USDA, 2021a). In those previous surveys, the population consisted of the East (Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Vermont, Virginia, and Wisconsin) and the West

(Arizona, California, Colorado, Idaho, Kansas, New Mexico, North Dakota, Texas, and Washington) (USDA, 2012). In comparison, the present data consisted of ranches from California (n = 2), Kansas (n = 4), New Mexico (n = 1), Texas (n = 2), Indiana (n = 4) and Ohio (n = 2). The herd sizes defined in previous surveys consisted of small (20 to 99 head), medium (100 to 999 head), and large (1,000 or more) whereas in the current survey the sizes were categorized as less than 1,000 (n = 6), 1,000 to 20,000 (n = 2), 20,000 to 50,000 (n = 3), and greater than 50,000 calves (n = 4) (USDA, 2010a: 200; USDA, 2012).

In the present data, none of the calf ranches solely owned the calves they raise. At 60% of the operations, the dairy of origin retained ownership of the calves, and the remaining 40% was a combination of dairy-owned and calf ranch-owned calves. In 3 surveys conducted asking farmers about their use of beef semen on dairy farms, the majority of respondents in each survey reported marketing their calves prior to the finishing phase (Halfman and Sterry, 2019; Pereira et al., 2022; Felix et al., 2023). One of the surveys was conducted in Wisconsin, Michigan, and Iowa, and 32 of the 45 farms marketed beef-on-dairy calves at a week old or less, and 9 of the farms retained ownership and marketed them as finished cattle (Halfman and Sterry, 2019). Similarly, the majority of surveyed dairy farms in Pennsylvania and the northeast (CT, DE, ME, MD, MA, NH, NY, RI, and VT) (89%; 398/448 farms) reported that they did not retain ownership and marketed calves before the finishing phase (Felix et al., 2023). This information contrasts what the participants reported in the present study. A difference to note is the location of the calf ranches surveyed in the cited surveys versus the operations from this dataset.

The NAHMS Dairy 2007 and Dairy 2011 studies reported the average age of arrival for preweaned heifers was 3.4 days, and similarly, most operations (n = 10) from the present survey reported receiving calves between 2 to 4 days of age (USDA, 2010a; USDA, 2012). Walker et al.

reported the median age of arrival for calves to heifer raising facilities and mixed heifer and bull calf raising operations was 2 to 3 days (Walker et al., 2012). However, it is important to note that in previous surveys, heifer raising facilities report receiving preweaned as well as weaned heifers (Wolf, 2003; USDA, 2010a; USDA, 2012). In 2003, Wolf reported the most common age heifers entered an off-site “custom dairy heifer grower” was following weaning, after 2 months of age and before 6 months of age (Wolf, 2003). In previous surveys, dairy replacement heifer raising facilities received both pre-weaned and weaned heifers, whereas all calf ranches in the present data only received pre-weaned calves. The calf ranches described in this survey raised calves from a very young age and raised them through weaning at least. As such, a shift can be seen in heifer growing facilities raising calves off-site from weaning as described in Wolf (2003) to calf ranches raising dairy as well as beef-on-dairy calves from as young as a day old as reported by NAHMS and the present data (Wolf, 2003; USDA, 2010a; USDA, 2012).

For these young calves, pre-weaned housing consisted of individual hutches outdoors at 9 operations, individual pens inside barns at 5 operations, and group pens inside a barn at 1 operation. In the 2011 NAHMS survey, there was a difference in housing of preweaned heifers based on region with more than 90% of operations in the West region (AZ, CA, CO, ID, KS, NM, ND, TX, WA) using individual hutches/pens outdoors, 42% of eastern operations (IN, IA, KY, MI, MN, MO, NY, OH, PA, VT, VA, WI) using individual pens inside barns, and only 30% of operations in the east using outdoor hutches/pens. There was 19.4% of eastern operations that housed preweaned heifers in a group pen inside a barn (USDA, 2012). These data are similar to the present as the 6 operations that housed preweaned calves indoors, in individual pens or group pens, were located in the Midwest (OH and IN). Although the present data represents a significantly smaller number of operations than those described by previous surveys, the

similarities found among regions show how housing choices could be dependent on the climates of different parts of the country. It would be interesting to know how housing varies based on the size of operation; however, the NAHMS data did not report types of housing based on herd size, only region. Thus, the authors cannot speculate on potential housing differences depending on the capacity of the operation.

When asked about type of milk fed, previous surveys reported that approximately 86% of all operations fed any milk replacer to preweaned heifers which is reflected in the present findings where 93% of participants fed milk replacer in some amount (USDA, 2012). There have been many studies investigating different milk feeding protocols related to milk allowance, milk feeding frequency, and feeding methods. Welk et al. performed a systematic review with a total of 69 articles and found increasing milk allowance can improve growth during preweaning and the use of gradual weaning methods can facilitate starter intake and allow calves fed higher amounts of milk to maintain growth advantages postweaning (Welk et al., 2023). The milk feeding protocols reported in the current survey were variable across operations. All operations fed milk twice per day upon arrival, however the amount of milk fed varied between 2 and 3 quarts per feeding among operations. Most operations (87%) reported gradually weaning calves off milk in the present survey. In the 2011 Dairy Heifer Raiser survey, 70% of all operations fed between 4 and 5 quarts of milk per day and 93% fed milk twice a day (USDA, 2012). However, it's difficult to make comparisons between the present and past data as the NAHMS survey did not describe potential changes in milk feeding practices over time. The primary equipment used to feed milk or milk replacer reported by NAHMS was buckets, whereas most operations in this survey used bottles. Thus, there were consistencies among operations in the present survey for

milk feeding protocols upon arrival, but changes in frequency of feedings and amount fed as the calves aged.

According to the NAHMS 2011 heifer raising survey, the average age at which calves received water and calf starter was 6 days (USDA, 2012). In the present survey, water and calf starter was offered within 2 days of arrival at all operations, with the majority offering both upon arrival. The NAHMS survey data from 2011 did not report about the type of starter feed, ingredients, amount, or frequency of starter fed. Ghaffari et al. performed a comprehensive review and meta-analysis of studies investigating different forms of calf starter (ground, pelleted, textured, ground diets blended with hay, and textured diets blended with hay) and their effects on starter intake of dairy calves (Ghaffari and Kertz, 2021). They concluded that feeding textured starter feed compared to pelleted feed resulted in greater intake levels, but there was not sufficient evidence for a recommended starter physical form due to the variation among calf studies (Ghaffari and Kertz, 2021). The grain sources for the studies included in the meta-analysis consisted of corn, barley, oats, and/or wheat middlings at various levels. The results from the present data described the ingredients used in starter feeds, however, the inclusion rate was not collected in this survey. The grains used consisted of cracked, rolled, steam-flaked, whole corn, or were proprietary. While the present data provides more information about the type of diet commercial calf ranches are feeding, it seems there is not a consistent practice across the industry for starter diets fed to pre-weaned calves.

For weaning age, traditionally raised beef calves are weaned at approximately 195 days (USDA, 2020). In heifer raising facilities, the average weaning age was 7 weeks, or about 45 to 50 days (USDA, 2012; Walker et al., 2012). In the present data, 54% of operations raising crossbred beef-on-dairy calves weaned at an age between 60 and 75 days, 13% weaned between

50 to 59 days, and 33% weaned at less than 50 days of age. The difference in weaning age between replacement dairy heifers and beef-on-dairy calves may be attributed to differences in production plans. Dairy replacement heifers are typically sent to off-site facilities and later return to the dairy of origin, with less emphasis on weight at weaning. In contrast, beef-on-dairy calves are generally sent to a feedlot or backgrounding facility prior to the feedlot. In this scenario, the weight at which the calves leave the facility is a key factor if calves are marketed on a weight basis. However, for dairy replacement heifers, body weight is less critical, as they are retained within their own dairy system and not typically sold to external buyers. This could be a reason for the difference seen in weaning age among these breeds of calves.

Region might also play a role in difference of weaning age as the 2011 NAHMS survey reported that weaning age was generally higher in the West region (8.9 weeks, 62 days) compared to the east (6.7 weeks, 47 days) (USDA, 2012). Similar results were reported in the present data where calves were weaned at a younger age in the Midwest (42 to 52 days) compared to the other regions (High Plains, 60 to 72 days; West, 56 to 65 days), however this data is confounded by operation size and housing type. All operations located in the Midwest had a total capacity of less than 1,000 calves and housed their calves individually within pens inside a barn. Thus, it is difficult to understand how region truly plays a role in weaning age due to potential confounding variables.

Most of the operations housed weaned calves in group dry lot pens. In dairy heifer raisers, less than 20% housed multiple weaned heifers in dry lot pens, 16% used freestall housing, 20% used bedded pack/ open shed housing, and 15% housed multiple heifers in an pen inside a barn (USDA, 2012). Therefore, the authors found little to no information that confirms the findings of this survey in relation to beef-on-dairy calves. There was also little reported data

regarding group housing for dairy heifer raising facilities; however, the management of weaned calves within these group pens mimics what is common practice for backgrounding beef calves in confined dry lot pens. Backgrounding is the phase between weaning and shipment to a feedlot for finishing where calves can acclimate to eating from bunks in a group setting. All operations included in this survey did house calves in a group setting post-weaning except for one. This operation housed calves in a group pen pre-weaning and shipped calves somewhere else immediately following weaning. There was variation among the operations on how they transitioned calves to group pens in the size of the pens, head count of pens, and whether calves were moved between multiple group pens. Therefore, it is difficult to identify any kind of pattern or potential industry standard among the surveyed operations.

There was also little to no published literature about the diet fed to calves in group pen settings following weaning. Machado and Ballou (2022) found in their literature review that most producers allow calves to continue eating calf starter for approximately a month after moving into group pens before switching them to a “transition diet”. Transition diets are typically TMRs that mimic the receiving diet cattle will be fed upon arrival to a feedlot. A meta-analysis of trials in grower Holstein calves was conducted to evaluate the level of starch concentration on growth and performance which demonstrates that research regarding formulation of post-weaning diets has been conducted (Hu et al., 2018). However, there is no survey data that describes post-weaning feed protocols in the commercial calf ranch or dairy heifer raising facility. The present data revealed inconsistencies among operations in the number of times fed per day, the amount fed, and the transition between multiple diets post-weaning. Feed delivery varied from once per day to as many as 6 times per day to automatic feed delivery as needed. The majority of operations fed *ad libitum* but there were 4 operations that managed

quantity fed through calling bunks. Five operations had feeding programs that consisted of multiple diets that calves transitioned to as they grew older. Eight operations fed a TMR, similar to that of a backgrounding facility or a feedlot, and 6 fed either a pellet or a texturized feed consisting of a pellet and roughage. Five of these 6 were located in the Midwest. More research is required to fully understand how the formulation of and transition from calf starter to a transition/grower diet affects calf performance. There are currently no peer-reviewed recommendations for formulating transition diets for commercial calf ranches that the authors found. Therefore, it is assumed that operations feeding a TMR are formulating the diet like they would a receiving diet found at a feedlot, however, there is no current literature comparing these types diets.

The health proportion of this survey showed that most operations (10/15) did not routinely measure total protein upon arrival to the calf ranch. Similarly, NAHMS reported that 60% of all operations did not measure serum proteins (USDA, 2012). When asked about treatment protocols for respiratory disease all operations treated with an antimicrobial, and a portion (4/15) administered an anti-inflammatory in addition to the antimicrobial (Table 4). Treating respiratory disease with an antimicrobial is standard practice within any sector of the cattle production system. For treatment of digestive diseases, 53% of operations treated with electrolytes in combination with another type of treatment. Many operations used IV fluids in addition to electrolytes (Table 5). Treatment of digestive diseases in calves, specifically scours, typically focuses on rehydrating the calf (Stoltenow and Vincent, 2003; Spence, 2006; Van Emon, 2024). However, the Dairy Heifer Raiser survey from 2011 did report that antibiotics were used to treat diarrhea in preweaned heifer on 85.7% of operations (USDA, 2012). This is interesting as less than 60% of operations in the present data reported use of an antimicrobial to

treat digestive disease. This slight decrease in the use of antimicrobials could be due to the rising concern of antimicrobial resistance among producers and consumers; however this cannot be confirmed with the data collected.

Limitations

A limitation of this study includes the sample size. The calf ranches that participated were identified and selected through convenience sampling. There were only 15 calf ranches that participated in this survey; however, the authors believe the results still provide valuable information about the management of beef-on-dairy calves due to the knowledge gap in published literature. It is also important to acknowledge that the health/vaccine protocol results from this survey were confounded by use of the same consulting veterinarian, specifically in the Midwest region. Other confounding variables include the region the operation was located.

Conclusions

The information provided by this survey is valuable as it provides insight to the management of beef-on-dairy calves within commercial calf ranches. As the number of beef-on-dairy calves increases, the need for more research on their raising, performance, growth, and health is pertinent. This research highlighted the knowledge gap surrounding the management of beef-on-dairy calves by identifying previous surveys conducted with dairy heifer raising facilities and describing management practices used at commercial calf ranches albeit in a small sample ($n = 15$). There has been speculation that beef-on-dairy calves raised alongside dairy heifers are managed differently, however the management practices of beef-on-dairy calves had not been previously described until now. Therefore, it is important to ask the industry these questions and determine the practices actually employed by calf ranches.

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Table 1.1 Ingredients used in starter diets reported as percentage of operations (n = 15) that use each ingredient. The starter diet is the first diet fed to calves upon or shortly following arrival to the calf ranch.

Ingredient	Count	% of Operations
Grains		
Cracked corn	2	13.3%
Rolled corn	1	6.7%
Steam-flaked corn	3	20.0%
Whole corn	3	20.0%
Proprietary/Unknown	6	40.0%
Total	15	100.0%
Roughage		
Cotton seed hulls	2	13.3%
Ground alfalfa	2	13.3%
Ground long-stem roughage	1	6.7%
Hay	1	6.7%
Proprietary/Unknown	6	40.0%
N/A	3	20.0%
Total	15	100.0%
Liquids		
Molasses	10	66.7%
Molasses; Fat	3	20.0%
Molasses; Soybean oil	1	6.7%
Molasses; Water; Agri-dyne Mix 30	1	6.7%
Total	15	100.0%
Feed Additives		
Bovamine	1	6.7%
Calf Insure	1	6.7%
Mineral	1	6.7%
Rumensin	1	6.7%
Bovamine and Rumensin	1	6.7%
Proprietary/Unknown	1	6.7%
N/A	9	60.0%
Total	15	100.0%

N/A: This ingredient was not used in the starter diet.

Table 1.2 Ingredients used in transition diets reported as percentage of operations (n = 15) that use each ingredient within the transition diet. Transition diets can be defined as the diet calves are fed after the starter diet in the post-weaning period.

Ingredient	Count	% of Operations
Grains		
Ground corn	1	6.7%
Steam-flaked corn	8	53.3%
Whole and steam-flaked corn	1	6.7%
Proprietary/Unknown	2	13.3%
N/A*	3	20.0%
Total	15	100.0%
Roughage		
Alfalfa	4	26.7%
Corn silage	2	13.3%
Chopped hay	1	6.7%
Alfalfa and cotton seed hulls	1	6.7%
Alfalfa and triticale	1	6.7%
Proprietary/Unknown	2	13.3%
N/A*	4	26.7%
Total	15	100.0%
Liquids		
Molasses	6	40.0%
Molasses; Fat	4	26.7%
Molasses; Water; Agridyne	1	6.7%
N/A†	4	
Total	15	100.0%
Feed Additives		
Bovamine	1	6.7%
Lasalocid	1	6.7%
Vitamins and trace minerals (VTM)	2	13.3%
Rumensin	2	13.3%
Bovamine and Rumensin	1	6.7%
VTM and lactobacillus	1	6.7%
N/A†	7	46.7%
Total	15	100.0%

N/A*: These are the operations that fed the starter diet for the entire duration of calf's time at the facility.

N/A†: Three of these operations fed the starter diet for the entire duration of calf's time at the facility. The remaining number did not use this ingredient in the transition diet.

Table 1.3 Health products administered at arrival and/or in the pre-weaning period reported as percentage of operations (n = 10) that gave a product of that category. The 6 operations from the Midwest were counted as 1 response because they all used the same consulting veterinarian and as a result used the same health protocols.

Type of product	Arrival	Pre-weaning
Viral respiratory vaccine	60.0% (6/10)	100.0% (10/10)
Clostridial vaccine	0.0% (0/10)	40.0% (4/10)
Bacterial respiratory vaccine	20.0% (2/10)	100.0% (10/10)
Autogenous vaccine	10.0% (1/10)	60.0% (6/10)
Metaphylaxis	0.0% (0/10)	10.0% (1/10)
Antiparasitic	0.0% (0/10)	10.0% (1/10)
Iron supplementation	0.0% (0/10)	10.0% (1/10)
Meloxicam	0.0% (0/10)	10.0% (1/10)

Table 1.4 Health products administered to treat respiratory disease.

Type of product	Count	% of Operations
Antimicrobial	15	100.0%
Anti-inflammatory drug	4	26.7%

Table 1.5 Health products administered to treat digestive disease reported as percentage of operations that use each product.

Type of product	Count	% of Operations
Electrolytes	12	80.0%
IV fluids	9	60.0%
Antimicrobial	7	46.7%
Anti-inflammatory drug	2	13.3%
Peptobismal	2	13.3%
Amino acids	1	6.7%
Serum antibodies	1	6.7%
Charcoal	1	6.7%
Probiotics	1	6.7%
Dextrose	1	6.7%
B vitamins	1	6.7%

Figure 1.1 Number of quarts of milk fed per day by percentage of operation by days of age. All ranches completely weaned calves off of milk by 72 days of age.

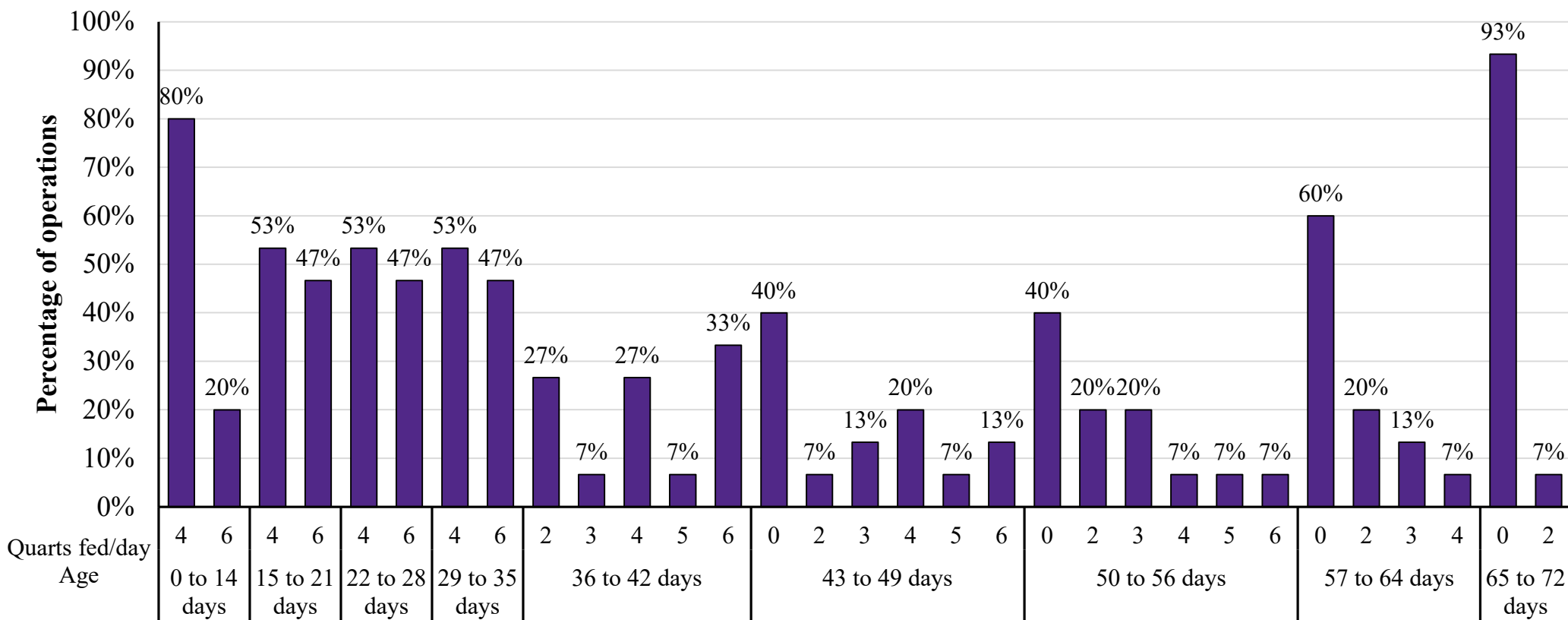


Figure 1.2 Average weaning (complete removal from milk) age by calf ranch.

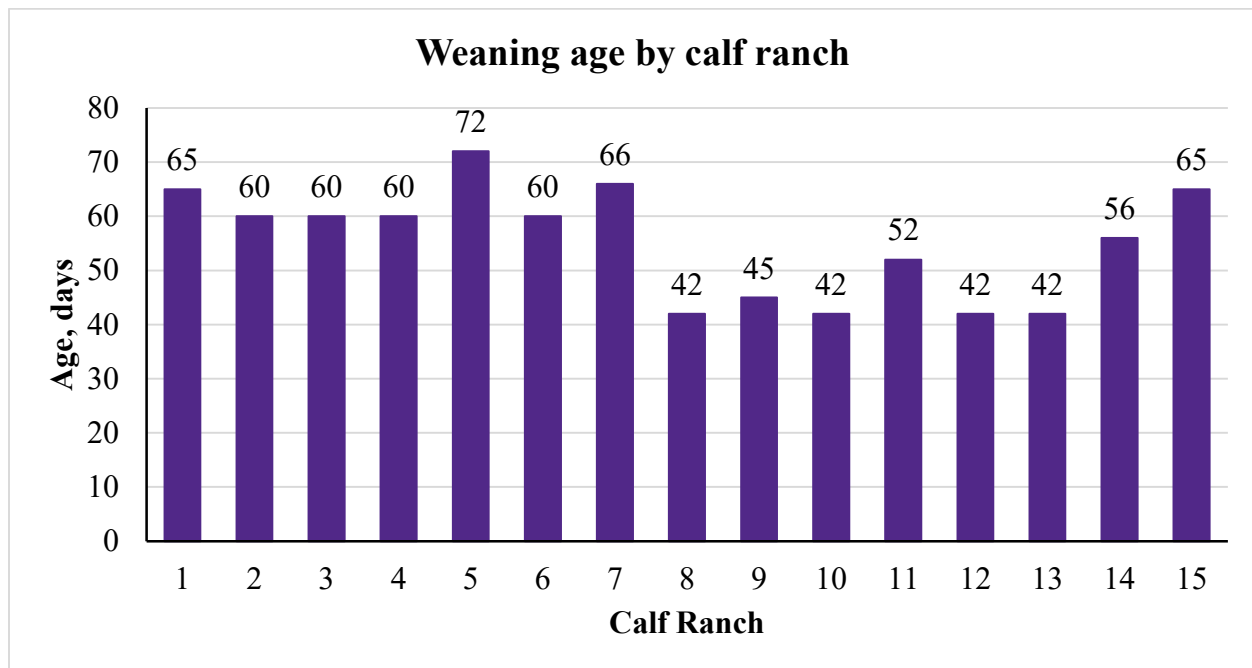


Figure 1.3 The age of calves when moved to a group pen. Ranch 13 shipped calves to a different facility following weaning.

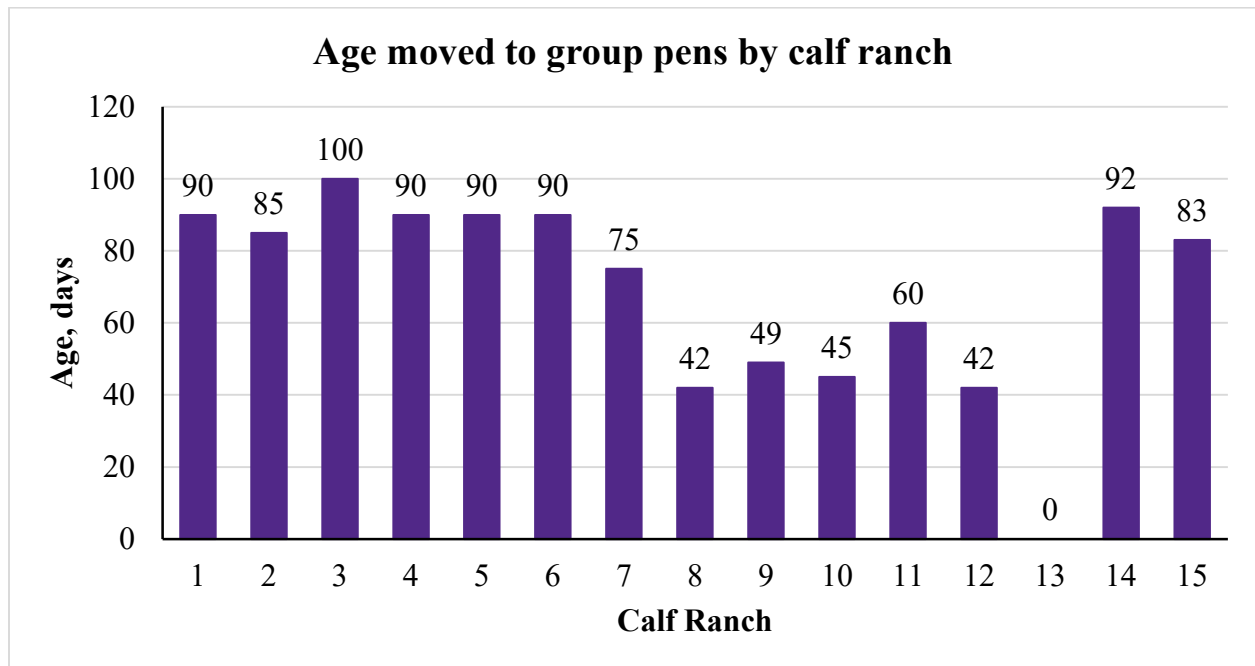
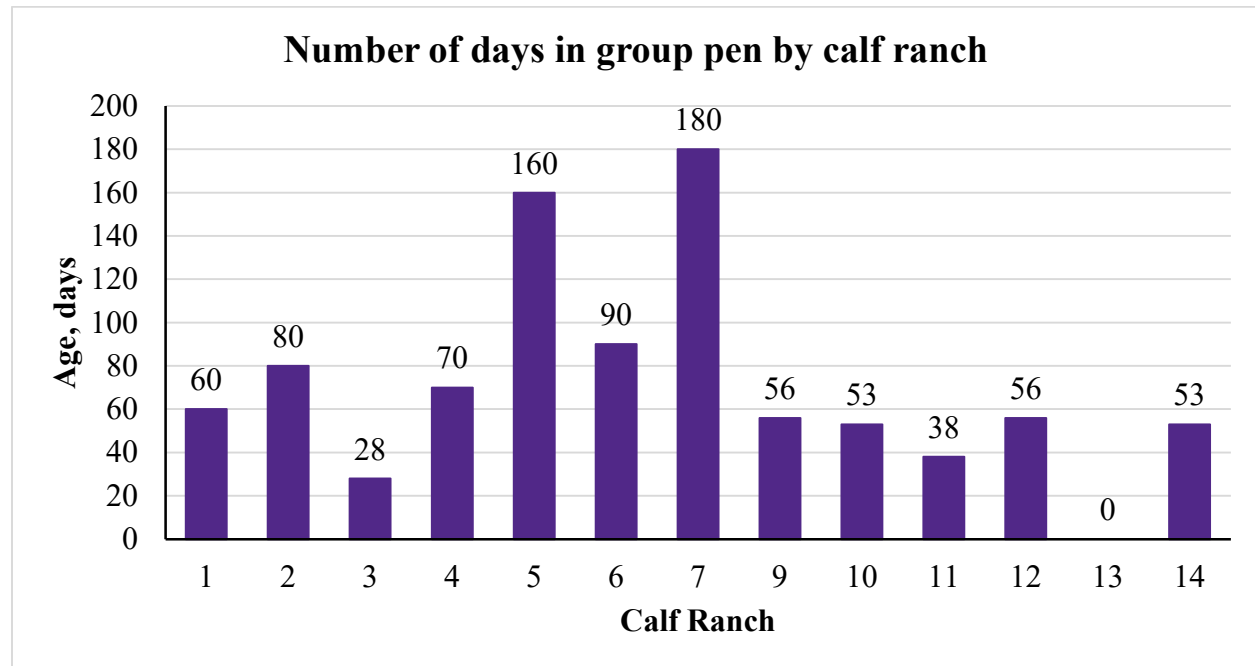


Figure 1.4 The number of days calves spent residing in a group pen following weaning. Ranch 8 shipped calves to another facility following weaning, however the authors were still able to collect information about the management of groups pens due to the interviewee's relation to the owner of the facility. Ranch 13 shipped calves to a different facility following weaning of unknown ownership. Ranch 15 was excluded as they shipped calves based on weight, not days of age. Therefore, they could not specify how long calves resided in a group pen.



Chapter 2 - Determining frequency of mortality by cause and association with days-of-age categories at 2 commercial calf ranches

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Abstract

Limited information is available describing mortalities of dairy and beef-dairy-cross calves in commercial calf ranches. Study objectives were to report frequency of gross mortality diagnoses at necropsy in commercial calf ranches and to determine potential associations of age with diagnosis. Full systematic necropsies (n=211) were performed at two Kansas calf ranches by field technicians with confirmed diagnoses by a single veterinarian. Mortality diagnoses were categorized as gastrointestinal (GI), respiratory (RESP), septicemia, or other based on gross lesions. A subset of calves had age data (n=145) which were categorized as (1 to 29, 30 to 59, 60 to 89, and greater than 90 days). A generalized linear model was used to evaluate probability of being classified as RESP or GI diagnoses based on breed type, sex, and age categories. Gross necropsy revealed 71.1% (150/211) of all mortalities were categorized as RESP, 18.5% (39/211) as GI, 7.1% (15/211) as septicemia, and 3.3% (7/211) as other. Breed type and sex were not associated with probability of RESP or GI diagnosis. Calves greater than 60 days of age were at greater ($P<0.05$) risk ($88\pm4\%$) for RESP diagnoses compared to calves less than 30 days

(37±8%). Probability of GI diagnosis (46±8%) was greater ($P<0.05$) for calves less than 30 days compared to calves between 60 and 89 days (5±3%). The frequency of multiple disease processes emphasize the importance of necropsy to determine diagnosis in each case. These data add valuable information about mortalities in commercial calf ranches.

Key Words

Calf ranch mortality, bovine respiratory disease, beef-dairy-cross, necropsy

Introduction

Breeding practices in the dairy industry have evolved with the introduction of using sex-selected semen from beef sires to produce beef-dairy-cross calves (BOD). These BOD cattle have improved attributes for commercial production of beef while also providing added value to bull calves born at dairies. According to the National Association of American Breeders, from 2022 to 2023, dairy semen sales decreased by 2.5 million units, while beef semen sales increased by about 1.5 million units (Weiker, 2024b). In 2023, U.S. dairy producers shifted to female-sex-selected dairy semen, which led sales at 8.4 million units, followed by male-sex-selected beef at 7.9 million units, and lastly, conventional dairy semen at 7 million units. Similar to dairy calves, young BOD calves are raised from 1 day of age without the dam. In the last several years, this process has evolved, and to increase production efficiency and specialization of management, BOD calves are often transported to a calf ranch or growing operation. A calf ranch can be defined as an operation that raises calves from as young as 1 day of age to a targeted weight which is dictated by the marketing plans for those calves. Some calf ranches raise cattle until weaning only, while others raise them through a longer growth phase. Unlike other phases of cattle production, limited information exists on frequency of mortality-causes in the calf ranch phase. There have been previous reports of mortality data and findings in the beef cow-calf

sector as well as the dairy industry (USDA, 2015; USDA, 2021b). With the increase in BOD animals, little to no previous literature has been reported on causes of mortality for these young calves and if there are differences in pathology compared to straightbred dairy calves.

Identifying specific contributing factors to mortalities is key to creating targeted prevention and intervention programs. Disease syndromes vary in frequency based on many factors including: animal age, exposure risks, and production-management. Accurately identifying disease in moribund calves and cause of mortalities can provide calf ranches with more information for management and health care decisions. Gross necropsy can be a valuable diagnostic tool to identify major pathological conditions and specific organ systems affected. Gross necropsy also gives producers more information about disease processes at time-of-death. Accurate diagnosis allows producers to better understand most frequent diseases on their operation and tailor preventative health programs to match disease syndromes. Additionally, gross necropsy diagnosis can be compared to clinical diagnosis in an effort to evaluate clinical diagnostic accuracy. Previous literature has shown that gross necropsy findings are often different than diagnoses made by producers visually assessing the live animal prior to death and based from treatment records (Sivula et al., 1996; McConnel et al., 2019). Understanding frequencies of specific disease syndromes is important in order for preventative and therapeutic measures to be targeted in the correct areas. For example, gross necropsies allow the producers to know if the most common type of respiratory disease is acute vs. chronic vs. embolic, which would each potentially require different interventions such as identifying disease earlier, different treatment protocols, or changing management of tubing calves.

Respiratory disease is the most frequent disease diagnosed in deceased feedyard cattle, but in pre-weaned beef cattle the leading cause of mortality varies by age class (Miles, 2009;

Smith et al., 2020; USDA, 1997). This same finding has been well-documented in pre-weaned dairy heifers, but limited work has evaluated causes of mortality in large calf ranches, or specifically evaluated mortality causes in BOD cattle (Agerholm et al., 1993; Virtala et al., 1996; Svensson et al., 2003; USDA, 2010b; USDA, 2021b).

The objectives of this research were to report the frequency of causes of mortality by gross necropsy in young cattle on commercial calf ranches and to determine the association of breed type (dairy vs. BOD), sex, and days of age with mortality diagnosis as determined by gross necropsy. Causes of mortality for the purpose of this research were determined by gross pathological findings rather than etiologic agent. Secondly, causes of mortality were described by breed type. Finally, the relationship between age and cause of mortality was investigated to determine the probabilities of different possible final diagnoses upon gross necropsy. The hypothesis was as age increases, the proportion of cause of death will shift from a greater number of gastrointestinal (GI) mortalities to greater numbers of different causes.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee (IACUC) was contacted regarding the project and no approval was needed due to evaluations of only deceased animals.

This cross-sectional observational study was designed with animal as the experimental unit to determine frequency of mortality causes in commercial calf ranches. Calf ranches (n=2) in the central high plains region of the U.S. were identified for participation, and deceased cattle were necropsied between June 15, 2023, and July 15, 2023. Mortalities were enrolled in the study on a convenience basis with necropsies conducted between 8 am and 3 pm each day. Not all cattle at each operation were necropsied each day due to time constraints. Cattle were

evaluated for outward signs of autolysis (e.g., tissue color, smell, texture), and only cattle with no or minimal gross autolysis were enrolled.

Full, systematic necropsies were performed as described in previous work by two field technicians [CC, CB] with confirmation of all diagnoses by a veterinarian [BJW] (Schmidt et al., 2023). Findings from each necropsy were recorded through a form including evaluation of all major organ systems and describing specific pathology(ies) observed. A specific individual identifier (ear tag) and multiple digital photographs were recorded for each animal.

Systematic necropsies were performed in a similar manner as described in previous work with feedyard cattle (Schmidt et al., 2023). Each animal evaluation was initiated with an external examination including identifying sex, breed type, and any outward signs of disease including swellings or signs of musculoskeletal conditions. The animal was then fully opened to evaluate internal organs and body systems including: oral cavity, esophagus, larynx pharynx, trachea, lungs, liver, abomasum, rumen, large and small intestine, kidney, bladder, and heart. Gross pathological lesions were recorded, and the summation of findings was used to generate the final diagnosis which were categorized into GI, RESP, septicemia, or other. Gastrointestinal diseases included inflammation and/or hemorrhage of the digestive tract, bloat, peritonitis, ulcerations on the mucosal surface of the digestive tract, abnormal digestive contents, and/or scours. In some cases, the presence of scours was confirmed based on external evidence on the hind quarters of the animal. Septicemia was diagnosed based on the appearance of major organs including lungs or heart observed to have signs consistent with septicemia or toxemia (Figure 1). In septicemia cases, petechiae and ecchymosis were often identified on both pulmonary and cardiac tissues.

Respiratory diseases were determined based on the gross examination of the pulmonary surface and cut sections of the lungs. In all cases, the lungs were removed in their entirety for full

examination. Respiratory pathologies were sub-categorized into 4 major groupings: acute bronchopneumonia, chronic bronchopneumonia, bronchopneumonia with an interstitial pattern (BIP), and aspiration/embolic pneumonia (Figure 2). Bronchopneumonia diagnosis was based on multiple characteristics including consolidated, firm lung lobes, presence of fibrin tags/adhesions, and presence of pulmonary abscesses. Pathological characteristics were not all present in every case and the extent of lesions varied by case. Bronchopneumonia cases were further categorized into acute or chronic based on the extent and type of lesions present. Cases with severe abscessation, large areas of consolidation, fibrinous adhesions, and most of the lung volume impacted were considered chronic. The diagnosis of BIP has been reported in feedyard cattle and is described as cattle with characteristics of both bronchopneumonia and interstitial pneumonia (Schmidt et al., 2023). Typically, in BIP cases, bronchopneumonia is diagnosed in the cranioventral region of the lungs with interstitial pneumonia in the caudodorsal regions. A final RESP diagnosis of aspiration/embolic pneumonia was based on finding pulmonary abscesses in varied parts of the lung without a specific pattern or area of consolidation. Cases not classified as GI, septicemia, or RESP were classified in the other category which included congenital defects (hernia, organ malformation) and cases where no diagnosis was apparent by gross necropsy.

Statistical Analysis

Descriptive statistics were performed on cases (n=211) relative to known demographic information. Due to lack of age information, 66 cases were removed prior to statistical assessment for probabilities of diagnoses by age. A generalized linear model was used to evaluate the probability of being classified as a RESP diagnosis in calves that died using the glm function from the stats package of R studio (R Core Team, 2023). Breed type, sex, and days of

age categories were included to determine the likelihood of a RESP diagnosis for each factor. Categories for age included less than 30 days, 30 to 59 days, 60 to 89 days, and greater than 90 days. A second generalized linear model was used to evaluate the likelihood of being classified as a GI diagnosis in calves that died using the glm function in R studio. Similarly, breed type, sex, and days of age categories were included to evaluate the likelihood of association between these factors and a GI diagnosis. Calf ranch was not included as a random effect in either model because the cases with known days of age were all from the same calf ranch.

Results

Two hundred and eleven necropsies were performed. Cattle demographics are shown in Table 1. Days of age information was collected for 145 calves, with values ranging from 2 to 150 days. Frequency of final diagnosis by disease category for each case necropsied can be seen in Table 2.

Relative to age categories, 28.3% (41/145) of cases were less than 30 days, 14.5% (21/145) were between 30 and 59 days, 44.1% (64/145) were between 60 and 89 days, and 13.1% (19/145) were greater than 90 days. The median age for GI diagnoses was 12 days. For “other”, the median age was 16 days, and for septicemia and RESP diagnoses, the median age was 61 and 71, respectively. The temporal distributions of cases for each diagnosis at time of gross necropsy are depicted in Figure 3.

Descriptively, specific to RESP diagnoses and age, 60% (9/15) of cases in calves less than 30 days were acute bronchopneumonia, 20% (3/15) were aspiration/embolic pneumonia, 20% (3/15) were chronic bronchopneumonia, and there was no bronchopneumonia with interstitial pattern cases. For calves between 30 and 59 days of age, 20% (3/15) were acute bronchopneumonia, 0% were aspiration/embolic pneumonia, 7% (1/15) were bronchopneumonia

with an interstitial pattern, and 73% (11/15) were chronic bronchopneumonia diagnoses. Similarly, chronic bronchopneumonia accounted for the greatest percentage (82%; 46/56) of cases in calves between 60 and 89 days, followed by acute bronchopneumonia (11%; 6/56), bronchopneumonia with an interstitial pattern (5%, 3/56), and finally, aspiration/embolic pneumonia (2%; 1/56). For calves greater than 90 days, 6% (1/18) of cases were acute bronchopneumonia, 6% (1/18) were aspiration/embolic pneumonia, 17% (3/18) were aspiration/embolic pneumonia, and the remaining 72% (13/18) were chronic bronchopneumonia.

Two generalized linear models were used to evaluate the probability of RESP or GI diagnoses in calves that died being associated with breed type, sex, and age categories. Breed and sex were not associated with the probability of RESP ($P = 0.32$, $P = 0.62$, respectively) or GI ($P = 0.16$, $P = 0.85$, respectively) diagnoses at gross necropsy. The probability of RESP and GI diagnoses was associated ($P < 0.001$, $P < 0.001$, respectively) with age category. Calves greater than 60 days were at greater ($P < 0.001$) risk ($88 \pm 4\%$) for RESP diagnoses compared to calves less than 30 days ($37 \pm 8\%$), but calves between 30 and 59 days were not different in risk from the other two groups ($70 \pm 11\%$). In contrast, probability of GI diagnosis ($46 \pm 8\%$) was greater ($P < 0.05$) for calves less than 30 days compared to calves between 60 and 89 days ($5 \pm 3\%$). Calves between 30 to 59 days and greater than 90 days were not different in risk from the other two groups ($14 \pm 8\%$; $6 \pm 6\%$, respectively). Probability of RESP or GI diagnoses at time of necropsy based on age can be seen in Figure 4 and 5, respectively.

Discussion

Causes of mortality in dairy and BOD calves have been poorly defined in previous literature with very limited verification through post-mortem evaluations such as systematic necropsies (USDA, 2010b; McConnel et al., 2019; USDA, 2021b). In 2007 and 2014, it was

reported that approximately 10% of operations in the U.S. with deaths in pre-weaned or weaned heifers performed necropsies on the mortalities, and on those operations, less than 5% of those deaths were necropsied to determine cause of death (USDA, 2021b). Given this information, many causes of death for dairy heifer calf mortalities could be misclassified, based upon previous treatment records rather than gross necropsy findings. A study conducted as part of the calf component of the National Animal Health Monitoring System's (NAHMS) Dairy 2014 study reported that approximately one-fourth of enrolled calves died from unknown causes, highlighting the importance of identifying and classifying cause of death through necropsy (Urie et al., 2018b).

The majority of mortalities in the present research were classified as RESP (71.1%; 150/211), with GI as the second highest recorded cause of death at 18.5% (39/211). These findings are consistent with previous studies, highlighting that RESP and GI diseases are the most common contributors to calf mortalities (Agerholm et al., 1993; Virtala et al., 1996; Svensson et al., 2003; Winder et al., 2016). According to the NAHMS data from 2015, the most frequent causes of death for calves across all operations were respiratory problems (26.9%), followed by calving-related problems (17.8%) and digestive problems (15.4%) (USDA, 2015). However, when looking at calf death loss by type of operation, dairies reported a higher percentage of calf mortalities due to digestive problems (28.1%) compared to beef operations (9.6%). Beef operations had a lower percentage of deaths due to respiratory diagnoses (23.0%) compared to dairies (32.7%), mixed (36.1%), or other (36.3%) operations which were primarily feedlots and stockers (USDA, 1997b; USDA, 2015). A mixed operation was defined as an operation with more than five beef cows and more than five milk cows, or if the number of beef and milk cows were equal. It is worth noting that the NAHMS survey did not include

information about age of calves related to cause of death, and the present research found an association between risk of respiratory or GI diagnoses with age categories. Similar to mortality, other findings reflect the same perception that GI problems and respiratory disease account for the majority of calf morbidity (Walker et al., 2012; Windeyer et al., 2014; Urie et al., 2018). Performing necropsies provides more accurate information than recording causes of death based on clinical diagnosis, which should help identify potential management routes for interventions.

In 2019, McConnel *et al.* performed 210 necropsies on dairy heifer calves at a 25,000-head dairy calf ranch with calves originating from multiple dairies and reported treatment-based diagnoses and necropsy-based diagnoses (McConnel et al., 2019). In addition, tissue samples were collected at time of necropsy and submitted to a laboratory for histopathology diagnosis. Categorized by age, 88% (184/210) of necropsy cases were less than 30 days, 9% (19/210) were between 30 and 60 days, and 3% (7/210) were weaned and greater than 60 days. Through input from calf health managers and treatment records, almost two-thirds (65%; 137/210) of the deaths were categorized as due to diarrhea or diarrhea and respiratory, and an additional 16% (34/210) were attributed to respiratory disease alone. In contrast, necropsy-based postmortem diagnoses categorized 21% (44/210) of deaths due to diarrhea or diarrhea and respiratory disease and only 6% (13/210) to respiratory disease alone. The “other digestive” category contained almost 50% (104/210) of cases due to necrotizing, ulcerative enteritis and typhilitis. The kappa statistic reported for agreement between cause of death based on treatment records and necropsy-based postmortem evaluation was 0.22, indicating fair agreement. Similar to the present data when considering age, there was a greater number of GI diagnoses in calves less than 30 days; however, the current research saw increased RESP diagnoses compared to what McConnel et al. reported. The discrepancies between McConnel’s findings and the present data could be due to

differences in populations, such as breed, the differences in age distribution of cases, in management practices, in time and duration of transportation of calves to the calf ranch facilities, as well as the method and time period of enrollment of cases. Even so, the findings of previous literature support that diagnosing causes of death based on prior treatment records compared to performing necropsies can lead to inaccuracies in the reported frequency of causes of mortalities.

