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Risk factors associated with calf mortality in Western Canadian cow-calf operations

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ABSTRACT

This study examined the influence of management practices and herd demographics on calf mortality proportions in Western Canadian cow-calf operations, utilizing data from the second Western Canadian Cow-calf Survey. The survey was conducted between October 23, 2017, and February 28, 2018. The survey, which was open to all cow-calf producers across Western Canada, provided producer-reported data regarding calf death loss and corresponding herd-level factors. A fractional logit model was employed to identify significant factors associated with calf mortality proportions. The findings revealed that shorter breeding seasons (<63 days), calves born within the same season, and regular pregnancy checks for breeding females were negatively associated with calf mortality proportions. Conversely, regular breeding soundness evaluations for breeding bulls, traditional weaning methods, and vaccinating heifers for scours showed positive associations with increased calf mortality proportions. Herd operations where dams were vaccinated against clostridial and bovine respiratory diseases had lower calf mortality proportions. Notably, operations with experienced primary decision-makers holding off-farm jobs had lower predicted calf mortality proportions compared to those managed by full-time cattle producers. Higher predicted calf mortality proportions were observed in operations employing a backgrounding system. The study's limitations included potential biases due to its cross-sectional nature and reliance on producer-reported data, which might lead to an underestimation of calf mortality proportions. Also, the limited sample size and missing data might have affected the statistical significance of some variables. This study contributed to the research on cow-calf operation by using a fractional logit model to analyze the correlation between risk factors and calf mortality proportions, and by identifying novel herd-level risk factors. It provided a basis for future research aimed at developing empirically-based management strategies to optimize calf health outcomes.

1. Introduction

Calf mortality is a significant challenge for the beef industry (Martin et al., 2019). The death of calves can have substantial consequences for the profitability of cow-calf operations (Motus et al., 2018) and genetic progress within herds (Engelken, 2008). Cow-calf producers recognize calf mortality as a crucial indicator of farm welfare and profitability at the herd level (Hyde et al., 2020; Ortiz-Pelaez et al., 2008). However, despite the critical nature of this issue, empirical research that includes calf mortality as a primary focus is lacking.

Some studies have investigated calf characteristics associated with calf mortality in beef cattle operations in various countries (Bleul, 2011; Bunter et al., 2013; Motus et al., 2018; Ring et al., 2018). Numerous research efforts have been focused on dairy operations, identifying herd-level risk factors linked to calf mortality (McConnel et al., 2015; Mee et al., 2008; Renaud et al., 2018). Other studies have explored the relationships between management practices and the prevalence of specific diseases, such as respiratory diseases, in cow-calf operations (e.g., Bendali et al., 1999; Hanzlicek et al., 2013; Schumann et al., 1990; Woolums, 2015; Woolums et al., 2013). However, only a few studies have assessed the associations between calf mortality, herd management, and environmental factors in Canadian cow-calf operations (e.g., Elghafghuf et al., 2014; Murray et al., 2016; Pearson et al., 2019; Waldner, 2014; Waldner et al., 2019). The significant difference between beef and dairy calf management, coupled with the limited research on beef calf mortality, underscores the need for additional investigation in this area. This research gap might be due to two major challenges faced by researchers studying cow-calf operation mortality: the difficulty in obtaining accurate records for estimating herd-level mortality incidence (Murray et al., 2016), and the absence of

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standardized case definitions for calf mortality in this field (Waldner et al., 2010b).

Traditionally, mortality is measured as a rate, expressed in terms of cases per animal unit relative to the population, or as a risk, indicating the probability over a specified period related to an individual animal (Houe et al., 2004; Thomsen, Houe, 2006). The calf mortality rate is a measure that captures the intensity of change in calf deaths, thus making it a more complex measure than the calf mortality proportion.

Academic literature presents a range of definitions, recording-keeping practices, and calculation methods for evaluating calf mortality (Santman-Berends et al., 2019). Some studies leave the exact metrics unspecified, complicating the comparison of mortality statistics between different studies. In this study, given the available cross-sectional data, calf mortality is defined as a proportion representing the herd-level percentage of preweaning mortality (e.g., Pearson et al., 2019). This concept is further elaborated in the data section.

Effective management is crucial for calf survival, welfare, and productivity in cow-calf operations (Murray et al., 2016). Data from herd-level surveys can offer valuable insights into the relationship between key management practices, herd health, and calf mortality. Such understanding can help direct resources towards practices posing the highest risks, facilitating the development of effective strategies and interventions to reduce calf mortality and alleviate associated economic losses. The objective of this study was to examine the relationships between management practices, herd demographics, and herd-level calf mortality proportions in cow-calf operations across western Canada.

2. Materials and methods

2.1. Data

The data for this study were obtained from the second Western Canadian Cow-Calf Survey, conducted between October 23, 2017, and February 28, 2018. This survey was open to all cow-calf producers across Western Canada. A total of 261 cow-calf producers participated in the survey, responding to 58 questions regarding their cattle operations, management, and marketing practices. The 261 surveys represented 34,479 breeding females, approximately 1% of the Western Canadian beef herd (WCCCS II, 2017). The survey was organized into multiple sections addressing herd demographics, calf crops (including calving season, calf death loss, and weaning details), and management practices related to the respondents' 2017 calf crop and operation, spanning from the summer of the 2016 breeding season to the fall of 2017. Participants were encouraged to respond only to questions they felt comfortable answering, and if an exact date or number was unknown, they were instructed to provide an estimate. In cases where the requested information was not recorded, participants were advised to indicate this in the "Other, please specify" section of their response.

In this study, the term "calf" refers to any young cattle of either sex that is less than one year of age. Respondents were asked to report the number of calves that died from birth to weaning, for both heifers and cows, due to various causes based on their own diagnoses. The potential causes of calf deaths included dystocia, scours/diarrhea, pneumonia/respiratory disease, lameness/injury, predation, and weather-related issues. If correspondents were uncertain about the cause of death, they could select an 'unknown' option. "Weather-related" covers all deaths that the respondents attributed to weather conditions such as extreme cold or heat, while "unknown" includes unclassified or unidentified causes. Additionally, they were allowed to specify other causes not listed above. The proportion of calf mortality was calculated using the following formula: the numerator is the sum of pre-weaning calf deaths from various producer-reported causes, while the denominator is the total number of calves born to both feeding heifers and cows, adjusted for the number of cow-calf pairs and baby calves bought, and subtracting the number of cow-calf pairs and baby calves sold.

2.2. Methods

2.2.1. Fractional logit model

In this study, our primary variable of interest is the proportion of calf mortality, which takes values in the closed interval [0,1]. The fractional logit model is an appropriate approach for modeling data in the form of continuous rates, such as event outcomes in veterinary epidemiologic research. Initially proposed for studying 401(k) participation rates (Papke and Wooldridge, 1996), the fractional logit model has been frequently employed in biomedical research (Meaney and Moineddin, 2014; Nienałtowski et al., 2021).

The fractional logit model has three main advantages (Papke and Wooldridge, 1996). First, it does not make parametric assumptions about the distribution of the dependent variable, relying only on the first two conditional moments: the conditional mean and the conditional variance. Second, it provides non-constant effects of predictors on the dependent variable through the average partial effects (APEs) (Green, 2012; Wooldridge, 2012), which is particularly useful when dealing with continuous variables such as years of experience in raising cattle. Lastly, it ensures that predictions from the specified model fall within the unit interval. Conventional linear methods, such as Ordinary Least Squares (OLS), are not suitable for modeling bounded variables because they often fail to constrain the predicted values of the dependent variables within the defined range (Wooldridge, 2012).

Following Papke and Wooldridge (1996), this study assumes a logistic form for the conditional mean of the dependent variable and employs the robust quasi-maximum likelihood method. Consider a random sample of $i = 1, \dots, n$ cow-calf operations and let y_i be the calf mortality proportion for herd operation i, with $0 \leq y_i \leq 1$, and x_i as a vector of k covariates representing management practices and herd demographics for operation i. Let β be the vector of parameters to be estimated. For any observed calf mortality proportion y_i, its conditional mean function is:

$$E(y_i|x_i) = g(x_i\beta) \tag{1}$$

Where the $g(\bullet)$ is a distribution function with $0 < g(\bullet) < 1$. The logistic function is chosen to satisfy the non-linear functional form of the link function, and the fractional logit model can be summarized as:

$$g(\bullet) = \frac{\exp(x_i\beta)}{1 + \exp(x_i\beta)} = \frac{1}{1 + \exp(-x_i\beta)} \tag{2}$$