Relative to age, probability of finding RESP disease upon gross necropsy was greater ($P < 0.001$) for calves greater than 60 days compared to calves less than 30 days. In contrast, the risk of GI-related diagnoses was greater ($P < 0.001$) in calves less than 30 days compared to calves between 60 and 89 days. This supports previous reports in young dairy heifers of higher risk of GI-related problems in the first three weeks of life and highest risk of pneumonia later in the calf's life at 10 weeks of age (Agerholm et al., 1993; Sivular et al., 1996; Urie et al., 2018). Similar trends can be seen by Windeyer *et al.* morbidity data of dairy heifer calves, where incidence risk for neonatal calf diarrhea was 21.2% before 14 days then decreased to 1.8% between 14 and 35 days (Windeyer et al., 2014). For BRD, incidence risk was 7.7% for calves younger than 14 days and increased to 8.0% and 9.5% for calves between 14 and 35 days and greater than 35 days, respectively (Windeyer et al., 2014). While the present data did not break down the age categories to the extent of Windeyer *et al.*, the trends remain similar with greater proportions of GI cases in younger calves compared to increased RESP cases in older calves. These previous findings support the present data showing that at a younger age, less than 30 days, calves are at greater risk for GI disease and at an older age, specifically greater than 60 days, their risk for RESP disease increases. However, it is important to note that while the probability of GI disease was greatest in calves less than 30 days old (46%), respiratory disease also played a significant role for this age category with a probability of 37%, and therefore

should also be taken into consideration when creating and implementing preventative and therapeutic protocols.

In this study, necropsies were performed on calves at varied days of age, sexes and breeds. Multiple pathologic conditions were diagnosed and no single risk factor tested clearly delineated the diagnosis. This work illustrates the importance of necropsy to evaluate health outcomes and ideally, these gross diagnoses could be used in conjunction with clinical diagnoses to improve management decisions. Gross necropsy is an important tool to identify actual cause of death.

Limitations of this study include that cases were recorded based on availability of deceased animals during a limited period of approximately 5 weeks in 2 different calf ranches. Therefore, the prevalence of cause of death diagnoses may vary based on season or location which cannot be evaluated in this study. Additionally, calf history which included age information was limited, leading to a smaller number of cases that met inclusion criteria for statistical analysis of association between cause of death and age category. Unfortunately, treatment information and clinical diagnoses were also not included in calf history. Another limitation includes the lack of histology for laboratory confirmation of diagnoses due to budgeting, time, and labor constraints. It can be difficult to differentiate between subsets of GI diseases without confirmatory diagnostic lab work, thus the authors categorized any GI disease as a GI diagnosis due to the lack of diagnostics such as histology. Similarly, diagnosing septicemia without additional diagnostic insight is difficult at best, however, all diagnoses in this study were based solely on gross necropsy findings.

Conclusions

Gross necropsy can be a valuable tool to identify pathological conditions and describe cause of death in mortalities at commercial calf ranches. Necropsy findings can be utilized to tailor preventative and therapeutic programs to specific situations. There is a need for further research regarding morbidity and mortality of dairy and BOD calves being raised on commercial calf ranch operations. The frequency of GI and RESP diagnoses in mortalities at calf ranches in this study were similar to what is reported in morbidities and mortalities among dairy heifer calves. However, while GI disease was most common in the first 30 days of age with a probability of 46%, respiratory disease played a significant role in the disease process during this time period as well with a probability of 37%. Finding both major disease processes in young calves at relatively high frequencies emphasizes the importance of necropsy when evaluating clinical diagnostic and therapeutic programs. While not directly comparable to previous literature, the information found in this research contributes to the small amount of knowledge surrounding mortalities at commercial calf ranches and could potentially help producers with building preventative and therapeutic protocols. Gross necropsy has value as an outcome evaluation tool for individual operations to customize health protocols based upon the disease syndromes identified at death. This is an important sector of the industry that continues to grow as the number of BOD animals increases. Thus, the need for further research to comprehensively describe health data is imperative for improving morbidity and mortality at the calf ranch.

Conflicts of Interest

Authors report no conflicts of interest.

Contribution

All authors contributed to the design, analysis, and writing of the current study.

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Table 2.1 The proportion of mortalities by sex and breed type (n = 211) with a subset of mortalities (n = 145) having days of age at death from 2 Kansas calf ranches. Necropsies were performed between June 15 and July 15, 2023.

	Category	Count	Percent Total
Sex	Heifer	99	46.9%
	Steer	112	53.1%
Breed Type	Beef x Dairy	115	54.5%
	Dairy	96	45.5%
Days of Age	Less than 29	41	28.3%
	30 to 59	21	14.5%
	60 to 89	64	44.1%
	Greater than 90	19	13.1%

Table 2.2 Frequency of final diagnosis by disease category for cases necropsied (n = 211) at 2 Kansas calf ranches. Necropsies were performed between June 15 and July 15, 2023.

Final Diagnosis	Cases	% of Cases
Respiratory		
Acute bronchopneumonia	29	13.7%
Chronic bronchopneumonia	104	49.3%
Bronchopneumonia with interstitial pattern	9	4.3%
Embolic pneumonia	8	3.8%
Gastrointestinal	39	18.5%
Other/Unknown	7	3.3%
Septicemia	15	7.1%
Total	211	100.0%

Figure 2.1 Example of lungs from calf diagnosed with septicemia based on gross necropsy at commercial calf ranch.



Figure 2.2 Example of each type of respiratory pathology (RESP) diagnosed from gross necropsy at two commercial calf ranches, including: acute bronchopneumonia (2a), chronic bronchopneumonia (2b), bronchopneumonia with interstitial pattern (2c), and embolic bronchopneumonia (2d).

2a. Acute bronchopneumonia.



2b. Chronic bronchopneumonia.



2c. Bronchopneumonia with interstitial pattern.



2d. Embolic bronchopneumonia.



Figure 2.3 Violin plot with boxplot overlay depicting the temporal distributions of each diagnosis at time of gross necropsy at 1 Kansas calf ranch. Box and whiskers represent the upper and lower quartiles, and the heavy vertical line within the box represents the median age for each diagnosis.

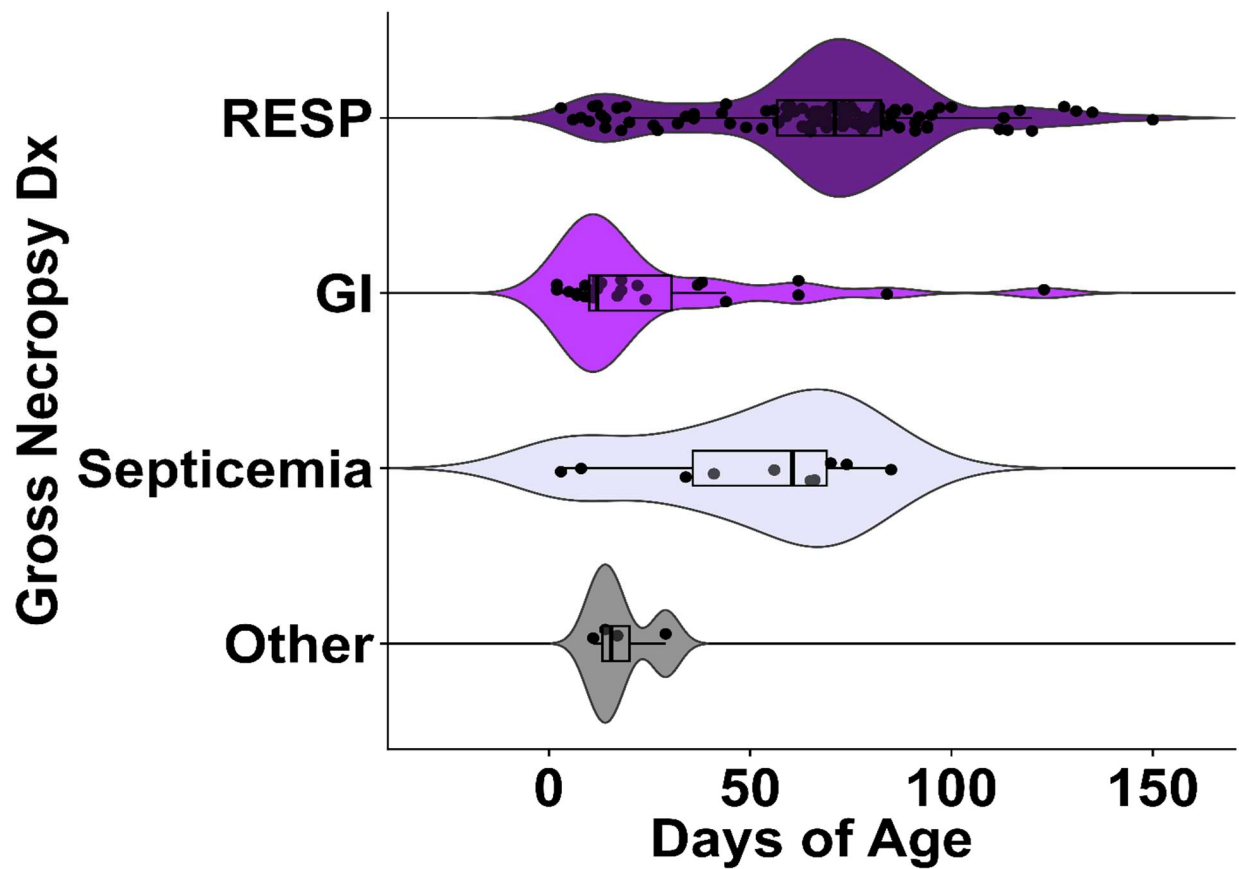


Figure 2.4 Probability of respiratory diagnosis in calves (n = 145) that died by days of age category at 1 Kansas calf ranch.

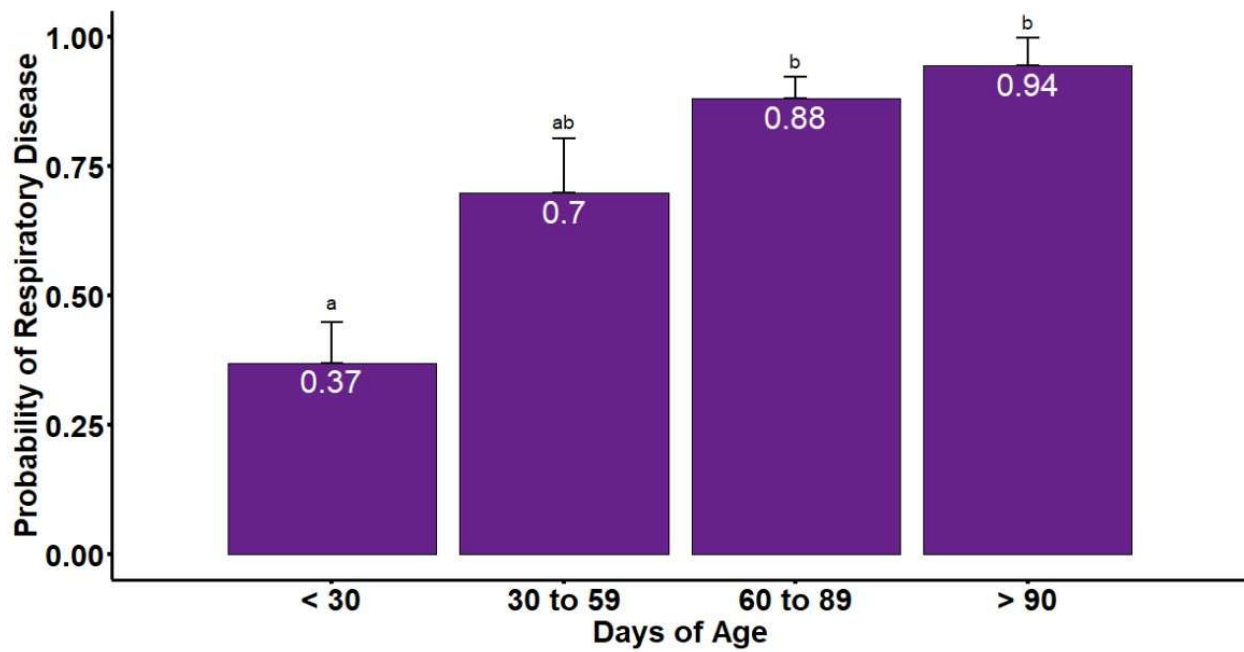
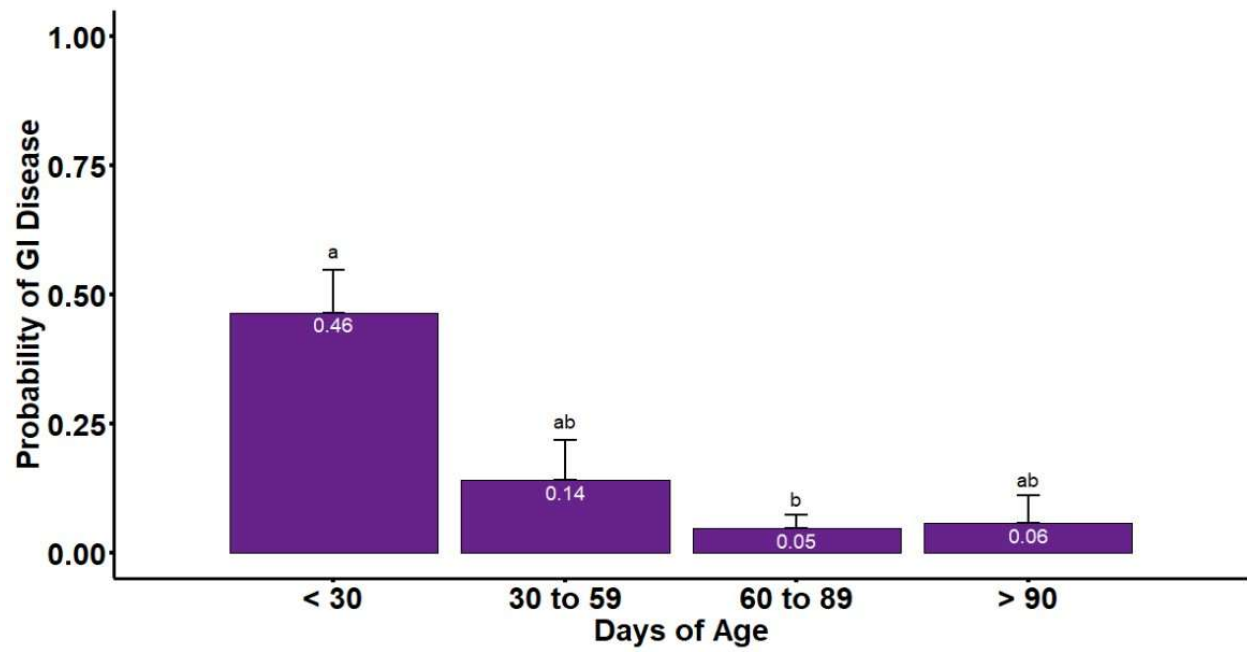


Figure 2.5 Probability of gastrointestinal (GI) diagnosis in calves (n = 145) that died by days of age category at 1 Kansas calf ranch.



Chapter 3 - Systematic assessment of mortalities in calves at commercial calf ranches and the association between cause of death and season

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Simple Summary

In the dairy industry, producers are using beef semen to produce beef-dairy calves, which has led to an increase in young calves being raised at off-site facilities known as calf ranches. However, little is known about the cause of death in these calves. In this study, researchers necropsied 243 calves that died on four ranches over a year to determine the main cause of death and whether that diagnosis differed by season, sex, breed, or ranch. Each calf was carefully examined after death, and the causes were grouped as respiratory disease, digestive disease, septicemia, or other problems. Respiratory disease was the most common cause, accounting for more than two-thirds of deaths. Digestive diseases, septicemia, and other causes were much less common. Most calves only had one diagnosis, but about 10% had a secondary disease present. There were no significant differences in cause of death based on season, sex, breed, or ranch. These findings provide valuable insight into the health challenges faced by calves raised in

commercial calf ranches and can help producers, veterinarians, and the industry develop better strategies to improve calf survival.

Abstract

As breeding practices in dairy industry shift toward use of beef semen, the number of calves sent off-site for rearing has increased. Limited literature describes mortalities by season, sex, or breed within calf ranches. The objectives were to identify primary and co-morbidities at necropsy in calf ranches and determine whether cause of death varied by season, sex, breed, or ranch. Systematic necropsies (n=243) were performed monthly over 12 months at four ranches by technicians with diagnoses confirmed by veterinarians. Mortalities were classified as respiratory (RESP), gastrointestinal (GI), septicemia (SEPT), or other (OTH) based on gross necropsy findings. A subset from ranches with 12-month necropsy data (n=175) was analyzed using generalized linear and multinomial models to evaluate associations between RESP diagnoses or GI lesion location and 4-month periods, sex, breed, and ranch. Respiratory was most common (67.5%), followed by GI (11.5%), SEPT (9.5%), and OTH (11.5%). Most (86.0%) lacked co-morbidities; RESP (7.0%) and OTH (3.7%) were the frequent primary diagnoses with co-morbidities. No significant associations were detected with time, sex, breed, or ranch ($P \geq 0.11$ for RESP; $P \geq 0.13$ for GI). Although inferences were limited by sample size, findings provide insight into calf mortalities and co-morbidities in commercial ranches.

Key Words

Calf ranch mortality; necropsy; respiratory disease; GI lesion; season

Introduction

In the dairy industry, traditionally most operations raise heifers on-site after birth. However, since 2002, the percentage of operations that send their heifers off-site for rearing and

development has increased 3-fold (USDA, 2021). In 2002, 7.4% of heifers were born on-site and sent to different off-site operations. By 2014, that percentage had increased to 25.7% according to USDA (USDA, 2021). Additionally, breeding practices within the dairy industry have shifted with more producers using semen from beef sires to produce beef-dairy cross calves to be raised for beef production. According to the National Association of American Breeders, the number of beef semen sales increased by 1.5 million units while the number of dairy semen units sold decreased by 2.5 million from 2022 to 2023 (Weiker, 2024). Beef-dairy cross calves are economically more valuable than dairy-bred bull calves due to their improved carcass characteristics that are beneficial for beef production. However, a major issue with beef-dairy cross cattle is the increased incidence of liver abscesses (2 to 3 times) compared to beef cattle (Foraker et al., 2022). Similar to dairy replacement heifers, beef-dairy cross calves are often separated from their dams as young as one day of age and shipped to an off-site operation. These facilities are often termed calf ranches or calf rearing operations. As described in previous work, a calf ranch can be defined as an operation that rears calves from a young age, typically less than 1 week old, to a specific weight or age dependent on the production plan for those calves (Rebecca A Bigelow et al., 2025; Rebecca A. Bigelow et al., 2025).

Mortalities have been described via post-mortem necropsies in the literature for the feedlot and dairy sectors (Kelly and Janzen, 1986; McConnel et al., 2009; McConnel et al., 2010; Thomsen et al., 2012; Bortoluzzi et al., 2023; Hagner et al., 2023; Schmidt et al., 2023a). Post-mortem evaluation of dairy replacement heifers has been described previously; however, there is little information published that discusses mortalities within commercial calf ranches, specifically regarding beef-dairy cross calves (Agerholm et al., 1993; Sivula et al., 1996; Virtala et al., 1996; McConnel et al., 2019). An important aspect of health in beef-dairy cross calves is

gastrointestinal lesions for a couple of reasons: 1) influence of neonatal diarrhea on mortality, and 2) the hypothesis that the primary pathogens of liver abscesses translocate the GIT through ruminal and/or intestinal lesions (Amachawadi and Nagaraja, 2022). Magrin et al. conducted a trial in Italy investigating the association of GIT lesions found at slaughter and on-farm mortality and feeding management in “batches” of veal calves (Magrin et al., 2021). Descriptive statistics reported more than 85% of inspected abomasa and 17% of inspected livers at slaughter showed lesions, however, the number of calves per batch was never specified. Therefore, the information is difficult to interpret externally. Thus, the investigation of gastrointestinal health of calves at commercial calf ranches is relatively lacking in the literature, especially related to identifying lesions in the gastrointestinal tract (GIT).

Bovine respiratory disease (BRD) is another significant health problem of interest in calves at commercial calf ranches. Necropsies conducted within feedlot operations report BRD as the most frequently found disease process among mortalities as well as among morbidities (USDA, 1997; Miles, 2009; Smith, 2009). The temporal patterns of BRD have been explored and correlations have been made between weather/season and clinical observations of BRD (Callan and Garry, 2002; Taylor et al., 2010; Cernicchiaro et al., 2012). For example, Cernicchiaro et al. found associations between weather variables pertaining to temperature change, mean wind chill temperature, and maximum wind speed in different lag periods, as well as interactions between these weather variables with cattle demographics, and the incidence of BRD in the 1st 45 days of the feeding period (Cernicchiaro et al., 2012). However, specific causal relationships between BRD and weather have not been verified. More often, authors conclude higher incidence of BRD in the fall is more closely related to the seasonal management practices and marketing of calves during the fall typical in the North American beef production system rather than weather

(Loneragan et al., 2001; Callan and Garry, 2002; Taylor et al., 2010; Murray et al., 2017). These practices often involve weaning, commingling at marketing points where calves may be introduced to a greater number of pathogens, and movement of those cattle to the feedlot, resulting in increased animal density within pens. Dairy and beef-dairy cross calves experience similar potential risk factors within the calf ranch production system, often being comingled and shipped on a truck as young as one day of age, then placed in individual hutches, introduced to a grain-based diet upon arrival, weaned from milk by 75 days of age, and eventually placed in a group pen with exposure to new animals (Machado and Ballou, 2022; Rebecca A Bigelow et al., 2025). Thus, the investigation of potential seasonal changes in the frequency of mortalities at commercial calf ranches similar to those found in the feedlot sector is of interest.

There is information published about the incidence of BRD during different seasons within calf ranches, but the results are conflicting where one reported higher incidence in the fall and the other in the spring (Dubrovsky et al., 2019a; Maier et al., 2019). While those studies focused on BRD morbidity, there is another study that reports about BRD-cause specific and overall mortalities in pre-weaned calves on California dairies that stated calves treated for BRD in the spring had an increased risk of mortality compared to calves treated in the summer, and mortalities in calves treated for BRD in the fall or winter did not differ significantly from the summer (Dubrovsky et al., 2019b). The season of calf mortality was not significant in their model (Dubrovsky et al., 2019b). Another study completed in California from January 1997 to October 1998 found calves arriving in February 1998 had a two-fold higher risk of dying compared to arrivals in September 1997 (Moore et al., 2002). Identifying seasonal patterns associated with mortalities within calf ranches could allow producers to alter management practices seasonally to adjust for this effect.

Thus, the objectives of this study were to conduct systematic necropsies to document the primary and co-morbidities which occur in commercial calf ranches and to determine whether the cause of mortality changes between seasons, sex, breed, and/or calf ranches.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee (IACUC) was contacted regarding the project, and no approval was needed due to the evaluation of only deceased animals.

Experimental Design

This cross-sectional, observational study aimed to identify the frequency of causes of mortality in commercial calf ranches where individual animals served as the experimental unit. Four calf ranches located in the central high plains of the United States participated in the study. Necropsies were conducted on deceased calves between February 22, 2024, and January 17, 2025, once a month at 3 of the 4 calf ranches. During the summer months, May through August, visits to each ranch were more frequent, twice a month. Necropsies at the 4th ranch took place from July 22 to July 26, 2024. Mortalities were selected for inclusion based on convenience sampling where the technicians necropsied the calves brought to them by the operation personnel within the time they were at the ranch. Due to time constraints, not all mortalities were necropsied at each ranch. Calves were evaluated for outward signs of autolysis prior to enrollment through assessment of tissue color, smell, and texture. Cattle with severe gross autolysis did not have a necropsy performed.

Systematic Gross Necropsy Process

Comprehensive, systematic necropsies were performed by trained field technicians, and all diagnoses were reviewed and confirmed by licensed veterinarians, following methodologies

previously described in feedlot cattle and calves at commercial calf ranches (Schmidt et al., 2023a; Rebecca A. Bigelow et al., 2025). A primary diagnosis was assigned to each case, and comorbidities were identified when present based on severity/chronicity of lesions. Information from each necropsy was recorded using a standardized paper form as well as a digital form that included assessments of all major organ systems and detailed descriptions of observed pathologies. For each calf, a specific individual case number was assigned, and multiple digital photographs were collected.

The necropsies were performed in a similar manner as described in previous work (Schmidt et al., 2023a; Rebecca A. Bigelow et al., 2025). Each evaluation began with an external inspection, noting sex, breed (dairy or dairy-beef cross), and any visible abnormalities or signs of disease, such as trauma, swelling within joints and/or limbs, or signs of musculoskeletal conditions. The calf was then fully opened for internal examination of the organs and body systems including the oral cavity, esophagus, pharynx, larynx, trachea, lungs, heart, liver, kidneys, bladder, spleen, abomasum, rumen, and intestines (both large and small). Observed gross lesions were recorded and used to determine the final diagnosis, which was then categorized into respiratory (RESP), gastrointestinal (GI), septicemia (SEPT), or other (OTH) causes.

Gastrointestinal lesions included abnormalities of the small and/or large intestine mucosa including ulcers, hemorrhage, thickened mucosa, necrosis, obstruction, inflammation, and/or strangulation of any portion of the intestine. Abnormalities within the abomasum such as hemorrhage or ulcers, and/or the rumen, which consisted of parakeratosis, hemorrhage, or ulcers were also considered GI lesions. Gastrointestinal cases included findings such as inflammation, hemorrhaging of the digestive tract, bloat, peritonitis, ulcers within the GI tract, abnormal

digestive contents, and/or scours. Scours were sometimes confirmed based on external evidence found on the hind quarters of the calf. Septicemia diagnoses were based on gross pathological changes in pulmonary and cardiac tissues, including the broad spread presence of petechiae and/or ecchymosis.

Respiratory diagnoses were identified through gross evaluation of both the pulmonary surface and cross-sections of the lungs with the entire lungs removed from the thoracic cavity for thorough examination. Respiratory diagnoses were further categorized into bronchopneumonia (BP), bronchopneumonia with an interstitial pattern (BIP), and aspiration or embolic pneumonia. Bronchopneumonia was characterized by findings such as pulmonary consolidation (firm lungs), fibrin adhesions, and abscesses, though not all these abnormalities were observed in every case. Chronic cases typically involved extensive lesions, widespread consolidation, abscessation, and/or adhesions. Cases that were BIP, which has been previously documented in feedyard cattle, typically presented with cranioventral bronchopneumonia and interstitial pneumonia in caudodorsal regions (Schmidt et al., 2023a). Aspiration or embolic pneumonia was diagnosed based on the presence of scattered pulmonary abscesses without a consistent pattern. Cases that could not be clearly categorized under GI, septicemia, or respiratory were placed in the “other” group, which included congestive heart failure, endo/myocarditis, diphtheria, hardware, umbilical infection, joint infection, or unknown.

Statistical Analysis

Descriptive statistics were performed on all cases. Statistical analyses were performed on a subset of cases. Necropsies were performed each month at 3 of the 4 calf ranches. At the 4th calf ranch, necropsies were performed only in the month of July, and thus these cases were removed from statistical analyses. To assess the effect of time on the likelihood of a RESP

diagnosis or observation of GI lesions, cases for each month were categorized into 4-month periods. The first 4-month period consisted of February, March, April, and May of 2024. The second period was June, July, August, and September of 2024, and the third period included October, November, December of 2024 and January of 2025. Cases from each month were grouped this way to ensure an equal distribution and representation of cases from each calf ranch within each time category. A generalized linear model was used to evaluate the probability of being diagnosed as RESP in calves that died using the glm function with the binomial family and logit link from the stats package in R studio. Period (1, 2, and 3), sex (male vs. female), breed (beef-dairy cross vs. dairy), and calf ranch (Ranch A, Ranch B, and Ranch C) were included to determine the likelihood of a RESP diagnosis for each factor. The outcome of RESP diagnosis was binomialized where 1 corresponded to a RESP diagnosis, and 0 represented any other diagnosis.

Using the multinom function from the nnet package in R studio, a multinomial model was used to evaluate the association of finding a GI lesion and the segment of the GI it was found with period, sex, breed, and calf ranch. The GI lesion outcomes were categorized as the following: 0 for no GI lesion, 1 for lesion(s) found in the upper GI tract (the rumen and/or abomasum) only, 2 for lesion(s) found in the lower GI tract (the small and/or large intestines) only, or 3 for lesions found in both the upper and lower GI tracts.

Results

Two hundred and forty-three necropsies were performed across 4 calf ranches between February 2024 and January 2025. Cattle demographics are shown in Table 1. The majority (67.5%; 164/243) of cases were classified as respiratory, followed by GI (11.5%; 28/243), OTH

(11.5%; 28/243), and finally SEPT (9.5%; 23/243). A detailed breakdown of primary diagnoses and co-morbidities can be found in Tables 2 and 3, respectively.

Descriptively, specific to the 4-month period subset ($n = 175$), 37.1% of cases (65/175) were necropsied in period 1, 31.4% (55/175) in period 2, and the remainder (31.4%; 55/175) in period 3 (Figure 1). Of the subset that was analyzed statistically, a majority were females (78%; 136/175). Over half of the cases (55%; 96/175) were beef-dairy cross, and the remainder were dairy calves. In period 1, 69.2% (45/64) of cases were RESP, 10.8% (7/65) were GI cases, 3.1% (2/65) were SEPT, and the remaining 16.9% (11/65) were classified as OTH. In period 2, most cases were RESP (67.3%; 37/55), followed by GI (16.4%; 9/55), then SEPT (9.1%; 7/55), and finally OTH (7.3%; 4/55). For period 3, 56.4% (31/55) of cases were RESP, 10.9% (6/55) of cases were GI, 12.7% (7/55) were SEPT and 20.0% (11/55) were OTH.

Relative to the RESP diagnoses and the 4-month period subset, in period 1, 88.9% (40/45) of RESP cases were BP and 11.1% (5/45) were BIP. In period 2, 86.5% (32/37) were BP, 8.1% (3/37) were BIP, and 5.4% (2/37) were aspiration or embolic pneumonia. For period 3, 87.1% (27/31) were BP, 9.7% (3/31) were BIP, and 3.2% (1/31) were aspiration or embolic pneumonia. For the GI lesion categories, in period 1, 43.1% (28/65) of cases had 0 GI lesions, 26.2% (17/65) had upper GI tract lesions only, 10.8% (7/65) had lower GI tract lesions only, and 20.0% (13/65) had lesions in both the upper and lower GI tract. In the second period, 45.5% (25/55) had no GI lesions, 16.4% (9/55) had upper GI tract lesions only, 14.5% (8/55) had lower GI tract lesions only, and 23.6% (13/55) had lesions in the upper and lower GI tract. In period 3, the majority (60.0%; 33/55) had no GI lesions, 20.0% (11/55) had lesions in the upper GI tract only, 12.7% (7/55) had lesions in the lower tract only, and 7.3% (4/55) had lesions in the upper

and lower sections of the tract. A 2x2 table describing the distribution of GI lesions and their locations from all 4-month periods can be found in Table 4.

A generalized linear model was used to evaluate the probability of a RESP diagnosis in mortalities and potential associations with period, sex, breed type, and the calf ranch. A multinomial model evaluated the association of these factors with the presence and location of GI lesions in mortalities. None of the factors tested were significantly associated with the probability of RESP diagnoses ($P \geq 0.11$) or the presence and location of GI lesion(s) ($P \geq 0.13$). Risk of diagnosing a calf with RESP at time of necropsy or of finding at least 1 GI lesion did not differ between 4-month periods, sex, breed, or calf ranches.

Discussion

In this study, most diagnoses made through gross necropsy were classified as RESP (67.5%; 164/243), followed by GI (11.5%; 28/243) and OTH (11.5%; 28/243), and finally SEPT (9.5%; 23/243). These findings are consistent with previous literature that reported RESP and GI diseases are the most common diagnoses in calf mortalities (Agerholm et al., 1993; Virtala et al., 1996; Svensson et al., 2003; Winder et al., 2016; McConnel et al., 2019; Rebecca A. Bigelow et al., 2025). The most frequently reported causes of death for calves as described by USDA National Animal Health Monitoring System (NAHMS) data were respiratory (26.9%), followed by calving-related deaths (17.8%), and digestive issues (15.4%) across both beef and dairy operations (USDA, 2015). There is little published in the literature about diagnosing septicemia at necropsy, but Wilson et al. re-reported 2 cases diagnosed with septicemia out of 457 dairy calves necropsied between 2008 and 2019 at the Utah Veterinary Diagnostic Laboratory that ranged from 6 days to 5 months old (Wilson et al., 2022). However, it's important to note the differences in how diagnoses were made between the current study and Wilson et al.. Wilson et

al. reported that diagnoses were confirmed with numerous diagnostic tests dependent on what the attending pathologists found indicated immediately at necropsy whereas in the present study, diagnoses were confirmed based solely upon gross pathology present at necropsy which is certainly a limitation. Similar to mortality, previous literature reports similar trends in calf morbidity with the majority of illnesses being GI-related or respiratory disease (Walker et al., 2012; Windeyer et al., 2014; Urie et al., 2018). Most of the cases (86.4%; 210/243) did not have a secondary co-morbidity, but the majority of co-morbidities found were categorized as OTH (7.0%; 17/243) or respiratory (4.1%; 10/243). The most common primary diagnoses that had a co-morbidity were RESP (7.0%; 17/243) and OTH (3.7%; 9/243). While co-morbidities of calf mortalities are not well-described in the literature, Pardon et al. analyzed the association between different pathological lesions like pneumonia, pleuritis, pericarditis, enteritis, abomasal ulceration, ruminal bloat, and peritonitis (Pardon et al., 2012). Concurrent enteritis and pneumonia were found in 24.2% (22/91) of necropsied calves, but the association between the diagnoses was not significant. Additionally, Pardon et al. described lesions found at necropsy in all cases (n = 91) in categories which consisted of pneumonia, enteritis, frothy ruminal bloat, peritonitis, pleuritis, pericarditis, congenital heart defects, omphalitis, and intussusception (Pardon et al., 2012); however, the categories in which lesions were recorded were not mutually exclusive from one another, and the authors did not clearly report which lesions were occurring concurrently.

In the present study, period, sex, breed, and calf ranch were not significantly associated with the probability of assigning a RESP diagnosis at time of necropsy nor with the chance of identifying GI lesions categorized by location within the GI tract. Dubrovsky et al. conducted a study in California to examine the associations between BRD-related mortality and dam and calf

management practices (Dubrovsky et al., 2019b). That study reported the season in which the calf died was not significantly associated with mortality, which agrees with present findings. However, Dubrovsky et al. did contrasts between seasons, comparing each season to summer as the selected reference season, and found calves diagnosed with BRD in the spring had an increased risk of BRD-caused mortality compared to calves diagnosed in the summer, and calves diagnosed in the fall and winter did not differ significantly from those in the summer (Dubrovsky et al., 2019b). It's important to note that comparisons were not made between the other seasons (spring vs. fall, for example) and that they were truly assessing case fatality risk as they focused on BRD-specific cause of death. Unfortunately, treatment records were not available for a large portion of the data in the present study. As stated in the introduction, seasonality has been shown to be related to BRD morbidity in feedlot cattle, but there is speculation as to whether this relationship is based on the actual seasonal patterns or the management practices that are employed during those seasons (Loneragan et al., 2001; Moore et al., 2002; Taylor et al., 2010; Winder et al., 2016; Dubrovsky et al., 2019a; Maier et al., 2019; Waldner et al., 2022).

The relationship between sex and calf mortality has not been described within the literature, but there are conflicting results describing the association for BRD morbidity and sex (Taylor et al., 2010). Previous studies found that male calves were at higher risk for BRD than females (Alexander et al., 1989; Muggli-Cockett et al., 1992; Gallo and Berg, 1995). In contrast, Loneragan completed a retrospective study of feedlot cattle that found higher incidence of BRD-associated mortality in beef heifers than beef steers from 1997 to 1999 (Loneragan et al., 2001). Breed was also investigated in that retrospective feedlot study, and dairy animals had increased relative risk of death of any cause compared to beef steers (Loneragan et al., 2001). More related to the commercial calf ranch, in veal herds of young calves, mortality was higher in beef cohorts

compared to dairy or cross-bred cohorts (Pardon et al., 2012). In contrast, in pre-weaned calves in California dairies, breed, consisting of Holstein, Jersey, and “Other” which consisted of other purebred breeds or cross-bred calves, was not significantly associated with BRD morbidity (Maier et al., 2019). However, it’s important to note that the majority of the calves in the study conducted in California were Holsteins ($71.4 \pm 4.0\%$). While the present data has a more even distribution of breeds (55% beef-dairy cross vs. 45% dairy breeds), sample size was a limitation of this study and could affect the results of statistical analyses.

Calf ranch was also not significantly associated with RESP diagnoses or GI lesion location in the present data. It is worth noting that while the distribution of mortality diagnoses did not differ, the overall incidence of disease related to these mortality diagnoses might have differed. However, incidence was not measured as this was outside of the scope of this research. Although only 3 calf ranches were represented within the data, it is important to recognize that management and health practices vary greatly across operations which is common among commercial calf ranches (Rebecca A Bigelow et al., 2025). There could be a number of things that affect calf morbidity and mortality regarding specific calf ranch practices such as age of arrival, how far they were shipped, arrival protocols, and health protocols such as metaphylaxis, vaccine programs, and treatment protocols, among other things. Moore et al. investigated the influence of calf supplier on survival of Holstein bull calves raised for beef in a calf ranch setting (Moore et al., 2002). A calf supplier was defined as a dairy producer or calf buyer who aggregates groups of calves from multiple sources for the calf ranch. A total of 120,197 calf records from 14 different calf suppliers were analyzed, comparing all other calf suppliers to supplier 13 as their reference because they supplied calves with the best overall survival rate. In the 1st three weeks following arrival, calves from all other suppliers had a higher hazard ratio of

mortality compared to supplier 13 ranging from 1.7 to 6.2 (Moore et al., 2002). Moore et al.'s study provided evidence that calf supplier could have an effect on calf survival, so while the present data did not reflect this idea, it's important for calf ranches to consider this if they are facing a consistent pattern of mortalities. It is possible the sample size was not big enough to find whether ranch was associated with respiratory diagnoses or GI lesion location. The number of cases recorded at each location every month varied greatly, and as a result, each calf ranch was not represented evenly across time.

The authors recognize that the lack of statistical findings could be due to a small sample size. A subset was taken from the dataset for statistical analyses due to the timeline of which necropsies were performed at 1 of the 4 ranches. At the 4th calf ranch, all necropsies were performed in the month of July, so these cases were removed from the analyses of period, sex, breed, and calf ranch association with RESP outcomes and GI lesion locations. It's also important to note that the number of cases necropsied varied by month ranging from 6 to 25 cases. Additionally, there were 2 months when 1 of the 3 ranches did not have any cases on the day the technicians were on-site. Therefore, the months were grouped into 4-month periods to account for this in the analyses. Other limitations also include the enrollment of cases based on availability of deceased animals during the monthly visit to each calf ranch. The technicians were not always able to necropsy all animals that died during the monthly visit to each ranch due to time constraints. Unfortunately, identification was not available for each case necropsied resulting in lack of age or treatment information for a large portion of the cases. Another limitation to consider is the lack of laboratory confirmation of diagnoses through histopathology. This was due to budgeting, time, and labor constraints for this study. These limitations related to diagnosing cause of death based on gross findings have been discussed in previous work

(Rebecca A. Bigelow et al., 2025). It can be difficult to differentiate between specific disease processes within each category (RESP, GI, etc.) without confirmatory diagnostic lab work as shown by Schmidt et al., however, necropsy diagnoses are often determined solely upon gross evaluation in the field (Schmidt et al., 2023b). Therefore, the data collected describing gross pathology is still valid.

Conclusions

Describing mortalities as well as co-morbidities found at necropsy within commercial calf ranches is valuable as it provides information about disease processes that could be affecting other calves on-site. This information is essential as the number of dairies that send their calves off-site for rearing continues to increase as the calf ranch sector expands. The frequency of RESP and GI diagnoses found in this study was similar to what has been reported in previous research conducted at dairy replacement heifer raising facilities. Seasonal differences in BRD incidence has been reported previously in feedlot cattle and calves raised in calf ranch settings, but the present study did not find an association between period and the probability of a RESP diagnosis at necropsy or with identifying GI lesions in different location of the GI tract. No significant associations were found between the outcomes of interest and sex, breed, or calf ranch either. The authors believe this could be due to the sample size as well as the distribution of the cases seasonally. While not statistically significant, the findings of this research do provide valuable information descriptively. The information recorded about the cause of death and co-morbidities contributes to the small amount of literature published surrounding mortalities at commercial calf ranches and can potentially allow producers to adjust health protocols for improved prevention and therapy of these disease processes. As the commercial calf ranch sector continues to grow,

the need for further research describing and analyzing health data is essential for understanding and improving morbidity and mortality within these operations.

Author Contributions

Conceptualization, R.A.B., P.A.L., B.J.W., T.R.B., M.E.T., and R.G.A.; methodology, R.A.B., B.J.W., P.A.L., and R.G.A.; validation, R.A.B., P.A.L., and B.J.W.; formal analysis, R.A.B., P.A.L., and B.J.W.; resources, P.A.L., B.J.W., T.R.B., M.E.T., and R.G.A.; data curation, R.A.B.; writing—original draft preparation, R.A.B., P.A.L., and B.J.W.; writing—review and editing, T.R.B., M.E.T., and R.G.A.; visualization, R.A.B., P.A.L., B.J.W., T.R.B., M.E.T., and R.G.A.; supervision, P.A.L. and B.J.W.; project administration, R.A.B., P.A.L., B.J.W., and R.G.A.; funding acquisition, P.A.L., B.J.W., M.E.T., and R.G.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The Kansas State University Institutional Animal Care and Use Committee (IACUC) was contacted regarding the project and no approval was needed due to the evaluation of only deceased animals.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data collected for this research were from cooperating entities and are not publicly available due to confidentiality and anonymity agreements.

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Conflicts of Interest

The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

USDA – United States Department of Agriculture

BRD – Bovine respiratory disease

RESP – Respiratory

GI – Gastrointestinal

SEPT – Septicemia

OTH – Other

BP – Bronchopneumonia

BIP – Bronchopneumonia with an interstitial pattern

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Table 3.1 The proportion of mortalities by sex, breed type, and calf ranch (n = 243) with a subset of mortalities (n = 175) by 4-month period that were statistically analyzed. Necropsies were performed between February 22, 2024 and January 17, 2025.

Category	Count	Percent Total
Sex		
Female	180	74.1%
Male*	63	25.9%
Breed Type		
Beef-dairy cross	152	62.6%
Dairy	91	37.4%
Calf Ranch		
Ranch A	74	30.5%
Ranch B	55	22.6%
Ranch C	46	18.9%
Ranch D**	68	28.0%
Period		
1	65	37.1%
2	51	31.4%
3	51	31.4%

*Male included steers as well as 1 bull calf.

**Cases from Ranch D were excluded from statistical analyses because this ranch was only visited during July while the other ranches were visited every month for a year.

Table 3.2 The frequency of primary diagnoses by disease category for all cases necropsied (n = 243) at 4 commercial calf ranches. Necropsies were performed between February of 2024 and January of 2025.

Primary Diagnosis	Cases	% of Cases
Respiratory		
Bronchopneumonia	148	60.9%
Bronchopneumonia with interstitial pattern	13	5.3%
Aspiration/Embolic pneumonia	3	1.2%
Gastrointestinal		
Bloat	1	0.4%
Scours	4	1.6%
Peritonitis	5	2.1%
Other GI	18	7.4%
Septicemia	23	9.5%
Other		
Congestive heart failure	2	0.8%
Diphtheria	4	1.6%
Endo/myocarditis	3	1.2%
Hardware	5	2.1%
Joint infection	1	0.4%
Umbilical infection	3	1.2%
Unknown	10	4.1%
Total	243	100.0%

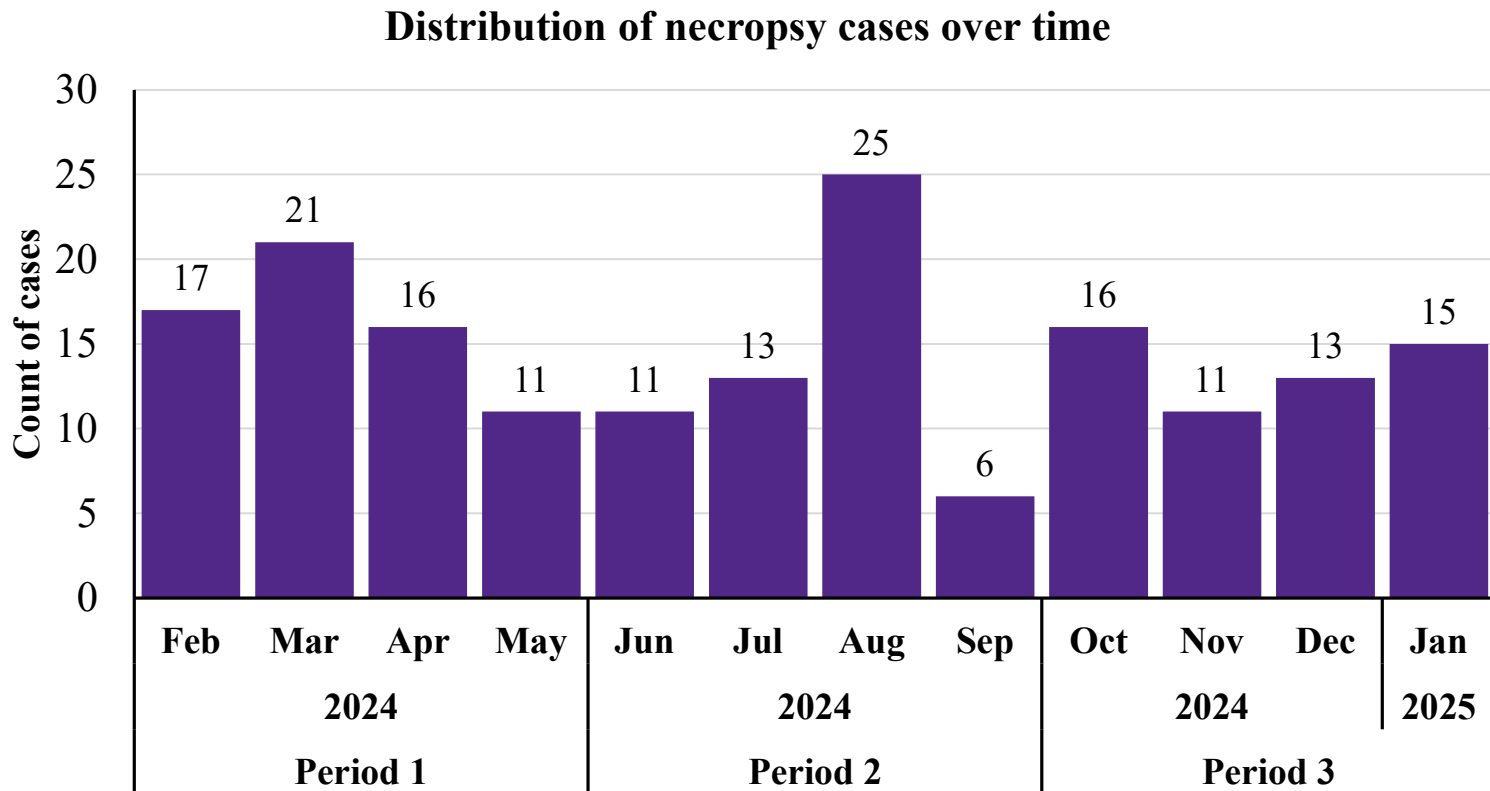
Table 3.3 The frequency of co-morbidities by primary diagnoses for all cases necropsied (n = 243) at 4 commercial calf ranches. Necropsies were performed between February 2024 and January 2025.

Co-morbidity	Primary Diagnoses			
	Resp	GI	Other	Septicemia
Respiratory				
Bronchopneumonia	-	1.2% (3/243)	2.9% (7/243)	0.0%
Embolic pneumonia	-	0.0%	0.0%	0.0%
Gastrointestinal				
Peritonitis	0.0%	-	0.0%	0.4% (1/243)
Other GI	0.4% (1/243)	-	0.0%	0.0%
Septicemia	0.8% (2/243)	0.8% (2/243)	0.0%	-
Other				
Congestive heart failure	2.5% (6/243)	0.0%	0.4% (1/243)	0.0%
Congenital defect	0.4% (1/243)	0.0%	0.0%	0.0%
Diphtheria	0.4% (1/243)	0.0%	0.0%	0.0%
Endo/myocarditis	1.6% (4/243)	0.0%	0.4% (1/243)	0.4% (1/243)
Hardware	0.4% (1/243)	0.0%	0.0%	0.0%
Musculoskeletal	0.4% (1/243)	0.0%	0.0%	0.0%
None	60.5% (147/243)	9.5% (23/243)	7.8% (19/243)	8.6% (21/243)
Total	67.5% (164/243)	11.5% (28/243)	11.5% (28/243)	9.5% (23/243)
- represents categories where there could be no overlay. For example, a primary RESP diagnosis with a RESP co-morbidity was not considered concurrent.				

Table 3.4 A 2x2 table describing the distribution of GI lesions and their locations for cases (n = 175) necropsied at 3 calf ranches. The upper GI tract consists of the rumen and abomasum. “Yes” for the upper GI tract means a lesion was found in the rumen and/or abomasum consisting of ulcers, hemorrhage, and/or parakeratosis. The lower GI tract consists of the small and large intestines. “Yes” for lower GI tract means a lesion was found in the small and/or large intestines consisting of hemorrhage, thickened tissue, obstruction, and/or inflammation. The percentage represents the number of cases in each category out of the total number of cases.

		Upper GI Tract		Totals
		No	Yes	
Lower GI Tract	No	86 (49%)	37 (21%)	123
	Yes	22 (13%)	30 (17%)	52
		108	67	175

Figure 3.1 The distribution of the subset of necropsy cases (n = 175) that were included in statistical analyses by month. Cases from the 4th calf ranch were excluded from analyses due to the fact that all cases were collected in July. The association of categorizing a case as a RESP diagnosis with 4-month period, sex, breed, or calf ranch was tested as well as the association of these factors and the probability of categorizing GI lesions by location found within the GI tract.



Chapter 4 - Evaluating the efficacy of Maternal Bovine Appeasing Substance (MBAS) administration on cortisol concentrations, animal behavior and welfare, and performance outcomes in beef-on-dairy calves during weaning

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Lay Summary

Weaning is an unavoidable stressor for dairy and beef calves, which can affect their growth and behavior. Cows naturally produce a pheromone (maternal bovine appeasing substance, MBAS) that soothes calves when nursing. The study objective was to determine if applying a synthetic version of that pheromone would decrease stress at weaning as measured through lowered blood cortisol, improved body weight (BW) and average daily gain (ADG), and altered behavior. Twenty-six beef-on-dairy calves were housed in single pens and given saline or MBAS on the first day of a 3-day step-down weaning process. Blood was collected on days 0, 1, 3, and 10. Weight gain and feed intake were measured throughout the study, and cameras, microphones, and accelerometers were used to evaluate behavior. Surprisingly, calves receiving

saline had lower overall cortisol concentration than MBAS calves. Bodyweight and ADG were not different between MBAS and saline calves. Calves treated with MBAS had fewer bouts of standing up and lying down, which could mean they were “restless”. These findings suggest that although MBAS changed calf behavior during weaning, it did not appear to reduce stress via cortisol levels or improve growth in the short term.

Teaser Text

This study found that a synthetic version of maternal bovine appeasing substance (MBAS) altered calf behavior during weaning but did not reduce stress via cortisol levels or improve growth by assessing bodyweight, average daily gain, and gain:feed conversions. This data offers insight into how weaning interventions may affect animal welfare through their behavioral changes.

Text Abstract

Weaning is an unavoidable stressor for dairy and beef calves. Maternal bovine appeasing substance (MBAS) is a naturally secreted pheromone that induces an appeasing effect on nursing offspring. Our objective was to determine if a single topical dose of synthetic MBAS analog would lower cortisol concentrations, improve performance, and alter behavior outcomes of beef-dairy calves during weaning. Twenty-six individually housed male beef-dairy (Angus-Holstein cross) calves were blocked by weight (72 ± 6 kg) and randomized to either saline (CONT) or MBAS (MBAS; FerAppease, Fera D&B, College Station, TX). Calves received a single 10 mL dose of the designated treatment (5 mL on the poll, 5 mL on the muzzle) on day 0 prior to 3-day step-down weaning. Blood was collected on days 0, 1, 3, and 10. Calf starter intake and refusals were weighed and recorded daily. Body weights (BW) were collected every other day for 10 days following weaning. Average daily gain (ADG) and gain-to-feed (G:F) were calculated.

Behavior was assessed using cameras, microphones, and accelerometers. Linear mixed models with effects of time, treatment and interaction were used to analyze cortisol, performance, and behavior variables with block and calf as random effects. Cortisol concentrations were significantly ($P < 0.05$) lower for CONT than MBAS. There were no treatment effects on BW or G:F between CONT and MBAS. Several treatment $\times$ time interactions ($P < 0.05$) were found for behaviors, with CONT having more lying bouts than MBAS on day 0. Additionally, CONT exhibited more nutritive oral behaviors ($P = 0.01$), defined as calf ingesting feed with their head over the feed bucket, post-treatment than MBAS. Vocalizations did not differ between treatments ($P > 0.32$) at any time during the trial. This research demonstrates that MBAS altered behavior during weaning, but it did not improve performance or blood cortisol compared to CONT.

Key Words

Beef-dairy cross, behavior, calves, pheromone, weaning

List of Abbreviations

ADG – Average daily gain

BW – Body weight

ELISA – Enzyme-linked immunosorbent assay

G:F – Gain:feed

HPA – Hypothalamic-pituitary-adrenal axis

MBAS – Maternal bovine appeasing substance

NOB – Nutritive oral behavior

NNOB – Non-nutritive oral behavior

Introduction

Calves in dairy and beef production systems go through many unavoidable stressors early in life including weaning (Hulbert and Moisé, 2016). Strategies for weaning beef calves have been well-documented in previous literature, but with increased use of beef semen to breed dairy cows, a greater number of beef-dairy calves are being produced and raised intensively (Boyles et al., 2007; Taylor et al., 2020; Weiker, 2024a). These calves are often transported to a calf ranch where they are housed individually and introduced to calf starter very early in life prior to being weaned off milk, similarly to replacement heifer calves (Rebecca A Bigelow et al., 2025). The stress associated with these processes can negatively impact their affective states by activating the hypothalamic-pituitary-adrenal axis (HPA) and the sympathetic nervous system, resulting in adrenocortical and acute-phase protein responses that can impact calf behavior, health, and performance (Carroll and Forsberg, 2007; Hulbert and Moisé, 2016).

Various weaning strategies, such as abrupt, fence line, nose-flap, etc. and their effects on health, performance, and stress response have been researched in beef and dairy calves (Boyles et al., 2007; Budzynska and Weary, 2008; Loberg et al., 2008; Taylor et al., 2020). An alternative to mitigating stress could include the use of appeasing pheromone analogs to elicit a calming effect on distressed animals (Liberles, 2014). The use of pheromones has been well-documented in swine, specifically during and following the weaning of piglets (McGlone and Anderson, 2002; Temple et al., 2016; Chasles et al., 2024). Additionally, previous trials have shown mixed effects of MBAS in different cattle production settings, such as in pre-weaned dairy heifers, weaning and pre-conditioning of beef calves, and prior to slaughter of finishing steers (Angeli et al., 2020; Schubach et al., 2020b; Bringhenti et al., 2023; Kvamme et al., 2024; Mackey et al., 2024). Several studies have evaluated calf behavior at time of weaning comparing

MBAS to a placebo, typically saline; however, these studies were conducted using *Bos indicus* calves that were at least 6 months of age that were weaned from a pasture setting (Schubach et al., 2020b; Vieira et al., 2023; Santos et al., 2025).

Maternal bovine appeasing substance (MBAS) is a pheromone naturally secreted by the sebaceous gland located on the skin of the mammary gland (Liberles, 2014). As the calf nurses, the pheromone stimulates the vomeronasal gland and desensitizes the amygdala and hypothalamus, preventing activation of the HPA axis, in order to decrease threat perception and elicit a calming effect on the offspring (Liberles, 2014). The synthetic analog of MBAS is based on a mixture of fatty acids to reproduce the composition of the naturally-secreted pheromone as described on the product label (FerAppease Bovine 300 mL, FERA Diagnostics and Biologicals, College Station, TX). This technology has gained interest from producers in the cattle industry, and to the authors' knowledge minimal research has been conducted to investigate the effects of MBAS on reducing the stress associated with weaning of individually housed calves in a calf ranch setting.

It was hypothesized that calves dosed with MBAS would have decreased cortisol concentrations, spend more time lying down, vocalize less, present fewer non-nutritive oral behaviors (NNOB), and would have improved performance and health outcomes with greater body weight (BW), average daily gain (ADG), gain to feed (G:F) compared to control calves receiving saline. The research objective was to determine if a single topical dose of MBAS at the start of step-down weaning would decrease cortisol concentrations in blood, produce changes in behavior, and improve performance outcomes of beef-dairy male calves during and following the weaning process.

Materials and Methods

All animal care and procedures were approved by the Kansas State University (KSU) Institutional Animal Care and Use Committee before study initiation (IACUC protocol: IACUC-4946). This trial was conducted at the KSU Sheep and Meat Goat Center (Manhattan, KS) from November to December 2023.

Experimental Design

Twenty-six pre-weaned castrated male beef-dairy calves (58 ± 4.8 days of age) from a single source in Kansas were used in this trial. Calves were individually weighed 4 days before the start of the trial. A complete randomized block design was used for this trial where calves were randomly allocated within weight block to treatment: similar color saline solution (Sterile Saline Solution – Saline Solution 0.9%, Vet One, MWI, Boise ID), and blue food coloring (Food Colors Assorted Neon, Kroger); CONT, n =13) or maternal bovine appeasing substance (MBAS; FerAppease Bovine 300 mL, Fera Diagnostics and Biologicals, College Station, TX, n=13). A study collaborator that did not participate in data collection or data analysis allocated calves to treatment to maintain blinding of calf caretakers and researchers collecting data. Randomization was accomplished using a random number generator (Microsoft Excel, Microsoft Corp.). Treatments were applied by an unblinded study collaborator, that did not participate in data collection or data analysis. A topical dose of the designated treatment was applied to the nuchal skin behind the poll (5 mL), and to the skin above the muzzle (5 mL) using a proprietary applicator as indicated per the manufacturer's recommendation.

Animal feeding management

Calves were housed in elevated individual pens in a naturally ventilated barn with two open doors and continuous airflow through the building. Wooden partitions were placed along all

four sides of each pen to prevent nose-to-nose contact between calves. Calves were weighed every other day starting on day 0. Prior to the 3-day step-down weaning process, calves received 1.85 liters of milk replacer (Land O Lakes® Herd Maker® Calf Milk Replacer, Arden Hills, MN) twice daily (6:30 AM and 5:00 PM), calf starter with 89% dry matter (Calf Grower B-68 16% Protein, Mid Kansas Coop, Manhattan, KS) at 1.02 kgs of feed per 45.36 kg of body weight (BW) once daily, and water *ad libitum*. Calves did not receive any type of roughage, such as hay, at any point in the study. On day 0, the calves only received the morning milk bottle and were not offered the evening milk bottle (removal of the second bottle). On this same day, CONT and MBAS treatment application took place at 0800 h. Milk feeding remained the same on days 1 and 2. On day 3, calves were completely weaned off milk and were offered dry feed (calf starter) only. The amount of calf starter was adjusted based upon BW and fed once daily on days 3 through 9 at 1.02 kg/45.36 kg of BW. On day 9, calf starter was fed at 1.13 kg/45.36 kg of BW, and the total fed amount was split evenly between morning and evening offerings. On day 11, calf starter was increased to 1.25 kg/45.36 kg of BW. Calves were fed and weighed on the morning of day 13 prior to study conclusion. Interim ADG and interim G:F were calculated using BW and feed intake. Interim ADG was calculated to get ADG for every 2-day increment that BW was collected. Similarly, interim G:F was calculated for every 2-day increment between BW collections.

Blood parameters collection

Approximately 10 mL of blood was collected via jugular venipuncture from each calf at the following timepoints: 1, 8-, 12-, and 24-hours following treatment application, day 3 at 0800 h, and 4-, 8-, 12-, and 24-hours following, and day 10 at 0800 h. Blood samples were labeled with a unique identifier, mixed by inverting the tube (Greiner Bio-One VACUETTE™ Lithium

Heparin Blood Collection Tube, Greiner Bio-One North America Inc., Monroe, NC, USA) immediately following collection, placed on ice and transported to the lab. Blood samples were centrifuged at 1000 g for 15 minutes, and serum was pipetted and stored in cryovials at -80°C until cortisol enzyme-linked immunosorbent assays were performed as described by Mancke et al. (2025). Intra-assay variability was 9.78%, and inter-assay variability was 5.25%.

Behavior data collection

Video cameras (Camera Bullet 4 Megapixel Motorized 2.8-12mm lens, Geovision, Taiwan) and microphones (Verifact® A Microphone, Louroe Electronics, Van Nuys, CA) were mounted on a wooden framework above the pens on a 45-degree angle to continuously record video and audio 24/7 for the duration of the study. A predetermined timeframe of 30 minutes after each intervention was used (milk bottle feeding, milk bottle removal/milk bottle not offered, and application of treatment) according to continuous recording approach described by Dawkins (2007) and similar to Vessier et al (2002). Therefore, subsets of 30-minute videos were rendered for behavior scoring 30 minutes after morning (AM videos) and evening (PM videos) milk feeding on the day prior to weaning (day -1), day 0, and day 3. Behavior was evaluated within the same temporal window to avoid confounding effect of natural diurnal variation in calf activity. This approach was to ensure that any detected differences were attributed to the weaning event and treatments rather than inherent differences in behavior between morning and afternoon periods. Videos were also rendered to cover 30 minutes after time of treatment application (PT videos) on day 0. Calves were allowed 15 minutes of rest after human contact before videos were rendered to minimize behavior changes associated with human presence. Two trained observers that were blinded to treatment analyzed videos. To measure reliability between the two observers, the functions ‘icc’ and ‘kappa2’ from the ‘irr’ package in RStudio

were used to calculate the intraclass correlation coefficient (ICC) and Kappa statistic, yielding an ICC of 1, indicating excellent reliability, and a Kappa of 0.66, indicating substantial agreement. An ethogram was created to describe behaviors evaluated (Table 1). Behaviors of interest included lying or standing, nutritive oral behavior (NOB), non-nutritive oral behavior (NNOB; Vessier et al., 2002; Vessier et al., 2013), grooming, play behavior, vocalizing, non-vocalizing, and residing spatially close to the bottle holder or distanced from the bottle holder. Triaxial accelerometers (HOBO Pendant G Data Logger, Bourne, MA) were secured to the left lateral aspect of the right hind leg using a small amount of tag cement (Kamar Adhesive) and veterinary bandaging tape (AmerisourceBergen, Conshohocken, PA) prior to treatment. Accelerometers were removed and replaced on day 6 to ensure continuous data collection. At this time, the new accelerometers were secured to the opposite medial aspect of the rear leg. The axis position was converted into a binomial variable of standing and lying based on a published protocol (UBC AWP, 2013). Data were summarized as total time lying and standing per day, number of standing and lying bouts indicating change in position from standing to lying or vice versa, and duration of standing and lying per bout. A bout was defined as the act of lying or standing for longer than 60 seconds. Accelerometer variables were summarized in 24 hour increments for analysis.

Statistical Analysis

Data transformation

All data were analyzed using RStudio (Version 2022.02.3, Boston, MA). Histograms and Shapiro-Wilk tests were used to assess normality of all outcome variables using the ‘hist’ function from ‘ggplot2’ package and ‘shapiro.test’ function of ‘stats’ package. Due to lack of normality of cortisol and behavioral data, outcome variables were transformed by multiple

methods. The final method of transformation was selected by using Shapiro-Wilk tests to determine which method was best-fitting. There were 3 models used to assess video behavior for different timepoints: 30 minutes post-treatment (PT), 30 minutes following AM milk feeding (AM), and 30 minutes following PM milk feeding (PM). Blood cortisol concentration, percentage of video time lying for AM and PM, percentage of NOB for AM and post-treatment (PT), percentage of NNOB for PT, percentage of time spent grooming for PT, percentage of time spent close to the bottle holder for PT, count of play behavior for AM and PM, and count of vocalizing for AM all required log-transformation ($\log_{10}+1$) for normalization prior to analysis. Count of vocalizations and grooming for the PM timepoint were square-root (square-root+1) transformed to achieve normalization before analysis. Accelerometer data was filtered for removal of incomplete data collection due to accelerometer malfunction where increments with less than or equal to 1400 minutes and greater than 1441 minutes in total time recorded were removed for each calf prior to analysis. If data within a 24-hour increment was incomplete, that 24-hour increment was removed from the analysis to maintain data integrity and prevent any misrepresentation or skewing of the results. The total number of lying bouts required a transformation for severely skewed data which was accomplished with the following equation: $"Severe" \text{ lie bouts} = \frac{1}{10 + \text{total \# of lie bouts}}$. Transformed data is reported as estimated marginal means and standard errors that were back-transformed, with p-values from model-associated transformed data. The remaining outcome variables did not require transformation prior to analysis.

Performance models

For performance variables of body weight, interim ADG, and interim ADG, linear mixed effects models were used to analyze outcomes of interest using 'lmer' function of 'lme4'

package of R. Fixed effects of treatment, time, and treatment $\times$ time were included in each model. Weight block and calf ID were included as random effects to account for repeated measures over time. Statistical analysis of the blood cortisol concentrations was accomplished using a linear mixed effects model with the fixed effects of treatment, time, and treatment $\times$ time and random effect of calf ID and weight block.

Accelerometer models

For analysis of accelerometer data, the total time lying in minutes per day, total time standing in minutes per day, total number of standing bouts per day, total number of lying bouts per day, average length of a standing bout, and average length of a lying bout were analyzed using linear mixed effects models with fixed effects of time, treatment, and time $\times$ treatment. Weight block and calf ID were included as random effects.

Camera behavior models

As mentioned previously, 3 models were used to analyze behavior: post-treatment (PT model) on day 0, behavior following morning milk feedings on days -1, 0, and 3 (AM model), and behavior following evening milk feedings on days -1, 0, and 3 (PM model). The variables assessed in each model included percentage of time with head still, lying, standing, performing NOB and NNOB, grooming, time spent distanced from the bottle holder, and time spent close to the bottle holder. Counts of play behavior, vocalization, and grooming were also analyzed. For the PT models, a linear mixed model was used and included the fixed effect of treatment and weight block was included as a random effect. For the AM and PM models, a linear mixed effects model was used with fixed effects of treatment, time, and treatment $\times$ time and calf ID and weight block were included as random effects. Estimated marginal means were adjusted using Tukey's method. Significance was established at $p \leq 0.05$.

Results

Performance results

When analyzing BW, there was no treatment difference ($P = 0.45$) between CONT and MBAS calves. There was a significant timepoint effect ($P \leq 0.01$), with BW increasing over time from day 0 to 13. For interim ADG, a treatment effect ($P = 0.02$) and timepoint effect ($P < 0.001$), but no treatment $\times$ timepoint interaction ($P = 0.47$) were identified. The CONT calves had a greater interim ADG of 0.47 kgs/day compared to 0.40 of the MBAS calves. For the timepoint effect, interim ADG increased over time from day 0 to 13 (Figure 1). Interim G:F conversion was not different among treatments ($P > 0.05$), but there was a significant timepoint effect ($P < 0.01$) where G:F increased from day 0 to day 13. Estimated marginal means and standard errors can be seen in Table 2.

Blood cortisol results

A treatment effect ($P < 0.05$) was found for blood cortisol concentrations. There was also a significant timepoint effect ($P < 0.05$) on cortisol concentrations; however, there was no treatment $\times$ timepoint interaction detected ($P > 0.05$). Calves in the CONT treatment group had lower overall cortisol concentrations than MBAS calves ($2,578 \pm 207$ pg/mL versus $3,064 \pm 246$ pg/mL, respectively). On day 3 at 1200 h and 1600 h, cortisol concentrations were highest, measuring 6,637 pg/mL and 5,938 pg/mL, respectively, and were significantly higher than cortisol measured at any time on day 0, day 1, at 2000 h on day 3, and day 10.

Accelerometer behavior results

For automated stand/lie behavior collected via accelerometer, no treatment effect was found for total time spent lying or standing in minutes per day. There was a significant time effect on total time spent lying and standing in minutes for all calves ($P < 0.001$) where calves

spent more time lying on days 1 and 2 than the start (day 0) and end (day 4) of the step-down weaning process. The total time standing during step-down weaning was the inverse of the lying time. There was a significant treatment $\times$ time interaction ($P = 0.04$) for the total number of lying bouts. The CONT calves tended to ($P = 0.06$) have a greater number of lie bouts on day 0, the first day of step-down weaning, and significantly ($P = 0.02$) had a greater number of lie bouts on day 2 (22.0 ± 0.2) compared to MBAS (15.7 ± 0.2) (Figure 2). For total number of standing bouts, there was no treatment effect or treatment $\times$ time interaction, but there was a significant timepoint effect ($P < 0.001$). The highest number of stand bouts were seen on day 0 and day 3 with an average of 20.2 ± 0.7 and 19 ± 0.7 bouts respectively, compared to the lowest number of stand bouts of 12.1 ± 0.7 on day 9. Similarly, there was a timepoint effect ($P < 0.001$) on the average length of each standing bout but no treatment or treatment $\times$ time effects ($P \geq 0.4$). During the step-down weaning process on days 0 through 3, each stand bout had a decreased average length compared to the post-weaning period including days 4, 5, 8, 9, and 10. For the average length of each lying bout, there was a significant time effect ($P < 0.001$) and a treatment $\times$ time trend ($P = 0.058$). The average length of each lying bout was lower on day 0 compared to days 4 through 13. For the interaction trend, CONT calves had shorter lie bouts than MBAS calves on day 2 (50.3 minutes versus 68.8 minutes, respectively), then CONT had longer lie bouts than MBAS calves on day 12 (75.2 minutes versus 61.0 minutes, respectively). Estimated marginal means for each logger outcome variable can be seen in Table 3.

Post-treatment camera behavior results

For analysis of PT outcomes, there were no significant treatment effects ($P > 0.05$) for percentage of time spent with head still, lying, standing, grooming, performing NNOB, residing close or distanced from the bottle holder, or count of vocalizations, play behavior, and grooming.

There was a treatment effect ($P = 0.01$) on the percentage of time performing NOB where CONT calves spent a greater percentage of time performing NOB than MBAS calves (Table 4).

AM camera behavior results

For AM and PM models, day -1 was the baseline from the day prior to treatment application, day 0 was the first day of step-down weaning as well as treatment application, and day 3 was the final day of step-down weaning i.e. the first day calves received no milk. In the AM models, no treatment, timepoint, or treatment $\times$ timepoint effects ($P > 0.05$) were found for the percentage of time residing close or distanced from the bottle holder, time spent standing or performing NNOB. A timepoint effect ($P < 0.05$) was found for percentage of time with head still, performing NOB, and count of vocalizations. The percentage of time with head still was greater on day 3 ($68.1 \pm 4.67\%$) than day -1 ($45.0 \pm 4.65\%$) or 0 ($49.2 \pm 4.65\%$). The percentage of time performing NOB was greater on day -1 ($4.30 \pm 1.27\%$) compared to day 3 ($1.76 \pm 0.66\%$). The count of vocalizations was at least 10 times higher on day 3 (45.21 ± 9.32) compared to day -1 (3.16 ± 0.83) and day 0 (4.52 ± 1.12). For count of grooming behaviors, there was a treatment, timepoint, and treatment $\times$ timepoint effect ($P \leq 0.04$). The count of grooming for MBAS calves did not change over time, but the count for CONT calves increased from day 0 to day 3 (2.77 ± 0.96 versus 8.23 ± 0.96 , respectively). Grooming behavior was greater for MBAS (7.69 ± 0.96) compared to CONT on day 0 (2.77 ± 0.96) (Figure 3).

PM camera behavior results

For the PM models, no treatment, timepoint, or treatment $\times$ timepoint effects ($P > 0.05$) were found for the percentage of time spent grooming. There was a significant timepoint effect ($P \leq 0.02$) for percentage of time lying, time spent close or distanced from the bottle holder, standing, performing NOB and NNOB, and count of vocalizations and grooming. The

percentage of time spent lying increased from day -1 ($11.7 \pm 1.59\%$) to day 3 ($20.9 \pm 2.73\%$). The percentage of time spent distanced from the bottle holder decreased from day -1 ($34.5 \pm 3.36\%$) to day 3 ($10.6 \pm 3.34\%$). In contrast, time spent near the bottle holder increased from day -1 ($65.5 \pm 3.36\%$) to day 3 ($89.4 \pm 3.34\%$). The percentage of time spent standing decreased from day -1 to day 3 (96.3% compared to 79.1% respectively). The percentage of time performing NNOB decreased from day -1 ($17.9 \pm 1.52\%$) to day 0 ($4.78 \pm 1.51\%$) and day 3 ($3.43 \pm 1.51\%$). Conversely, the percentage of time performing NOB increased from day -1 ($14.4 \pm 3.97\%$) to day 0 ($38.8 \pm 3.94\%$) and day 3 ($45.2 \pm 3.94\%$). Counts of vocalizations decreased from day -1 to day 3 with 15.9 counts compared to 6.02, respectively. The counts of grooming decreased from day -1 with a count of 6.74 compared to day 3 with 3.34. There was a treatment effect ($P < 0.001$) and treatment $\times$ timepoint effect ($P = 0.004$) for count of play behavior. The CONT calves showed no play behavior compared to the MBAS calves who had increased counts of play behavior during the AM period on day -1 (0.53 ± 0.11) compared to day 0 (0.05 ± 0.08). Estimated marginal means for each camera behavior for the AM and PM analyses can be seen in Table 5.

Discussion

The present findings demonstrated no treatment differences of MBAS vs CONT on BW and G:F conversion in beef-dairy calves for 10 days post-weaning. In contrast, previous studies demonstrated increased BW when comparing control treatment to MBAS. Angeli et al. (2020) compared performance measures between individually housed pre-weaned dairy heifers that received a placebo treatment (bovine appeasing substance (BAS) carrier, diethylene glycol monoethyl ether; $n = 70$) to calves that received bovine appeasing substance (BAS; IRSEA Group, Quartier Salignon, France; $n = 70$). In comparison to the present data, Angeli et al. (2020)

had a longer period for step-down weaning, 3 days vs 31, respectively, MBAS was applied 5 times throughout the weaning process, and ADG was measured at 14-day intervals for 70 days vs 2-day intervals for 13 days in the present data. It was reported that calves receiving BAS had greater BW at weaning as well as increased ADG from days 42 to 56 and tended to be higher from day 56 to weaning on day 70 compared to the calves who received the placebo (Angeli et al., 2020).

Brighenti et al. (2023) also conducted a study using individually-housed, pre-weaned dairy heifer calves that showed an increase in BW for MBAS-treated calves compared to a control group 7 days after calves were moved from the individual pen to group pens. Other studies have shown differences in BW between a control and MBAS treatment in group settings, such as application prior to weaning calves on pasture, prior to arrival at the feedlot, and prior to shipping for harvest (Cooke et al., 2020; Fonseca et al., 2021; Mackey et al., 2024). While there was no difference in final BW in the shipping trial, BW 45 days post-treatment was higher for calves who received MBAS at weaning or those who received MBAS prior to transport to the feedlot (Cooke et al., 2020; Fonseca et al., 2021; Mackey et al., 2024). Conversely, there have been studies that support the present findings in which no difference in BW was found between control and MBAS calves (Schubach et al., 2020a; Schubach et al., 2020b; Kvamme et al., 2024). Similarly, for ADG there have been conflicting reports of significant treatment or treatment $\times$ timepoint effects on ADG, as well as, reports of no differences found in ADG between calves receiving MBAS and those who did not (Angeli et al., 2020; Cooke et al., 2020; Schubach et al., 2020a; Fonseca et al., 2021). The present findings showed a treatment effect on interim ADG with increased ADG for CONT calves at 0.47 kgs/day compared to 0.40 kgs/day for the MBAS group.

In previous literature, only one study demonstrated a difference in overall feed efficiency where Fonseca et al. reported that when applied prior to transport, calves that received MBAS compared to those that did not, had greater overall G:F (Fonseca et al., 2021). The remaining literature where G:F was reported showed no differences between control and MBAS groups and supports the present data; however, those studies calculated feed efficiency over a 40 to 42 day period (Schubach et al., 2020a; Schubach et al., 2020b; Kvamme et al., 2024).

Previous literature evaluated cortisol concentration in the plasma of weaned calves in the feedlot and found no differences between CONT and MBAS treatment groups (Cooke et al., 2020; Schubach et al., 2020a; Schubach et al., 2020b; Fonseca et al., 2021; Kvamme et al., 2024). This differs from the present data as overall cortisol concentrations were found to be lower for CONT calves compared to MBAS, measuring $2,578 \pm 207$ pg/mL versus $3,064 \pm 246$ pg/mL, respectively. Kvamme et al. reported cortisol levels ranging from 1,400 pg/mL to 3,100 pg/mL over a 42-day pre-conditioning period; however, these were reported values for post-weaned older calves than the population in the present study. It is important to recognize that the cited research differs from the present as it was performed in older animals housed in group settings prior to transportation to a feedlot or to pasture, and the present data evaluated individually housed calves experiencing the stress of weaning. It's also important to note that cortisol is released during distress and eustress, and it is difficult to differentiate between the two. Thus, while researchers can measure cortisol levels in the plasma, there's no way to tell whether it's a response to distress, what some consider "bad stress", and eustress, considered "good stress".

Accelerometers have been used in previous literature to determine patterns and monitor changes in behavior in dairy and beef cattle (Robert et al., 2009; Bonk et al., 2013). To date, only

one trial was found where physical activity was assessed between groups of calves who received MBAS or a placebo. However, Schubach et al. used pedometers to assess steps/day only whereas the present data used triaxial accelerometers to assess lying/standing time and bouts (Schubach et al., 2020b). In the present data, a treatment $\times$ timepoint interaction was identified for the total number of lying bouts. The CONT calves tended to be more active than MBAS calves on day 0, the first day of step-down weaning, and day 2, the middle of step-down weaning, as they were getting up and lying down more frequently compared to 5 days post-weaning and beyond. Overvest et al. (2018) examined how social housing influences the lying behavior of calves by comparing lying time and lying bouts between individually housed calves and calves housed in pairs throughout and following the weaning process (Overvest et al., 2018). Their results noted that lying bouts and lying time decreased by day during the weaning and postweaning period. This alteration in lying behavior was attributed to the calves adapting their feeding habits to cope with receiving less and then no milk (Overvest et al., 2018). The present data shows a similar trend over time with the total number of lying bouts decreasing for CONT and MBAS calves from the first day of the step-down weaning to post-weaning. Numerically, the CONT calves had a greater number of lie bouts until day 10 when lie bouts for the MBAS calves were greater, but the differences after the step-down weaning period were not statistically significant. Another weaning trial investigating two weaning methods, gradual weaning versus abrupt weaning, used automatic activity sensors that measured standing and lying bouts, time standing and lying, and duration of bouts (Scoley et al., 2019). That study found that abruptly weaned calves displayed a reduced number of lying bouts as well as decreased lying time in the post-weaning phase when compared to gradually weaned calves.

In the present data, there was a timepoint effect for total time lying, total time standing, total number of standing bouts, and the average length of each lying or standing bout. The calves had a greater number of standing bouts shorter in average length during step-down weaning compared to days post-weaning. This data demonstrates that the calves were standing up and lying down more frequently for shorter amounts of time throughout the weaning process than 5 to 7 days post-weaning. It is likely the more frequent bouts of shorter lengths could represent distress of some sort in the form of restlessness, and as the calves adapted to not receiving milk during the post-weaning phase, their behaviors were altered as well which has been shown in previous literature (Thomas et al., 2001; De Paula Vieira et al., 2008).

There have been many anecdotal testimonies about the use of MBAS to reduce stress in calves through changes in behavior such as showing signs of relaxation. In this trial, behaviors were evaluated after application of MBAS or saline to determine if there was a statistically significant behavioral change between the treatments. The CONT calves spent a greater percentage of their time performing NOB than MBAS calves. This means the CONT calves spent more time with their head over the bucket ingesting feed. Schubach et al. (2020) reported the mean proportion of calves per pen feeding was greater for calves that received MBAS compared to a control group (Schubach et al., 2020b). This is a slightly different behavior sample method than the present data, where the proportion of calves ingesting feed was measured (scan sampling) rather than the percentage of time (duration over a set period of time). However, the two findings are conflicting where Schubach et al. (2020) report increased feeding proportion in the MBAS group, and the results from the current trial report increased NOB in the CONT group. It is important to note the differences between these trials; the present data was collected on 42-to-56-day old beef-on-dairy calves raised in individual pens at and following weaning,

while Schubach et al. (2020) used 233-day old beef calves housed in group pens after weaning in a 42-day pre-conditioning period. The observations in Schubach's trial also were not taken immediately following treatment application. To date, the authors have not found other literature evaluating the effects of MBAS on calf behavior.

There was a timepoint effect for the percentage of time with head still, performing NOB, and count of vocalizations for the period following AM feeding. The increase in vocalization over time was expected, however, there was no difference found between treatment groups. This data supports findings of previous literature where calves showed strong vocal responses to weaning with increased counts of vocalization following weaning (Budzynska and Weary, 2008; Jasper et al., 2008; Bittar et al., 2020). In the present data, percentage of time spent performing NOB decreased over time, meaning the calves spent less time with their head over the starter bucket ingesting feed after the step-down weaning process compared to the day before weaning. Bittar et. al. reported that calves that were gradually weaned compared to abrupt weaning spent less time eating starter during the week following weaning, then increased as they got older (Bittar et al., 2020). Grooming behavior did not change over time for MBAS calves, nevertheless grooming increased from day 0 to day 3 for CONT calves. The CONT group also groomed significantly less than the MBAS calves on day 0. This difference could be due to the oily consistency of the MBAS product versus the watery saline. Eckert et. al. (2015) conducted a weaning trial with Holstein calves comparing weaning at 6 weeks of age versus 8 weeks, and it was reported that grooming tended to decrease during the step-down weaning period (Eckert et al., 2015). It is important to note the present research was conducted using beef-on-dairy calves, and the period where behaviors were evaluated was shorter than the period used by Eckert et al., (2015), 4 days compared to 4 weeks respectively.

For behavior evaluations after PM feedings, the percentage of time spent close to the bottle holder increased from day -1 to day 3, which corresponds to the day prior to weaning and the first day calves did not receive any milk. The evaluations took place 30 minutes following when PM feeding normally took place, so residing close to the bottle holder is most likely attributed to the calves expecting and waiting for a milk bottle. The percentage of time lying increased from day -1 to day 3 while the percentage of time standing decreased. This shows a shift in behavior from standing on their feet to lying down more often throughout and following the weaning process. The percentage of time performing NNOB decreased over time from day -1 to day 3. This data is supported by reports from Veissier et. al. (2013) who reported a decrease in NNOB after weaning compared to before weaning in both of their treatment groups, calves reared with their dam and calves artificially reared drinking milk from a bottle (Veissier et al., 2013). In contrast, the present data showed an increase in NOB from day -1 to 3. This could be explained as increased ingestion of starter to attain lack of calories previously provided by milk offered. Count of vocalizations decreased following PM feedings from day -1 to day 3. This may be due to the calves acclimating to not receiving milk in the evenings. As they adjusted to expecting but not receiving milk at night, their vocalizations decreased by the end of the step-down weaning process. Count of play behavior was the only behavior outcome in the PM evaluation that had a significant treatment $\times$ timepoint interaction. The CONT calves did not display any play behavior throughout the period evaluated, and the MBAS calves displayed more play behavior on day -1 prior to weaning than on day 0 which was the first day of the step-down weaning as well as day of treatment application, however, this could be due to variation between calves. Vázquez Diosdado et al. (2024) reported that compared to pre-weaned calves, total play time significantly increased during step-down weaning and when weaning was completed, which

was not reflected in the present data. However, there were differences in breed and sample size as Vázquez Diosdado et al. followed 3 cohorts of 15 Holstein calves for up to 18 weeks and the present data evaluated behavior of 26 beef-on-dairy calves over a 4-day period.

Limitations

A limitation of this research includes the short duration of the study as well as the small sample size used. Calf performance outcomes were measured and calculated over a total period of 14 days, and behavior was assessed over the 4-day period from pre-weaning, through the step-down process, to post-weaning. Another limitation includes the volatilization of the MBAS product, and although partitions were placed between pens, the product could have spread in the ambient air inside the barn. Further research is warranted to investigate how the application of MBAS would alter performance, blood cortisol concentration, and behavior in a large-scale setting more similar to calf-raising facilities found in the industry.

Conclusion

In summary, the administration of MBAS prior to step-down weaning did not lower blood cortisol concentration or improve performance outcomes of body weight or G:F in the present study. Interim ADG was increased for CONT compared to MBAS calves. Behavior as measured by accelerometers and video recordings was altered from pre-weaning through the step-down process and post-weaning. For behaviors evaluated post-treatment application, the CONT calves spent more time performing NOB compared to MBAS calves. Further research is needed to evaluate the effects of MBAS on a larger-scale operation that is more similar to the calf ranches where beef-dairy calves are typically raised. However, this research provides novel findings regarding the alteration of behaviors in beef-dairy calves during and following weaning when housed individually as there is little to no literature about this population.

Conflicts of Interest

There are no conflicts of interest to report.

Author Contributions

Rebecca Bigelow (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft), Eduarda M. Bortoluzzi (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - review & editing), Brad White (Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing - review & editing), Phillip Lancaster (Conceptualization, Investigation, Methodology, Supervision, Writing - review & editing), Alyssa Hobbs (Data curation, Writing - review & editing), and Payton Dahmer (Writing - review & editing).

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Table 4.1 Behavior ethogram defining each behavior evaluated post-treatment, post-AM feeding, and post-PM feeding.

Structural Behaviors	Definition
Nutritive Oral Behavior (NOB)	Calf is ingesting feed, head is over the bucket.
Non-nutritive Oral Behavior (NNOB)*	Non-Nutritive Oral Behavior: sucking on milk holder or other inanimate objects, biting on fence, licking fence, suckling/pulling on bottle when milk is gone.
Head Still	Any behavior that is not included in other behaviors, such as: licking nose, licking lips, chewing with head out of bucket, yawning, coughing, sneezing.
Grooming	Calf is licking its hair
Play Behavior	Bowing where calf lowers its head and front legs in playful manner, jumping
Vocalizing	Mouth is open and sound is matched up to microphone audio- or if no audio, appears to vocalize and there is paralumbar movement as if vocalizing.
Lying	Lying is characterized as when the calf has all legs on the ground.
Standing	Standing is characterized as when the calf has 3 or more legs vertical.
Spatial Behaviors	
Close to bottle holder	When >50% of calf is closer to the bottle holder than the gate
Distanced from bottle holder	When >50% of calf is closer to the gate than the bottle holder
*As described in Veissier et al. (2002)	

Table 4.2 Estimated marginal means and standard error of the means for CONT (n = 13) and MBAS (n = 13) calves over time for performance outcomes of body weight, periodic average daily gain, and gain:feed.

Outcomes	Treatments		SEM	<i>p</i> -Value		
	CONT	MBAS		Treatment	Time	Trt × Time
Body weight, kg				0.45	<0.001	0.87
d 0	72.0	72.5	2.13			
d 3	73.0	72.9	2.13			
d 5	73.3	73.6	2.13			
d 7	75.1	75.5	2.13			
d 9	76.3	76.4	2.13			
d 11	78.5	78.6	2.13			
d 13	80.8	80.7	2.13			
Interim average daily gain, kg/d				0.02	<0.001	0.47
d 0 to 3	0.33	0.14	0.06			
d 3 to 5	0.25	0.21	0.06			
d 5 to 7	0.45	0.42	0.06			
d 7 to 9	0.55	0.43	0.06			
d 9 to 11	0.59	0.55	0.06			
d 11 to 13	0.68	0.63	0.06			
Overall ADG, kg/d	0.68	0.63	0.09	0.38		
Gain:Feed, kg/d						
d 0 to 3	0.10	0.03	0.04	0.21	<0.001	0.59
d 3 to 5	0.06	0.13	0.04			
d 5 to 7	0.29	0.29	0.04			
d 7 to 9	0.17	0.13	0.04			
d 9 to 11	0.28	0.28	0.04			
d 11 to 13	0.28	0.25	0.04			

Table 4.3 Estimated marginal means for CONT (n = 13) and MBAS (n = 13) calves for HOBO logger associated outcome variables.