The conditional variance of the dependent variable is assumed to be:

$$V(y_i|x_i) = \sigma^2 g(x_i\beta)[1 - g(x_i\beta)] \tag{3}$$

Robust estimators of the variance-covariance matrix are applied because the variance is unlikely to be constant when $0 \leq y_i \leq 1$(Papke and Wooldridge, 1996). The estimation of the parameters of the model is performed via maximization of the Bernoulli log-likelihood function with the individual contribution (McCulloch, 2000):

$$LL_i(\beta) = y_i \log[g(x_i\beta)] + (1 - y_i)\log[1 - g(x_i\beta)] \tag{4}$$

Estimation results from Eq. (4) provide indications of the predictors' signs and statistical significance. Estimation of the fractional logit model was carried out using FRAREG in STATA (StataCorp, 2021).

2.2.2. Variable selection approach

Variable selection is a critical step in constructing a sparse model that includes essential variables and improves interpretability. Variables should be included in a model based on their theoretical foundations, supported by data-mining algorithms (Heinze et al., 2018). Two steps were adopted in variable selection. The first step involved generating initial working set of variables based on existing studies and relevant background knowledge. We evaluated potential variables based on their direct or indirect influence on calf mortality, or their role as indictors of general health and management practices.

Once the initial set was prepared, the adaptive least absolute shrinkage and selection operator (LASSO) technique, a penalized log-likelihood variable selection method, was used (Zou, 2006). Lasso selection, introduced by Tibshirani (1996), is a constrained least squares method. In contrast to the conventional LASSO, which applies the same penalty to all coefficients, the adaptive LASSO assigns varying penalties to different coefficients according to their importance, with more important variables receiving lower penalties (Zhang and Lu, 2007).

The adaptive LASSO is efficient in selecting critical variables in high-dimensional selection problems and has become widely used in fields where researchers face the challenge of selecting critical variables in high-dimensional model selection problems (e.g., Haem et al., 2017; He et al., 2019). Moreover, it enables model stability testing by using model selection frequencies to quantify the likelihood of a particular set of predictors being selected, a feature absents in stepwise procedures (George, 2000). Some studies suggest that multicollinearity can affect the consistency of model selection (Zhao and Yu, 2006). Therefore, we conducted an initial assessment of correlations (<0.5) before applying the adaptive LASSO procedure. The adaptive LASSO approach was executed using the PROC GLMSELECT procedure in SAS (SAS Institute Inc, 2013). The variables were ordered based on the frequency with which they were selected as an effect, and only those parameters that appeared in at least 20% of the selected models were considered eligible as variables for the model. The final list of variables was re-evaluated for multicollinearity using the variance inflation factor (VIF>5 is considered multicollinear).

3. Results

3.1. Descriptive statistics

Potential risk factors were identified using a variable selection approach. These risk factors could generally be classified into categories such as calf breeding and calving timing, reproductive practices involving breeding females and bulls, castration and weaning strategies, considerations of feed and water quality, vaccination practices, and herd demographics. Although the survey included responses from approximately 261 cow-calf producers, not all producers completed the entire survey, limiting the actual sample size used in the fractional logit model. As more independent variables were added to the fractional logit model, the number of observations decreased. The most parsimonious model, benefiting from a larger number of observations, ended up with 122 observations.

Table 1 and Table 2 provide detailed descriptions and summary statistics, respectively, for the variables chosen for the fractional logit model. Among the respondents, 46 herds were located in Alberta, 31 in Saskatchewan, 34 in Manitoba, and 11 in British Columbia. Herd sizes ranged from 9 to 1387 with an average of 161 breeding females. The discussion of descriptive statistics is limited to the observations used in the empirical model. For more information about the entire survey, readers are encouraged to consult the 2017 Western Canadian Cow-calf Survey Aggregate Results (WCCCS II, 2017).

Out of the 122 observations recorded, the average calf mortality proportion was 3.16%. Producers identified various causes of calf losses: 13.11% were attributed to dystocia, 11.57% to scours/diarrhea, and 16.45% to pneumonia/respiratory diseases. The remaining 58.87% of calf losses were attributed to a range of factors, such as injury, predator attacks, weather conditions, unknown causes, and others. The most frequently reported causes of death were weather conditions and unknown factors, each accounting for 25.61% and 24.06% of deaths from birth to weaning, respectively.