Behavior	Treatments		SEM	<i>p</i> -Value		
	CONT	MBAS		Trt	Time	Trt x Time
Total time lying, minutes per day	1028.0	1006.0	16.00	0.19	< 0.001	0.50
Total time standing, minutes per day	407.0	428.0	16.20	0.14	< 0.001	0.53
Lying bouts, n per day	16.7	16.3	0.15	0.06	< 0.001	0.04
Standing bouts, n per day	16.3	14.4	0.67	0.36	< 0.001	0.37
Average length of lie bout, minutes	63.6	64.5	3.38	0.14	< 0.001	0.06
Average length of stand bout, minutes	27.2	31.9	2.31	0.45	< 0.001	0.70

Table 4.4 Estimated marginal means for CONT (n = 13) and MBAS (n = 13) calves for camera behavior outcome variables following 30 min post treatment application.

Behavior	Treatments		SEM	<i>p</i> -Value
	CONT	MBAS		Trt
Head still, %	62.0	80.3	7.66	0.10
Lying, %	54.6	55.2	7.47	0.95
Standing, %	45.3	44.8	7.47	0.95
Distanced from bottle, %	67.2	76.0	7.52	0.41
Close to bottle, %	16.9	17.8	5.92	0.91
NOB, %	1.0	0.1	0.35	0.01
NNOB, %	3.1	3.7	1.50	0.77
Grooming, %	1.5	3.4	0.86	0.051
Vocalizations, n	0.0	0.07	0.05	0.32
Play behavior, n	0.0	0.07	0.05	0.32
Grooming, n	4.9	8.4	0.09	0.13

Table 4.5 Estimated marginal means for CONT (n = 13) and MBAS (n = 13) calves for camera behavior outcome variables for 30-min intervals following AM and PM feeding.

Behavior	Treatments		SEM	<i>p</i> -Value		
	CONT	MBAS		Trt	Time	Trt xTime
AM timepoint						
Head still, %	54.5	53.7	4.06	0.75	0.004	0.82
Lying, %	20.7	16.0	2.95	0.28	0.09	0.73
Standing, %	80.1	86.9	4.22	0.64	0.15	0.91
Distanced from bottle, %	46.0	41.7	4.68	0.99	0.76	0.74
Close to bottle, %	54.0	57.0	4.51	0.92	0.78	0.67
NOB, %	3.5	2.8	1.01	0.46	0.02	0.24
NNOB, %	12.6	19.2	3.17	0.19	0.61	0.92
Grooming, %	2.0	3.0	0.35	0.11	0.05	0.11
Vocalizations, n	7.6	11.2	2.41	0.91	<0.001	0.49
Play behavior, n	0.5	0.4	0.15	0.66	0.08	0.58
Grooming, n	5.0	7.2	0.58	0.04	<0.001	0.005
PM timepoint						
Head still, %	41.0	35.7	3.15	0.46	0.06	0.77
Lying, %	15.1	13.4	1.94	0.86	<0.001	0.37
Standing, %	87.5	91.9	3.41	0.92	<0.001	0.24
Distanced from bottle, %	24.3	23.8	2.87	0.77	<0.001	0.45
Close to bottle, %	75.7	76.2	2.87	0.77	<0.001	0.45
NOB, %	28.7	36.9	3.27	0.91	0.004	0.21
NNOB, %	7.5	9.9	1.43	0.21	<0.001	0.21
Grooming, %	2.8	2.7	0.57	0.91	0.94	0.31
Vocalizations, n	12.2	12.9	1.72	0.91	0.01	0.99
Play behavior, n	0.0	0.2	0.05	<0.001	1.00	0.004
Grooming, n	5.6	6.7	0.58	0.88	0.02	0.10

Figure 4.1 Treatment (CONT vs MBAS) and timepoint effects shown for periodic average daily gain. The CONT calves (n = 13) had a greater ADG of 0.47 kg/day compared to 0.40 kg/day of the MBAS calves (n = 13). For the timepoint effect, ADG was not different from days 0 to 5, and increased from 5 to 9, achieving its highest from days 11 and 13.

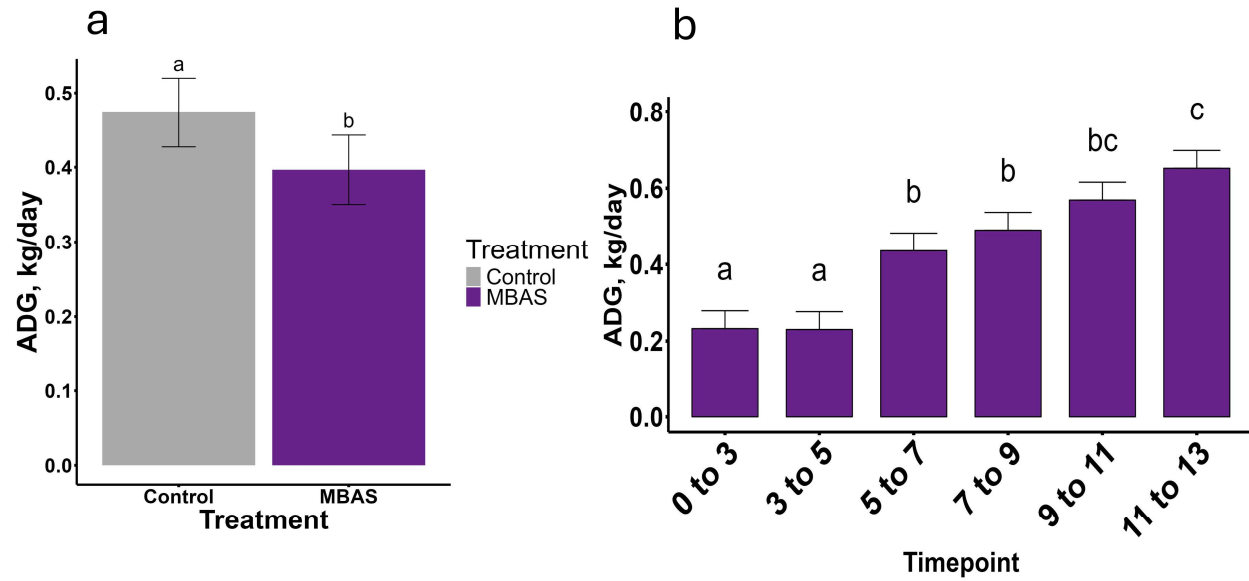


Figure 4.2 Average count of lie bouts per day for the 14-d study period for CONT (n = 13) and MBAS calves (n = 13) from baseline (day 0) to end of study (day 13). A bout was defined as the act of lying or standing for longer than 60 s. Treatment application and the first day of step-down weaning occurred on day 1 where the evening bottle of milk was withheld from calves. Calves were completely weaned off milk on day 3. Values shown here are back-transformed estimated marginal means and confidence intervals.

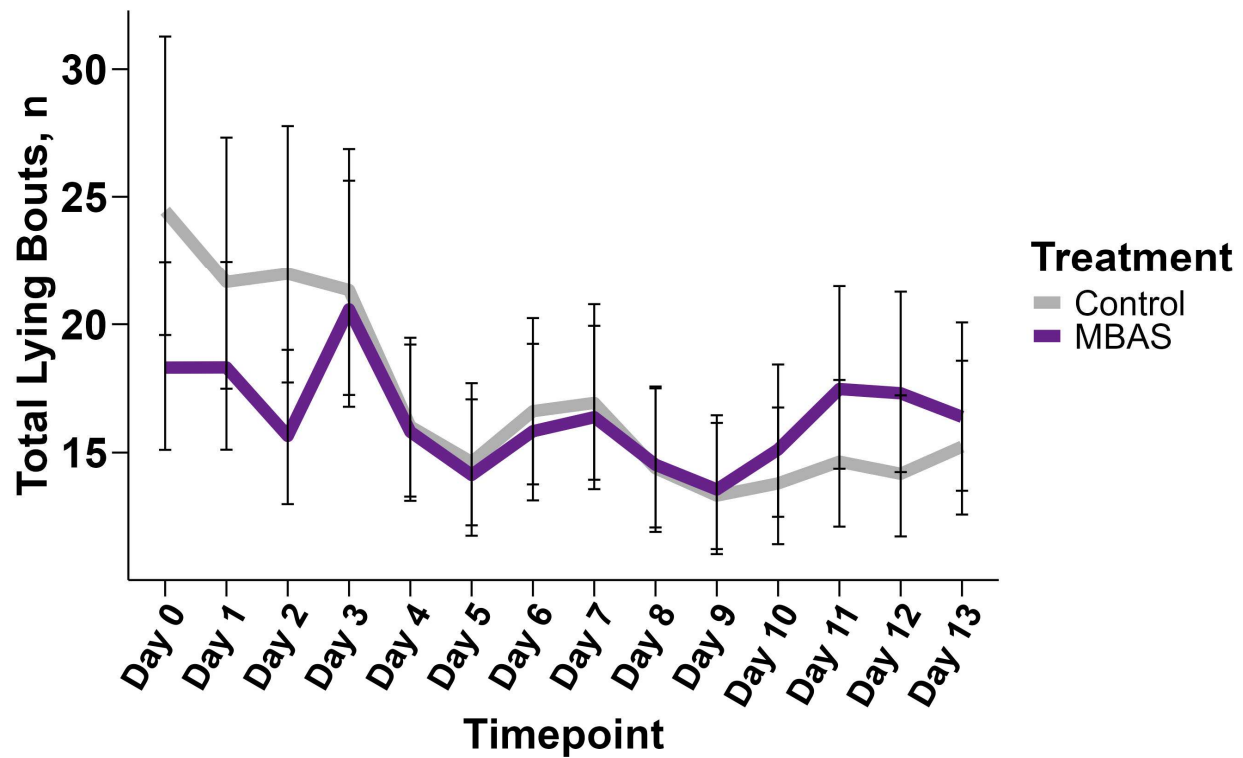
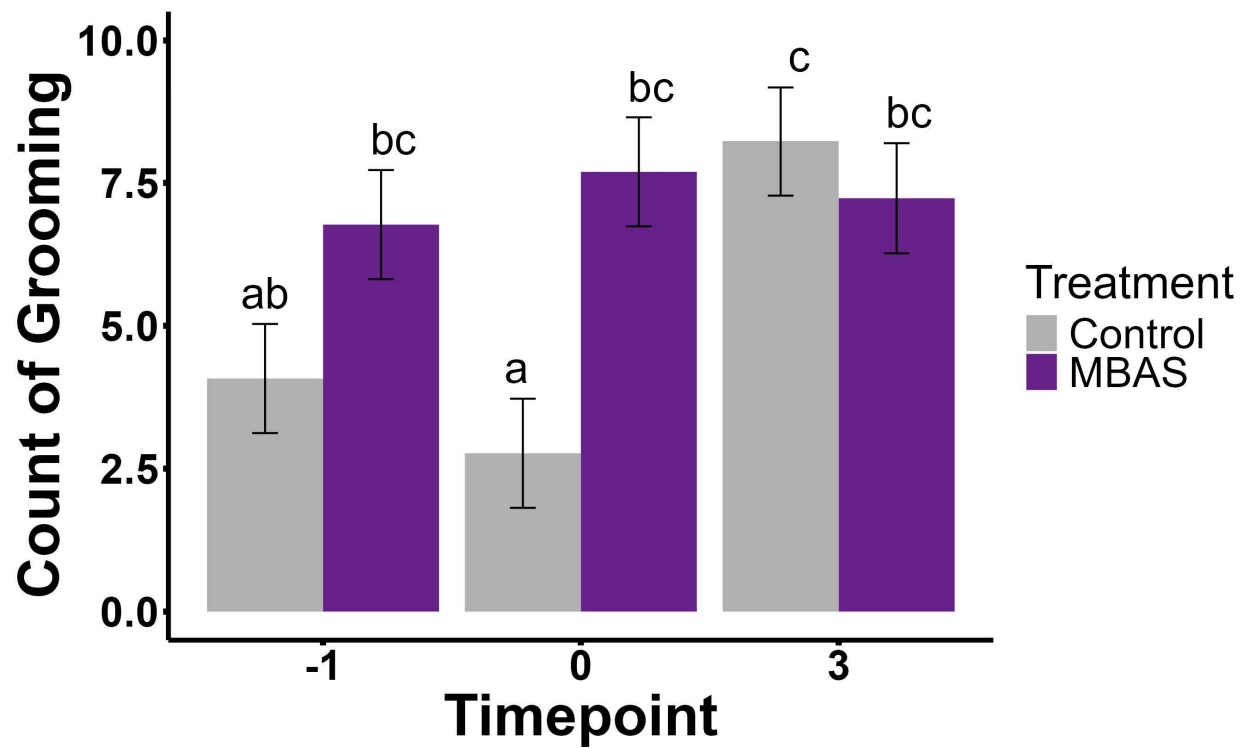


Figure 4.3 Average count of grooming following morning feedings for CONT (n = 13) and MBAS (n = 13) from baseline (day -1) to treatment application and start of step-down weaning (day 0) to the first day fully weaned from milk (day 3).



Chapter 5 - Age and contact status influence the probability of disease treatment between adjacent hutch calves within a commercial calf ranch

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Abstract

Objective: To determine probability of treatment within 12 days of an adjacent calf being treated for diarrhea or respiratory disease.

Methods: A prospective observational study was conducted at a commercial calf ranch from March 21, 2024, to February 11, 2025. Electronic identification and hutch location were linked to daily health records. Calves treated for diarrhea or respiratory disease without an adjacent calf treated in the previous 12 days were classified as “noncontact”, whereas calves with an adjacent treated calf were classified as “contact”. Generalized linear mixed models estimated daily probability of treatment for both diseases by contact status, age categories, and potential interactions including calf ID as a random effect.

Results: Records were collected for 9,756 calves initially. Daily probability of treatment was significantly affected by interaction between contact status and age. Calves < 30 (vs ≥ 30) days

old had significantly higher probability of diarrhea treatment. For respiratory disease, contact calves had significantly higher probability of treatment within each age group, although magnitude of difference varied by age.

Conclusions: Treatment probability increased with adjacent cases within 12 days and varied by calf age and disease.

Clinical Relevance: These findings indicate proximity between hutches may influence disease and should be considered in management strategies, such as having greater space between hutches or removing sick calves to reduce exposure to adjacent calves.

Key Words

Calf health, pre-weaned calves, respiratory disease, diarrhea, hutch proximity, calf management, GIS

Introduction

The health of pre-weaned calves raised in hutches is important as it can greatly impact lifetime performance. Health challenges are complicated as pre-weaned calves have variable immunity and increased disease exposure within calf ranch systems. According to the USDA's survey of trends in dairy cattle health and management, 16% of all pre-weaned heifers were treated with antibiotics for diarrhea or other digestive problems, and 11.4% were treated for respiratory disease (USDA, 2021). Diarrhea is a major concern in calves younger than 30 days of age while respiratory disease is considered a risk throughout the pre-weaning period and beyond weaning (Windeyer et al., 2014; Dubrovsky et al., 2019; Virtala et al., 1996).

Previous literature supports ideas that calthood illnesses in dairy replacement heifers affect future performance. Waltner-Toews *et al.* observed heifers treated for pneumonia in the first 90 days of life had increased odds of mortality compared to those not treated, and those

treated for diarrhea early in life were more likely to be sold from the herd and had increased odds of delayed first calving (Waltner-Toews et al., 1986). A meta-analysis performed by Buczinski *et al.* reported heifers diagnosed with respiratory disease during calthood had higher odds of mortality, of herd removal prior to first calving, and reduced average daily gain and milk production during first lactation (Buczinski et al., 2021). To our knowledge, no literature describes differences in morbidity of beef-on-dairy (BxD) calves raised alongside dairy replacement heifers in commercial calf ranches; however, analysis of mortality data in this setting suggests there is no difference in cause of death due to digestive or respiratory disease between dairy and BxD calves (Bigelow et al., 2025). Therefore, the assumption can be made morbidity may be similar between dairy replacement heifers and BxD calves raised within commercial calf ranches. Additionally, commercial calf ranches may receive calves from multiple regions of the US and Canada, and calves can be shipped from less than 5 to more than 1,000 miles from birth site to a calf ranch (Bigelow et al., 2025; USDA, 2012). While calves are not often commingled in groups upon arrival, there is potential for a calf to be housed adjacent to calves from multiple sources which could increase the exposure to novel pathogens.

Although etiology and management practices have been explored in relation to calf morbidity, the proximity between individual hutches or pens and effect of that distance on disease risk has not been analyzed previously to the authors' knowledge (Frank and Kaneene, 1993; Johnson et al., 2017; Klein-Jöbstl et al., 2014; Smith et al., 2003, Urie et al., 2018). Producers have prompted investigation by asking the questions, “Do hutches need to be distanced further apart to control and/or prevent disease transmission?” and “If healthy calves are housed next to clinically ill calves, do they have a higher risk of becoming sick as well?” The objectives of this study were to determine probability of morbidity of calves within 12 days of an

adjacent calf being treated for respiratory disease or diarrhea and to investigate if clusters of treatments over time were present through spatial analyses.

Methods

The Kansas State University Institutional Animal Care and Use Committee was contacted regarding the research, and no approval was needed due to data being obtained from operation databases and no procedures were performed on calves.

Data Collection

This prospective, observational study was designed with animal as the experimental unit to determine the probability of treating a calf dependent on the adjacent calves' treatment record. This study took place at a commercial calf ranch located in the central High Plains region of the U.S., and calves were enrolled monthly from March of 2024 to February of 2025. The ranch housed calves individually in plastic hutches with a wire fenced-in run, approximately 3.0 m² per calf, in 28 rows consisting of at least 100 hutches per row. Space allowance between hutches varied from approximately 6 to 12 inches. The calf population consisted of about 50% born at the dairy on-site and 50% shipped from other locations between 1 and 4 days old. Calves from one arrival shipment were typically housed adjacently as calves were placed directly in hutches upon unloading. Once a calf was placed in a hutch, it would stay in that location until movement to a group pen post-weaning. The operation did not clean hutches between turns of calves.

Calves were fed 2.84 liters of milk replacer via bottles twice daily until 45 days of age. Calves were then fed one 2.84 liter bottle once per day until weaned off milk at approximately 65 days. Calves were then moved to group pens between 75 and 100 days of age depending on size and health of the calf. Calves were offered texturized calf starter and water *ad libitum* via buckets upon placement in the hutches.

Once a month, a team of 2 field technicians walked down a subset of rows scanning the electronic identification (EID) tags of calves housed within the hutches using an EID scanning stick reader (Allflex; Merck & Co., Inc.). The reader recorded each EID scanned and counted the number of tags scanned. The hutches were also counted by one of the field technicians during the scan, for data collection verification. For the first and last hutch in every row, the visual ID (VID) written on the calf's ear tag was recorded manually. Additionally, for any calf that did not have an EID, the VID and hutch number were recorded for that calf. If a calf was missing all forms of identification (EID and VID), a hutch was empty, or there were multiple calves in one hutch, the hutch number was noted, and "N/A" was recorded for EID.

Each row was scanned once every 3 months to ensure there were different calves occupying the hutches during each scan as the ranch typically moved calves from hutches to group pens at 90+ days of age. The repetition of scanning each row was recorded in the data as timepoint with "A" representing the first scan of that row, "B" representing the second, and "C" the third. Every hutch was assigned a unique identifier by combining row and hutch number (ex. R1H1, R1H2, etc.) and identified by GPS coordinates (Google Earth Pro, version 7.3.6; Google LLC). Next, health records for every calf on-site from November 1, 2023, to June 26, 2025, were downloaded from the operation's database (DairyComp 305, version 24.11; Valley Agricultural Software). Each record included VID, EID, event, age at time of event, and date of event. The events consisted of respiratory treatments (CAFPNEU), diarrhea treatments (SCOURS), weaning (WEANED), and deaths (DIED). The WEANED event corresponded to the date the calf was moved from a hutch to a group pen.

Data Processing

All data handling and analyses were performed with standard software (R Core Team, 2024). First, the list of EIDs was matched to the health records by “EID” in a “many-to-one” relationship to account for calves that had multiple records such as multiple treatments, and/or a treatment event plus the “WEANED” event. Any EIDs for calves without a WEANED or DIED event were removed as there was no record of the age the calf was moved out of the hutch. The next step was to identify adjacent calves to each hutch. This was accomplished by matching a calf’s row number, hutch number, and scan timepoint to the calves in the same row, with a hutch number ± 1 , and the same timepoint. This resulted in identifying “adjacent 1” and “adjacent 2”, the calves in the preceding hutch (hutch number $- 1$) and the following hutch (hutch number $+ 1$), respectively. Because each hutch was scanned multiple times in 3-month intervals, the timepoint was included to ensure adjacent calves were identified within the same scan to prevent mismatching across timepoints.

At this point, the dataset consisted only of recorded events for each calf, including CAFPNUE, SCOURS, WEANED and/or DIED. The next step was to expand the dataset by creating “calf-day” records which consisted of generating a record for every day a calf spent inside the hutch. Essentially, the missing days, days in which no event occurred, were filled in with the calf’s information (EID, hutch location, the date, age of the calf on that date) and the “Event” column remained blank. The date and age of the calf were calculated using the date and age recorded at the time of an existing event within that calf’s record.

The data were then analyzed for 2 different disease processes: diarrhea and respiratory. The process of identifying treatment events and classifying contact status was the same for both diseases. Calf ranch personnel used their standard protocols as written by the consulting

veterinarians to identify calves that required treatment for diarrhea through observation of symptoms such as loose/watery feces, anorexia, depression, and/or irregular feces on the rear of the animal. Respiratory disease was identified by observation of a combination of the following signs such as anorexia, lethargy, nasal discharge, cough, and/or impaired respiration. First, the treatment event was identified, and a column titled “is_treated” was created where 1 corresponded to “Treated” and 0 was “Not treated”. On the day of the treatment and for 11 days following (12 days total), the “is_treated” column was populated with a 1. Contact status was classified based on the actual treatment event (i.e., the day the animal was treated), not the 11 days following the treatment. Calves could be classified as “Noncontact, (0)” or “Contact, (1)” based on the adjacent calf’s treatment history (Figure 1). If a calf was not treated and neither of the adjacent calves were treated within a 12-day window prior, the calf was classified as noncontact. If a calf was treated and neither of the adjacent calves were treated within a 12-day window prior, the calf was identified as “patient 0” meaning it was the calf of contact for adjacent calves. These calves were categorized as noncontact as well. If an adjacent calf was treated, the calf of interest was labeled as contact for a 12-day window following the adjacent calf’s treatment. After the 12-day interval was over, the calf returned to a noncontact status unless another adjacent treatment event occurred.

A 12-day window was chosen based on a literature review performed by Grisset *et al.* that described immune responses of cattle to viral and bacterial pathogens that are involved in bovine respiratory disease etiology (Grissett et al., 2015). Twelve days was chosen as the contact status window by looking at the 75th percentile of days when an animal was in the peak of showing clinical signs for each pathogen. Of all the agents, the highest number of days was for bovine respiratory syncytial virus at 12 days. The highest number of days compared between all

pathogens was selected because the authors wanted to ensure the “peak” of clinical signs was caught for all other pathogens within those 12 days. Thus, a 12-day window was used for classification of contact status.

Descriptive Analysis

Descriptive data such as number of cases, morbidity, and first treatment success were calculated for both diarrhea and respiratory disease. Morbidity was calculated by dividing the number of calves treated at least once for each respective disease by total number of calves scanned. First treatment success was calculated by dividing the number of calves treated for the respective disease only once with no “DIED” event by total number of calves treated for the disease at least once.

Statistical Analysis

Two generalized linear mixed effects models were used to evaluate probability of treating a calf for diarrhea or respiratory disease based on contact status and age in using the *glmer* function from the “lme4” package with the “bobyqa” optimizer specified to improve model convergence (R Core Team, 2024; Bates et al., 2015). Contact status (noncontact vs. contact) and age categories were included as fixed effects, and EID was included as a random effect to account for repeated measures per calf. In the diarrhea model, age was categorized as < 30 days or ≥ 30 days due to the limited number of calves treated for diarrhea that were ≥ 30 days of age. For the respiratory model, age was categorized as < 30 days, 30 to 59 days, 60 to 89 days, or ≥ 90 days, as previously described (Bigelow et al., 2025). The interactions between contact status and age categories were tested. Additionally, an ANOVA type III Wald χ^2 test was performed for each model to test overall contribution of each predictor variable alone as well as the interaction between variables with significance tested at $P < 0.05$. The model-estimated mean probability $\pm$

SEM of diarrhea treatment and of respiratory treatment were reported as number of cases per 100,000 calf-days, calculated based on the odds ratio from the model output. The number of cases per 100,000 calf-days were calculated by multiplying the model-estimated mean probability $\pm$ SEM by 100,000, and the 95% CIs were model-estimated.

Spatial Analysis

For spatial analysis, separate datasets were prepared for diarrhea and respiratory treatments consisting of treatment events and hutch locations with longitude and latitude coordinates. Using a mapping application, a raw density heatmap was created by counting number of treatments per hutch coordinate (QGIS Development Team, 2024). Significance of clustering was tested using the Global Moran's I test (R Core Team, 2024; Bates et al., 2015), which measures spatial autocorrelation (resulting values, -1 to 1) based on locations and values simultaneously. A spatial autocorrelation higher than 0.3 and lower than -0.3 is considered meaningful (Brazil, 2023). This analysis was performed separately for clustering of diarrhea treatments and respiratory treatments. First, adjacent hutches were defined using the k-nearest neighbor approach. This method finds the k closest observations for each hutch location, where k is an integer, $k = 2$ in this case. For each observation, (ie, treatment within a hutch), the 2 closest observations were considered neighbors to the hutch. Next, the Moran's I test was run using the *moran.test* function from the "spdep" package to analyze significance of clustering by measuring spatial autocorrelation based on location and treatment count simultaneously and to evaluate whether expressed patterns are clustered, dispersed, or random (Bivand and Wong, 2018).

Results

Two datasets were compiled: the list of EIDs ($n = 9,756$) with hutch location and timepoint scanned, and the data frame of all event records ($n = 107,163$) from November 2023 to

June 2025. The list of EIDs was matched to event records resulting in a dataset with 32,569 observations for 9,676 unique EIDs. All EIDs for calves without a WEANED or DIED event were removed ($n = 1,109$), which reduced the total EID list to 8,567 and the final dataset to 30,557 observations.

There were 626 calves treated at least once for diarrhea, resulting in a first treatment morbidity prevalence of 7.3% (626/8,567). There were 18 calves treated multiple times for diarrhea. The first treatment success rate was 96.2% (602/626). There were 3,847 calves treated at least once for respiratory disease and 1,575 of those were treated multiple times. Morbidity prevalence due to respiratory disease was 44.9% (3,847/8,567). First treatment success rate was 58.7% (2,257/3,847). Data were compiled for number of days from first contact with a clinical respiratory or diarrhea calf to treatment, if the contact calf was treated (Figure 2). Most respiratory and diarrhea treatments occurred within 1 to 2 days after contact with a clinically ill calf. However, there were still between 5% and 10% of treatments occurring at 11 to 12 days post-contact. Thus, the 12-day window was sufficient to encompass treatments thought to be related to contact status.

Model Results

Contact status and age category, alone or in combination, were significantly ($P < 0.01$) associated with daily probability of being treated for diarrhea. Contact (vs noncontact) calves had greater odds and daily probability of diarrhea treatment; however, the magnitude of probability varied dependent on age category (Figure 3). Calves < 30 days of age had greater odds of treatment for diarrhea (OR = 10.0; 95% CI: 8.37 to 12.1), and the model-estimated mean $\pm$ SEM incidence of diarrhea treatment (number of cases per 100,000 calf-days) and odds ratio were significantly ($P < 0.01$) higher for contact calves (2.98 ± 0.49 cases; 95% CI of the mean: 2.16 to

4.12 cases) compared to noncontact calves (0.30 ± 0.05 cases; 95% CI of the mean: 0.22 to 0.40 cases). This could be interpreted as 3 cases in 1,000 calves observed for 100 days if they were in contact with an adjacent calf that had been treated prior. The magnitude of daily probability of diarrhea treatment in calves ≥ 30 days old was half the probability of calves < 30 days old. For contact calves ≥ 30 days old, the model-estimated mean $\pm$ SEM was significantly ($P < 0.01$) higher (1.53 ± 0.43 cases; 95% CI of the mean: 0.88 to 2.64 cases; OR: 63.4; 95% CI of OR: 39.0 to 103.0) compared to noncontact calves (0.02 ± 0.004 cases; 95% CI of the mean: 0.02 to 0.03 cases).

Similarly, for the respiratory model, daily probability of being treated was significantly affected by contact status, age category, and their interaction ($P < 0.001$). Overall, the odds of treatment for respiratory illness were greater for contact (vs noncontact) calves. Magnitude of daily probability of respiratory disease treatment based on contact status varied by calf age (Figure 4). Lower ($P < 0.01$) probabilities were observed in calves < 30 days of age with model-estimated means $\pm$ SEM of 405.6 ± 25.2 (95% CI of the mean: 359.1 to 458.1 cases; OR: 1.82; 95% CI of OR: 1.70 to 1.95) versus 223.1 ± 12.5 cases (95% CI of the mean: 199.8 to 249.1 cases) per 100,000 calf-days in contact and noncontact calves, respectively. For calves between 30 to 59 days of age, the probability significantly ($P < 0.01$) increased with $1,273.6 \pm 73.1$ (95% CI of the mean: 1,137.9 to 1,425.2 cases; OR: 1.66; 95% CI of OR: 1.59 to 1.73) cases for contact and 773.4 ± 42.8 cases (95% CI of the mean: 693.8 to 862.0 cases) per 100,000 calf-days for noncontact calves. The greatest difference in probability between contact and noncontact calves was seen in calves aged 60 to 89 days with $2,297.3 \pm 132.9$ (95% CI of the mean: 2,050.8 to 2,572.7 cases; OR: 3.35; 95% CI of OR: 3.18 to 3.53) versus 697.0 ± 38.7 cases (95% CI of the mean: 625.2 to 777.1 cases) per 100,000 calf-days, respectively. In calves ≥ 90 days of age,

1,008.3 $\pm$ 104.6 cases (95% CI of the mean: 822.7 to 1,235.3 cases; OR: 1.38; 95% CI of OR: 1.16 to 1.64.) per 100,000 calf-days occurred in contact calves compared to 732.1 $\pm$ 42.7 cases (95% CI of the mean: 653.0 to 820.7 cases) in calves that were classified as noncontact.

Regardless of disease process, daily treatment probability increased if an adjacent calf was treated within 12 days and the magnitude of difference varied with calf age.

Spatial Analyses Results

For diarrhea treatments, the observed Moran's I was 0.114 ($P < 0.001$), indicating a weak positive spatial autocorrelation. This means hutches with similar treatment counts for diarrhea tended to be clustered, but the effect was not very strong. The standard deviate, or Z-score, was 8.21 which shows observed clustering was far from what would be expected if the clusters occurred due to random chance.

For respiratory treatments, the observed Moran's I was 0.347 ($P < 0.001$). This is a moderately strong, positive spatial autocorrelation, meaning hutches with similar treatment counts tended to be clustered together rather than randomly distributed spatially. This means hutches with higher treatment counts tended to be near other hutches with high treatment counts. The Z-score was 24.9, indicating the observed clustering was significantly different than would be expected if clustering was distributed at random. Maps of frequency of diarrhea and respiratory treatments can be seen in Figure 5.

Discussion

In this prospective, observational study, daily probability of treatment for 2 disease processes was analyzed by contact status and age. For both diseases, there was significant interaction between contact status and age. Calves had the highest probability of being treated for diarrhea when in contact with a clinically ill calf at < 30 days old. Our findings were consistent

with those of Sivula *et al.*,¹⁹ who reported that the risk of enteritis was highest at birth (900 cases per 100,000 calf-days) and declined rapidly to 100 cases per 100,000 calf-days by 21 days of age. While various risk factors for diarrhea in dairy calves has been explored, little is known about whether hutch-to-hutch proximity influences diarrhea and respiratory disease management (Johnson et al., 2017; Gulliksen et al., 2009; Vasseur et al., 2010). Although distance was not directly quantified in the present study, calves housed adjacent to clinically ill calves had higher probability of diarrhea treatments, especially under 30 days of age. This evidence supports the contagious aspect of diarrhea.

One method of preventing diarrhea transmission in the cow-calf sector is the Sandhills Calving System. Smith *et al.* describe management practices designed to prevent effective contacts by segregating calves by age to prevent transmission from older to younger calves (Smith et al., 2003). This approach is meant to apply to cow-calf herds, but a similar mentality is already applied in the commercial calf ranch. Calf ranches typically fill rows by truckload, so the animals would be assumed to be of similar age. Contact between sick and healthy calves increased probability of treatment, so perhaps there are biosecurity measures that could reduce this probability such as removal of calves upon first treatment, placing partitions between hutches, or distancing hutches farther apart. In 1985, Sanders wrote that diseases do not spread as readily from one hutch to another as they do in an enclosed barn where calves may be housed in individual pens (Sanders, 1985). While their comparison of disease transmission between outdoor hutches and indoor individual pens may be true, the present data demonstrates that disease transmission is still occurring between calves when housed in outdoor hutches and thus proximity between hutches may be important in preventing disease spread. Hutch sanitation may

also be of great importance related to pathogen load shared from older calves moved out to group pens to younger calves arriving to the hutch.

Similar patterns were observed for respiratory disease, with higher probabilities for calves in contact with clinically-ill calves than noncontact calves. Respiratory disease probability was higher in contact calves across all age categories, and probability for noncontact calves stayed relatively even across all ages (~ 700 cases per 100,000 calf days). However, the magnitude of the respiratory disease probability increased between 60 to 89 days. These data are supported in part by Sivula *et al.*'s findings where the risk for respiratory disease was increased at about 70 days of age at 1,200 cases per 100,000 calf-days (Sivula et al., 1996). Additionally, the age range between 60 and 89 days is when calves are typically weaned off milk within the operation of the present study. Speculation as to why the difference is much larger for these ages include increased post-weaning behavior among calves such as suckling on pen fixtures or on the adjacent calf through wire panels. This behavior could contribute to disease transmission as many respiratory pathogens can be transmitted orally, nasally, or via aerosol (Mars et al., 2000; Deepak et al., 2021). Pempek *et al.* evaluated differences between housing Jersey calves in hutches furnished with enrichment (chains, brushes, artificial teats, etc.) versus standard hutches with no enrichment (Pempek et al., 2017). There was no effect of furnished vs. standard on the amount of time calves spent suckling on pen fixtures, and an effect of week was observed as suckling increased as calves aged with increased frequency of suckling found at weeks 5 and 7 (Pempek et al., 2017). These data support the idea that as calves age and are weaned off milk, they may be participating in more behaviors that are conducive to spreading disease. Another explanation could be that older calves are bigger and thus able to expel a larger volume of air from their lungs, which could contain more pathogens. Additionally, as calves grow, the authors

speculate participating in these behaviors would become easier as larger calves may be able to reach over or through wire paneling that encircles the area in front of the hutch.

The spatial analyses reported diarrhea treatments tended to be clustered, but displayed weak correlation. Previous studies have observed differences in management practices between dairy farms on incidence of calf diarrhea, but to the authors' knowledge, little to no work has been done observing clustering within one operation (Calderón-Amor and Gallo, 2020; Klein-Jöbstl et al., 2014). Spatial analyses have been conducted for various pathogens across countries and states (Fernandes et al., 2018; Sato et al., 2001). Gorden and Plummer suggest outdoor hutches be spaced at least 4 feet apart for prevention of respiratory disease and other diseases, however the data supporting this distance is unclear (Gorden and Plummer, 2010). Mars *et al.* tested airborne transmission of Bovine Herpes Virus-1 (BHV-1) between 5 inoculated and 5 naïve calves housed in boxes 4 meters from one another (Mars et al., 2000). They found that BHV-1 infections were transmitted to all naïve calves within 3 week post inoculation as measured by BHV1 titers and PCR results from nasal fluid samples, and the distance estimated to sufficiently reduce transmission between groups was 4.4 meters (Mars et al., 2000).

Sato *et al.* conducted spatial and temporal clustering of *Salmonella* serotypes in adult dairy cattle exhibiting diarrhea in California (Sato et al., 2001). Significant clustering in space was detected for 10 of 13 serotypes, concentrating in the Central Valley of California, where most of the dairy farms were located (Sato et al., 2001). These data were collected in a different population and observed the pathogen itself. Conversely, the present data used treatment as a proxy for disease and revealed a weak clustering of diarrhea treatments across hutch locations within the commercial calf ranch. The incidence of diarrhea treatments was relatively low in this dataset, 7.3%, thus the effect of clustering may have been difficult to detect.

For respiratory disease, hutches with higher counts of treatments tended to be clustered. Similar to calf diarrhea, previous literature has evaluated how management practices may be associated with respiratory disease, but reports on spatial clustering of respiratory disease within an operation are scarce (Brscic et al., 2012; Calderón-Amor and Gallo, 2020) Fernandes *et al.* conducted a spatial analysis for BHV-1 in northeastern Brazil and found significant clustering of BHV-1 positive herds (Fernandes et al., 2018); however, that study evaluated herds, whereas the present study investigated individual hutch location. The results of the present study indicate geographic distinctions of each disease process persisted across multiple groups of calves cycling through the hutches; however, many potential factors could have contributed to these findings including environmental persistence of pathogens, proximity to other areas of the operation, or other factors not measured in this study.

A major limitation of the present study is diagnosis of disease based on clinical signs exhibited by the calf. It's been reported in previous research that the diagnosis of respiratory disease based on clinical signs has poor sensitivity and specificity (White and Renter, 2009; Timsit et al., 2016). This could be due to the subjective nature of assessing clinical signs. Additionally, clinical signs observed when diagnosing respiratory disease are non-specific and may be associated with other disease processes as well (Portillo, 2014). However, this also provides external validity as clinical signs are the primary diagnostic used in commercial operations. This study was also completed on a single location which retained ownership compared to a custom raising operation. Another limitation includes lack of information about environmental factors like season, wind, and drainage, as well as route of feeding and/or diagnosing and treating calves by the crew as disease spread could be carried via different vectors. Various management factors such as the influence of calf nutrition on immune status,

pathogen load as a result of sanitation practices, and stocking density may also play a role in disease treatment among calves; however these data were not collected in this study and thus could not be evaluated. Additionally, the spatial analyses consisted of multiple “turns” of calves and was tailored to focus on clustering of treatments in specific hutch locations rather than contact status between calves. This analysis was driven by a question posed by the specific calf ranch where the study was conducted.

In the present study, the probability of being treated for diarrhea or respiratory disease increased if a calf was in contact with an adjacent calf that had been treated previously for either disease. Effect of contact status varied based on calf age for both disease processes. This research reinforces previous knowledge of the contagious transmissibility of both diseases. However, these data also highlight the importance of management and its potential role in prevention of spreading disease. These results suggest that commercial calf ranches should consider 1) proximity between hutches when building or organizing hutch lines within operations, or 2) the possibility to implement other strategies such as removal of calves treated for disease to prevent an increased risk of treatment for adjacent calves, or 3) placing partitions between calves treated and those not treated. While these practices may result in increased labor, time, and effort, further research is needed to determine their potential value for reducing morbidity within vulnerable calf populations as well as unrealized detriments to calf behavior.

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Figure 5.1 Histograms of the number of days between contact and treatment for the calves described in Figure 1, grouped on the basis of treatment for respiratory disease (A) or diarrhea (B).

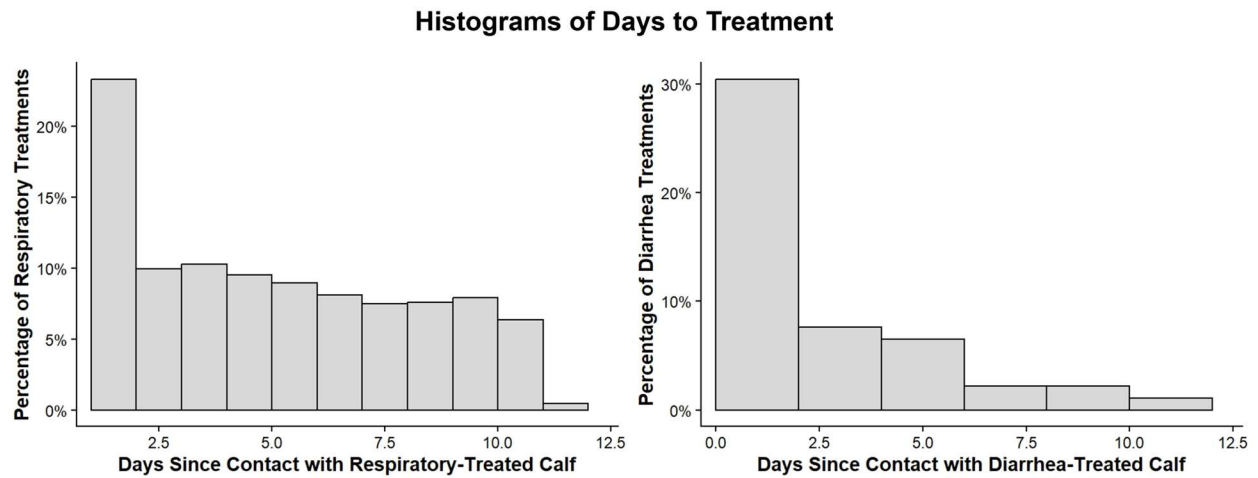


Figure 5.2 The study details are described in the caption of Figure 1. There were 626 calves treated for diarrhea at least once during the study. The interaction between contact status and age category was significant ($P < 0.005$) in relation to probability of daily treatment of diarrhea. The bars represent that model-estimated probability of treatment, and the whiskers represent the standard error of the mean. Bars with differing letters are statistically different from each other.

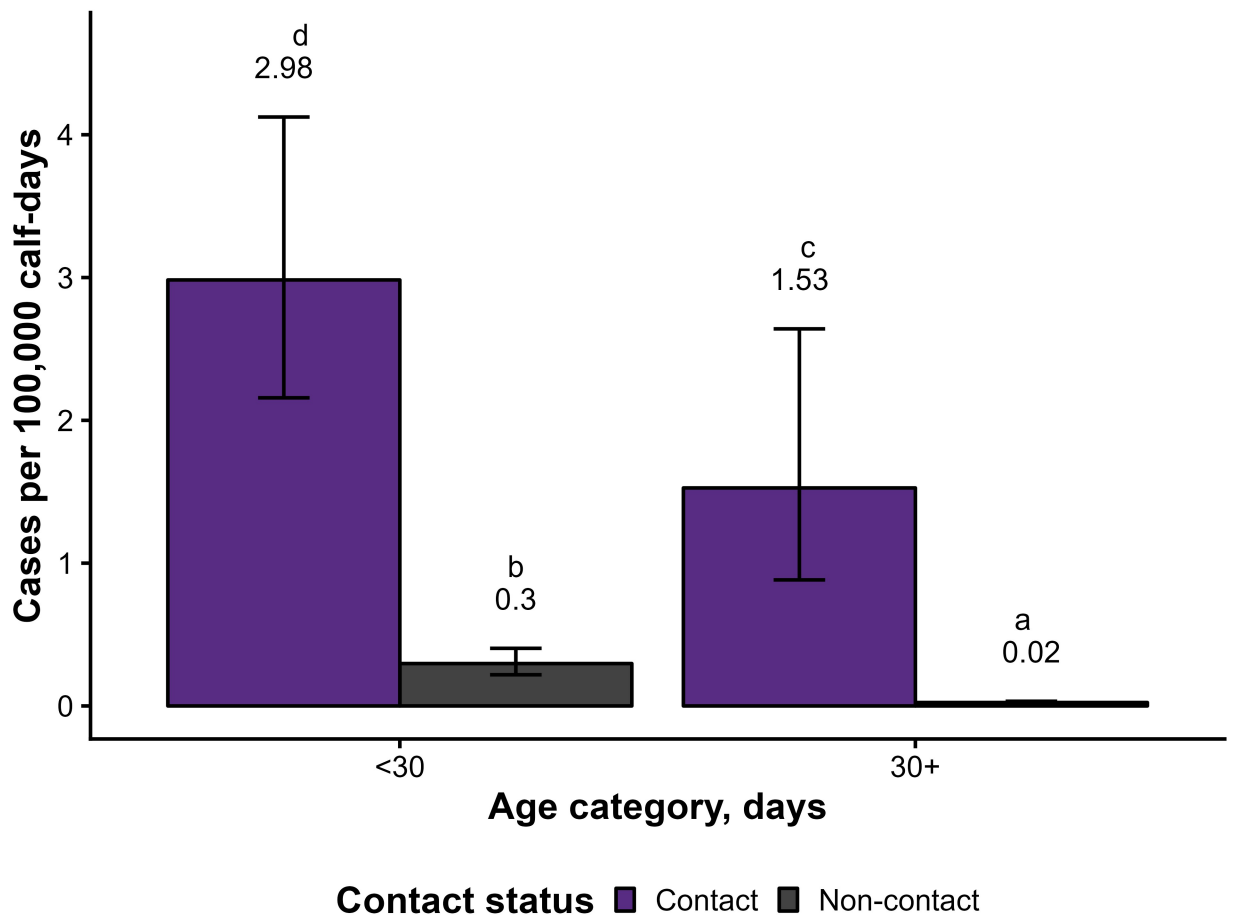


Figure 5.3 The study details are described in the caption of Figure 1. There were 3,847 calves treated for respiratory disease at least once during the study. The interaction between contact status and age category was significant ($P < 0.01$) in relation to probability of daily treatment of respiratory disease. The bars represent that model-estimated probability of treatment, and the whiskers represent the standard error of the mean. Bars with differing letters are statistically different from each other.

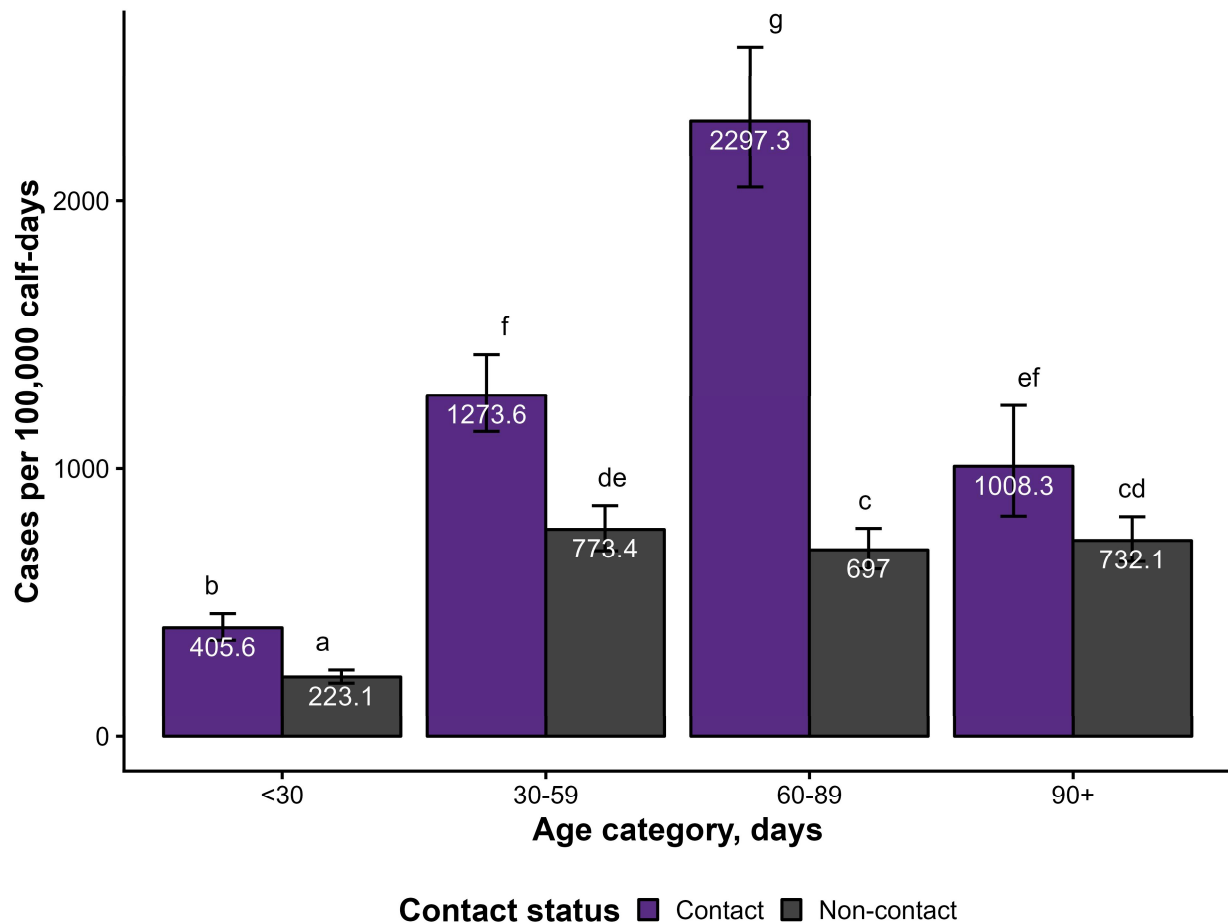
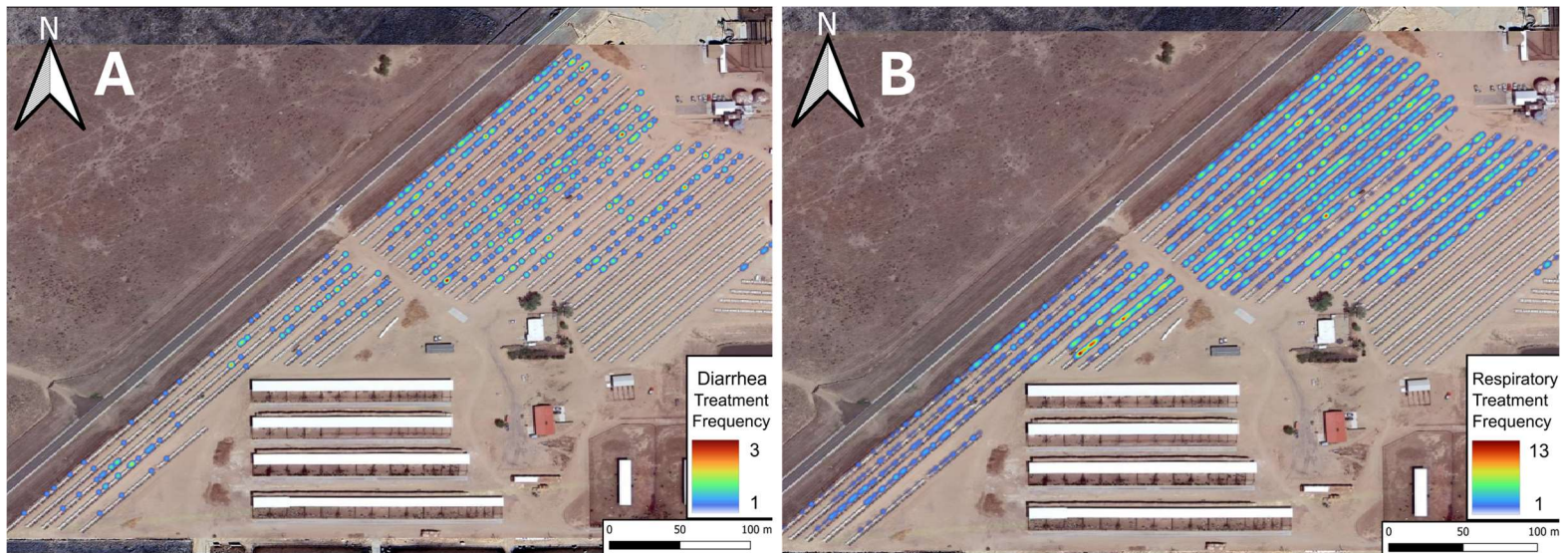


Figure 5.4 Results of spatial analyses for treatment of diarrhea (A) or respiratory disease (B) for the calves described in Figure 1. The frequency of diarrhea or respiratory disease treatments per hutch location is represented by the gradient scale where blue corresponds to a lower count of treatments, and red represents the highest number of treatments observed in one location. These treatments could be derived from multiple treatments for one calf or one treatment for multiple calves that have been housed in that hutch location among different timepoints. The observed Moran's I was 0.114 for diarrhea treatments and 0.347 for respiratory disease treatment.



Chapter 6 - Association of origin, performance, and health metrics of beef-on-dairy feedyard cattle with liver abscess at harvest

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Lay Summary

Beef-on-dairy (BxD) cattle have higher frequency of liver abscesses (LA) at harvest than native beef breeds and Holsteins, though cause of increased LA remains unclear. We evaluated associations between origin, performance, and health metrics with LA at harvest in BxD cattle. Feedyard data and liver scores were collected from two sources (Dataset 1, n = 330 cohorts; Dataset 2, n = 386 cohorts). For Dataset 1, livers were scored using Elanco's liver scoring system with 4 outcomes of interest: Total LA (All scores; D1TA), Severe LA (Scores A+, A+Adhered, A+Open; D1SA), Severe+ LA (A+Adhered and A+Open; D1S+A), and Severe as proportion of Total LA (D1ST). For Dataset 2, livers were scored in 3 non-mutually exclusive categories: Abscessed (D2TA), Condemned (D2CL), and Adhered (D2AdL). Multiple risk factors such as sex, days on feed, average shipping weight, percentage of cohort railed, and origin were associated with D1TA, D1SA, D1S+A, and D1ST. Average daily gain (ADG) and quarter harvested were associated with D2TA and D2CL. Average shipping weight and origin were also associated with D2TA. The only risk factor associated with D2AdL was sex. These results

identify factors associated with LA in BxD cattle; further research is needed to determine management strategies to mitigate LA occurrence.

Teaser Text

Beef-on-dairy cattle have a higher prevalence of liver abscesses than beef breeds and Holsteins, but contributing factors remain unclear. This study identifies production, health, and origin metrics associated with liver abscess risk, providing insight for targeted management strategies to reduce occurrence.

Text Abstract

Beef-on-dairy cattle (BxD) exhibit a higher prevalence of liver abscesses (LA) at harvest compared to native beef breeds and Holsteins. The objective was to evaluate associations of origin, performance, and health metrics with LA prevalence and severity at harvest in BxD feedyard cattle. Operational data and liver scores were collected from two sources (Dataset 1, n = 330 cohorts; Dataset 2, n = 386 cohorts). For Dataset 1, livers were scored using Elanco's liver scoring system with 4 outcomes of interest: Total LA (All scores; D1TA), Severe LA (Scores A+, A+Adhered, A+Open; D1SA), Severe+ LA (A+Adhered and A+Open; D1S+A), and Severe as proportion of Total LA (D1ST). For Dataset 2, livers were scored in 3 non-mutually exclusive categories: Abscessed (D2TA), Condemned (D2CL), and Adhered (D2AdL). Generalized linear mixed models estimated probability of LA outcomes with a beta-binomial distribution to account for overdispersion. Fixed effects included sex, days on feed (DOF), shipping weight, head received, average daily gain (ADG), mortality, railers, average daily feed delivery per head, quarter of arrival/harvest, and region of origin. Feedyard was included as a random effect. Multiple risk factors such as sex, DOF, shipping weight, railers, and origin were associated with D1TA, D1SA, D1S+A, and D1ST. Quarter harvested and ADG were associated with D2TA and

D2CL. Shipping weight and origin were also associated with D2TA. Sex was the only risk factor associated with D2AdL. Steer cohorts had higher probability ($P \leq 0.05$) of D1TA, D1SA, D1S+A, D1ST, and D2AdL than heifer cohorts. Cohorts on feed > 300 days had higher probability ($P \leq 0.05$) of D1TA, D1SA, and D1S+A than cohorts with fewer DOF. Cohorts with shipping weights of 680 to 725 kgs had higher risk ($P = 0.03$) of D1SA than those > 726 kgs. Average daily gain was associated with ($P \leq 0.02$) D2TA and D2CL. Cohorts with < 0.5% railed had the lower probability ($P \leq 0.04$) of LA outcomes than those with > 0.5% railed. Cattle harvested in quarter 3 had lower risk ($P \leq 0.03$) of D2TA and D2CL. Cohorts originating from region 3 had lower risk ($P \leq 0.05$) of D1TA, D1SA, D1S+A, and D1ST than those from regions 1 and 4. These results identify associations among BxD cattle demographics, origin, performance, and health metrics with LA prevalence at harvest. Further research is needed to evaluate management strategies to mitigate LA occurrence.

Key Words

Beef-on-dairy cattle, liver abscess, management practices, cohort tracing, feedyard cattle, feedyard performance

List of Abbreviations

Ad - Adhered

ADG – average daily gain

BxD – Beef-on-dairy

D1TA – Dataset 1 Total Abscesses

D1SA – Dataset 1 Severe Abscesses

D1S+A – Dataset 1 Severe+ Abscesses

D1ST – Dataset 1 Severe as proportion of Total Abscesses

D2TA – Dataset 2 Liver Abscesses

D2CL – Dataset 2 Condemned Livers

D2AdL – Dataset 2 Adhered Livers

DOF – days on feed

LA – liver abscess(es)

Op - Open

SI – small intestine

Introduction

Breeding practices in the dairy industry have shifted to using beef semen to produce crossbred beef-on-dairy (BxD) calves that enter the beef production system. This practice increases the value of the calves produced from dairies as BxD cattle have improved feedyard performance, carcass quality, and meat attributes compared to Holsteins. A major issue with BxD cattle is the high incidence of liver abscesses (LA) which is 2 to 3 times greater than crossbred beef cattle (Foraker et al., 2022a). Liver abscesses are the most common liver abnormality detected at the time of slaughter, with recent estimates indicating that associated economic losses to the U. S. beef industry may exceed \$250 million annually (Taylor et al., 2025). Liver abscesses are thought to occur mainly in the finishing phase due to diets consisting of high concentrations of highly fermentable carbohydrates fed for a long period of time (Bryant and Jennings, 2022). Common finishing diets are believed to lower ruminal pH, causing ruminal acidosis that leads to damage of the rumen epithelium acting as a pathway for ruminal bacteria to enter the portal blood supply, and cause infections and abscesses in the liver (Amachawadi and Nagaraja, 2022). Previous research has explored the associations between various factors such as demographics (sex, breed, arrival/ shipping weight, days on feed (DOF), etc.) and management

(roughage level, feedstuff particle size, grain type and inclusion, etc.) with the prevalence of LA in native beef cattle at harvest or necropsy (Nagaraja and Chengappa, 1998; Amachawadi and Nagaraja, 2016; Broadway et al., 2024; Hales, 2024; Champagne et al., 2025a). Identifying feedyard variables associated with LA could provide an avenue for producers to attempt to control LA through adjusting management practices. This would be beneficial, as the current method for control and prevention of LA consists of continuous in-feed administration of antimicrobials such as tylosin phosphate (Theurer and Amachawadi, 2022; Word et al., 2024; Young et al., 2026). There is growing concern of antimicrobial resistance, so if producers could modify management practices to reduce LA, this could promote more judicious use of in-feed antibiotics.

There has also been speculation early life feeding practices and management may predispose cattle to LA later in life. Beef-on-dairy cattle are raised similarly to dairy replacement heifers as they are separated from their dams as early as one day after birth. Calves are typically offered a variation of calf starter consisting of either pelleted feeds, a combination of pellets and a roughage source, or a total mixed ration as soon as they are placed in a hutch or pen (Bigelow et al., 2025). This early introduction to grain is believed to potentially compromise the integrity of rumen or small intestine (SI) epithelium, leading to impaired gut function once the calf reaches the feeding phase. During a year-long necropsy trial across 3 commercial calf ranches, only two abscessed livers were recorded out of 243 necropsies, one of which resulted from an umbilical infection (Bigelow et al., 2025). Thus, LA are likely not occurring at young ages, but management practices may affect their occurrence later in life. One of the challenges with identifying associations between management practices at the calf ranch phase, feeding phase, and harvest is the lack of traceability of cohorts through the different production systems.

Therefore, the authors opted to explore region of origin as a proxy for calf ranch to identify if there was evidence warranting further exploration of specific management practices. A limitation of this approach was the reality that origin information provided to the feedyard could represent calf ranch origin, backgrounding operation, or an auction barn that calves were marketed through. Therefore, the objective of this research was to evaluate associations of origin, performance, and health metrics with cohort-level prevalence and severity of LA at harvest in BxD feedyard cattle.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee (IACUC) was contacted regarding the research, and no approval was needed due to data being obtained from operation databases and no procedures were performed on live cattle.

Data Collection

Operational closeout records were collected from 11 US feedyards across the High Plains region spanning 2020 to 2025. Closeout records consisted of information such as feedyard ID, cohort ID, sex of the cohort, number of head received, number of head shipped for harvest, dates received/shipped, weight of cohort at arrival/shipping, number of head days, number of deaths and railers, the total pounds of feed delivered to the cohort over the entire feeding period, and origin which typically consisted of a town and state. Harvest data were collected from two different sources from 2021 to 2025. The livers from Dataset 1 (D1) were scored at harvest using a modified version of Elanco's liver abscess scoring system (n = 343 cohorts) and consisted of cattle from 8 feedyards. These scores were mutually exclusive categories as described in Table 1. For D1, the analyses consisted of four outcomes of interest: Total abscessed livers (D1TA; count of all LA scores / count of cattle without LA), Severe abscessed livers (D1SA; count of A+,

A+Adhered (Ad), A+Open (Op), and A+Ad&Op / count of cattle without Severe LA), Severe+ abscessed livers (D1S+A; count of A+Ad, A+Op, and A+Ad&Op /count of cattle without Severe+ LA), and Severe LA as a proportion of total LA (D1ST; count of A+, A+Ad, A+Op, and A+Ad&Op / count of LA scores A- and A). The outcome D1S+A was of interest because it consists of the most severe LA scores that typically cause loss of trim and cause the chain to stop in the harvesting process which are both large sources of economic loss (Taylor et al., 2025). The outcome D1ST was chosen because the authors expected that the frequency of severe abscesses would increase with overall abscess prevalence; however, the data did not support this expected relationship.

For Dataset 2 (D2), three categories were used to score livers per the source's internal scoring system, but they were not mutually exclusive categories and consisted of cattle from 5 feedyards (n = 409 cohorts). The categories consisted of livers that were abscessed, condemned and/or adhered to the diaphragm and/or other organs, and livers could be counted in no, one or multiple categories. Livers were classified as abscessed when any abscess was present regardless of severity. They were classified as condemned if the liver was condemned and removed from entering the food chain. Livers were classified as adhered if there was any adhesion present to the diaphragm. For D2, the outcomes of interest were total abscessed livers (D2TA; count of abscessed livers / count of cattle without abscessed livers), condemned livers (D2CL; count of condemned livers / count of cattle without condemned livers), and adhered livers (D2AdL; count of adhered livers / count of cattle without adhered livers). Separate outcomes were calculated for D1 and D2 due to the different scoring systems used during collection of liver data.

The scoring system used in Dataset 1 was completely independent from the system used in Dataset 2. There was no overlap between the two datasets or liver scores/classifications.

Data Manipulation

For operational data, DOF was calculated by subtracting the arrival date from the shipping date. Average arrival and shipping weights were calculated by dividing the cohort arrival and shipping weights by head received and head shipped, respectively. Average daily gain with deads included (ADG – deads in) was calculated by subtracting the total cohort arrival weight from total cohort shipping weight and dividing by head days. Average daily gain with deads excluded (ADG – deads out) was calculated by subtracting the average arrival weight per head from the average shipping weight per head and dividing by DOF. Mortality was calculated by dividing the number of deaths by the number of head received and multiplying by 100 to get a percentage of the cohort. Similarly, the percentage of the cohort railed was calculated by dividing the number of head railed by the number of head received and multiplying by 100. Dates of arrival and shipment to harvest were categorized into quarters (Q1: January, February, March; Q2: April, May, June; Q3: July, August, September; Q4: October, November, December). Origin was categorized into regions based on the map used in the USDA’s “Health Management on U.S. Feedyards 2021 Phase 1 Questionnaire” (USDA-APHIS, 2020b).

Statistical Analyses

Continuous variables were categorized and adjusted based on data distributions. Predictors of interest included sex of the cohort, DOF, shipping weight, arrival weight, head received, head shipped, ADG – deads out, ADG – deads in, mortality, railers, average daily amount of feed delivered per head, quarter of arrival, quarter shipped, and region of origin. Correlations between predictor variables were tested using a Pearson correlation matrix. If two variables were strongly correlated (Pearson correlation coefficient (r) > 0.70), one of the variables was removed from the final models and the other was retained. Head received and head

shipped were strongly correlated (Pearson correlation coefficient (r) = 0.95), so head received was left in the final models and head shipped was removed. Similarly, ADG – deads in and ADG – deads out had a Pearson correlation coefficient of 0.87. In the final models, ADG – deads out was retained and ADG – deads in was removed. Shipping weight and arrival weight were strongly correlated as well (r = 0.93), so shipping weight was kept and arrival weight was removed from the final models. Variance inflation factors were tested for each final model to ensure there was no multicollinearity between predictor variables.

Outcomes of interest were analyzed in RStudio (Version 2024.04.2+764, Boston, MA) using the *glmer* function from the “lme4” package. Outcomes were analyzed as successes/failures per cohort in generalized linear mixed models (GLMM) using a beta-binomial distribution to account for overdispersion of the data. A GLMM was used to analyze each outcome with the following fixed variables: sex of cohort, DOF, shipping weight, head received, ADG – deads out, mortality, railers, average daily feed delivery per head, quarters of arrival and harvest, and region of origin. Feedyard was included as a random effect. Backwards step-wise regression was used to build the final models where all predictor variables were included initially. The variable with the highest P -value was removed until all remaining variables were statistically significant with a P -value less than 0.05. The same model-building process used for D1 analyses was used for D2 analyses.

Results

Descriptives

Operational feedyard data and liver abscess scores at harvest were analyzed for 343 and 409 cohorts from D1 and D2, respectively. Cohorts of mixed sexes and/or cattle other than BxD (Native, Mexican, etc.) were removed from the datasets prior to analyses (D1: n = 13 cohorts;

D2: n = 23 cohorts). This resulted in 330 cohorts for D1 and 386 cohorts for D2. Demographic information and liver abscess outcomes are reported in Table 2. For D1, the average D1TA prevalence was 51.2%, and the median was 49.7% with cohorts ranging from 9.8 to 92.4%. The average D1SA prevalence was 32.6%, with a median of 30.0% and a range from 3.5 to 83.5%. The average prevalence of D1S+A was 23.9% with a median of 21.6% and ranged from 2.5 to 71.9%. For D2, the average prevalence of D2TA was 10.6%, with a median of 9.5%, and a range of 0 to 60.2%. Average prevalence of D2CL was 27.9%, and the median was 26.8% ranging from 0 to 57.1%. For D2AdL, average prevalence was 22.6%, with a median of 21.4%, and cohorts ranging from 0 to 73.1%.

Model Results: Dataset 1

Backwards step-wise regression was used to generate the final GLMM that evaluated the probabilities of four different LA outcomes (D1TA, D1SA, D1S+A, and D1ST) being associated with sex of cohort, DOF, shipping weight, head received, ADG – deads out, mortality, railers, daily feed delivered per head, quarters of arrival and harvest, and region of origin. For D1TA, the final model included sex of cohort, DOF, shipping weight, railers, and region of origin. The D1SA model included sex, DOF, shipping weight, railers, and region of origin. Similarly, the D1S+A included all of these variables as well as quarter of harvest. For D1ST, only sex of the cohort and region of origin remained in the final model.

Steer cohorts had a greater risk ($P \leq 0.01$; Figure 1) compared to heifer cohorts for D1TA ($52.4 \pm 4.5\%$ vs. $46.1 \pm 4.3\%$, respectively), D1SA ($35.4 \pm 3.5\%$ vs. $29.6 \pm 4.3\%$), D1S+A ($22.9 \pm 3.6\%$ vs. $18.4 \pm 2.9\%$), and D1ST ($71.6 \pm 4.7\%$ vs. $65.7 \pm 5.2\%$). Days on feed was significantly associated with ($P \leq 0.02$) D1TA, D1SA, and D1S+A scores where cattle on feed for more than 300 days had a greater risk than cattle on feed 250 to 299 days, 200 to 249 days,

and less than 200 days (Figure 2). Shipping weight was associated with ($P \leq 0.04$) D1TA, D1SA, and D1S+A scores with cohorts between 680 and 725 kgs having a greater risk (D1TA: $53.3 \pm 4.4\%$; D1SA: $37.6 \pm 4.9\%$; D1S+A: $23.6 \pm 3.6\%$) of such scores than cohorts with shipping weights of 726+ kgs (D1TA: $45.4 \pm 4.7\%$; D1SA: $29.5 \pm 4.6\%$; D1S+A: $18.8 \pm 3.2\%$).

Percentage of cohort railed was associated ($P \leq 0.01$) with D1TA, D1SA, and D1S+A. For D1TA and D1S+A, cohorts with 0.5 to 0.99% (D1TA: $50.5 \pm 4.5\%$; D1S+A: $21.6 \pm 3.4\%$), 1.0 to 1.49% (D1TA: $51.1 \pm 4.5\%$; D1S+A: $22.2 \pm 3.5\%$), and 1.5 to 1.99% (D1TA: $50.2 \pm 4.6\%$; D1S+A: $21.7 \pm 3.5\%$) of the arrival head railed had a greater risk of LA outcomes compared to cohorts with less than 0.5% of the arrival head railed (D1TA: $44.9 \pm 4.2\%$; D1S+A: $17.5 \pm 2.8\%$). Cohorts with 0.5 to 0.99 ($33.2 \pm 4.7\%$), 1.00 to 1.49 ($34.3 \pm 4.9\%$), 1.50 to 1.99 ($34.2 \pm 4.9\%$), and greater than 2% ($32.3 \pm 4.7\%$) of arrival head railed had greater risk of D1SA compared to cohorts with fewer than 0.5% railed ($28.1 \pm 4.2\%$).

Quarter of harvest was associated with ($P = 0.03$) D1S+A. Cohorts harvested in quarter 4 had a lower risk ($17.0 \pm 3.1\%$) of D1S+A compared to cohorts harvested in quarter 2 ($21.9 \pm 3.2\%$) or quarter 3 ($23.4 \pm 3.5\%$). Region of origin was associated ($P \leq 0.05$) with D1TA, D1SA, D1S+A, and D1ST where calves originating from region 3 had a lower risk of LA outcomes (D1TA: $43.6 \pm 4.1\%$, D1SA: $27.4 \pm 4.0\%$, D1S+A: $18.1 \pm 2.8\%$, D1ST: $64.2 \pm 5.2\%$) compared to calves from regions 1 (D1TA: $49.8 \pm 4.1\%$, D1SA: $33.0 \pm 4.4\%$, D1S+A: $21.3 \pm 3.1\%$, D1ST: $68.2 \pm 4.9\%$), 4 (D1TA: $52.2 \pm 4.1\%$, D1SA: $34.4 \pm 4.5\%$, D1S+A: $22.6 \pm 3.2\%$, D1ST: $69.7 \pm 4.7\%$) and region 2 for D1SA ($32.7 \pm 4.7\%$; Figure 4).

Feedyard was included as a random effect in the model for each outcome, and the marginal and conditional R^2 report how much of the variance was explained by fixed effects or fixed and random effects, respectively. For D1TA, the marginal R^2 was 0.29, and the conditional

R^2 was 0.84. This means that including feedyard as a random effect improved the explanation of the variance by 55.2 percentage units. For D1SA, the marginal R^2 was 0.22 and conditional R^2 was 0.81, meaning the inclusion of feedyard as a random effect explained 58.9 percentage units more variation than the inclusion of fixed effects alone. For D1S+A, the marginal R^2 was 0.24 and the conditional R^2 was 0.74. Including feedyard as a random effect improved the explanation of the variance by 49.6 percentage units. The effect of including feedyard as a random effect was more pronounced for D1ST with a marginal and conditional R^2 of 0.06 and 0.97, respectively. These values indicate that there were differences between feedyards that were not adequately captured within the collected operational data.

Model Results: Dataset 2

Outcomes of interest for D2 were proportion of abscessed livers, condemned livers, and adhered livers which were assessed using the same model-building process used for D1. For D2TA, shipping weight, ADG, quarter of harvest, and region of origin were retained in the final model. For D2CL, head received, ADG, and quarter of harvest made up the final model. The final model for D2AdL included only sex of the cohort.

Steer cohorts had a greater ($P < 0.01$; Figure 1) risk of D2AdL ($27.4 \pm 1.5\%$) compared to heifer cohorts ($20.5 \pm 1.3\%$), but sex was not associated with D2TA or D2CL. Shipping weight was associated with ($P < 0.01$) D2TA where cohorts with an average shipping weight less than 589 kgs had a lower probability of LA ($5.0 \pm 1.7\%$) than cohorts between 680 and 725 kgs ($9.1 \pm 1.5\%$) and those between 635 and 679 kgs ($10.0 \pm 1.4\%$). The number of head received was associated with ($P = 0.03$) D2CL where cohorts of more than 250 head had a lower risk ($16.8 \pm 4.6\%$) compared to cohorts between 200 and 249 head ($30.0 \pm 2.9\%$), 150 and 199 head ($32.0 \pm 2.9\%$), and less than 150 head ($30.5 \pm 2.7\%$). Average daily gain was significantly

associated with ($P \leq 0.02$) D2TA and D2CL. For D2TA, cohorts with an ADG between 1.36 and 1.46 kg/d had a lower risk ($6.6 \pm 1.1\%$) compared to cohorts between 1.13 and 1.24 kg/d ($9.1 \pm 1.6\%$), and were not different from cohorts with ADG between 1.25 and 1.36 kg/d ($7.6 \pm 1.3\%$), less than 1.13 ($6.6 \pm 1.3\%$), and equal to or greater than 1.47 kg/d ($7.8 \pm 1.3\%$; Figure 3). For D2CL, cohorts with ADG between 1.36 and 1.46 kg/d had a lower risk ($24.4 \pm 2.8\%$) compared to cohorts with an ADG between 1.13 and 1.24 kg/d ($29.2 \pm 3.3\%$) and between 1.25 and 1.35 kg/d ($28.3 \pm 3.1\%$).

Quarter of harvest was significantly associated with ($P \leq 0.01$) D2TA and D2CL. Cohorts shipped to harvest in quarter 3 had a lower risk of D2TA ($6.3 \pm 1.1\%$) compared to cohorts harvested in quarter 4 ($8.9 \pm 1.4\%$) For D2CL, cattle shipped to harvest in quarter 3 had the lowest probability of the outcome ($21.0 \pm 2.6\%$), followed by quarters 2 ($25.3 \pm 2.9\%$) and 4 ($28.3 \pm 3.1\%$), and cohorts shipped in quarter 1 had the greatest risk of condemnation of livers ($33.4 \pm 3.5\%$).

Region of origin was associated with ($P \leq 0.01$) D2TA where cohorts originating from regions 1 and 4 had lower risks of the outcome ($2.3 \pm 1.6\%$ and $7.6 \pm 0.8\%$, respectively) compared to cohorts from regions 2 ($10.2 \pm 0.08\%$), 3 ($10.2 \pm 1.1\%$) and 5 ($12.1 \pm 2.0\%$).

In D2, random effect of feedyard contributed little to the explained variation compared to D1 models. For D2TA and D2AdL, variation among feedyards was negligible, with essentially no difference in marginal and conditional R^2 . The marginal R^2 for the D2TA model was 0.30, and the reported conditional R^2 was 0.30 due to the extremely small effect of feedyard as a random effect. The marginal R^2 for the D2AdL model was 0.15, and the conditional R^2 was 0.20 indicating that feedyard did not help explain variation in the data for this outcome. For D2CL livers, the inclusion of feedyard as a random effect did improve the amount of variation

explained; marginal R^2 was 0.26 and conditional R^2 was 0.53, resulting in an additional 26.3% of the variation explained.

Discussion

As the number of BxD cattle harvested continues to grow, the economic losses due to liver abscesses can be expected to increase as well. Identifying potential risk factors that are associated with LA outcomes may provide producers with management practices to lower prevalence of LA at harvest. The results of this research indicated that sex, DOF, shipping weight at harvest, the number of head received upon arrival to the feedyard, ADG, railers, quarter of harvest and region of origin were associated with various LA outcomes from D1 and D2. Dataset 1 consisted of mutually exclusive liver scores which were used to calculate four outcomes of interest (D1TA, D1SA, D1S+A, and D1ST). The scoring system used for D2 had 3 non-mutually exclusive categories that were used as outcomes (D2TA, D2CL, D2AdL). Dataset 1 had a larger prevalence of LA compared to D2; however, this is most likely due to the differences in scoring systems used.

Dataset 1 consisted of cohorts from 8 feedyards located in the High Plains which were included as a random effect in analyses. Dataset 2 consisted of cohorts from 5 feedyards located in the High Plains. The differences in marginal and conditional R^2 provided by feedyard as a random effect varied between the outcomes and the data sets (D1 vs D2). In D1, the difference in the marginal and conditional R^2 values ranged from 49.6 to 91.0 percentage units. This range of difference between the R^2 values indicated that feedyard-level factors contributed strongly to variation in ways that were not captured in the variables provided by the operational data. The effect of feedyard was not as strong for D2 ranging from negligible to 26.3 percentage units, indicating the feedyard-level factors did not contribute as strongly to variation in these data. This

could be due to the different method of data collection which consisted of non-mutually exclusive groups of abscessed, condemned, and/or adhered livers. Either way, these data indicate considerable differences among feedyards that was not captured in the predictor variables evaluated in this study and warrants further research.

Similar to the results of the current study, previous literature has reported similar findings that Native and Holstein steers are more likely to have LA than heifers (Smith, 1998; Amachawadi and Nagaraja, 2016; Grimes et al., 2024; Champagne et al., 2025a). However, the previous findings were reported for Native, Holstein, and BxD cattle whereas the present study consisted of only BxD cattle. The increased risk for steers is thought to be related to increased dry matter intake (DMI) as well as longer DOF compared to heifers as steers eat greater quantities of feed for a longer period of time, there would be more opportunities for rapid fermentation of large quantities of carbohydrates to occur leading to frequent acidotic events (Amachawadi and Nagaraja, 2016). This could contribute to increased ruminal epithelial insult allowing for bacteria to escape and translocate to the liver to form LA (Nagaraja and Lechtenberg, 2007). However, we did not find an association between average daily feed delivered per head and any LA outcome.

The finding that cattle on feed for longer had a higher risk of LA outcomes is supported by previous literature (Reinhardt et al., 2009; Grimes et al., 2024; Champagne et al., 2025a). Champagne *et al.* reported in feedyard mortalities that cattle on feed for longer than 100 days had a higher probability of LA with cattle ranging from 1 to 226 DOF (Champagne et al., 2025a). In the present data, DOF ranged from 176 to 402 for D1 and 148 to 421 for D2. Dairy and BxD cattle may arrive at a feedyard weighing less than traditionally raised beef animals and thus must be on a high-grain finishing diet for a longer duration (Reinhardt and Hubbert, 2015a;

Amachawadi and Nagaraja, 2016). Thus, the total number of days BxD cattle are fed high-concentrate diets may result in greater ruminal wall insult due to prolonged exposure (Nagaraja and Lechtenberg, 2007). Chronic acidosis and rumenitis could lead to more LA formation due to their role in the pathogenesis of LA as discussed above. Shipping weight was also significantly associated with the risk of multiple LA outcomes; however, the probability of LA was higher for cohorts between 680 and 725 kgs compared to 726+ kgs. This was surprising as one would expect the heaviest cattle to have the highest risk of LA due to prolonged DOF and higher intake. But there were fewer cohorts with an average shipping weight of 726 + kgs and thus should be interpreted carefully.

The number of head in a cohort was significantly associated with D2CL where cohorts of fewer cattle had higher risk than those with more. The biological relevance of this finding is unknown, and to the authors' knowledge, there is no literature assessing the relationship of cohort size and LA outcome. An explanation could be lack of competition for bunk space in smaller cohorts. This would allow cattle to spend more time at the bunk and potentially increase feed intake which could contribute to more subacute rumen acidosis events. However, previous literature has not found differences in feed intake when comparing various bunk space allowance (Harrison and Oltjen, 2021; Duncan et al., 2022).

Average daily gain was also found to be associated with D2TA and D2CL (Figure 3). Cattle with an ADG between 1.13 and 1.24 kgs/d had a higher risk of D2TA than cohorts with an ADG between 1.36 and 1.46 kgs/d and cohorts with an ADG less than 1.13 kgs/d. For D2CL, cattle with an ADG between 1.13 and 1.35 kgs/d had a higher risk than those between 1.36 and 1.46 kgs/d. Fox *et al.* (2009) reported the presence of liver abscess at harvest tended to decrease ADG. Similarly, another study reported reduced ADG with severe LA (A+) and severe rumenitis

lesions found at harvest (Rezac et al., 2014). Due to the observational nature of this dataset, it is impossible to determine whether the presence of LA reduced ADG or if a reduction in ADG caused LA. Additionally, there is no way to know when LA develop or resolve prior to harvest.

The percentage of the cohort that was railed was associated with D1TA, D1SA, and D1S+A scores. Cohorts with fewer than 0.5% of cattle railed had a lower risk of these outcomes. A cohort with increased railers likely indicates increased incidence of BRD and potentially subclinical BRD. Animals previously suffering from BRD may be less capable of combating pathogenic bacteria entering the gastrointestinal epithelium leading to liver abscess. The authors hypothesized if an animal is spending biological resources to control a liver infection/abscess, their immune system may struggle to fend off other disease processes such as bovine respiratory disease (BRD). If an animal is suffering from BRD, this may result in the decision to rail the animal rather than risk mortality.

Quarter of harvest was associated with outcomes from both datasets: D1S+A, D2TA, and D2CL. For D1S+A, the risk was higher for those harvested in quarters 2 and 3 compared to quarter 4. Risk of D2TA and D2CL was highest for cohorts harvested in quarter 1 or 4, intermediate for quarter 2, and lowest for quarter 3. Previous literature reports mixed results regarding seasonality of LA. Brown and Lawrence (2010) did not observe a relationship between harvest month and abscess prevalence on an individual-animal basis, but other studies have found that LA and/or other abnormalities were highest in quarters 2 and 3 (Harman et al., 1989; Brown and Lawrence, 2010; Grimes et al., 2024). Grimes *et al.* (2024) reported total liver abscess risk on an individual-animal basis was lowest in January (Quarter 1) for both datasets analyzed and highest in August (Quarter 3) and April (Quarter 2; database 1) and May and June (Quarter 2; database 2). Another study had similar findings with highest liver abnormalities

reported in April and June (Quarter 2) on a cohort-level basis (Harman et al., 1989). The risk for condemned livers was highest in January (Quarter 1) which disagrees with Grimes *et al.*'s findings; however, this could be due to population differences. The present data includes data from 2021 to 2025 that was analyzed as success/failures on a cohort-level and consists only of BxD cattle across 3 processing plants and 11 feedyards, whereas Grimes' *et al.* data were collected on an individual-animal basis representing 26 processing plants and 138 different feedyards. Based on the present data and previous literature, there does not appear to be a consistent pattern for recorded liver abnormalities found at harvest. This inconsistency highlights the need for additional research to elucidate the underlying risk factors and mechanisms driving these findings.

Region of origin was associated with D1TA, D1SA, D1S+A, D1ST, and D2TA (Figure 4). For all D1 outcomes, cohorts of cattle that originated from region 3 (AZ, NM, OK, TX) had a lower risk than cohorts from regions 1 (CA, ID, NV, OR, WA) and 4 (IA, IL, IN, MI, MN, MO, OH, WI). Regions 2 and 5 were not different from the other regions for D1TA, D1S+A, and D1ST, but region 2 (CO, KS, MT, NE, ND, SD, UT, WY) was higher risk than region 3 for DISA. Conversely, for D2TA, cohorts originating from regions 2, 3, and 5 had higher risk compared to those from regions 1 and 4. This variable was included as a proxy for commercial calf ranch of origin, however, the origin recorded in the operational data could have corresponded to a calf ranch, backgrounding operation, or auction market. Thus, the results should be interpreted with caution. To the authors' knowledge, there is no previous literature that describes LA based on the region where the cattle were raised as calves. Grimes *et al.* (2024) analyzed LA by processing plant and feedyard location and attributed differences to variation in grain type and processing method as well as environmental factors. In the present data, all of the

processing plants and feedyards were located in the High Plains region, thus the authors would not expect to see differences associated with locations where cattle were finished and harvested.

Although results were primarily descriptive, a survey of calf ranch management practices applied to BxD calves observed regional differences in housing, calf starter, and weaning protocols (Bigelow et al., 2025). Similar findings were reported by the USDA NAHMS Survey where the majority of heifer raising facilities in the West region (AZ, CA, CO, ID, KS, NM, ND, TX, WA) housed calves in individual hutches/pens outdoors while the East (IN, IA, KY, MI, MN, MO, NY, OH, PA, VT, WI) primarily housed calves indoors (USDA, 2012). Additionally, calves in the East were typically weaned at lower age than calves in the West, as young as 42 days compared with 72 days, respectively (USDA, 2012; Bigelow et al., 2025). Again, these results were purely descriptive and region was not statistically analyzed, but the authors believe these data provide evidence that differences in management practices during calfhood may influence outcomes later in an animal's life and warrants further research.

Conclusion

Liver abscesses are a major economic loss to the beef industry, particularly in beef-on-dairy cattle due to higher prevalence. The cause of increased prevalence is not entirely known, and there is speculation that management of beef-on-dairy calves throughout their production lifecycle may be contributing to increased LA compared to native beef breeds. This study identified associations between LA prevalence at harvest and cohort-level factors such as cattle demographics, origin, and performance and health metrics during the finishing phase. Significant variation among feedyards was also observed in these data and provide evidence that there may be variables that are currently not measured or recorded in standard operational data that contribute to increased prevalence of LA. There is still a large need for further exploration of

management strategies to mitigate the risk of LA. A more comprehensive understanding of both early-life and finishing-phase management practices will be essential to develop effective, evidence-based strategies for reducing live abscess prevalence in beef-on-dairy production systems.

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Conflicts of Interest

The authors have no conflicts of interest to report.

Contributions

All authors contributed to the study in at least two of the various categories: conceptualization, funding acquisition, investigation, methodology, data collection, validation, project administration, supervision, writing – original draft, writing – reviewing and editing, and/or resources.

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Table 6.1 Liver scores used to evaluate livers at harvest in the processing plants.¹

Liver Scores by Dataset	Description
Dataset 1	
O	Normal liver with no lesions
A ⁻²	1 to 2 small abscesses less than an inch in diameter
A ²	2 to 4 abscesses less than an inch in diameter
A ^{+2, 3, 5}	1 or more large abscesses more than one inch in diameter
A+Adhered ^{2, 3, 4, 5}	Abscess present with adhesion(s) to diaphragm or other organs
A+Open ^{2, 3, 4, 5}	Abscess present with a ruptured abscess
A+Adhered/A+Open ^{2, 3, 4, 5}	Abscess present with both adhesions and a ruptured abscess
Dataset 2	
Abscessed ⁶	Any liver abscess present
Condemned ⁷	Any liver with ruptured abscess
Adhered ⁸	Any liver with an adhesion to diaphragm or other organs
¹ Livers from Dataset 1 were scored using a modified version of Elanco's liver abscess scoring system. Scores were mutually exclusive categories. Livers from Dataset 2 were scored using the processing plant's internal scoring system. Livers could be classified as abscessed, condemned, and/or adhered. These categories were not mutually exclusive. ² Scores included in Total LA outcome in Dataset 1 (D1TA) ³ Scores included in Severe LA outcome in Dataset 1 (D1SA) ⁴ Scores included in Severe+ LA outcome in Dataset 1 (D1S+A) ⁵ Scores included in Severe La as a proportion of Total outcome in Dataset 1 (D1ST) ⁶ Outcome in Dataset 2 (D2TA) ⁷ Outcome in Dataset 2 (D2CL) ⁸ Outcome in Dataset 2 (D2AdL)	

Table 6.2 Cohort-level population demographics and the proportion of liver abscess by scores. Operational data was pulled from feedyard databases and harvest data was collected in the processing plant between March 2024 and June 2025.