Among the 122 surveyed herds, 23% had a breeding season of less than 63 days. About 17.2% had calves born in the same season, with an average calving span of 74.77 days (ranging from 24.5 to 262 days) for cows and heifers. Spring (March-May) was the most common calving season, with 81 out of the 122 herds beginning their calving during this period. Approximately 66.4% of the herds always or almost always performed pregnancy checks on their breeding females over the past three years. Similarly, 68% of the herds always or almost always performed a breeding soundness evaluation of their breeding bulls during that time. The majority of the herds regularly conducted body condition scoring on their breeding females (77.9%) and castrated their bulls within three months of birth (83.6%). The traditional weaning method, which involves abruptly separating calves from their dams, was adopted by 63 out of 122 herds (51.6%). Furthermore, 76 out of 122 herds (62.3%) tested feed quality annually over the last three years, while 49 out of 122 herds (40.2%) performed lab testing on livestock's drinking water. Approximately 85% of winter feed was homegrown, with the range varying from 0% to 100%.

Vaccination rates varied across different diseases. Of the 122 herds, 54 (44.3%) vaccinated calves against reproductive diseases like BVDV and IBR in the last 12 months, while 20 (16.4%) vaccinated calves

Table 1
Descriptions of the Dependent and Independent Variables.

Variable	Type	Description
Mortality[1]	Continuous	Dependent variable: Calf mortality proportions from birth to weaning based on producer-reported death causes (%).
Breeding	Dummy	Cow breeding season less than 63 days: 1 =yes, o=no
Single	Dummy	All calves from cows and heifers were born in the same season: 1 =yes, 0 =no
Length	Continuous	Average length of the calving season for cows and heifers (measured in days)
Season	Dummy	The season when the first calf from cows was born: 1 =March, April, or May, 0 =December, January, or February
Pregnancy	Dummy	Conducted pregnancy checks at least twice in the past 3 years, 1 =yes, 0 =no
BSE	Dummy	Conducted breeding soundness evaluation always or almost always over the past three years, 1 =yes, 0 =no
BCS	Dummy	Regularly performed body conditioning scoring using hands or visual appraisal: 1 =yes, 0 =no
Castration	Dummy	Bull calves castrated within 3 months of birth: 1 =yes, 0 =no
Weaning	Dummy	Employed traditional weaning method: 1 =yes, 0 =no
Feed	Dummy	Tested feed quality annually over the past three years: 1 =yes, 0 =no
Water	Dummy	Conducted lab testing of livestock's drinking water annually over the past three years: 1 =yes, 0 =no
homegrown	Continuous	Percentage of winter feed that is homegrown (%)
Reproductive	Dummy	Vaccinated calves for reproductive diseases (BVDV, IBR) in the past 12 months: 1 =yes, 0 =no
Scours1	Dummy	Vaccinated calves for scours in the past 12 months: 1 =yes, 0 =no
Clostridial	Dummy	Vaccinated heifers for 7, 8, or 9 way for Clostridial diseases in the past 12 months; 1 =yes, 0 =no
BRD	Dummy	Vaccinated cows for Bovine respiratory diseases (BRDs) (includes numerous pathogens such as; BVD, IBR, BRSV, PI3, M. Haemolytica, M. Bovis and H. Somni) in the past 12 months: 1 =yes, 0 =no
Vibrio	Dummy	Vaccinated heifers for Vibrio (Campylobacter fetus or Cfv) in the past 12 months: 1 =yes, 0 =no
Scours2	Dummy	Vaccinated heifers for scours in the past 12 months:1 =yes, 0 =no
Experience	Continuous	Years of experience in raising cattle
Work	Dummy	If the primary decision works part-time or full-time off the farm: 1 =yes, 0 =no
Backgrounder	Dummy	Does the livestock enterprise include backgrounder/ grasser/stocker? 1 =Yes; 0 =No

Note:1 The calculation of calf mortality proportion was performed using the following formula: the numerator was the sum of pre-weaning calf deaths from various causes as reported by producers, while the denominator was the total number of calves born to both feeding heifers and cows. This number was adjusted by adding the number of purchased cow-calf pairs and baby calves and subtracting the number of sold cow-calf pairs and baby calves.