Category	Count	Percent Total	Category	Count	Percent Total
Source A (n = 330 cohorts, 59,210 head)			Source B (n = 386 cohorts, 46,884 head)		
Sex			Sex		
Heifer	178	53.9%	Heifer	203	52.6%
Steer	151	45.8%	Steer	183	47.4%
Days on feed categories			Days on feed categories		
< 200	13	3.9%	< 200	53	13.7%
200 - 249	92	27.9%	200 - 249	124	32.1%
250 - 299	155	47.0%	250 - 299	130	33.7%
≥ 300	70	21.2%	≥ 300	79	20.5%
Shipping weight categories (kgs)			Shipping weight categories (kgs)		
< 589	13	3.9%	< 589	67	17.4%
589 - 634	62	18.8%	589 - 634	124	32.1%
635 - 679	123	37.3%	635 - 679	106	27.5%
680 - 725	95	28.8%	680 - 725	81	21.0%
≥ 726	37	11.2%	≥ 726	8	2.1%
Average daily gain, kgs/day			Average daily gain, kgs/day		
< 1.13	19	5.8%	< 1.13	35	9.1%
1.13 - 1.24	60	18.2%	1.13 - 1.24	58	15.0%
1.25 - 1.35	106	32.1%	1.25 - 1.35	97	25.1%
1.36 - 1.46	72	21.8%	1.36 - 1.46	104	26.9%
≥ 1.47	73	22.1%	≥ 1.47	92	23.8%
Percent of the cohort railed ¹			Percent of the cohort railed ¹		
< 0.5	116	35.2%	< 0.5	226	58.5%
0.5 - 0.99	70	21.2%	0.5 - 0.99	47	12.2%
1.0 - 1.49	56	17.0%	1.0 - 1.49	47	12.2%
1.49 - 1.99	34	10.3%	1.49 - 1.99	15	3.9%
≥ 2.0	54	16.4%	≥ 2.0	21	5.4%
Region of origin			Region of origin		
1	98	29.7%	1	3	0.8%
2	41	12.4%	2	259	67.1%
3	81	24.5%	3	44	11.4%
4	107	32.4%	4	66	17.1%
5	3	0.9%	5	14	3.6%
Total livers evaluated	59,210		Total livers evaluated	46,884	

Total LA ²	30,332	51.2%	Abscessed livers ⁵	4,985	10.6%
Severe LA ³	19,285	32.6%	Condemned livers ⁵	13,069	27.9%
Severe+ LA ⁴	14,156	23.9%	Adhered livers ⁵	10,605	22.6%

¹A "railed" animal is sent to harvest prior to the rest of its cohort because it is not expected finish with its penmates

²Total LA consists of all LA scores: A-, A, A+, A+Adhered, A+Open, A+Adhered/A+Open

³Severe LA consists of A+, A+Adhered, A+Open, A+Adhered/A+Open

⁴Severe+ LA consists of A+Adhered, A+Open, A+Adhered/A+Open

⁵Liver score categories from Source B are not mutually exclusive

Figure 6.1 The association between cohort sex and various liver abscess (LA) outcomes was analyzed for two datasets: Dataset 1 (n = 330 cohorts) and Dataset 2 (n = 386 cohorts). Each panel shows the probability of a LA outcome: A = Total LA from Dataset 1 (D1TA), B = Severe LA from Dataset 1 (D1SA), C = Severe+ LA from Dataset 1 (D1S+A), D = Severe LA as a proportion of Total LA (D1ST), and E = Adhered livers from Dataset 2 (D2AdL). The white numbers represent the probability of that outcome, and the black bar represent the standard error of the mean. Columns within each graph with different letters denote statistical differences ($P < 0.05$).

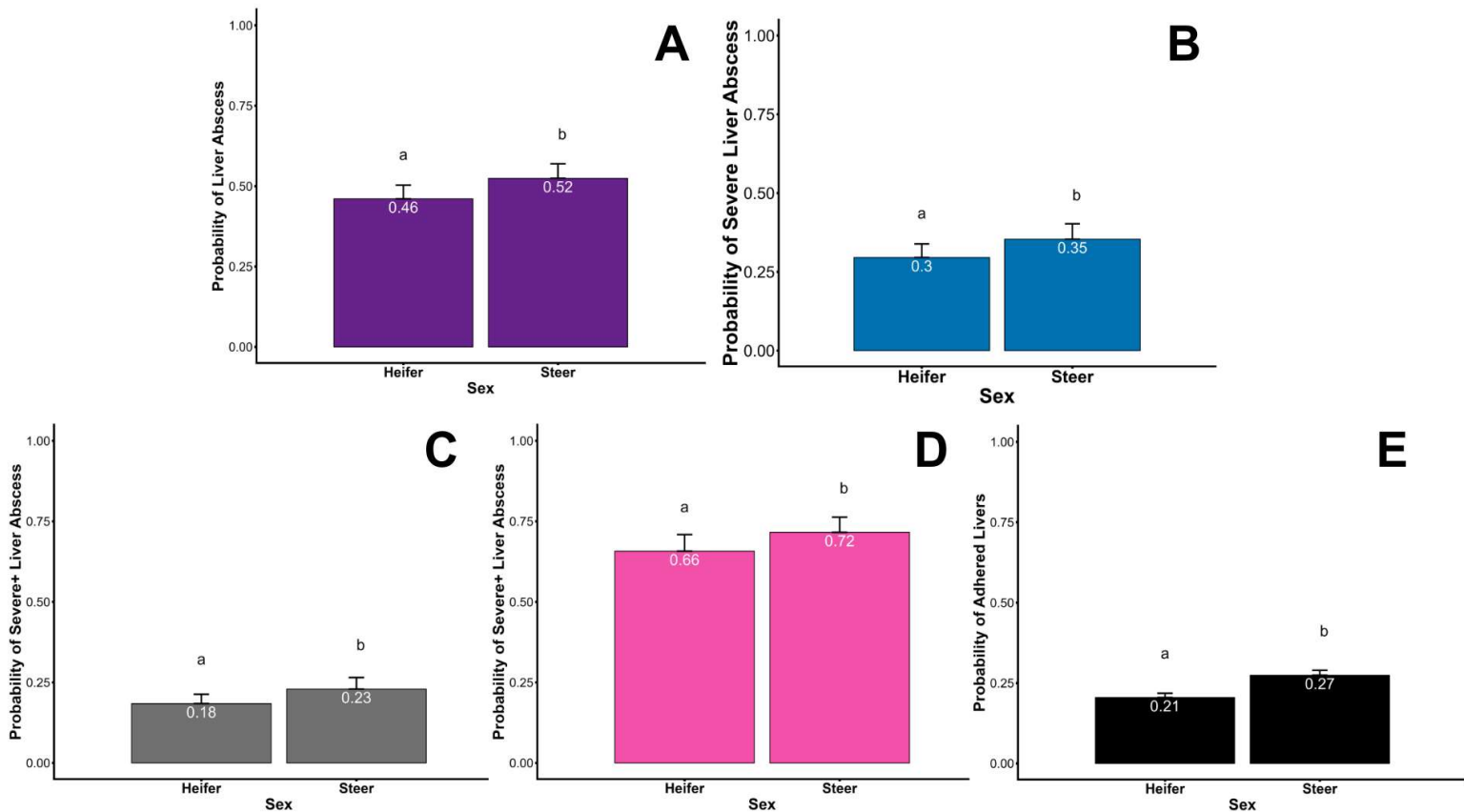


Figure 6.2 The association between DOF and various LA outcomes was analyzed for two datasets; however, only outcomes from Dataset 1 (n = 330 cohorts) were significantly associated with DOF. Each panel shows the probability of a LA outcome: A = Total LA, B = Severe LA, and C = Severe+ LA. The white numbers represent the probability of that outcome, and the black bars represent the standard error of the mean. Columns within each graph with different letters denote statistical differences ($P \leq 0.05$).

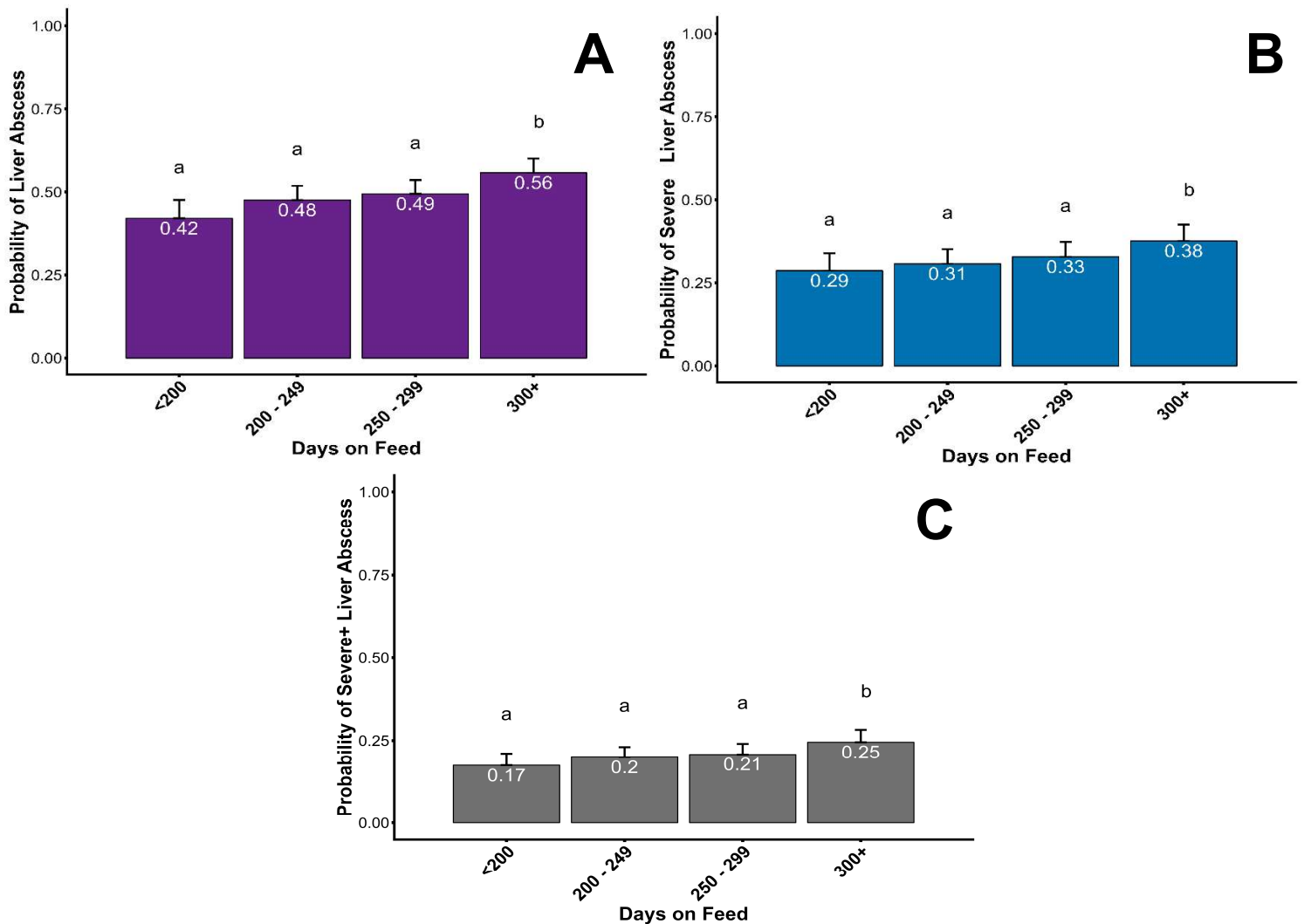


Figure 6.3 The association between ADG and various LA outcomes was analyzed for two datasets; however, only outcomes from Dataset 2 (n = 386 cohorts) were significantly associated with ADG. Each panel shows the probability of a LA outcome: A = Abscessed livers (D2TA), and B = Condemned livers (D2CL). The white numbers represent the probability of that outcome, and the black bars represent the standard error of the mean. Columns within each graph with different letters denote statistical differences ($P \leq 0.05$).

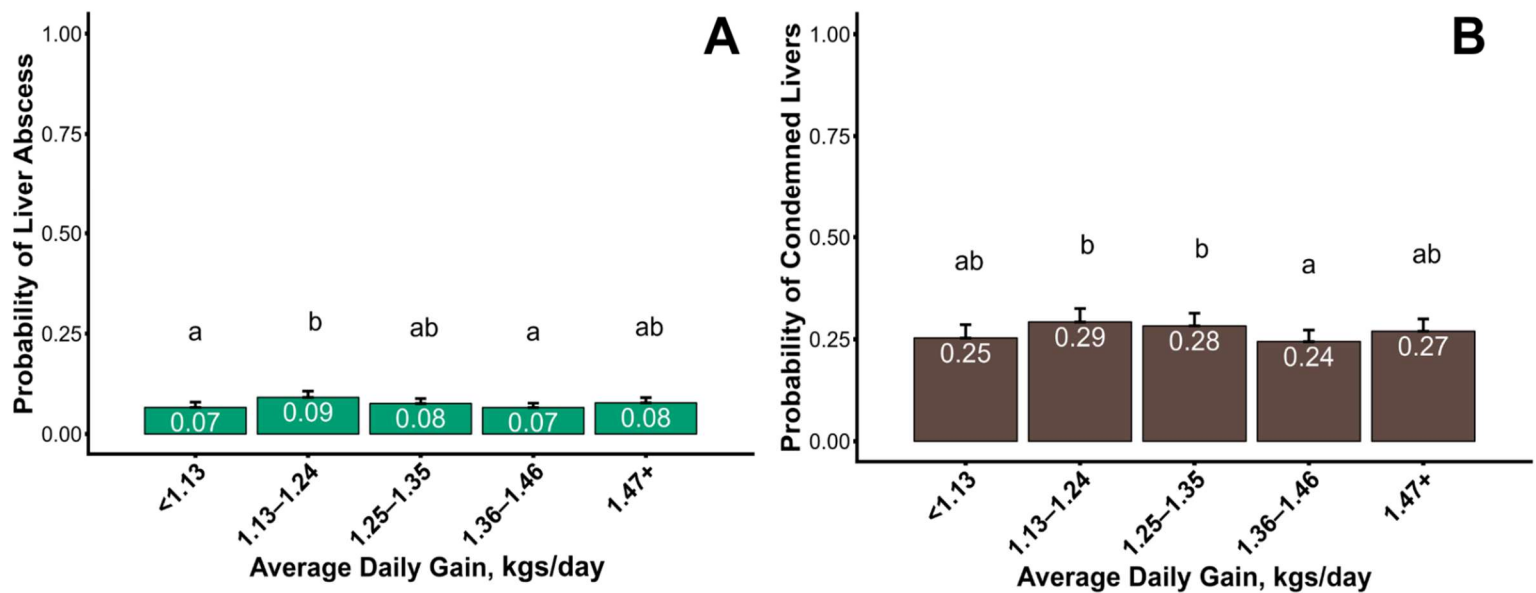
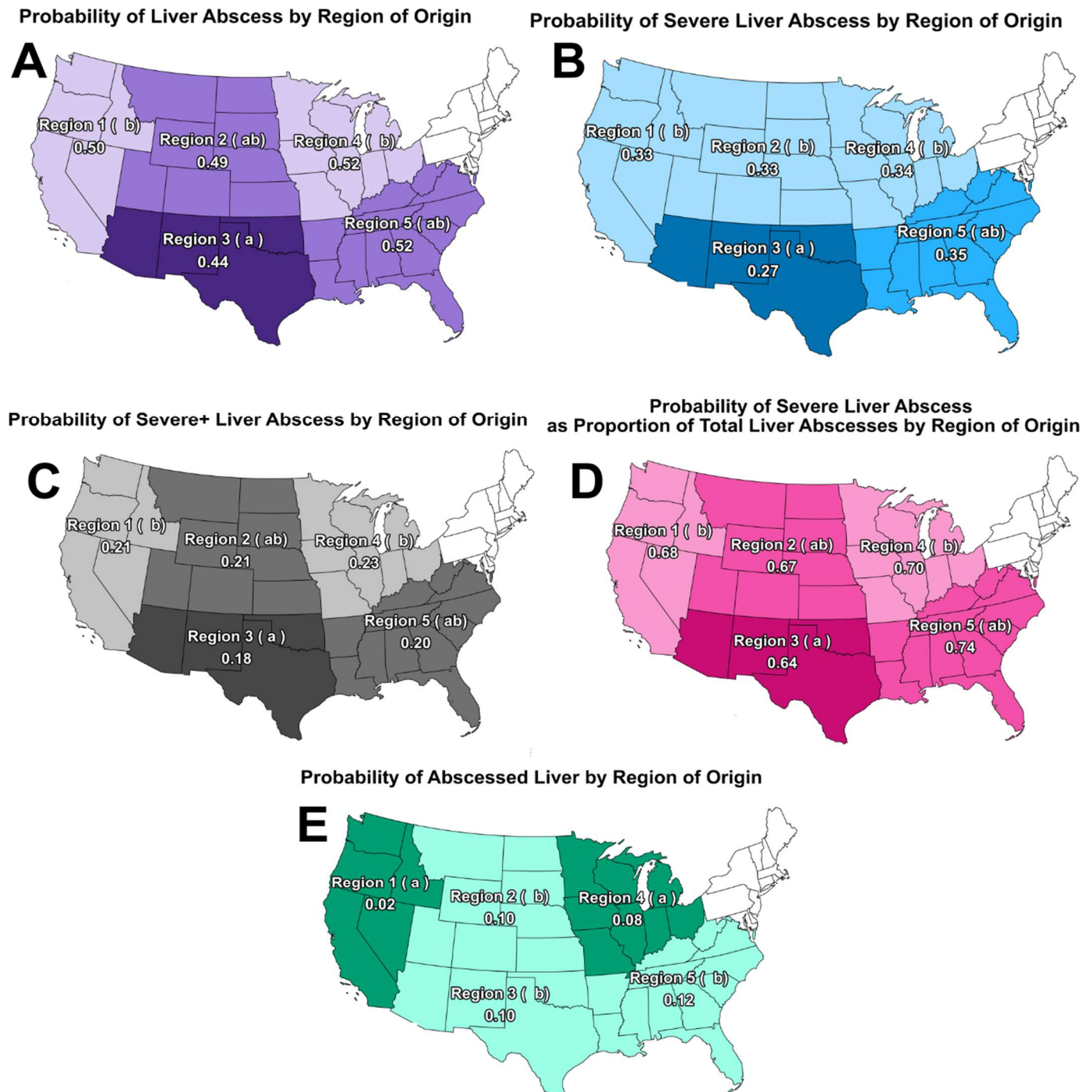


Figure 6.4 The association between region of origin and various LA outcomes was analyzed for two datasets: Dataset 1 (n = 330 cohorts) and Dataset 2 (n = 386 cohorts). Each panel shows the probability of a LA outcome: A = Total LA from Dataset 1, B = Severe LA from Dataset 1, C = Severe+ LA from Dataset 1, D = Severe LA as a proportion of Total LA from Dataset 1, and E = Abscessed livers from Dataset 2. No cohorts originated from Region 6 (the Northeastern states). Regions within each graph with different letters denote statistical differences ($P \leq 0.05$).



Chapter 7 - Characterization of feed intake curves and the association with liver abscess prevalence at harvest in feedyard beef-on-dairy cattle

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Text Abstract

Beef-on-dairy (BxD) cattle, produced by breeding dairy cows to beef sires, generally have improved carcass characteristics than dairy breeds but a higher prevalence of liver abscesses than native beef breeds. Liver abscess development is multifactorial, with feed and starch intake as major contributors. The objective was to use operational feedyard data to generate and characterize feed intake patterns, quantify intake through calculations and AUC across defined DOF and days to ship (DTS) periods, cluster feed intake patterns, and evaluate associations between feedyard- and intake-derived variables and cohort-level LA prevalence at harvest in beef-on-dairy cattle. Cohort-level closeout and daily feed delivery records were collected from 5 feedyards in the High Plains from 2021 to 2025 (n = 378 cohorts). Liver scores were collected at harvest using a modified version of Elanco's scoring system with 4 outcomes

of interest: Total LA (All scores; TA), Severe LA (Scores A+, A+Open, A+Adhered; SA), Severe+ LA (Scores A+Open and A+Adhered; S+A), and Severe as proportion of Total LA (ST). Daily feed delivered per head as percent of arrival body weight was calculated using daily feed records. Missing data were interpolated using generalized additive models (GAMs). Feeding patterns were described using several metrics: cluster analysis, area under the curve (AUC), descriptive measures during different periods relative to days on feed (DOF) and days to ship (DTS), and the number of decreases in intake from the previous day's intake. All predictors from operational and feed intake data ($n = 78$) were tested for associations with TA, SA, S+A, and ST via univariate generalized linear mixed models (GLMM) with a beta-binomial distribution with feedyard as a random effect. Any variable with a p -value ≤ 0.3 was then tested in a multivariate model. Backwards stepwise selection was used to eliminate predictors with the highest p -value until all remaining variables were significant ($P \leq 0.05$). The final models for each outcome consisted of 45 variables for TA, 36 variables for SA, 21 variables for S+A, and 11 variables for ST. Measures of central tendency and variability of feed intake during different periods, cluster, and AUCs were significantly associated with multiple LA outcomes. For the DOF periods, as average intake increased, the probability of TA, SA, and S+A increased as well. For measures of variation, cohorts in the largest standard deviation category had lower probabilities of TA, SA, and S+A compared to cohorts with smaller standard deviations. Cluster was associated with TA and ST where cluster 5 had the highest probability of TA compared to clusters 2, 3 and 4. For ST, clusters 5 and 1 had lower probabilities of ST than cluster 4. There seemed to be a pattern where lower AUCs had greater probabilities of LA outcomes, and the probability decreased as AUC increase; however, this was not consistent across DOF/DTS periods or outcomes. Average intake, clustering of feed curves, and measures of variation were

significantly associated with LA and could help identify management practices to reduce LA prevalence in beef-on-dairy cattle.

Key Words

Beef-on-dairy, days on feed, dry matter intake, feed intake, feedyard cattle, liver abscess

Introduction

Beef-on-dairy (BxD) cattle are the product of the dairy industry shifting to the use of beef semen to add value to the bull calves born on-site. The number of BxD cattle in the United States beef production system has continued to increase due to improved feedyard performance and carcass quality compared to Holsteins (Foraker et al., 2022). While BxD may have enhanced meat attributes compared to dairy breeds, they tend to have a greater incidence of liver abscesses (LA) than native beef breeds (Foraker et al., 2022b). Liver abscesses are a source of major economic loss within the beef industry, exceeding losses of \$250 million annually (Taylor et al., 2025). The cause of LA is multifactorial; however, a major contributor is thought to be acidosis caused by increased consumption of highly-fermentable starch-based finishing diets (Amachawadi and Nagaraja, 2016; Bryant and Jennings, 2022). Previous literature has examined differences of LA based on demographics such as breed and sex, feed management such as timing and amount, as well as various feedstuffs like roughage levels and particle size, but assessment of feed intake patterns in relation to LA has not been previously described (Amachawadi and Nagaraja, 2016; Broadway et al., 2024; Hales, 2024; Champagne et al., 2025b; Schneid et al., 2026).

Several studies have investigated the effect of fiber inclusion on liver abscess in finishing feedyard cattle (Pereira et al., 2021; Wilson et al., 2023; McDaniel et al., 2024; Paterson et al., 2024). Wilson *et al.* (2023) reported that cattle fed a lower corn silage inclusion rate without

tylosin had a greater prevalence of LA than cattle fed higher silage inclusion rates or diets containing tylosin. Similarly, Pereira *et al.* (2021) found fiber source (barley vs. wheat) and physically effective neutral detergent fiber (peNDF; high vs. low) interacted to influence severe LA prevalence, with cattle fed low peNDF barley silage exhibiting lowest incidence of severe abscesses compared to those fed high peNDF fiber sources. These findings suggest that fiber inclusion rate, source, and physical effectiveness may influence LA development, although underlying mechanisms are not clear.

Several studies have also evaluated the relationship between grain processing, starch concentration, and LA prevalence, although findings have been inconsistent. Schneid *et al.* (2024) reported that cattle fed a high-starch diet had a greater prevalence of LA than cattle fed a low-starch diet. Similarly, Mader *et al.* (1991) found cattle fed ground and/or rolled high-moisture corn tended to have a greater incidence of LA than cattle fed whole corn. In contrast, studies evaluating steam-flaked corn and sorghum flake density found no differences in LA incidence among processing treatments despite differences in ruminal pH or condemned livers (Reinhardt et al., 1997; Ponce et al., 2013). These findings suggest that grain processing and starch concentration may influence LA development, but the relationship remains inconsistent across studies.

One type of data that has not been utilized frequently in regard to LA is feed intake data, specifically feed intake patterns over the course of a feeding period. Hicks *et al.* analyzed feed intake records from commercial feedyards for beef steers, beef heifers, and Holstein steers to determine the relationship between daily voluntary dry matter intake (DMI) to initial weight, time on feed, and season of the year in which cattle were received. Using this data, Hicks *et al.* developed equations to customize feed intake estimates for individual pens for improved

accuracy of gain projections (R.B. Hicks et al., 1990; R. B. Hicks et al., 1990). However, to our knowledge, no previous literature exists describing how feed intake patterns may be associated with LA. Others have reported that greater feed intake is associated with increased LA although these findings are not consistent (Brink et al., 1990; Amachawadi and Nagaraja, 2016; Smock et al., 2021; Broadway et al., 2024). Brink *et al.* investigated relationships of gain, intake, and feed efficiency with severity of LA and found that cattle with higher incidence of LA tended to consume less feed than those with non-abscessed livers (Brink et al., 1990). In another study, bunk management programs related to intake (slick bunk vs. *ad libitum*) were compared, and there was no difference in either intake nor LA scores between the management programs (Smock et al., 2021). Inconsistencies within previous findings highlight the complexity of LA pathogenesis and incidence. Feed intake data currently remains unexplored in relation to LA. Therefore, our objective was to use operational feedyard data to generate and characterize feed intake patterns, quantify intake through calculations and AUC across defined DOF and days to ship (DTS) periods, cluster feed intake patterns, and evaluate associations between feedyard- and intake-derived variables and cohort-level LA prevalence at harvest in beef-on-dairy cattle.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee (IACUC) was contacted regarding this research, and no approval was needed due to data being obtained from operation databases. No procedures were performed on live animals.

Data Collection

Cohort-level closeout records were collected from 5 feedyards located in the High Plains region of the United States spanning October 2021 to June 2025. A cohort is a group of cattle that arrived to the feedyard together and was harvested together. Cohorts can be housed across

multiple pens, but pens did not contain cattle from multiple cohorts. Closeout records included information such as feedyard ID, cohort ID, sex of the cohort, number of head received, number of head shipped for harvest, dates received and shipped, cohort-level weight at arrival and shipping, number of deaths and railers, and the total amount of feed delivered to the cohort during the entire feeding period. Daily feed records were collected from feedyard databases and consisted of either running cumulative amount of feed delivered to a cohort per day or the amount of feed delivered to each pen each day as well as the head count in each pen. Individual livers were scored at harvest and counts of scores were summed on a cohort-level using a modified version of Elanco's liver abscess scoring system with mutually exclusive scores as described in Table 1.

Feedyard Operational Data

Days on feed were calculated by subtracting the arrival date from the shipping date for each cohort. Average arrival and shipping weights were calculated by dividing the cohort's arrival and shipping weights by the number of cattle received and shipped, respectively. Average daily gain with deaths included (ADG – deaths in) was calculated by subtracting total cohort arrival weight from total cohort shipping weight and dividing by head days. Average daily gain with deaths out (ADG – deaths out) was calculated by subtracting average arrival weight per head from the average shipping weight per head and dividing by DOF. Mortality was calculated per cohort by dividing the number of deaths by the number of head received and multiplying by 100 to get a percentage. Similarly, percentage of the cohort railed was calculated by dividing the number of cattle railed by the number of head received and multiplying by 100. An animal that is “railed” is an animal that was shipped to harvest earlier than the rest of its cohort due to health reasons. These variables were then categorized and adjusted based on distribution of the data.

Dates of arrival and shipping to harvest were categorized into quarters (Q1: January, February, March; Q2: April, May, June; Q3: July, August, September; Q4: October, November, December).

Feedyard Feed Intake Data

Feed intake data were collected in 2 formats. For 3 feedyards, feed intake data consisted of pen-level cumulative feed delivery reported as a daily cumulative amount over the entire period. Feed records after the cohort's slaughter date were removed from the dataset. To calculate daily amount of feed delivered per cohort while accounting for pen movements within a cohort, such as splitting or merging pens, a function was built using various commands from the “dplyr” package in RStudio (Version 2022.02.3, Boston, MA). The code identified days when cohorts were split into new pens or merged into one pen and adjusted the amount of feed delivered by head count when pen movements occurred to avoid double-counting feed delivered. The amount of feed delivered across pens was then aggregated to a cohort-level by day, and cumulative totals were converted into true daily changes by subtracting the previous day's feed delivered from the present day's feed amount. Then the daily feed delivered per head was calculated by dividing the total amount of feed delivered per day by the number of head in the cohort on that day.

The other format of feed data from 2 feedyards consisted of the individual daily feed delivery per pen. Thus, the same function was applied to handle feed delivery across multiple pens within one cohort and aggregating to the cohort-level, but no subtraction occurred between the previous and present-day records. The daily feed delivered per head was calculated by dividing the total amount of feed delivered per day by the number of head in the cohort on that day.

Interpolation of Feed Data

The daily feed records contained missing days. Missing daily feed records were imputed separately for each unique cohort using generalized additive models (GAMs). Feed intake records were first aggregated across pens within each cohort for each DOF, such that the resulting longitudinal curve represented the average cohort-level feed delivery over time. Cohorts could be housed across multiple pens, but pens could not contain cattle from multiple cohorts. For each cohort, the feeding curve was modeled as:

$$Y_t = f(t) + \varepsilon_t,$$

where Y_t denotes the observed dry matter intake per head (DM_Hd) on day-on-feed t , $f(t)$ is an unknown smooth function of DOF, and ε_t represents residual error. The smooth function was estimated using penalized regression splines implemented through the “mgcv” package in R. Specifically, the fitted model took the form:

$$Y_t = \beta_0 + \sum_{j=1}^K \beta_j B_j(t) + \varepsilon_t,$$

where $B_j(t)$ denotes spline basis functions and β_j are regression coefficients estimated from the data. Cubic shrinkage splines were used to allow increased local flexibility while avoiding overfitting in regions with sparse information.

For each cohort, the complete sequence of DOF was reconstructed from minimum observed DOF through the estimated total feeding duration using slaughter date. Missing days were identified as gaps within the daily sequence. Following model estimation, predicted values $\hat{Y}_t = \hat{f}(t)$ were generated for missing days only, while observed feed values were retained unchanged. Spline complexity was controlled through a basis dimension parameter selected adaptively according to the number of observed feeding days available within each cohort. Smoothing parameters were estimated using restricted maximum likelihood (REML), with a

reduced smoothing penalty ($\gamma = 0.8$) to permit greater local responsiveness in the fitted feeding curves. Cohorts with sparse observations were handled using reduced spline basis dimensions, and linear interpolation was used as a fallback when insufficient observations were available for stable spline estimation. One cohort was removed from analysis due to insufficient number of daily feed records.

This modeling framework was selected because feed intake curves in feedyard cattle are expected to evolve gradually over time while still allowing for nonlinear temporal dynamics associated with acclimation, growth, dietary transitions, environmental stressors, and disease processes. Relative to simple linear interpolation, the GAM-based approach provides a flexible semiparametric framework capable of recovering biologically plausible feeding curves without imposing a rigid parametric form. Importantly, transient reductions in feed intake are biologically meaningful in feedyard systems and may correspond to short-term health or management disruptions. Consequently, the spline specification was intentionally selected to preserve localized decreases in intake rather than excessively smoothing abrupt deviations toward the overall mean feed intake.

The interpolation procedure was intended to reconstruct incomplete longitudinal feeding records for downstream analyses rather than to infer mechanistic physiological processes underlying short-term feeding disruptions. Interpolated values should therefore be interpreted as statistically plausible estimates conditional on neighboring observed intake days within each cohort. Because periods of missingness may overlap with biologically meaningful transient intake reductions, interpolated values may still attenuate extreme unobserved deviations occurring entirely within missing intervals. Nevertheless, the approach provides a practical and

biologically interpretable framework for generating complete longitudinal feeding records while preserving observed temporal structure and localized variation in cohort-level feed intake curves.

Feed Intake Variable Calculations

After interpolation, variables were calculated to characterize the mean and variation within each feed intake curve. First, the amount of feed delivered per head per day was standardized across cohorts by calculating the daily feed delivered per head per day as a percentage of the average arrival body weight for each cohort (Percent_dm_hd). This was done to account for cohorts arriving at different body weights, which is known to affect the feed intake pattern (Hicks, 1990). The initial, day 30, and maximum intake were recorded for each cohort. The DOF half- and three-quarters of the way through the feeding period were identified for each cohort. Then, the intake on those days was divided by the maximum intake and multiplied by 100 to calculate what percentage of their maximum intake the cohort was at on those DOF.

Measures of central tendency, variation, and area under the curve (AUC) were collected for periods within the feeding curve. The feed intake curves were then partitioned into multiple DOF periods: less than 30 DOF, 30 to 59, 60 to 89, 90 to 119, and 120 to 150. For each DOF period, the minimum, maximum, and average intake were recorded as well as the standard deviation and coefficient of variation (CV). The same principle was applied moving backwards from the slaughter date of each cohort, resulting in “days to ship” (DTS). Days to ship periods consisted of less than 30 DTS, 30 to 59, 60 to 89, 90 to 119, and 120 to 149 DTS. The same variables collected for DOF were computed for these time periods for each cohort. The AUC was also measured for each DOF and DTS periods. The DOF and DTS time periods were created to collect information from the beginning and end of the feeding period. At the beginning (DOF), the cohorts did not arrive at similar body weights. Measuring variables at the end of the period

(DTS) allowed us to collect information when all cohorts were approaching harvest and were thus more similar in body weight. The categories were chosen based on the range of DOF for all cohorts: 154 to 402 days.

Additionally, the number, duration, and intensity of major feeding anomalies were calculated. The number of “drops” was recorded by counting the number of days where feed delivered was less than the day prior. The magnitude of those changes in percentage units was calculated by subtracting the previous day’s intake from the present day’s intake and dividing by the previous day’s intake and multiplying by 100. The percent changes ranged from less than a 5.0% change to greater than 20.0%. The number of drops was counted for each of the categories: drops between 5 and 10%, 10 to 20% and 20 to 50%. Next, the slope was calculated for the first 30 DOF and from day 50 to the end of each cohort’s feed intake curve.

Finally, feed intake curves were clustered using the *hclust* function of the “zoo” package in RStudio. The “ward.D2” method was used by the *hclust* function which groups observations in order to minimize within-cluster variance.

All feed intake curve variables were then categorized based on the distribution of the data visualized via histograms. This was done to avoid assumptions of linear relationships between the variables and outcomes of interest. Bins were adjusted to ensure there was at least 30 observations were present in each bin. In combination with the operational feedyard variables, 78 predictors were evaluated for association with LA outcomes. Predictors and their bins are defined in Table 2.

Model-Building Process

Liver scores were grouped to create 4 outcomes of interest for analyses as seen in previous work: Total abscessed livers (TA; count of all LA scores / count of cattle without LA),

Severe abscessed livers (SA; count of A+, A+Adhered (Ad), A+Open (Op), and A+Ad&Op / count of cattle without Severe LA), Severe+ abscessed livers (S+A; count of A+Ad, A+Op, and A+Ad&Op / count of cattle without Severe+ LA), and Severe LA as a proportion of total LA (ST; count of A+, A+Ad, A+Op, and A+Ad&Op / count of LA scores A- and A). The outcome S+A was created as a subset of SA because it consists of LA scores associated with loss of trim and/or stopping the chain during harvest for additional trimming which both contribute largely to the economic losses discussed previously (Taylor et al., 2025). Upon collecting the data, it was expected that the frequency of severe abscesses within a cohort would increase as total LA did. However, the data did not support this assumption, thus the outcome ST was created to further explore the relationship.

First, all predictor variables ($n = 78$) were tested with each outcome (TA, SA, S+A, and SR) via univariate models using the *glmmTMB* function from the “glmmTMB” package in RStudio (Version 2024.04.2, Boston, MA). The outcomes were analyzed as success/failures per cohort in generalized linear mixed models (GLMM) using a beta-binomial distribution with a logit link function to account for overdispersion of the data. Feedyard was included as a random effect. Each variable was tested independently, and any variable with a P-value > 0.3 was removed from further testing (TA: $n = 9$ variables removed; SA: $n = 14$ variables removed; S+A: $n = 10$ variables removed; ST: $n = 27$ variables removed). Remaining variables were tested in a beta-binomial GLMM using backwards stepwise selection where all predictors with univariate $P \leq 0.30$ were included initially. The “nlminb” optimizer was used, and feedyard was included as a random effect. The variable with the highest P-value was removed sequentially and the model reran until all remaining variables were statistically significant ($P \leq 0.05$). This model-building process was

repeated for all outcomes of interest: TA, SA, S+A, and ST. The variance inflation factors (VIFs) were tested for each final model to ensure no multicollinearity between predictor variables.

Model diagnostics were evaluated using simulated residuals via the “DHARMA” package. The quantile-quantile (QQ) plots and residual plots were created to assess the model fit. The plots of residuals vs. predicted were scattered and evenly distributed for all final models. The QQ plots were bow-shaped for SA, S+A, ST; however, due to the large sample size and categorical variables, the Kolmogorov-Smirnov test becomes hyper-sensitive and flags minor, meaningless differences within the tails of the distribution. Due to the large categorical matrix, overall variable significance was determined via Likelihood Ratio Tests using the *drop1* function. Predicted probabilities, standard errors (SEM), and 95% confidence intervals (CIs) were calculated for each significant variable as estimated marginal means (least-squares means) using the *emmeans* package, holding all other covariates constant.

Results

Descriptives

Operational feedyard data, feed intake data, and liver abscess scores at harvest were collected for 384 cohorts. Cohorts of cattle other than BxD (Native, Mexican, etc.) were removed from the dataset prior to analyses (n = 3 cohorts), and cohorts without feed intake data were removed (n = 3 cohorts) resulting in 378 cohorts for analysis. For TA, the average prevalence was 53.3%, and the median was 52.8% with cohorts ranging from 9.8% to 92.4%. The average prevalence of SA was 32.9%, and the median was 29.1% with the proportion of SA ranging from 3.5% to 83.5%. For S+A, the average prevalence was 24.1%, and the median was 21.4% with cohorts ranging from 1.5% to 71.9%. For ST, the average was 59.1%, and the median was 57.4% with a range from 16.3% to 98.6%.

Model Results

For TA, 69 variables had a univariate significance ≤ 0.3 and were tested in the multivariate model. The final model for TA consisted of 45 predictors. For SA, 64 predictors were retained for testing in the multivariate model, and the final model consisted of 36 predictor variables. For S+A, 68 variables were tested in the multivariate model, and 21 remained in the final model. For ST, 51 variables were retained for testing in the multivariate model, and 11 predictors were significant in the final model. Significant predictor variables and their p-values can be seen in Table 3.

Feedyard Operational Data Predictors

Model-estimated means $\pm$ standard error (SE) are reported throughout the results. Sex of the cohort was significantly associated ($P < 0.01$) with all LA outcomes of interest. Steer cohorts had a higher probability of TA ($25.4 \pm 7.7\%$ vs. $19.7 \pm 6.3\%$, respectively), SA ($20.9 \pm 7.2\%$ vs. $16.8 \pm 5.8\%$, respectively), S+A ($14.3 \pm 4.0\%$ vs. $10.7 \pm 2.9\%$, respectively), and ST ($54.3 \pm 10.6\%$ vs. $48.8 \pm 10.4\%$, respectively) compared to heifer cohorts. Number of head received upon arrival (4 categories: < 150 to ≥ 250 head) was significantly associated ($P < 0.01$) with TA where cohorts of 200 to 249 head had a lower probability ($16.0 \pm 5.4\%$) compared to cohorts < 150 head ($19.7 \pm 6.3\%$), between 150 to 199 head ($19.6 \pm 6.2\%$), and ≥ 250 head ($19.0 \pm 6.0\%$). Number of head shipped to harvest from the cohort (4 categories: < 150 head to ≥ 250 head) was significantly associated ($P < 0.01$) with SA and S+A. Cohorts with 200 to 249 head shipped had a lower probability of SA ($13.9 \pm 4.9\%$) than other categories (< 150 : $16.8 \pm 5.8\%$; 150 to 199: $17.7 \pm 6.0\%$; ≥ 250 : $18.3 \pm 6.2\%$). Similarly, the probability for S+A was lower for cohorts with 200 to 249 head shipped ($7.2 \pm 2.1\%$) compared to other categories (< 150 : $10.7 \pm 2.9\%$; 150 to 199: $9.8 \pm 2.8\%$; ≥ 250 : $8.6 \pm 2.5\%$).

Total DOF (4 categories: < 200 to ≥ 300 DOF) was significantly associated ($P < 0.01$) with SA and S+A. Cattle on feed for < 200 days had the lowest probability of SA ($16.8 \pm 5.8\%$) and S+A ($10.7 \pm 2.9\%$) compared to those on feed from 200 to 249 days (SA: $27.8 \pm 9.0\%$; S+A: $15.0 \pm 4.5\%$), 250 to 299 days (SA: $24.5 \pm 8.7\%$; S+A: $13.5 \pm 4.2\%$), and ≥ 300 days (SA: $26.6 \pm 9.5\%$; S+A: $18.2 \pm 5.7\%$). Average daily gain (deads out; 5 categories: < 1.13 to ≥ 1.47 kg/d) was significantly associated ($P < 0.01$) with TA where cohorts in extreme ADG categories between 1.13 and 1.24 kg/d and ≥ 1.47 kg/d had lower probabilities ($15.8 \pm 5.4\%$ and $18.3 \pm 6.1\%$, respectively) than cohorts in the middle ADG categories between 1.36 and 1.46 kg/d ($24.0 \pm 7.4\%$) and between 1.25 and 1.35 kg/d ($25.5 \pm 7.6\%$).

Mortality of the cohort (4 categories: < 0.99 to $\geq 5.0\%$) was significantly associated ($P < 0.01$) with all outcomes. For TA, cohorts with a mortality between 3 and 4.99% had the highest probability ($23.5 \pm 7.4\%$) compared to 0 to 0.99% ($19.7 \pm 6.3\%$), 1 to 2.99% ($18.2 \pm 6.2\%$), and $\geq 5.0\%$ ($18.3 \pm 6.2\%$). For SA, cohorts with mortality $\geq 5\%$ had a greater probability of $20.1 \pm 6.9\%$ compared to cohorts with mortality less than 0.99% ($16.8 \pm 5.8\%$) and between 1 and 2.99% ($14.4 \pm 5.1\%$) with cohorts having mortality 3 to 4.99% being intermediate ($19.4 \pm 6.6\%$). For S+A, cohorts with mortality between 3 and 4.99% and $\geq 5\%$ had a greater probability ($13.0 \pm 3.5\%$ and $13.8 \pm 3.8\%$, respectively) than cohorts between 1 to 2.99 and less than 0.99% ($11.1 \pm 3.1\%$ and $10.7 \pm 2.9\%$, respectively). Similarly, for ST, cohorts with mortality of 3 to 4.99 and $\geq 5\%$ had a greater probability ($54.4 \pm 10.5\%$ and $56.6 \pm 10.5\%$, respectively) than those between 1 and 2.99 and less than 0.99% ($48.9 \pm 10.6\%$ and $48.8 \pm 10.4\%$, respectively). Percentage of the cohort railed (5 categories: < 0.5% to $\geq 2.0\%$) was significantly associated ($P < 0.01$) with TA, SA, and S+A outcomes. For TA, cohorts with 1 to 1.49% railed had a higher probability ($27.9 \pm 8.2\%$) than cohorts with $\geq 2.0\%$ ($24.4 \pm 7.5\%$) and

< 0.5% railed ($19.7 \pm 6.3\%$), with cohorts between 0.5 to 0.99 and 1.5 to 1.99% being intermediate ($26.8 \pm 7.9\%$ and $26.8 \pm 8.1\%$, respectively). For SA, cohorts with 0.5 to 0.99% railed had a higher probability ($23.4 \pm 7.6\%$) than cohorts with $\geq 2.0\%$ ($17.8 \pm 6.2\%$) and < 0.5% railed ($16.8 \pm 5.8\%$), with cohorts between 1.0 to 1.49 and 1.5 to 1.99% being intermediate ($20.6 \pm 7.0\%$ and $20.4 \pm 7.0\%$, respectively). For S+A, cohorts with 1.0 to 1.49% and 0.5 to 0.99% railed had greater probabilities ($14.6 \pm 4.0\%$ and $13.0 \pm 3.6\%$, respectively) compared to cohorts with < 0.5% ($10.7 \pm 2.9\%$) and $\geq 2.0\%$ railed ($10.0 \pm 2.9\%$), with cohorts between 1.5 and 1.99% being intermediate ($10.7 \pm 2.9\%$).