Table 2
Summary Statistics for Dependent and Independent Variables in the Fractional Logit Model.

Variable	Mean	Std. dev.	Min	Max
Mortality	0.032	0.037	0	0.149
Breeding	0.230	0.422	0	1
Single	0.172	0.379	0	1
Length	74.770	31.792	24.5	262
Season	0.664	0.474	0	1
Pregnancy	0.664	0.474	0	1
BSE	0.680	0.468	0	1
BCS	0.779	0.417	0	1
Castration	0.836	0.372	0	1
Weaning	0.516	0.502	0	1
Feed	0.623	0.487	0	1
Water	0.402	0.492	0	1
homegrown	0.850	0.278	0	1
Reproductive	0.443	0.499	0	1
Scours1	0.164	0.372	0	1
Clostridial	0.803	0.399	0	1
BRD	0.689	0.465	0	1
Vibrio	0.131	0.339	0	1
Scours2	0.426	0.497	0	1
Experience	29.795	13.616	3	73
Work	0.475	0.501	0	1
Backgrounder	0.344	0.477	0	1

Note: the number of observations is 122.

against scours during the same period. Ninety-eight herds (80.3%) vaccinated heifers for Clostridial disease in the last 12 months, and 16 (13.1%) vaccinated them for Vibrio. Moreover, 52 herds (42.6%) vaccinated heifers for scours in the last 12 months, while 84 (68.9%) vaccinated cows for Bovine Respiratory Disease (BRD) in the same period.

The average years of experience in raising cattle was 29.80 years, ranging from 3 to 73 years. The primary decision-maker in 56 of the 122 herds (47.5%) worked part-time or full-time off the farm. Additionally, 42 herds (34.4%) had a backgrounder, grasser, or stocker.

3.2. Risk factor analysis

Table 3 shows the fractional logit model coefficients of independent variables, along with the marginal effects calculated at the means of the independent variables. The model results were established with a significance threshold of $p = 0.05$. According to the results of the fractional logit model, several risk factors were found to be significantly correlated with the proportion of calf mortality. Factors such as the breeding season interval (less than 63 days), calves born in the same season, pregnancy checking frequency, breeding soundness evaluation, weaning method, vaccination practices (including vaccination against clostridial diseases, BRD, and scours), years of experience in raising beef cattle, employment status of primary decision-makers, and backgrounder operations were all found to have associations with calf mortality proportions.

Specifically, cow-calf operations with a breeding season interval of no more than 63 days had a 1.5% lower calf mortality proportion than those with longer intervals. Additionally, operations with calves born in the same season also experienced a 1.8% lower mortality proportion. Herd operations that had their female animals undergo pregnancy checking at least twice in the last 3 years had a 1.8% lower mortality proportion compared to those that did not. However, breeding soundness evaluations were positively associated with calf mortality proportions; operations that always or almost always conducted a breeding soundness evaluation to their breeding bulls over the last 3 years had a 3.0% higher mortality proportion.

Weaning method was associated with calf mortality proportions; herd operations that used traditional separation methods, such as abrupt weaning, had a higher mortality proportion of 1.3% compared to those that utilized non-traditional weaning methods like fence line separation,

Table 3
Parameter Estimates and Average Marginal Effects of Independent Variables Impacting Calf Mortality Proportions Using the Fractional Logit Model.

Variable	Original estimation		Average marginal effect	
	Coefficient	Robust Std. Err.	Coefficient	Delta-Method Std. Err.
Breeding	-0.503 * **	0.218	-0.015 * **	0.007
Single	-0.611 *	0.304	-0.018 *	0.009
Length	0.001	0.002	0.000	0.000
Season	-0.424	0.222	-0.013	0.007
Pregnancy	-0.601 * *	0.186	-0.018 * *	0.006
BSE	0.996 * **	0.254	0.030 * **	0.007
BCS	-0.377	0.270	-0.011	0.008
Castration	-0.259	0.245	-0.008	0.007
Weaning	0.447 *	0.202	0.013 *	0.006
Feed	0.156	0.202	0.005	0.006
Water	-0.253	0.193	-0.008	0.006
homegrown	-0.466	0.259	-0.014	0.008
Reproductive	-0.340	0.189	-0.010	0.006
Scours1	0.051	0.283	0.002	0.008
Clostridial	-0.493 *	0.238	-0.015 *	0.007
BRD	-0.444 *	0.221	-0.013 *	0.007
Vibrio	-0.088	0.245	-0.003	0.007
Scours2	0.558 *	0.184	0.017 *	0.005
Experience	-0.035 * **	0.008	-0.001 * **	0.000
Work	-0.705 * **	0.191	-0.021 * **	0.006
Backgrounder	0.677 * **	0.182	0.020 * **	0.005
Constant	-1.217 *	0.535		
Model Fit				
Log pseudolikelihood	-15.902			
Wald chi squared	127.880			
Pseudo R squared	0.071			
Obs.	122			