Quarter of arrival to the feedyard was significantly ($P < 0.01$) associated with TA, SA, and S+A. Cohorts arriving in Q4 (Oct, Nov, Dec) and Q2 (Apr, May, June) had greater probabilities of TA ($27.9 \pm 7.6\%$ and $26.0 \pm 7.4\%$, respectively) than Q1 (Jan, Feb, Mar) and Q3 (July, Aug, Sept) ($19.7 \pm 6.3\%$ and $20.5 \pm 6.2\%$, respectively). For SA, cohorts arriving in Q4 had a greater probability for LA ($22.0 \pm 6.9\%$) than Q2 ($15.6 \pm 5.5\%$), Q1 ($16.8 \pm 5.8\%$), and Q3 ($17.0 \pm 5.8\%$). For S+A, cohorts arriving in Q4 had a greater probability of LA ($13.4 \pm 3.5\%$) than Q2 ($8.7 \pm 2.5\%$), Q1 ($10.7 \pm 2.9\%$), and Q3 ($11.0 \pm 3.0\%$). Average arrival weight of the cohort was only significantly associated ($P = 0.04$) with ST where cohorts weighing ≥ 363 kg had a greater probability of LA ($56.6 \pm 8.8\%$) compared to cohorts weighing 272 to 317 kg ($45.7 \pm 9.5\%$) and 317 to 362 kg ($49.4 \pm 9.3\%$). Quarter shipped was significantly associated ($P = 0.01$) with TA only where cohorts shipped in Q3 had a greater probability ($23.0 \pm 6.6\%$) compared to Q2 ($19.5 \pm 5.9\%$) and Q4 ($16.0 \pm 5.1\%$) with Q1 being intermediate ($19.7 \pm 6.3\%$). Average shipping weight of the cohort (5 categories: < 590 to ≥ 726 kg) was significantly associated ($P < 0.01$) with SA and S+A. For SA and S+A, cohorts with an average shipping weight of 726 kg or greater had a lower probability of LA (SA: $10.1 \pm 3.8\%$; S+A: 6.1

$\pm 1.2\%$) compared to cohorts < 590 kg (SA: $16.8 \pm 5.8\%$; S+A: $10.7 \pm 2.9\%$), 590 to 634 kg (SA: $14.6 \pm 5.1\%$; S+A: $9.9 \pm 1.9\%$), 635 to 680 kg (SA: $16.6 \pm 5.7\%$; S+A: $10.1 \pm 2.8\%$), and 680 to 725 kg (SA: $15.7 \pm 5.5\%$; S+A: $11.0 \pm 3.0\%$).

Feed Intake Curve Variables

AUC for DOF and DTS periods

For TA, the AUC from 0 to 29 and 60 to 89 DOF was significant ($P \leq 0.01$; Table 3). From 0 to 29 DOF, the probability of TA was greater ($19.7 \pm 6.3\%$) when the AUC was lower (< 55) and decreased as AUC increased (≥ 85 ; $8.8 \pm 3.9\%$). In contrast, from 60 to 89 DOF, the probability of TA was greater when the AUC was higher (95 to 104; $23.9 \pm 7.9\%$) compared to when the AUC was lower (75 to 84; $15.8 \pm 5.5\%$). The AUC from 90 to 119 days was significantly associated ($P \leq 0.02$) with TA and SA and the AUC for days 120 to 149 was significantly associated ($P \leq 0.02$) TA, SA, and S+A where probability of LA increased as AUC decreased. For DTS, AUC for days 0 to 29 from harvest were significantly associated ($P \leq 0.02$) with TA and S+A. From 0 to 29 DTS, the probability of TA increased as AUC increased, but for S+A, the inverse was true where probability of S+A decreased as AUC increased. The AUC for 30 to 59 DTS was significantly associated ($P < 0.01$) with TA where probability of LA decreased as AUC increased. From 60 to 89 days, the probabilities of TA, SA, and S+A increased as AUC increased. The AUC from 90 to 119 DTS was significantly associated ($P \leq 0.01$) with TA, SA, and ST. For TA and SA, the probability of LA increased as AUC increased, but for ST, no clear pattern was observed. For 120 to 149 DTS, the AUCs were associated ($P \leq 0.02$) with TA, SA, and S+A where probability of TA and SA decreased as AUC increased. For S+A, the probability of LA was greatest when AUC was ≥ 130 compared to all other categories. Estimated marginal means and SEMs for AUCs for DOF and DTS periods are reported in Table 3. There did not

seem to be a consistent pattern of the relationship between AUC and probability of LA outcomes across DOF or DTS periods.

Clustering

There were 5 clusters identified across all cohorts. Cluster was significantly associated ($P < 0.01$) with TA and ST (Figure 1). For TA, cluster 1 ($19.7 \pm 6.3\%$) was not different from clusters 2 ($23.5 \pm 8.3\%$) and 3 ($29.4 \pm 9.9\%$), but cluster 1 did have lower probability of LA than clusters 4 ($44.1 \pm 12.5\%$) and 5 ($68.6 \pm 12.8\%$). Clusters 2, 3, 4, and 5 were all statistically different from each other. For ST, clusters 5 and 1 had lower probabilities of LA ($47.9 \pm 11.5\%$ and $48.8 \pm 10.4\%$, respectively) than cluster 4 ($59.9 \pm 10.7\%$). Clusters 2 and 3 were intermediate and not different from the other clusters with probabilities for ST of $56.5 \pm 10.4\%$ and $55.6 \pm 10.8\%$, respectively.

Measures of Central Tendency for DOF and DTS periods

The estimated marginal means $\pm$ SEM for measures of central tendency for DOF and DTS periods are reported in Table 5. The average intake from 0 to 29 DOF (4 categories: $< 2.25\%$ to $\geq 2.75\%$) was significantly associated ($P < 0.01$) with TA where cohorts with an intake less than 2.25% of arrival body weight had a lower probability ($19.7 \pm 6.3\%$) than 2.25 to 2.49% ($33.7 \pm 9.5\%$), 2.5 to 2.74% ($35.5 \pm 9.6\%$), and $\geq 2.75\%$ intake ($33.7 \pm 9.5\%$). Average intake between 30 and 59 DOF was not significantly associated ($P > 0.05$) with any outcome of interest. The average intake between 60 and 89 DOF (6 categories: < 2.75 to $\geq 3.75\%$) was significantly associated ($P = 0.02$) with S+A where cohorts with an average intake between 2.75 and 2.99% and between 3.0 and 3.24% had lower probabilities ($9.3 \pm 2.7\%$ and $10.3 \pm 3.1\%$, respectively) than cohorts with an average intake between 3.25 and 3.49% ($13.2 \pm 4.0\%$). Average intake between 90 and 119 DOF (6 categories: < 2.75 to $\geq 3.75\%$) was significantly associated ($P <$

0.01) with TA, SA, and S+A. For TA in this DOF period, an average intake $\geq 3.75\%$ had the greatest probability of LA ($24.8 \pm 10.4\%$) compared to intakes between 3.0 and 3.24% ($15.4 \pm 5.9\%$) and 3.25 and 3.49% ($13.5 \pm 5.4\%$) with the remaining categories being intermediate ($< 2.75\%$: $19.7 \pm 6.3\%$; 2.75 to 2.99%: $20.4 \pm 6.9\%$; and 3.5 to 3.74%: $18.7 \pm 7.6\%$). Similarly, for SA, cohorts with an average intake $\geq 3.75\%$ had the greatest probability ($32.1 \pm 12.6\%$) compared to cohorts with intakes between 3.0 and 3.24% ($14.5 \pm 5.8\%$), 2.75 and 2.99% ($16.7 \pm 6.1\%$), and 3.25 and 3.49% ($17.3 \pm 7.0\%$) with the other categories remaining intermediate ($< 2.75\%$: $16.8 \pm 5.8\%$; 3.5 to 3.74%: $24.6 \pm 9.5\%$). Cohorts with an average intake $\geq 3.75\%$ had the greatest probability of S+A ($29.9 \pm 8.7\%$) compared to cohorts between 3.5 and 3.74% ($22.3 \pm 6.8\%$), 3.25 and 3.49% ($15.9 \pm 4.9\%$), 2.75 and 2.99 ($14.7 \pm 4.0\%$), and those $< 2.75\%$ ($10.7 \pm 2.9\%$). The remaining category of 3.0 to 3.24% was intermediate ($14.7 \pm 4.5\%$). The average intake between 120 and 149 DOF (7 categories: < 2.75 to $\geq 4.0\%$) was significantly associated ($P < 0.01$) with TA where cohorts with an average intake between 3.75 and 4.0% had the greatest probability of LA ($43.3 \pm 15.8\%$) compared to those between 2.75 and 2.99% ($25.8 \pm 10.2\%$), $\geq 4.0\%$ ($20.6 \pm 11.5\%$), and < 2.75 ($19.7 \pm 6.3\%$) with cohorts having average intake between 3.0 and 3.74% being intermediate ($36.5 \pm 13.0\%$, $35.2 \pm 13.3\%$, and $36.6 \pm 13.7\%$ for 3.0 to 3.24, 3.25 to 3.49, and 3.5 to 3.74%, respectively).

For 0 to 29 DTS, TA, SA, and ST were significantly associated ($P < 0.01$) with average intake (6 categories: < 2.5 to $\geq 4.5\%$; Table 5) as a percentage of arrival body weight. For TA, cohorts with an average intake $\geq 4.5\%$ had the lower probability of LA ($2.8 \pm 2.6\%$) followed by those $< 2.5\%$ ($19.7 \pm 6.3\%$) compared with cohorts between 4.0 and 4.49% who had the greatest probability of TA ($37.3 \pm 12.4\%$) with cohorts having an average intake between 2.5 and 3.99% being intermediate ($28.0 \pm 8.7\%$, $31.3 \pm 9.7\%$, and $34.9 \pm 11.3\%$ for 2.5 to 2.99%, 3.0 to 3.49%,

and 3.5 to 3.99%, respectively). Similarly for SA, cohorts with an average intake $\geq 4.5\%$ between 0 to 29 DTS had the lowest probability of SA ($14.8 \pm 7.8\%$) compared to those between 4.0 and 4.49% ($23.8 \pm 9.7\%$) and those between 3.0 and 3.49% ($28.2 \pm 9.5\%$) with those $< 2.5\%$, between 2.5 and 2.99%, and between 3.5 and 3.99 being intermediate ($16.8 \pm 5.8\%$, $22.4 \pm 8.0\%$, and $21.8 \pm 8.5\%$, respectively). For ST, those with an average intake $< 2.5\%$ had the lowest probability ($48.8 \pm 10.4\%$) compared to those between 2.5 and 2.99 ($56.4 \pm 10.8\%$), 3.0 and 3.49% ($61.0 \pm 10.7\%$), 3.5 and 3.99% ($62.5 \pm 10.9\%$), and 4.0 and 4.49% ($71.4 \pm 9.8\%$) with cohorts having an average intake $\geq 4.5\%$ being intermediate ($59.9 \pm 12.4\%$). The only outcome associated ($P < 0.01$) with average intake from 30 to 59 DTS was TA (4 categories: < 3.0 to $\geq 4.0\%$) where cohorts consuming $< 3.0\%$ on average had a lower probability of LA ($19.7 \pm 6.3\%$) compared to those between 3.0 and 3.49% ($28.8 \pm 8.5\%$), 3.5 and 3.99% ($30.0 \pm 9.3\%$), and $\geq 4.0\%$ ($34.3 \pm 11.9\%$). No outcome of interest was associated with average intake between 60 and 89 DTS nor 120 to 149 DTS. Average intake between 90 and 119 DTS (4 categories: < 3.0 to $\geq 4.0\%$) was significantly associated ($P < 0.01$) with TA and SA. For TA, cohorts with an average intake $< 3.0\%$ had a greater probability of TA ($19.7 \pm 6.3\%$) compared to those between 3.0 and 3.49% ($11.9 \pm 4.5\%$) and 3.5 and 3.99% ($12.5 \pm 5.0\%$) with cohorts having an average intake $\geq 4.0\%$ being intermediate ($11.9 \pm 5.3\%$). For SA, cohorts with an average intake $\geq 4.0\%$ between 90 and 119 DTS had the lowest probability ($6.1 \pm 3.0\%$) compared to those between 3.5 and 3.99% ($11.2 \pm 4.8\%$), 3.0 and 3.49% ($13.9 \pm 5.1\%$), and cohorts $< 3.0\%$ ($16.8 \pm 5.8\%$).

Measures of Variability for DOF and DTS periods

The standard deviation (SD) of daily feed intake for each DOF and DTS period was analyzed for association with the outcomes of interest (Table 6). The SD for 0 to 29 DOF (5 categories: < 0.3 to ≥ 0.6) was significantly associated ($P < 0.01$) with TA, SA, and S+A. For

TA, cohorts with a greater SD (≥ 0.6) during 0 to 29 DOF had a lower probability ($15.3 \pm 5.4\%$) compared to cohorts with lower SD (0.3 to 0.39: $23.2 \pm 7.1\%$, 0.4 to 0.49: $21.6 \pm 6.9\%$, and 0.5 to 0.59: $21.5 \pm 6.9\%$) with cohorts having a SD < 0.3 being intermediate ($19.7 \pm 6.3\%$). Similarly for SA, a SD ≥ 0.6 had a lower probability of SA ($14.6 \pm 5.8\%$) compared to a SD between 0.5 and 0.59 ($20.4 \pm 7.3\%$), 0.4 and 0.49 ($21.0 \pm 7.3\%$), and 0.3 and 0.39 ($22.7 \pm 7.5\%$) with a SD < 0.3 being intermediate ($16.8 \pm 5.8\%$). For S+A, cohorts with a SD ≥ 0.6 had the lowest probability ($6.4 \pm 2.0\%$) than those with a SD between 0.5 to 0.59 ($10.2 \pm 2.9\%$), 0.4 and 0.49 ($9.6 \pm 2.7\%$), 0.3 and 0.39 ($12.1 \pm 3.3\%$), and < 0.3 ($10.7 \pm 2.9\%$). The SD from 90 to 119 DOF (3 categories: < 0.05 to ≥ 0.15) was significantly associated ($P < 0.01$) with SA where cohorts with a SD ≥ 0.15 had a greater probability ($18.6 \pm 6.1\%$) compared to those between 0.05 and 0.14 ($14.6 \pm 5.0\%$). The SD category < 0.05 was intermediate ($16.8 \pm 5.8\%$) and not different from the other categories. The SD from 30 to 59, 60 to 89, and 120 to 149 DOF were not associated ($P > 0.05$) with any outcomes of interest. The SD for 0 to 29, 90 to 119, and 120 to 149 DTS were not associated ($P > 0.05$) with any outcomes. The SD for 30 to 59 DTS (5 categories: < 0.05 to ≥ 0.2) was associated ($P = 0.04$) with TA where a cohort with a SD between 0.1 and 0.14 had a lower probability ($16.1 \pm 5.3\%$) than cohorts with SD between 0.05 and 0.09 ($18.4 \pm 5.9\%$), < 0.05 ($19.7 \pm 6.3\%$), and between 0.15 and 0.19 ($20.3 \pm 6.5\%$) with cohorts with a SD ≥ 0.2 being intermediate ($18.3 \pm 5.9\%$). For 60 to 89 DTS (5 categories: < 0.05 to ≥ 0.2), SD of intake was associated ($P = 0.05$) with ST where a cohort with a SD between 0.1 and 0.14 had a lower probability ($48.4 \pm 10.3\%$) than cohorts with a SD between 0.05 and 0.09 ($51.8 \pm 10.3\%$) and ≥ 0.2 ($55.2 \pm 10.3\%$). The cohorts with a SD < 0.05 and between 0.15 and 0.19 were intermediate ($48.8 \pm 10.4\%$ and 49.3 ± 10.4 , respectively).

Measures of Range for DOF and DTS periods

The DOF when the cohort was at its maximum intake (6 categories: < 100 to ≥ 300 DOF) was significantly associated ($P \leq 0.01$) with all outcomes of interest in at least one DOF category. For TA, cohorts with a maximum intake between 200 and 249 DOF had a greater probability of LA ($24.6 \pm 7.6\%$) compared to maximum intake at < 100 DOF ($19.7 \pm 6.3\%$), between 100 and 149 DOF ($18.9 \pm 6.4\%$), and between 150 to 199 DOF ($17.4 \pm 5.9\%$). Cohorts at maximum intake between 250 and 299 DOF or ≥ 300 DOF were intermediate ($22.6 \pm 7.3\%$ and $19.5 \pm 6.9\%$, respectively). For SA, cohorts with a maximum intake between 250 and 299 DOF had the greatest probability of SA ($22.3 \pm 7.4\%$), followed by 100 to 149 DOF ($17.2 \pm 6.1\%$), ≥ 300 DOF ($17.1 \pm 6.2\%$), < 100 DOF ($16.8 \pm 5.8\%$), and 150 and 199 DOF ($15.8 \pm 5.6\%$) with cohorts reaching their maximum between 200 and 249 DOF being intermediate ($20.4 \pm 6.9\%$). For S+A, the cohorts with maximum intake occurring during 250 and 299 DOF had the greatest probability of S+A ($12.4 \pm 3.6\%$), and cohorts with maximum intake occurring ≥ 300 DOF had the lowest probability of S+A ($8.3 \pm 2.7\%$). For ST, cohorts with maximum intake occurring between 250 and 299 DOF and 200 and 249 DOF had greater probabilities ($56.0 \pm 10.3\%$ and $55.7 \pm 10.4\%$, respectively) compared to maximum intake occurring between 150 and 199 DOF ($50.6 \pm 10.3\%$), 100 and 149 DOF ($49.5 \pm 10.4\%$), < 100 DOF ($48.8 \pm 10.4\%$), and ≥ 300 DOF ($48.4 \pm 10.6\%$).

The initial intake as percent of body weight (3 categories: < 1.5 to $\geq 2.0\%$) was significantly associated ($P \leq 0.04$) with TA and SA. For TA, cohorts with an initial intake of $< 1.5\%$ had a greater probability of LA than those with an initial intake between 1.5 and 1.99% ($19.7 \pm 6.3\%$ vs. $17.4 \pm 5.8\%$, respectively) with cohorts with an initial intake $\geq 2.0\%$ being intermediate ($19.8 \pm 6.7\%$). For SA, cohorts with an initial intake between 1.5 and 1.99% had a

lower probability ($13.2 \pm 4.8\%$) than cohorts with an initial intake $< 1.5\%$ ($16.8 \pm 5.8\%$) or $\geq 2.0\%$ ($17.9 \pm 6.4\%$). Intake at 30 DOF (7 categories: < 2.25 to $\geq 3.5\%$) was significantly associated ($P < 0.01$) with TA where those with an intake $< 2.25\%$ had a greater probability of LA ($19.7 \pm 6.3\%$) compared to intermediate categories [2.25 to 2.49% ($14.4 \pm 5.0\%$), 2.5 to 2.74% ($13.4 \pm 4.7\%$), 2.75 to 2.99% ($11.2 \pm 4.1\%$), 3.0 to 3.24% ($13.3 \pm 4.8\%$), and 3.25 to 3.49% ($11.6 \pm 4.4\%$)]. Cohorts with an intake at 30 DOF $\geq 3.5\%$ did not differ from any other category. The maximum intake was significantly associated ($P < 0.01$) with TA where all categories differed from each other, reported from lowest to greatest probability: $< 3.0\%$: $19.7 \pm 6.3\%$ probability; 3.0 to 3.99% : $34.1 \pm 9.5\%$; 4.0 to 4.99% : $46.2 \pm 10.9\%$; and $\geq 5.0\%$: $67.9 \pm 11.0\%$.

The estimated marginal mean probabilities and SEM for significant minimum and maximum measurements per DOF and DTS period are reported in Tables 7 and 8, respectively. The minimum intake for 0 to 29 DOF was significantly associated ($P = 0.05$) with SA where the probability of SA was lowest when the minimum intake was $< 1.4\%$ and was greater for cohorts with a minimum intake between 1.4 to 1.59 , 1.6 to 1.79 , and $\geq 1.8\%$. The minimum intake for 30 to 59 DOF and 60 to 89 DOF were not associated ($P > 0.05$) with any outcomes of interest. Minimum intake for 90 to 119 DOF was significantly associated ($P < 0.01$) with SA where probability of SA was lowest for cohorts with a minimum intake $< 2.5\%$ and was greater for cohorts with a minimum intake between 2.5 to 2.99 , 3.0 to 3.49 , and $\geq 3.5\%$. Similarly, for 120 to 149 DOF, minimum intake was associated ($P < 0.01$) with TA, SA, and S+A where the probability of LA increased as minimum intake increased.

For DTS, minimum intake for 0 to 29 DTS was associated ($P < 0.01$) with TA, SA, and S+A. For TA, cohorts with a minimum intake between 2.5 to 2.99% had the lowest probability

of LA compared to 3.0 to 3.49 and 3.5 to 3.99%, with < 2.0, 2.0 to 2.49, and $\geq 4.0\%$ being intermediate. For SA, cohorts with a minimum intake < 2.0%, between 2.0 to 2.49, or 2.5 to 2.99% had lower probabilities of SA compared to cohorts with minimum intakes between 3.0 to 3.49, 3.5 to 3.99, and $\geq 4.0\%$. For S+A, cohorts with a minimum intake < 2.0 or between 2.5 to 2.99% had lower probabilities of S+A than cohorts with a minimum intake between 2.0 to 2.49 and 3.0 to 3.49%, and cohorts between 3.5 to 3.99% had the greatest probability of S+A, with cohorts $\geq 4.0\%$ being intermediate. Minimum intake for 30 to 59 DTS and 60 to 89 DTS were associated ($P \leq 0.03$) with TA and SA. For TA during 30 to 59 DTS, cohorts with a minimum intake between 3.0 to 3.49 and 3.5 to 3.99% had lower probabilities of LA compared to 2.5 to 2.99, 4.0 to 4.49, and $\geq 4.5\%$, with cohorts with a minimum intake < 2.5% being intermediate. For SA, cohorts with a minimum intake $\geq 4.5\%$ had a greater probability of SA than all other categories: < 2.5, 2.5 to 2.99, 3.0 to 3.49, 3.5 to 3.99, and 4.0 to 4.49. For TA during 60 to 89 DTS, the probability of LA was greatest for cohorts between 2.5 and 2.99% compared to cohorts with a minimum intake $\geq 4.5\%$, with < 2.5, 3.0 to 3.49, 3.5 to 3.99, and 4.0 to 4.49% being intermediate. For SA between 60 to 89 DTS, probability of SA was lowest for 4.0 to 4.49%, followed by 3.5 to 3.99%, 3.0 to 3.49, 2.5 to 2.99, and < 2.5% where all differed. Cohorts with a minimum intake $\geq 4.5\%$ were intermediate. Minimum intake for 90 to 119 DTS was associated ($P < 0.01$) with SA, where cohorts with a minimum intake between 3.0 to 3.49% had the lowest probability compared to 4.0 to 4.49 and $\geq 4.5\%$, with < 2.5, 2.5 to 2.99, and 3.5 to 3.99% being intermediate. Minimum intake for 120 to 149 DTS was associated ($P = 0.02$) with ST where cohorts with a minimum intake between 3.0 to 3.49 had the lowest probability of ST, followed by 3.5 to 3.99, then $\geq 4.0\%$ with the greatest probability. Cohorts with a minimum intake < 2.5 and between 2.5 to 2.99% were intermediate. A similar pattern seemed to occur for DTS periods

where probability of LA seemed to increase as the minimum intake did, but this pattern was not consistent across all DTS periods.

The maximum intake for 0 to 29 DOF was associated ($P = 0.01$) with SA where cohorts with a maximum intake between 2.5 to 2.99% had the lowest probability compared to cohorts < 2.5 , 3.0 to 3.49, and $\geq 3.5\%$. For 30 to 59 DOF, maximum intake was associated ($P \leq 0.04$) with SA where cohorts with a maximum intake between 3.5 and 3.99% had the lowest probability of SA compared to < 2.5 , 2.5 to 2.99, 3.0 to 3.49, and $\geq 4.0\%$. Maximum intake for 60 to 89 DOF was associated ($P < 0.01$) with TA and S+A where cohorts with a maximum intake between 3.5 to 3.99% had the lowest probability for both outcomes compared to cohorts in the other categories: < 3.0 , 3.0 to 3.49, and $\geq 4.0\%$. Maximum intake for 90 to 119 DOF was associated ($P = 0.02$) with TA only where cohorts with a maximum intake between 3.0 to 3.49 and $\geq 4.5\%$ had lower probabilities of LA compared to cohorts between 3.5 to 3.99%. Cohorts with maximum intakes < 3.0 and between 4.0 to 4.49% were intermediate. For 120 to 149 DOF, maximum intake was associated ($P \leq 0.01$) with TA and SA. For TA, cohorts with a maximum intake between 4.0 to 4.49% had a lower probability of LA compared to cohorts between 3.0 to 3.49 and 3.5 to 3.99, with cohorts < 3.0 and $\geq 4.5\%$ being intermediate. For SA, cohorts with a maximum intake between 4.0 to 4.49 and $\geq 4.5\%$ had lower probabilities than cohorts with a maximum intake < 3.0 , between 3.0 to 3.49, and 3.5 to 3.99%. There seemed to be an inverse relationship where probability for LA outcomes decreased as the maximum intake increased; however, this was not a consistent pattern.

For DTS, maximum intake from 0 to 29 DTS was associated ($P < 0.01$) with TA, SA, and ST. For TA, cohorts with a maximum intake between 4.0 to 4.49 and 4.5 to 4.99% had lower probabilities of LA compared to 3.0 to 3.49, 3.5 to 3.99, and < 3.0 , with $\geq 5.0\%$ being

intermediate. For SA, cohorts with a maximum intake between 3.5 to 3.99, 4.0 to 4.49, and 4.5 to 4.99 had the lowest probabilities compared to 3.0 to 3.49, followed by < 3.0 which had the highest probability of SA, and cohorts with a maximum intake $\geq 5.0\%$ were intermediate. For ST, the probability of ST was lowest for cohorts with a maximum intake between 4.5 to 4.99, followed by 3.5 to 3.99, 3.0 to 3.49, and < 3.0 , with cohorts between 4.0 to 4.49 and $\geq 5.0\%$ being intermediate. Maximum intake for 30 to 59 DTS was associated ($P = 0.01$) with SA where cohorts with a maximum intake between 3.0 to 3.49 had the lowest probability of SA compared to 3.5 to 3.99, 4.0 to 4.49, and 4.5 to 4.99%, with those < 3.0 and $\geq 5.0\%$ being intermediate. Maximum intake from 60 to 89 DTS was associated ($P = 0.03$) with TA where cohorts with a maximum intake between 3.0 to 3.49% had a lower probability than those $< 3.0\%$, and all other categories were intermediate (3.5 to 3.99, 4.0 to 4.49, $\geq 4.5\%$). Maximum intake from 90 to 119 DTS was associated ($P \leq 0.01$) with TA and S+A. For TA, cohorts with a maximum intake between 4.0 to 4.49% had the lowest probability of LA, followed by $< 3.0\%$, and $\geq 4.5\%$ with the greatest probability, and cohorts between 3.0 to 3.49 and 3.5 to 3.99% were intermediate. For S+A, cohorts with a maximum intake $\geq 4.5\%$ had the lowest probability of S+A, followed by 4.0 to 4.49, 3.5 to 3.99, and 3.0 to 3.49% with $< 3.0\%$ being intermediate. For 120 to 149 DTS, maximum intake was associated ($P < 0.01$) with TA and SA. For TA, cohorts with maximum intake < 3.0 and between 3.5 to 3.99% had lower probabilities than 3.0 to 3.49, 4.0 to 4.49, and $\geq 4.5\%$. For SA, cohorts with a maximum intake between 3.5 to 3.99 and $\geq 4.5\%$ had lower probabilities of SA compared to those between 4.0 to 4.49%, with those < 3.0 and 3.0 to 3.49% being intermediate. No clear pattern was observed for DTS periods and maximum intake. There was no consistent directionality of differences between categories.

Other Measures of Feed Intake Patterns

The percentage of the maximum intake was measured halfway and three-fourths of the way through the feeding period. The percent of maximum intake halfway through the feeding period (5 categories: < 80 to $\geq 95\%$) was associated ($P < 0.01$) with TA where cohorts that were $< 80\%$ of their maximum intake halfway through their feeding period had the lowest probability of LA ($19.7 \pm 6.3\%$) followed by 80 to 84% ($24.4 \pm 6.9\%$), and 85 to 89% ($29.8 \pm 7.9\%$).

Cohorts consuming 90 to 95% of their maximum intake halfway through the feeding period had the greatest probability of LA ($34.0 \pm 8.5\%$) and cohorts consuming $\geq 95\%$ of their maximum intake halfway through the feeding period were intermediate ($33.2 \pm 8.2\%$). The percent of maximum intake three-fourths of the way through the feeding period (5 categories: < 80 to $\geq 95\%$) was associated ($P \leq 0.04$) with TA and SA. For TA, cohorts eating $\geq 95\%$ of their maximum intake had the lowest probability of LA ($16.7 \pm 5.5\%$) compared to those eating between 85 and 89% ($20.0 \pm 6.2\%$) and between 80 and 84% ($22.8 \pm 6.8\%$). Cohorts eating between 90 and 94% and $< 80\%$ were intermediate for probability of TA ($18.4 \pm 5.8\%$ and $19.7 \pm 6.3\%$, respectively). For SA, cohorts eating $\geq 95\%$ of their maximum intake three-fourths of the way through the feeding period and between 90 and 94% had lower probabilities ($14.4 \pm 4.8\%$ and $14.7 \pm 4.8\%$, respectively) than those eating between 85 and 89% ($17.4 \pm 5.6\%$) and 80 to 84% ($18.4 \pm 5.9\%$). Cohorts eating $< 80\%$ of their maximum intake three-fourths of the way through the feeding period were intermediate for probability of SA ($16.8 \pm 5.8\%$).

The slope of the feed intake curve from the 50th DOF to the end of the feeding period (5 categories: < -0.002 and ≥ 0.004) was significantly associated ($P < 0.01$) with TA. Cohorts with a slope between 0.002 and 0.004 had a lower probability of LA ($18.0 \pm 5.9\%$) than cohorts with a

slope ≥ 0.004 ($22.0 \pm 7.0\%$), between 0 and 0.002 ($23.1 \pm 7.0\%$), and < -0.002 ($24.8 \pm 7.5\%$).

Cohorts with a slope of -0.002 to 0 were intermediate for probability of TA ($19.7 \pm 6.3\%$).

The number of decreases of any size in feed intake from the previous day (5 categories; < 75 to ≥ 150) within the feeding curve was significantly associated ($P < 0.01$) with TA, SA, and S+A. For TA, cohorts with < 75 decreases from the previous day's intake had a higher probability of LA ($19.7 \pm 6.3\%$) than those with 75 to 99 decreases or ≥ 150 decreases ($13.6 \pm 4.9\%$ and $12.3 \pm 5.3\%$, respectively). Cohorts with 100 to 124 or 125 to 149 decreases were intermediate ($16.1 \pm 6.0\%$ and $15.0 \pm 5.8\%$, respectively). For SA, cohorts with < 75 decreases from the previous day's intake or between 100 and 124 decreases had greater probabilities of LA ($16.8 \pm 5.8\%$ and $12.8 \pm 5.6\%$, respectively), compared to cohorts with 75 to 99 decreases ($10.3 \pm 4.4\%$). Cohorts with 125 to 149 or ≥ 150 decreases were intermediate ($12.1 \pm 5.5\%$ and $14.6 \pm 6.9\%$, respectively). For S+A, cohorts with 75 to 99 decreases had the lowest probability ($8.6 \pm 2.9\%$), and cohorts with 100 to 124 decreases had the greatest probability ($11.8 \pm 4.1\%$). The other categories were intermediate ($9.2 \pm 3.9\%$, $10.3 \pm 3.9\%$, and $10.7 \pm 2.9\%$ for ≥ 150 , between 125 and 149, or < 75 decreases categories, respectively) and did not differ from these.

The number of decreases that were 5 to 10% less the previous day (5 categories: < 2 to ≥ 8 decreases) was significantly associated ($P < 0.01$) with TA and SA. For TA, cohorts with 2 to 3 decreases that were 5 to 10% less than the previous day's intake had a lower probability of LA ($16.6 \pm 5.5\%$) compared to cohorts with < 2 decreases ($19.7 \pm 6.3\%$), ≥ 8 decreases ($21.7 \pm 6.5\%$), and cohorts with 6 to 7 decreases ($24.9 \pm 7.5\%$) with cohorts having between 4 and 5 decreases being intermediate ($18.5 \pm 5.9\%$). Similar to TA, cohorts with 2 to 3 or 4 to 5 decreases had lower probabilities of SA ($15.4 \pm 5.4\%$ and $14.1 \pm 4.9\%$, respectively) compared

to those with ≥ 8 decreases ($19.3 \pm 6.3\%$) and those with 6 to 7 decreases ($19.6 \pm 6.5\%$). Cohorts with < 2 decreases were intermediate ($16.8 \pm 5.8\%$).

The number of decreases that lasted at least 2 days in a row (6 categories: < 15 to ≥ 35 decreases) was significantly associated ($P \leq 0.03$) with SA and S+A. For SA, cohorts with 15 to 19 decreases that were at least 2 days had the greatest probability of SA ($20.3 \pm 6.4\%$) compared to 20 to 24 decreases ($16.2 \pm 5.6\%$), 25 to 29 decreases ($15.8 \pm 5.5\%$), and ≥ 35 decreases ($15.1 \pm 5.6\%$) with cohorts having 30 to 34 or < 15 decreases being intermediate ($16.3 \pm 5.8\%$ and $16.8 \pm 5.8\%$, respectively). For S+A, cohorts with 20 to 24 decreases that were at least 2 days in a row had the lowest probability of S+A ($9.3 \pm 2.6\%$) compared to 15 to 19 decreases ($12.4 \pm 3.3\%$) with every other category being intermediate ($9.6 \pm 3.0\%$, $10.3 \pm 3.0\%$, $10.3 \pm 3.0\%$, and $10.7 \pm 2.9\%$ for ≥ 35 , 30 to 34, 25 to 29, and < 15 decreases that were at least 2 days in a row).

Discussion

It is widely accepted that feed management is a major contributor to the pathogenesis of LA. Whether that is due to diet formulation, processing of the ingredients, feed intake of the animals over time, or a combination is not fully understood. Most likely it is a combination of all the above as well as other factors. The results of this research identified significant associations between feedyard operational data variables, feed intake curve-derived variables, and the clustering of feed intake curves with LA prevalence at harvest in BxD cattle.

Similar to previous findings, steer cohorts were reported to have higher probabilities for all LA outcomes (Amachawadi and Nagaraja, 2016; Grimes et al., 2024; Champagne et al., 2025a). Additionally, the total DOF was significantly associated with SA and S+A where cattle on feed for fewer than 200 days had lower probabilities of severe LA compared to cohorts on feed for a longer duration. This information is supported by previous literature (Reinhardt and

Hubbert, 2015b; Champagne et al., 2025a); however, these studies focused on all LA scores. Mortality was significantly associated with multiple outcomes. Cohorts with mortality of 3 to 4.99% or $\geq 5.0\%$ had greater probabilities of SA, S+A, and ST outcomes compared to cohorts with $< 0.99\%$ or between 1 to 2.99% mortality. A cohort with increased mortality likely indicates incidence of another disease within the pen that would negatively affect the animals' ability to mount a sufficient immune response against liver abscess pathogens. If an animal's immune system is already fighting a different disease process, it is likely unable to suppress a secondary infection elsewhere in the body such as LA. The probability of TA did not follow this pattern as cohorts with $\geq 5.0\%$ mortality had a lower probability than those between 3 and 4.99%. The outcomes consisting of severe LA scores (SA, S+A, and ST) followed a different pattern than when all scores were analyzed, such as the TA outcome, leading us to believe that increased mortality within a cohort may contribute to more severe LA scores.

Quarter of arrival was associated with multiple outcomes (TA, SA, and S+A), and quarter of harvest was associated with TA. Harman *et al.* reported that cattle started on feed in November and January had greater incidence of liver abnormalities than cattle started during the other months of the year (Harman et al., 1989), which is similar to the current results where cattle arriving to the feedyard during Q4 (Oct, Nov, Dec) had greater probability of LA compared to other quarters. However, it is important to note differences in population as the cattle studied in Harman *et al.*'s work were crossbred steers of predominantly British breeding and the cattle in the present study were BxD steers and heifers. To the authors' knowledge, no other reports have been made on the relationship between time of arrival at the feedyard and LA. For quarter of harvest, cattle shipped from the feedyard in Q3 (July, Aug, Sep) had a greater probability of TA than those shipped in Q2 and Q4. Previous literature provides mixed results

about the relationship between time of harvest and LA. Brown and Lawrence (2010) did not report a relationship between harvest time and LA; however, other studies have observed higher LA prevalence in Q2 and Q3 (Harman et al., 1989; Brown and Lawrence, 2010; Grimes et al., 2024); however, these studies did not specify whether cattle were native beef breeds only or a combination of native and BxD.

Other variables were calculated from the daily feed intake over time for the cohorts, specifically across two time periods: DOF and DTS. The total DOF for the study population ranged from 154 to 402 DOF, thus we chose to calculate feed variables for the first 150 DOF and last 150 days until harvest since that was close to the minimum total DOF of the cohorts. Due to the wide range in total DOF, for some cohorts, the DOF and DTS periods overlapped more than other cohorts.

The AUC was measured for various time periods based on DOF and DTS. There did seem to be a pattern where lower AUCs had greater probabilities of LA outcomes and the probability decreased as AUC increased; however, this pattern was not consistent across the periods or outcomes. This was unexpected as the assumption would be the higher the AUC, the more feed the cattle are consuming. Increased feed consumption would increase volatile fatty acid (VFA) production, leading to acidosis, a proposed precursor to LA development (Amachawadi and Nagaraja, 2022). We hypothesize cohorts with a higher probability of LA at lower AUCs may have backed off feed during that period due to other circumstances such as illness, weather events, processing, etc. Additionally, differences in LA probabilities seen among the DOF periods could be due to differing arrival body weights, transitioning animals from the receiving diet to a finishing diet, and differences in total DOF periods. The first 30 DOF of a cohort arriving at 272 kg compared to 408 kg could be vastly different, as the total DOF would

be too. The DTS periods were included to address this issue, as it is assumed that all animals in the final 30 days of their feeding period, regardless of how long the total period was, would be similar in physiologic stage close to harvest.

Feed intake curves were clustered by grouping cohorts with similar feed intake patterns over time. Cluster was associated with TA and ST. For TA, cluster 5 had the highest probability of LA, followed by 4, 2, and 3. Cluster 5 appears to have the greatest slope of all the curves across the whole period with increasing intake whereas clusters 2 and 3 remain flatter and more stable throughout the 150 DOF (Figure 1). We speculate cluster 5 had a greater probability of TA due to increased feed intake as well as more variation in feed intake over time. Consuming more feed will contribute to greater opportunities for acidosis and thus LA. Conversely, for ST, clusters 1 and 5 had lower probabilities of ST than cluster 4. The biological reason behind this shift is unknown, but due to the relationship seen for TA, perhaps cohorts in cluster 5 had less severe LA (A+, A+Open, A+Adhered) but more A- and A scores than those in cluster 4.

The average intakes for various DOF and DTS periods were significantly associated with all LA outcomes in at least one DOF or DTS period. For 0 to 29 DOF, the risk of TA was lowest for the lowest average intake category and increased with the increasing average intake which was expected. However, other DOF periods did not follow a consistent pattern. The probability of a LA outcome was typically lower when average intake was lower, but this did not follow a linear pattern that increased as average intake increased. The probability generally increased as average intake did, but there were higher categories that were intermediate in differences as denoted by subscripts sharing the same letters in Table 5. For example, the probability of SA and S+A during 90 to 119 DOF was lower when average intake was lower (2.75 to 2.99 and 3.0 to 3.24%) compared to greater average intakes (3.5 to 3.74 and $\geq 3.75\%$). However, for TA, the

probability of TA was higher for average intakes between 2.75 to 2.99 than 3.0 to 3.24 and 3.25 to 3.49%. In previous literature, average feed intake has been used as a tool for predicting the hazard of BRD in feedyard cattle (Wolfger et al., 2015). Wolfger *et al.* reported an increase in mean meal intake was associated with decreased hazard for developing BRD up to a week before feedyard personnel observed clinical signs (Wolfger et al., 2015). Due to etiology, the opposite would most likely be true for prediction of LA which is demonstrated by our findings of increased probability of LA as average intake increased in the earlier DOF periods. A source of stress that may cause cattle to have a lower average intake in the 90 to 119 DOF time frame is reimplantation. This is the period where the pattern described above was disrupted.

For DTS periods, the opposite was observed where cohorts with the greatest average intake during 0 to 29 and 90 to 119 DTS had the lowest probability of a TA or SA outcome. For ST, those with the lowest average intake had the lowest probability as seen in the DOF periods. From 30 to 59 DTS, cohorts with the lowest average intake had the lowest probability of TA, and the probability increased as average intake increased. These data show that the relationship between intake and LA changes over the duration that cattle are on feed. At the beginning (DOF periods), a higher intake corresponded to a greater probability of LA whereas at the end of the feeding period (DTS), the opposite appeared to be true.

The SD of daily feed intake was measured and analyzed for each DOF and DTS period and outcome of interest. From 0 to 29 DOF, e.g. the beginning of the feeding period for each cohort, cohorts with a larger SD had smaller probabilities for TA, SA, and S+A than cohorts with smaller SD. This means that cohorts with greater dispersion in intake had lower risk of LA found at harvest than cohorts with less dispersed intake. We are not sure how to explain this relationship, as we expected that lower variation in feed intake would correspond to lower

probabilities of LA. This pattern was not observed for the DTS categories, which highlights the differences in feed intake curves from the beginning to the end of the feeding period. For DTS, there seemed to be a U-shaped pattern where cohorts with a SD in the middle categories for 30 to 59 and 60 to 89 DTS had a lower probability of TA than cohorts with lower or higher SD. A retrospective study evaluated feeding behavior of crossbred beef steers during the last 60 to 90 days on feed and found that intake variability was not associated with liver abscess prevalence (Bradford et al., 2026). Other variables such as lower ADG, more frequent meals, smaller meal sizes, greater day-to-day changes in eating time or meal frequency were associated with increased LA risk (Bradford et al., 2026). These previous findings, in combination with our data, provide evidence that feed intake and feeding behavior may be important in LA risk and development.

Another measure of variation was the number of decreases in intake from the previous day which was associated with TA, SA, and S+A. For TA and SA, cohorts with < 75 decreases had greater probabilities of LA outcomes than those between 75 and 99 decreases. For S+A, those with 100 to 124 decreases had a greater probability than those between 75 and 99. All other categories were intermediate. The authors are unsure about the biological reason for these associations as it was expected that with increasing number of decreases in feed intake from the previous day would result in a higher probability for LA due to inconsistent feed intake. However, the data does not fully support this notion. The number of drops that were 5 to 10% less than the previous day was measured as well, and cohorts with higher counts of decreases of this magnitude had higher probabilities of TA and SA than those with fewer of these decreases. This is to be expected because fewer drops of this magnitude means fewer disruptions in feed intake. The number of consecutive (≥ 2 days) decreases was also analyzed, and fewer

consecutive day decreases had higher probabilities of SA and S+A than a greater number of decreases. We are currently unable to explain the biology underlying these associations.

Bradford *et al.* reported that greater day-to-day changes in feeding times was associated with increased LA; however, they assessed variability in intake as well and it was not significantly associated with cattle having liver abscess (Bradford et al., 2026).

The DOF at which a cohort reached their maximum intake was analyzed. For TA and SA, if the cohort was later into the feeding period when they reached their maximum intake, they had a greater probability of LA outcomes compared to those that reached their maximum intake earlier in the feeding period. This pattern is reasonable as DOF is known to be associated with LA (Reinhardt et al., 2009; Amachawadi and Nagaraja, 2016; Champagne et al., 2025a). The current belief is the longer cattle are fed, the higher the potential for LA to be observed at harvest. This pattern did not continue for S+A and ST, where cohorts reaching their maximum intake between 200 and 299 DOF had a greater probability than those reaching their maximum after 300 DOF. Perhaps cattle reaching their maximum intake earlier in the feeding phase affects the severity of the abscesses, not the presence of abscesses.

The initial intake of the cohort was associated with TA and SA, where cohorts with intermediate initial intake (1.5 to 1.99%) had a lower probability of LA outcomes than cohorts with an initial intake $< 1.5\%$. For SA, cohorts with an initial intake $\geq 2.0\%$ also had a lower probability of SA than the intermediate category. Potential explanations for this relationship could be cohorts that were not exposed to eating out of bunks prior to arrival at the feedyard, leading to decreased initial intake causing increased gut permeability i.e. “leaky gut”. Previous research has shown that “leaky gut” can be induced through restricted feeding programs due to increased gut permeability which is thought to be a potential cause of LA (Zhang et al., 2013b;

Zhang et al., 2013a). Thus, if cattle were not consuming as much feed upon arrival, that could have disrupted the integrity of the gastrointestinal barrier and increased permeability, predisposing calves to LA later in the feeding period.

Measures of range, such as the minimum and maximum, were assessed for each DOF and DTS period for association with LA outcomes. The minimum intake for 0 to 29, 90 to 119, and 120 to 149 DOF seemed to follow a similar pattern where the probability of TA, SA, and/or S+A increased as the minimum intake increased. For DTS, the probabilities followed a similar pattern, increasing as the minimum intake increased 0 to 29, 30 to 59, 90 to 119, and 120 to 149 DTS. However, from 60 to 89 DTS, the opposite seemed to be true with the probability of TA and SA decreasing as minimum intake increased. The increase in probability as minimum intake increases is reasonable as increased feed intake can contribute to LA development as previously discussed.

The maximum intake for each DOF/DTS period did not follow the same pattern as the minimum intake. For the DOF periods, the probability of TA, SA, and S+A decreased as maximum intake increased which was unexpected. In the DTS periods, no clear pattern was discernable within the timeframes. The biological explanation for these relationships is unclear.