Notes: the number of observations is 122. * ** , * *, and * denote statistical significance at the 0.001, 0.01, and 0.05 levels, respectively. The dependent variable is the calf mortality proportion.

nose paddle/two-stage, or natural weaning (i.e., leaving the calf with the cow). Administering vaccines for clostridial disease (e.g., blackleg, red water, malignant edema etc.) to heifers was linked to a 1.5% decrease in mortality proportions, while vaccinating cows for BRD was associated with a reduction in calf mortality proportions by 1.3%. Conversely, vaccinating heifers against scours was positively correlated with higher calf mortality proportions, increasing them by 1.7%.

On average, having more years of experience in raising beef cattle was linked to a 0.1% lower mortality proportion. When the primary decision makers had more experience in cattle raising, it was associated with a lower calf mortality proportion at the herd level. As shown in

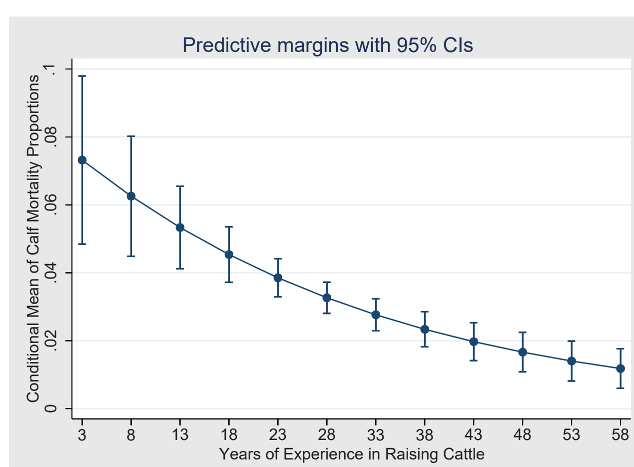

Fig. 1. The Convex Curve Indicates a Diminishing Marginal Effect of Years of Experience Raising Cattle on Calf Mortality Proportions.

Fig. 1, the impact of this variable was not constant. For example, when the years of experience were 3, the partial effect was 0.011. This effect decreased to 0.005 and 0.002 when the years of experience in raising cattle were 28 and 53, respectively, demonstrating the diminishing marginal effect as the years of experience increased (Fig. 1).

Calf mortality proportions in herd operations were associated with the employment status of the primary decision makers. Those who worked part-time off the farm had a 2.1% lower mortality proportion among their beef cattle compared to full-time counterparts. Lastly, herd operations with a backgrounder operation were found to have a 2.0% higher mortality proportion.

4. Discussion

Employing data from the second Western Canadian Cow-calf Survey, we utilized a fractional logit model to assess and quantify the correlations between management practices, herd demographics, and calf mortality proportions. Model results identified several risk factors significantly associated with producer-reported calf mortality proportions.

One pivotal managerial decision for a cattle operator involves determining the length of the breeding season. Our model's findings indicated that cow herds with a breeding season no more than 63 days experienced a reduced proportion of calf mortality. According to the 2017 Western Canadian Cow-Calf Productivity Survey, it was advisable to have a breeding season no longer than 63 days to ensure the effectiveness of herd health programs and other cattle management practices. This duration was also endorsed by the North Dakota Beef Cattle Improvement Association Cow Herd Appraisal Performance Software (CHAPS) program, which suggested that 63% of the mature cow herd should calve within the first 21 days, 87% by 42 days, and 96% by 63 days of the calving season (Amundson, 2023). The industry standard thus recommended a calving season length of 63 days for cows. To date, no studies have empirically examined whether a breeding season of less than 63 days is associated with a decrease in calf mortality.