The percentage of maximum intake was measured halfway through the feeding period. For TA, there seemed to be a linear relationship between percentage of maximum intake and probability of LA. As cattle consumed more feed, closer to their maximum intake, halfway through their DOF, the probability for LA increased as well. Cattle that were consuming < 80% of their maximum intake had a probability of 19.7%, which increased to 33.2% if they were eating $\geq 95\%$ of their maximum. This may be attributed to how quickly cattle reach their maximum intake. If a cohort is already consuming $\geq 95\%$ of their maximum intake halfway

through their feeding period, they're most likely consuming large amounts of highly fermentable feed, which increases VFA production, lowers rumen pH, and contributes to LA development. The percentage of maximum intake was also measured three-fourths of the way through the feeding period, but the cohorts consuming $\geq 95\%$ of their maximum intake had the lowest probability of LA compared to those eating 80 to 85% of their maximum. Again, perhaps the closer a cohort gets to harvest, the relationship between feed intake changes as observed between other variables measured for both the DOF and DTS periods. The authors are unsure of the biological significance of this shift though.

The slope was measured from 50 DOF to the end of the feeding period. An intermediate slope of 0.002 to 0.004 had the lowest probability of TA compared to ≥ 0.004 , 0 to 0.002, and < -0.002 . We hypothesize that if an illness or stressful event occurs, this could result in a negative overall slope. With this type of data, there is no way to know whether the feed intake caused LA or LA affected the performance of the cohort at the feedyard. Perhaps a proportion of the cohorts with negative overall slopes had LA that were decreasing their intake and the overall performance of the cohort. Additionally, interpreting the slope of the overall feed curve is difficult due to the method of fitting a line for best fit. Using this method does not account for the daily fluctuation in the curve.

Limitations of this research include the observational nature of the data. With this research, we were able to identify associations between variables and the LA outcomes; however, further research is needed to fully understand the complexity of these relationships. Additionally, the origin and background of the cohorts were unknown, so there was no information about whether these cattle had previously been bunk-trained prior to arrival at the feedyard. The differences in arrival weight and thus overall DOF for each cohort is also

something to consider. A cohort arriving at a lower weight would remain on feed for much longer than a cohort that has been backgrounded and arrived at a greater weight. We attempted to assess these variables by testing the arrival weight and total DOF in the models, but arrival weight was only associated with ST and total DOF was only associated with SA and S+A. This is why we opted to also measure variables backwards from the cohort's shipping/harvest date with the DTS periods. The assumption was made that the cohorts would be more similar in physiologic state and have more similar feed intake patterns prior to harvest.

Conclusion

Liver abscesses continue to be a major source of economic loss in the harvest of BxD cattle due to higher prevalence of LA than native beef cattle. It is widely accepted that feed management plays a large role in LA development. Research has been conducted to assess inclusion rates, grain processing, and alternative ingredients that could be used in finishing diets to reduce LA occurrence. While finishing diet formulation certainly plays a role, it can only be modified to a limited extent. Other factors such as demographics, health and performance metrics, and feed intake curves should be considered in LA development. This study identified associations between LA prevalence and cohort-level variables captured from feedyard operational and daily feed data. Demographics, health metrics, measures of average feed intake, variability of intake, and differences within timing of the feeding period (DOF and DTS) were associated with multiple LA outcomes of varying severity. These findings provide a direction for further exploration such as adjusting management practices based on feed intake curves or possible predictive models based on feed intake.

Conflicts of Interest

The authors have no conflicts of interest to report.

Contributions

All authors contributed to the study in at least two of the various categories: conceptualization, funding acquisition, investigation, methodology, data collection, validation, project administration, supervision, writing – original draft, writing – reviewing and editing, and/or resources.

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Table 7.1 Liver scores used to evaluate livers at harvest in the processing plant.

Liver Scores	Description
O	Normal liver with no lesions
A ⁻¹	1 to 2 small abscesses less than an inch in diameter
A ¹	2 to 4 abscesses less than an inch in diameter
A+ ^{1, 2, 4}	1 or more large abscesses more than one inch in diameter
A+Adhered ^{1, 2, 3, 4}	Abscess present with adhesion(s) to diaphragm or other organs
A+Open ^{1, 2, 3, 4}	Abscess present with a ruptured abscess
A+Adhered/A+Open ^{1, 2, 3, 4}	Abscess present with both adhesions and a ruptured abscess
¹ Scores included in Total LA outcome (TA)	
² Scores included in Severe LA outcome in (SA)	
³ Scores included in Severe+ LA outcome in (S+A)	
⁴ Scores included in Severe La as a proportion of Total outcome (ST)	

Table 7.2 The number of categories for each predictor variable that was significantly associated with at least 1 of the 4 outcomes of interest: Total LA, Severe LA, Severe+ LA, and Severe as a proportion of Total LA.

Predictor	Number of Categories
Operational Data	
Sex	2 categories: male vs. female
Average Daily Gain, kgs/d	5 categories: < 1.13 to $\geq$ 1.47 kg/d
Days on Feed	4 categories: < 200 to $\geq$ 300 days
Number of Head Received	4 categories: < 150 to $\geq$ 250 head
Number of Head Shipped	4 categories: < 150 to $\geq$ 250 head
Average Arrival Weight	5 categories: < 227 to $\geq$ 363 kg
Average Shipping Weight	5 categories: < 590 to $\geq$ 726 kg
Mortality, % of cohort	4 categories: < 0.99 to $\geq$ 5.0%
Railers, % of cohort	5 categories: < 0.5 to $\geq$ 2.0%
Quarter of Arrival	4 categories: Q1, Q2, Q3, Q4
Quarter of Shipping	4 categories: Q1, Q2, Q3, Q4
AUC for DOF/DTS Periods	
0 to 29 DOF	5 categories: < 55 to $\geq$ 85
30 to 59 DOF	5 categories: < 70 to $\geq$ 100
60 to 89 DOF	6 categories: < 75 to $\geq$ 115
90 to 119 DOF	6 categories: < 75 to $\geq$ 115
120 to 149 DOF	6 categories: < 80 to $\geq$ 120
0 to 29 DTS	7 categories: < 80 to $\geq$ 130
30 to 59 DTS	7 categories: < 80 to $\geq$ 130
60 to 89 DTS	7 categories: < 80 to $\geq$ 130
90 to 119 DTS	7 categories: < 80 to $\geq$ 130
120 to 149 DTS	7 categories: < 80 to $\geq$ 130
Cluster	5 categories: 1, 2, 3, 4, and 5
Mean Intake for DOF /DTS Periods	
0 to 29 DOF	4 categories: < 2.25 to $\geq$ 2.75%
30 to 59 DOF	6 categories: < 2.5 to $\geq$ 3.5%
60 to 89 DOF	6 categories: < 2.75 to $\geq$ 3.75%
90 to 119 DOF	6 categories: < 2.75 to $\geq$ 3.75%
120 to 149 DOF	7 categories: < 2.75 to $\geq$ 4.0%
0 to 29 DTS	6 categories: < 2.5 to $\geq$ 4.5%
30 to 59 DTS	4 categories: < 3.0 $\geq$ 4.0%
60 to 89 DTS	5 categories: < 3.0 to $\geq$ 4.5%
90 to 119 DTS	4 categories: < 3.0 to $\geq$ 4.0%
120 to 149 DTS	6 categories: < 2.5 to $\geq$ 4.5%
Minimum Intake for DOF/DTS Periods	
0 to 29 DOF	4 categories: < 1.4 to $\geq$ 1.8%
30 to 59 DOF	4 categories: < 2.0 to $\geq$ 3.0%

60 to 89 DOF	4 categories: < 2.5 to $\geq$ 3.5%
90 to 119 DOF	4 categories: < 2.5 to $\geq$ 3.5%
120 to 149 DOF	5 categories: < 2.5 to $\geq$ 4.0%
0 to 29 DTS	6 categories: < 2.0 to $\geq$ 4.0%
30 to 59 DTS	6 categories: < 2.5 to $\geq$ 4.5%
60 to 89 DTS	6 categories: < 2.5 to $\geq$ 4.5%
90 to 119 DTS	6 categories: < 2.5 to $\geq$ 4.5%
120 to 149 DTS	5 categories: < 2.5 to $\geq$ 4.0%
Maximum Intake for DOF/DTS Periods	
0 to 29 DOF	4 categories: < 2.5 to $\geq$ 3.5%
30 to 59 DOF	5 categories: < 2.5 to $\geq$ 4.0%
60 to 89 DOF	4 categories: < 3.0 to $\geq$ 4.0%
90 to 119 DOF	5 categories: < 3.0 to $\geq$ 4.5%
120 to 149 DOF	5 categories: < 3.0 to $\geq$ 4.5%
0 to 29 DTS	6 categories: < 3.0 to $\geq$ 5.0%
30 to 59 DTS	6 categories: < 3.0 to $\geq$ 5.0%
60 to 89 DTS	5 categories: < 3.0 to $\geq$ 4.5%
90 to 119 DTS	5 categories: < 3.0 to $\geq$ 4.5%
120 to 149 DTS	5 categories: < 3.0 to $\geq$ 4.5%
Standard Deviation for DOF/DTS Periods	
0 to 29 DOF	5 categories: < 0.3 to $\geq$ 0.6
30 to 59 DOF	4 categories: < 0.1 to $\geq$ 0.3
60 to 89 DOF	3 categories: < 0.05 to $\geq$ 0.15
90 to 119 DOF	3 categories: < 0.05 to $\geq$ 0.15
120 to 149 DOF	3 categories: < 0.05 to $\geq$ 0.15
0 to 29 DTS	4 categories: < 0.1 to $\geq$ 0.3
30 to 59 DTS	5 categories: < 0.05 to $\geq$ 0.2
60 to 89 DTS	5 categories: < 0.05 to $\geq$ 0.2
90 to 119 DTS	5 categories: < 0.05 to $\geq$ 0.2
120 to 149 DTS	5 categories: < 0.05 to $\geq$ 0.2
Maximum Intake	4 categories: < 3.0 to $\geq$ 5.0%
DOF at Maximum Intake	6 categories: < 100 to $\geq$ 300 days
Initial Intake	3 categories: < 1.5 to $\geq$ 2.0%
Intake at 30 DOF	7 categories: < 2.25 to $\geq$ 3.5%
Percent of Maximum Intake at Half DOF	5 categories: < 80 to $\geq$ 95%
Percent of Maximum Intake at Three-Quarters DOF	5 categories: < 80 to $\geq$ 95%
Slope of Feed Curve from 50 DOF to End	5 categories: < -0.002 to $\geq$ 0.004
Number of Decreases in Intake	5 categories: < 75 to $\geq$ 150
Number of 5 to 10% Decreases	5 categories: < 2 to $\geq$ 8 decreases
Number of Consecutive Day Decreases	6 categories: < 15 to $\geq$ 35 decreases

AUC = Area under the curve.

DOF = Days on feed.

DTS = Days to ship.

Table 7.3 Predictor variables that were significant ($P < 0.05$) and remained in the final model for each outcome of interest: Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe LA as a proportion of Total LA (ST).

Predictor	TA	SA	S+A	ST
	P-value	P-value	P-value	P-value
Operational Data				
Sex	< 0.01	< 0.01	< 0.01	< 0.01
Average Daily Gain, kg/d	< 0.01	-	-	-
Days on Feed	-	< 0.01	< 0.01	-
Number of Head Received	0.01	-	-	-
Number of Head Shipped	-	< 0.01	< 0.01	-
Average Arrival Weight	-	-	-	0.04
Average Shipping Weight	-	< 0.01	< 0.01	-
Mortality, % of cohort	< 0.01	< 0.01	0.01	< 0.01
Railers, % of cohort	< 0.01	< 0.01	< 0.01	-
Quarter of Arrival	< 0.01	< 0.01	< 0.01	-
Quarter of Shipping	0.01	-	-	-
AUC for DOF/DTS Periods				
0 to 29 DOF	< 0.01	-	-	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF	0.01	-	-	-
90 to 119 DOF	< 0.01	0.02	-	-
120 to 149 DOF	0.01	0.01	0.02	-
0 to 29 DTS	< 0.01	-	0.02	-
30 to 59 DTS	< 0.01	-	-	-
60 to 89 DTS	< 0.01	< 0.01	< 0.01	-
90 to 119 DTS	< 0.01	0.01	-	0.02
120 to 149 DTS	0.01	0.01	< 0.01	-
Mean Intake for DOF /DTS Periods				
0 to 29 DOF	< 0.01	-	-	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF	-	-	0.02	-
90 to 119 DOF	< 0.01	0.01	< 0.01	-
120 to 149 DOF	< 0.01	-	-	-
0 to 29 DTS	< 0.01	< 0.01	-	< 0.01
30 to 59 DTS	< 0.01	-	-	-
60 to 89 DTS	-	-	-	-
90 to 119 DTS	< 0.01	< 0.01	-	-
120 to 149 DTS	-	-	-	-
Minimum Intake for DOF/DTS Periods				
0 to 29 DOF	-	0.05	-	-

30 to 59 DOF	-	-	-	-
60 to 89 DOF	-	-	-	-
90 to 119 DOF	-	< 0.01	-	-
120 to 149 DOF	< 0.01	< 0.01	< 0.01	-
0 to 29 DTS	< 0.01	< 0.01	< 0.01	-
30 to 59 DTS	< 0.01	0.03	-	-
60 to 89 DTS	< 0.01	< 0.01	-	-
90 to 119 DTS	-	< 0.01	-	-
120 to 149 DTS	-	-	-	0.02
Maximum Intake for DOF/DTS Periods				
0 to 29 DOF	-	0.01	-	-
30 to 59 DOF	-	0.02	-	0.04
60 to 89 DOF	< 0.01	-	0.01	-
90 to 119 DOF	0.02	-	-	-
120 to 149 DOF	0.01	< 0.01	-	-
0 to 29 DTS	< 0.01	< 0.01	-	< 0.01
30 to 59 DTS	-	0.01	-	-
60 to 89 DTS	0.03	-	-	-
90 to 119 DTS	< 0.01	-	0.01	-
120 to 149 DTS	< 0.01	< 0.01	-	-
Standard Deviation for DOF/DTS Periods				
0 to 29 DOF	< 0.01	< 0.01	< 0.01	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF	-	-	-	-
90 to 119 DOF	-	< 0.01	-	-
120 to 149 DOF	-	-	-	-
0 to 29 DTS	-	-	-	-
30 to 59 DTS	0.04	-	-	-
60 to 89 DTS	-	-	-	0.05
90 to 119 DTS	-	-	-	-
120 to 149 DTS	-	-	-	-
Cluster	< 0.01	-	-	< 0.01
Maximum Intake	< 0.01	-	-	-
DOF at Maximum Intake	< 0.01	< 0.01	0.01	0.01
Initial Intake	0.04	< 0.01	-	-
Intake at 30 DOF	< 0.01	-	-	-
% of Maximum Intake at Half DOF	< 0.01	-	-	-
% of Maximum Intake at Three-Fourths DOF	0.02	0.04	-	-
Slope of Feed Curve from 50 DOF to End	< 0.01	-	-	-
Number of Decreases in Intake	< 0.01	< 0.01	< 0.01	-
Number of 5 to 10% Decreases	< 0.01	< 0.01	-	-

Number of Consecutive Day Decreases	-	0.03	0.01	-
All feed per head measurements were converted to a percentage of arrival body weight for standardization across cohorts.				
DOF = Days on feed.				
DTS = Days to ship.				

Table 7.4 Estimated marginal mean probabilities $\pm$ SEM for LA outcomes of interest associated with area under the curve (AUC) for DOF and DTS periods.

	TA	SA	S+A	ST
AUC for DOF periods				
0 to 29 DOF				
< 55	19.7 $\pm$ 6.3 ^c	-	-	-
55 - 64	18.2 $\pm$ 6.3 ^c	-	-	-
65 - 74	13.1 $\pm$ 5.0 ^b	-	-	-
75 - 84	14.4 $\pm$ 5.6 ^b	-	-	-
$\geq$ 85	8.8 $\pm$ 3.9 ^a	-	-	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF				
< 75	19.7 $\pm$ 6.3 ^{ab}	-	-	-
75 - 84	15.8 $\pm$ 5.5 ^a	-	-	-
85 - 94	17.8 $\pm$ 6.2 ^a	-	-	-
95 - 104	23.9 $\pm$ 7.9 ^b	-	-	-
105 - 114	24.1 $\pm$ 8.5 ^{ab}	-	-	-
$\geq$ 115	21.2 $\pm$ 9.5 ^{ab}	-	-	-
90 to 119 DOF				
< 75	19.7 $\pm$ 6.3 ^{ab}	16.8 $\pm$ 5.8 ^{ab}	-	-
75 - 84	17.2 $\pm$ 6.4 ^{ab}	21.6 $\pm$ 7.4 ^b	-	-
85 - 94	16.8 $\pm$ 6.6 ^{ab}	21.3 $\pm$ 7.6 ^b	-	-
95 - 104	18.8 $\pm$ 7.5 ^b	18.6 $\pm$ 7.3 ^b	-	-
105 - 114	11.4 $\pm$ 5.4 ^a	12.3 $\pm$ 5.5 ^a	-	-
$\geq$ 115	19.6 $\pm$ 9.5 ^b	15.2 $\pm$ 7.5 ^{ab}	-	-
120 to 149 DOF				
< 80	19.68 $\pm$ 6.3 ^c	16.8 $\pm$ 5.8 ^c	10.7 $\pm$ 2.9 ^c	-
80 - 89	11.3 $\pm$ 5.4 ^{bc}	15.5 $\pm$ 6.0 ^c	9.5 $\pm$ 3.0 ^c	-
90 - 99	7.5 $\pm$ 3.9 ^a	10.5 $\pm$ 4.5 ^{ab}	6.5 $\pm$ 2.3 ^b	-
100 - 109	7.9 $\pm$ 4.3 ^{ab}	11.0 $\pm$ 5.0 ^{abc}	6.2 $\pm$ 2.3 ^b	-
110 - 119	9.4 $\pm$ 5.3 ^{abc}	12.0 $\pm$ 5.8 ^{bc}	4.2 $\pm$ 1.8 ^a	-
$\geq$ 120	15.1 $\pm$ 4.2 ^{abc}	7.3 $\pm$ 4.2 ^a	3.3 $\pm$ 1.6 ^a	-
AUC for DTS periods				
0 to 29 DTS				
< 80	19.7 $\pm$ 6.3 ^{bc}	-	10.7 $\pm$ 2.9 ^{ab}	-
80 - 89	21.2 $\pm$ 7.2 ^{bc}	-	11.4 $\pm$ 3.3 ^b	-
90 - 99	17.7 $\pm$ 6.6 ^{bc}	-	11.3 $\pm$ 3.5 ^b	-
100 - 109	11.9 $\pm$ 5.3 ^a	-	8.1 $\pm$ 2.8 ^a	-
110 - 119	18.6 $\pm$ 8.3 ^b	-	7.9 $\pm$ 2.8 ^a	-
120 - 129	30.8 $\pm$ 13.1 ^c	-	9.8 $\pm$ 3.7 ^{ab}	-
$\geq$ 130	85.9 $\pm$ 11.2 ^d	-	10.4 $\pm$ 4.2 ^{ab}	-

30 to 59 DTS				
< 80	19.7 ± 6.3 ^{abc}	-	-	-
80 - 89	20.7 ± 7.2 ^{bc}	-	-	-
90 - 99	29.1 ± 9.7 ^d	-	-	-
100 - 109	29.0 ± 10.8 ^{cd}	-	-	-
110 - 119	29.8 ± 11.8 ^{cd}	-	-	-
120 - 129	15.7 ± 8.2 ^b	-	-	-
≥ 130	9.0 ± 5.9 ^a	-	-	-
60 to 89 DTS				
< 80	19.7 ± 6.3 ^a	16.8 ± 5.8 ^{ab}	10.7 ± 2.9 ^{ab}	-
80 - 89	20.2 ± 6.9 ^a	18.0 ± 6.5 ^a	10.0 ± 3.0 ^a	-
90 - 99	22.2 ± 8.0 ^a	22.4 ± 8.3 ^b	11.1 ± 3.6 ^{ab}	-
100 - 109	22.7 ± 8.6 ^a	20.7 ± 8.2 ^{ab}	9.9 ± 3.5 ^a	-
110 - 119	46.0 ± 13.0 ^b	31.8 ± 11.6 ^c	14.6 ± 5.1 ^b	-
120 - 129	66.2 ± 12.9 ^c	52.6 ± 14.7 ^d	20.3 ± 7.1 ^c	-
≥ 130	63.5 ± 16.5 ^{bc}	50.8 ± 17.5 ^{cd}	15.9 ± 6.7 ^{abc}	-
90 to 119 DTS				
< 80	19.7 ± 6.3 ^a	16.8 ± 5.8 ^a	-	48.8 ± 10.4 ^{ab}
80 - 89	30.0 ± 9.2 ^b	24.1 ± 8.3 ^b	-	52.1 ± 10.6 ^{ab}
90 - 99	37.7 ± 10.8 ^c	34.5 ± 10.8 ^c	-	56.6 ± 10.6 ^b
100 - 109	23.8 ± 9.2 ^{ab}	30.8 ± 11.0 ^{bc}	-	55.2 ± 10.8 ^b
110 - 119	17.5 ± 8.1 ^a	30.8 ± 11.5 ^{bc}	-	55.0 ± 11.2 ^b
120 - 129	18.2 ± 9.5 ^{ab}	29.9 ± 13.2 ^{abc}	-	45.8 ± 11.6 ^a
≥ 130	17.9 ± 10.1 ^{ab}	30.7 ± 15.2 ^{abc}	-	56.7 ± 11.9 ^b
120 to 149 DTS				
< 80	19.7 ± 6.3 ^c	16.8 ± 5.8 ^{bd}	10.7 ± 2.9 ^a	-
80 - 89	15.5 ± 5.8 ^c	13.0 ± 4.9 ^{abcd}	11.4 ± 3.5 ^a	-
90 - 99	11.7 ± 4.8 ^b	10.8 ± 4.2 ^{ac}	10.1 ± 3.4 ^a	-
100 - 109	10.1 ± 4.7 ^b	13.3 ± 5.5 ^{abcd}	9.3 ± 3.3 ^a	-
110 - 119	5.8 ± 3.2 ^a	10.5 ± 5.0 ^{abcd}	11.1 ± 4.3 ^a	-
120 - 129	6.0 ± 3.8 ^{ab}	9.1 ± 4.9 ^{ab}	13.4 ± 5.6 ^a	-
≥ 130	8.4 ± 5.7 ^{abc}	17.0 ± 9.1 ^{cd}	24.6 ± 9.8 ^b	-

- represents non-significant association with that outcome of interest.

Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe as a proportion of Total LA (ST).

DOF = Days on feed.

DTS = Days to ship.

Table 7.5 Estimated marginal mean probabilities $\pm$ SEM for LA outcomes of interest associated with average intake for DOF and DTS periods.

	TA	SA	S+A	ST
Average intake for DOF periods				
0 to 29 DOF				
< 2.25	19.7 $\pm$ 6.3 ^a	-	-	-
2.25 - 2.49	34.3 $\pm$ 9.3 ^b	-	-	-
2.5 - 2.74	35.5 $\pm$ 10.0 ^b	-	-	-
$\geq$ 2.75	33.7 $\pm$ 9.5 ^b	-	-	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF				
< 2.75	-	-	10.7 $\pm$ 2.9 ^{ab}	-
2.75 - 2.99	-	-	9.3 $\pm$ 2.7 ^a	-
3.0 - 3.24	-	-	10.3 $\pm$ 3.1 ^a	-
3.25 - 3.49	-	-	13.2 $\pm$ 4.0 ^b	-
3.5 - 3.74	-	-	11.2 $\pm$ 3.8 ^{ab}	-
$\geq$ 3.75	-	-	9.3 $\pm$ 3.6 ^{ab}	-
90 to 119 DOF				
< 2.75	19.7 $\pm$ 6.3 ^{abc}	16.8 $\pm$ 5.8 ^{ab}	10.7 $\pm$ 2.9 ^a	-
2.75 - 2.99	20.4 $\pm$ 6.9 ^c	16.7 $\pm$ 6.1 ^a	14.7 $\pm$ 4.0 ^b	-
3.0 - 3.24	15.4 $\pm$ 5.9 ^{ab}	14.5 $\pm$ 5.8 ^a	14.7 $\pm$ 4.5 ^{ab}	-
3.25 - 3.49	13.5 $\pm$ 5.4 ^a	17.3 $\pm$ 7.0 ^a	15.9 $\pm$ 4.9 ^b	-
3.5 - 3.74	18.7 $\pm$ 7.6 ^{bc}	24.6 $\pm$ 9.5 ^{bc}	22.3 $\pm$ 6.8 ^c	-
$\geq$ 3.75	24.8 $\pm$ 10.4 ^{bc}	32.1 $\pm$ 12.6 ^c	29.9 $\pm$ 8.7 ^d	-
120 to 149 DOF				
< 2.75	19.7 $\pm$ 6.3 ^{abcd}	-	-	-
2.75 - 2.99	25.8 $\pm$ 10.2 ^{abe}	-	-	-
3.0 - 3.24	36.5 $\pm$ 13.0 ^{ef}	-	-	-
3.25 - 3.49	35.2 $\pm$ 13.3 ^{bdef}	-	-	-
3.5 - 3.74	36.6 $\pm$ 13.7 ^{cdf}	-	-	-
3.75 - 3.99	43.3 $\pm$ 15.8 ^f	-	-	-
$\geq$ 4.0	20.6 $\pm$ 11.5 ^{abe}	-	-	-
Average intake for DTS periods				
0 to 29 DTS				
< 2.5	19.7 $\pm$ 6.3 ^b	16.8 $\pm$ 5.8 ^{ac}	-	48.8 $\pm$ 10.4 ^a
2.5 - 2.99	28.0 $\pm$ 8.7 ^c	22.4 $\pm$ 8.0 ^{bd}	-	56.4 $\pm$ 10.8 ^b
3.0 - 3.49	31.3 $\pm$ 9.7 ^c	28.2 $\pm$ 9.5 ^c	-	61.0 $\pm$ 10.7 ^{abc}
3.5 - 3.99	34.9 $\pm$ 11.3 ^c	21.8 $\pm$ 8.5 ^{abcd}	-	62.5 $\pm$ 10.9 ^{bc}
4.0 - 4.49	37.3 $\pm$ 12.4 ^c	23.8 $\pm$ 10.0 ^{cde}	-	71.4 $\pm$ 9.8 ^d
$\geq$ 4.5	2.8 $\pm$ 2.6 ^a	14.8 $\pm$ 7.8 ^{ab}	-	59.9 $\pm$ 12.4 ^{abc}
30 to 59 DTS				

< 3.0	19.7 ± 6.3 ^a	-	-	-
3.0 - 3.49	28.8 ± 8.5 ^b	-	-	-
3.5 - 3.99	30.0 ± 9.3 ^b	-	-	-
≥ 4.0	34.3 ± 11.9 ^b	-	-	-
60 to 89 DTS	-	-	-	-
90 to 119 DTS				
< 3.0	19.7 ± 6.3 ^b	16.8 ± 5.8 ^b	-	-
3.0 - 3.49	11.9 ± 4.5 ^a	13.9 ± 5.1 ^b	-	-
3.5 - 3.99	12.5 ± 5.0 ^a	11.2 ± 4.8 ^b	-	-
≥ 4.0	11.9 ± 5.3 ^{ab}	6.1 ± 3.0 ^a	-	-
120 to 149 DTS	-	-	-	-

- represents non-significant association with that outcome of interest.

Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe as a proportion of Total LA (ST).

DOF = Days on feed.

DTS = Days to ship.

Table 7.6 Estimated marginal mean probabilities $\pm$ SEM for LA outcomes of interest associated with standard deviation of feed intake for DOF and DTS periods.

	TA	SA	S+A	ST
Standard deviation for DOF periods				
0 to 29 DOF				
< 0.3	19.7 $\pm$ 6.3 ^{ab}	16.8 $\pm$ 5.8 ^{ab}	10.7 $\pm$ 2.9 ^{bc}	-
0.3 - 0.39	23.2 $\pm$ 7.1 ^c	22.7 $\pm$ 7.5 ^c	12.1 $\pm$ 3.3 ^c	-
0.4 - 0.49	21.6 $\pm$ 6.9 ^{bc}	21.0 $\pm$ 7.3 ^c	9.6 $\pm$ 2.7 ^b	-
0.5 - 0.59	21.5 $\pm$ 6.9 ^{bc}	20.4 $\pm$ 7.3 ^{bc}	10.2 $\pm$ 2.9 ^b	-
≥ 0.6	15.3 $\pm$ 5.4 ^a	14.6 $\pm$ 5.8 ^a	6.4 $\pm$ 2.0 ^a	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF	-	-	-	-
90 to 119 DOF				
< 0.05	-	16.8 $\pm$ 5.8 ^{ab}	-	-
0.05 - 0.14	-	14.6 $\pm$ 5.0 ^a	-	-
≥ 0.15	-	18.6 $\pm$ 6.1 ^b	-	-
120 to 149 DOF				
Standard deviation for DTS periods				
0 to 29 DTS	-	-	-	-
30 to 59 DTS				
< 0.05	19.7 $\pm$ 6.3 ^b	-	-	-
0.05 - 0.09	18.4 $\pm$ 5.9 ^b	-	-	-
0.1 - 0.14	16.1 $\pm$ 5.3 ^a	-	-	-
0.15 - 0.19	20.3 $\pm$ 6.5 ^b	-	-	-
≥ 0.2	18.3 $\pm$ 5.9 ^{ab}	-	-	-
60 to 89 DTS				
< 0.05	48.8 $\pm$ 10.4 ^{ab}	-	-	-
0.05 - 0.09	51.8 $\pm$ 10.3 ^b	-	-	-
0.10 - 0.14	48.4 $\pm$ 10.3 ^a	-	-	-
0.15 - 0.19	49.3 $\pm$ 10.4 ^{ab}	-	-	-
≥ 0.2	55.2 $\pm$ 10.3 ^b	-	-	-
90 to 119 DTS	-	-	-	-
120 to 149 DTS	-	-	-	-
- represents non-significant association with that outcome of interest.				
Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe as a proportion of Total LA (ST).				
DOF = Days on feed.				
DTS = Days to ship.				

Table 7.7 Estimated marginal mean probabilities $\pm$ SEM for LA outcomes of interest associated with minimum intake for each DOF and DTS periods.

	TA	SA	S+A	ST
Minimum Intake for DOF				
0 to 29 DOF				
< 1.4	-	16.8 $\pm$ 5.8 ^a	-	-
1.4 - 1.59	-	20.6 $\pm$ 6.9 ^b	-	-
1.6 - 1.79	-	20.9 $\pm$ 7.0 ^b	-	-
$\geq$ 1.8	-	22.2 $\pm$ 7.6 ^b	-	-
30 to 59 DOF	-	-	-	-
60 to 89 DOF	-	-	-	-
90 to 119 DOF				
< 2.5	-	16.8 $\pm$ 5.8 ^a	-	-
2.5 - 2.99	-	24.0 $\pm$ 7.7 ^b	-	-
3.0 - 3.49	-	26.6 $\pm$ 8.3 ^b	-	-
$\geq$ 3.5	-	29.7 $\pm$ 10.4 ^b	-	-
120 to 149 DOF				
< 2.5	19.7 $\pm$ 6.3 ^{ab}	16.8 $\pm$ 5.8 ^a	10.7 $\pm$ 2.9 ^a	-
2.5 - 2.99	17.8 $\pm$ 5.9 ^a	20.4 $\pm$ 6.8 ^a	11.9 $\pm$ 3.4 ^a	-
3.0 - 3.49	25.9 $\pm$ 8.1 ^c	28.9 $\pm$ 9.1 ^{bc}	17.4 $\pm$ 4.9 ^b	-
3.5 - 3.99	25.8 $\pm$ 8.4 ^{bc}	28.7 $\pm$ 9.7 ^c	17.9 $\pm$ 5.5 ^b	-
$\geq$ 4.0	19.7 $\pm$ 7.5 ^{abc}	19.8 $\pm$ 8.2 ^{ab}	19.4 $\pm$ 6.4 ^b	-
Minimum Intake for DTS				
0 to 29 DTS				
< 2.0	19.7 $\pm$ 6.3 ^{ab}	16.8 $\pm$ 5.8 ^a	10.7 $\pm$ 2.9 ^a	-
2.0 - 2.49	20.4 $\pm$ 6.5 ^{ab}	18.2 $\pm$ 6.0 ^a	13.5 $\pm$ 3.6 ^b	-
2.5 - 2.99	18.4 $\pm$ 6.0 ^a	18.2 $\pm$ 6.1 ^a	11.5 $\pm$ 3.1 ^a	-
3.0 - 3.49	27.3 $\pm$ 7.8 ^c	23.6 $\pm$ 7.5 ^b	15.4 $\pm$ 4.1 ^b	-
3.5 - 3.99	33.3 $\pm$ 8.9 ^d	26.4 $\pm$ 8.1 ^b	19.9 $\pm$ 5.0 ^c	-
$\geq$ 4.0	25.0 $\pm$ 7.8 ^{bc}	28.0 $\pm$ 8.7 ^b	16.6 $\pm$ 4.7 ^{bc}	-
30 to 59 DTS				
< 2.5	19.7 $\pm$ 6.3 ^{ab}	16.8 $\pm$ 5.8 ^a	-	-
2.5 - 2.99	19.7 $\pm$ 6.5 ^b	15.9 $\pm$ 5.8 ^a	-	-
3.0 - 3.49	15.9 $\pm$ 5.5 ^a	16.9 $\pm$ 6.1 ^a	-	-
3.5 - 3.99	14.0 $\pm$ 5.3 ^a	19.6 $\pm$ 7.3 ^a	-	-
4.0 - 4.49	24.7 $\pm$ 9.0 ^b	15.8 $\pm$ 6.5 ^a	-	-
$\geq$ 4.5	43.4 $\pm$ 14.3 ^c	34.7 $\pm$ 13.1 ^b	-	-
60 to 89 DTS				
< 2.5	19.7 $\pm$ 6.3 ^{abc}	16.8 $\pm$ 5.8 ^c	-	-
2.5 - 2.99	22.8 $\pm$ 7.5 ^c	20.3 $\pm$ 7.2 ^d	-	-
3.0 - 3.49	16.8 $\pm$ 6.2 ^{ab}	15.7 $\pm$ 6.2 ^c	-	-

3.5 - 3.99	14.8 ± 6.1 ^{ab}	11.6 ± 5.0 ^b	-	-
4.0 - 4.49	16.3 ± 7.1 ^{bc}	7.2 ± 3.7 ^a	-	-
≥ 4.5	9.5 ± 5.5 ^a	6.8 ± 4.0 ^{ab}	-	-
90 to 119 DTS				
< 2.5	-	16.8 ± 5.8 ^{cd}	-	-
2.5 - 2.99	-	11.6 ± 4.5 ^{ab}	-	-
3.0 - 3.49	-	11.7 ± 5.0 ^a	-	-
3.5 - 3.99	-	16.0 ± 6.5 ^{bc}	-	-
4.0 - 4.49	-	26.3 ± 11.2 ^d	-	-
≥ 4.5	-	32.3 ± 14.2 ^d	-	-
120 to 149 DTS				
< 2.5	-	-	-	48.8 ± 10.4 ^{ab}
2.5 - 2.99	-	-	-	46.7 ± 10.7 ^{ab}
3.0 - 3.49	-	-	-	47.6 ± 10.9 ^a
3.5 - 3.99	-	-	-	53.5 ± 11.1 ^b
≥ 4.0	-	-	-	65.4 ± 11.0 ^c

- represents non-significant association with that outcome of interest.

Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe as a proportion of Total LA (ST).

DOF = Days on feed.

DTS = Days to ship.

Table 7.8 Estimated marginal mean probabilities $\pm$ SEM for LA outcomes of interest associated with maximum intake for each DOF and DTS periods.

	TA	SA	S+A	ST
Maximum Intake for DOF				
0 to 29 DOF				
< 2.5	-	16.8 $\pm$ 5.8 ^b	-	-
2.5 - 2.99	-	12.3 $\pm$ 4.5 ^a	-	-
3.0 - 3.49	-	13.7 $\pm$ 5.0 ^{ab}	-	-
≥ 3.5	-	11.6 $\pm$ 4.7 ^{ab}	-	-
30 to 59 DOF				
< 2.5	-	16.8 $\pm$ 5.8 ^b	-	-
2.5 - 2.99	-	14.2 $\pm$ 5.1 ^b	-	-
3.0 - 3.49	-	12.2 $\pm$ 4.6 ^b	-	-
3.5 - 3.99	-	9.4 $\pm$ 3.8 ^a	-	-
≥ 4.0	-	12.8 $\pm$ 5.2 ^b	-	-
60 to 89 DOF				
< 3.0	19.7 $\pm$ 6.3 ^b	-	10.7 $\pm$ 2.9 ^b	-
3.0 - 3.49	17.6 $\pm$ 6.2 ^b	-	9.6 $\pm$ 2.9 ^b	-
3.5 - 3.99	9.5 $\pm$ 3.8 ^a	-	6.0 $\pm$ 2.0 ^a	-
≥ 4.0	11.6 $\pm$ 5.5 ^{ab}	-	7.6 $\pm$ 2.9 ^{ab}	-
90 to 119 DOF				
< 3.0	19.7 $\pm$ 6.3 ^{ab}	-	-	-
3.0 - 3.49	17.6 $\pm$ 6.3 ^a	-	-	-
3.5 - 3.99	22.7 $\pm$ 8.1 ^b	-	-	-
4.0 - 4.49	16.2 $\pm$ 7.6 ^{ab}	-	-	-
≥ 4.5	11.5 $\pm$ 6.3 ^a	-	-	-
120 to 149 DOF				
< 3.0	19.7 $\pm$ 6.3 ^{bc}	16.8 $\pm$ 5.8 ^b	-	-
3.0 - 3.49	19.9 $\pm$ 6.8 ^c	14.7 $\pm$ 5.6 ^b	-	-
3.5 - 3.99	19.7 $\pm$ 6.9 ^c	15.7 $\pm$ 6.2 ^b	-	-
4.0 - 4.49	10.2 $\pm$ 4.4 ^a	7.1 $\pm$ 3.2 ^a	-	-
≥ 4.5	10.5 $\pm$ 5.3 ^{ab}	7.2 $\pm$ 3.8 ^a	-	-
Maximum Intake for DTS				
0 to 29 DTS				
< 3.0	19.7 $\pm$ 6.3 ^c	16.8 $\pm$ 5.8 ^c	-	-
3.0 - 3.49	14.0 $\pm$ 5.1 ^b	12.1 $\pm$ 4.6 ^b	-	-
3.5 - 3.99	14.5 $\pm$ 5.5 ^b	8.9 $\pm$ 3.6 ^a	-	-
4.0 - 4.49	8.1 $\pm$ 3.5 ^a	7.1 $\pm$ 3.0 ^a	-	-
4.5 - 4.99	8.5 $\pm$ 3.6 ^a	6.2 $\pm$ 2.7 ^a	-	-
≥ 5.0	7.8 $\pm$ 4.0 ^{a^b}	8.9 $\pm$ 4.4 ^{abc}	-	-
30 to 59 DTS				

< 3.0	-	16.8 ± 5.8 ^{ab}	-	-
3.0 - 3.49	-	16.4 ± 6.0 ^a	-	-
3.5 - 3.99	-	20.9 ± 7.7 ^{bc}	-	-
4.0 - 4.49	-	26.1 ± 9.5 ^{cd}	-	-
4.5 - 4.99	-	32.9 ± 12.3 ^d	-	-
≥ 5.0	-	21.0 ± 10.1 ^{abc}	-	-
60 to 89 DTS				
< 3.0	19.7 ± 6.3 ^b	-	-	-
3.0 - 3.49	14.1 ± 5.3 ^a	-	-	-
3.5 - 3.99	16.3 ± 6.3 ^{ab}	-	-	-
4.0 - 4.49	13.6 ± 6.1 ^{ab}	-	-	-
≥ 4.5	17.1 ± 8.1 ^{ab}	-	-	-
90 to 119 DTS				
< 3.0	19.7 ± 6.3 ^d	-	10.7 ± 2.9 ^{bc}	-
3.0 - 3.49	12.1 ± 4.6 ^{bc}	-	10.5 ± 3.2 ^c	-
3.5 - 3.99	14.9 ± 5.8 ^{cd}	-	11.3 ± 3.6 ^c	-
4.0 - 4.49	8.3 ± 3.9 ^b	-	7.3 ± 2.7 ^b	-
≥ 4.5	26.4 ± 1.7 ^a	-	4.1 ± 1.9 ^a	-
120 to 149 DTS				
< 3.0	19.7 ± 6.3 ^a	16.8 ± 5.8 ^{ab}	-	-
3.0 - 3.49	28.0 ± 8.8 ^b	16.8 ± 6.4 ^{ab}	-	-
3.5 - 3.99	22.4 ± 8.1 ^a	14.0 ± 5.8 ^a	-	-
4.0 - 4.49	33.6 ± 11.3 ^b	22.2 ± 9.2 ^b	-	-
≥ 4.5	32.3 ± 12.5 ^{ab}	14.0 ± 7.0 ^a	-	-

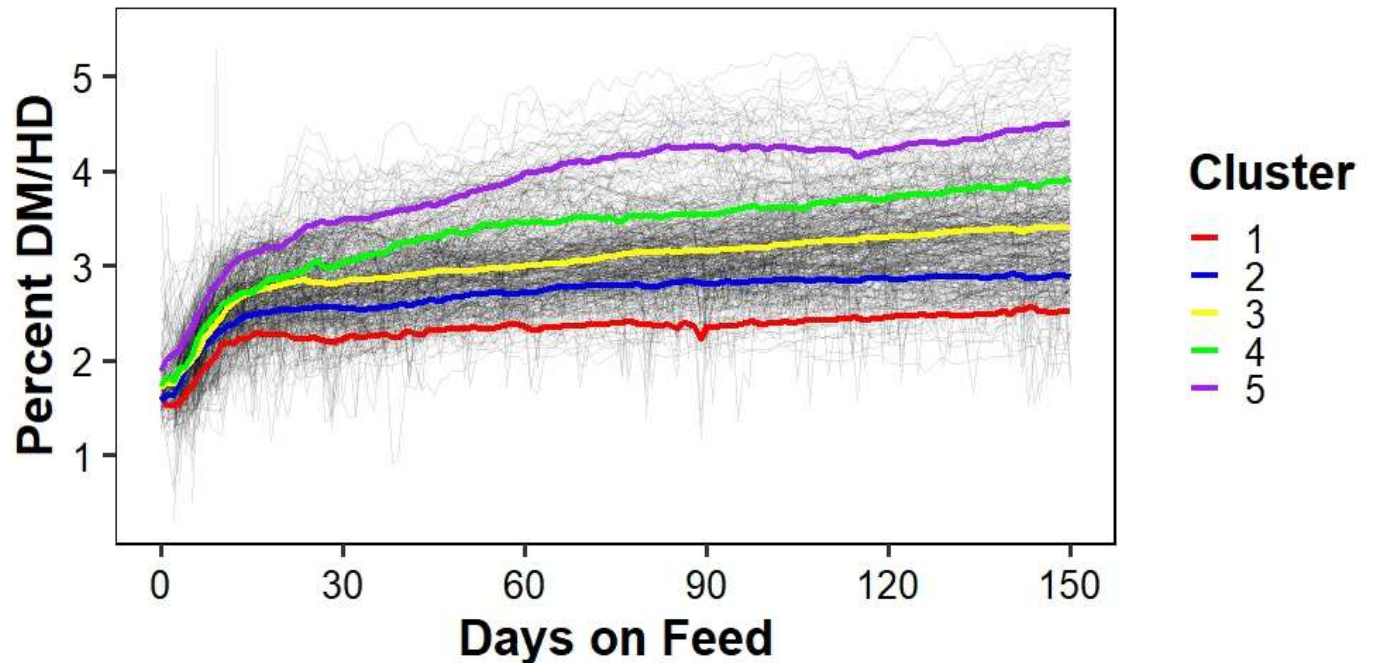
- represents non-significant association with that outcome of interest.

Total LA (TA), Severe LA (SA), Severe+ LA (S+A), and Severe as a proportion of Total LA (ST).

DOF = Days on feed.

DTS = Days to ship.

Figure 7.1 Feed intake curves were clustered by grouping curves with similar shape and low variance within groups. The colored lines represent the average feed intake for each cluster. For total liver abscesses consisting of all LA scores (TA), cluster 1 had the lowest probability of TA (19.7%) followed by cluster 2 (23.5%), 3 (29.4%), 4 (44.1%), and finally cluster 5 (68.6%), but cluster 1 was not significantly different from clusters 2 and 3. Cluster was also significantly associated with severe abscesses as a proportion of total abscesses (ST), where cluster 5 and 1 had the lowest probabilities (47.9% and 48.8%, respectively) compared to cluster 4 (59.9%).



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