The duration of the breeding season significantly impacted the health and reproductive performance of calves (Dziuk and Bellows, 1983). A prolonged breeding season could lead to an extended calving season, while a short breeding season was associated with a relatively lower calving rate (Larson et al., 2004). In a study conducted by Rogers et al. (1985) on cow-calf herds in Ontario, they discovered a significant correlation between restricted breeding seasons and increased live birth rates. The length of the breeding season impacted production costs, with longer breeding seasons resulting in increased costs and decreased production (Ramsey et al., 2005). By setting a specific breeding season, it is possible to improve the overall health of both the herd and the calves by scheduling a well-planned regimen of calf management, identification, vaccinations, deworming, and processing at predetermined intervals (Benner et al., 2018). In our sample of 122 observations, only 23% had a set breeding season, meaning many herd operations could potentially reduce calf death loss by implementing a defined breeding season.

According to model findings, a concentrated calving season, where all calves were born in the same season, was linked to a decreased mortality proportion. This was likely because a concentrated calving season resulted in a more consistent and uniform group of calves, which could be managed and marketed more effectively (Benner et al., 2018). The breeding season and calving season are closely related in beef cattle farming. The commencement of the breeding season has been linked to calf losses (Waldner et al., 2019). Cows that were impregnated in April or earlier to initiate the calving process in late December or January had a higher probability of experiencing calf losses during delivery. By synchronizing breeding and calving, producers can create a short and concentrated calving season, which allows them to better plan for the arrival of calves and reduces the calves' exposure to escalating doses of pathogens (Larson et al., 2004). Conversely, a continuous calving season causes cows to give birth at various times throughout the year, resulting in uneven calving patterns and inconsistent management practices (Triplett and Johns, 1981). Only 17.2% of sampled operations had their calves born in the same season, with the majority being born in the spring. This timing aligned with the availability of forage in summer (Durunna et al., 2014).

Operations that had conducted pregnancy checks on their cows at least twice in the past three years were associated with lower calf mortality proportions. Approximately 66.4% of observations reported that cows were checked at least twice within this period. Pregnancy checking is an effective reproductive management practice in beef herds and is often viewed as an indicator for recommended management practices that can enhance calving management and reduce calf mortality (Waldner, 2014). Pregnancy checking can identify pregnancy-related complications, thereby decreasing dystocia and calf mortality (Larson et al., 2004). In addition, it allows producers to differentiate between pregnant and non-pregnant cows, facilitating appropriate management practices that can improve the handling of cows and their offspring (Prince et al., 1987). Thus, it is unsurprising that our findings showed that herd operations regularly conducting pregnancy tests for their breeding females exhibited lower predicted calf mortality.

The breeding soundness evaluation (BSE) is a crucial aspect of bull assessment, helping to identify bulls with undesirable traits or lower pregnancy rates within a restricted breeding season (Barth, 2018). BSE acts an indicator of a bull's fertility, indirectly affecting calf mortality by influencing the timing of conception, and subsequently, the health status of both females and calves (Waldner et al., 2010a). In western Canada, most bulls being sold for breeding must undergo this evaluation prior to sale (Waldner et al., 2010a). Although the evaluation aims to protect the purchaser of the bull, it does not ensure the absence of viruses or other infectious agents in the bull's semen (Armstrong, Koziol, 2022). Only a small percentage of survey respondents, who had their breeding bulls evaluated in the past three years, also tested for Trichomoniasis (19.7% or 24 out of 122) or Vibriosis (18% or 22 out of 122).

A basic statistical analysis of our sample observations suggested that herd operations that tested their bulls for BSE were more likely to have higher female-to-bull ratios and generate greater sales income from beef cattle production, especially those with a purebred breeding system. Herd owners often report having their herd bulls evaluated, even without a written record (Barth and Waldner, 2002). Our survey's dataset relied on producers' self-reporting and recollection, with or without records of breeding soundness evaluations performed within the past three years. It is likely that many producers assess only bulls suspected of fertility issues, rather than evaluating all bulls in the herd (Waldner et al., 2010a). While BSEs are a standard tool in assessing male breeding potential, their impact on herd-level calf mortality (Rogers et al., 1985) and calf crop output (Holroyd et al., 2002) in beef cattle operations has not been widely studied, and their inclusion in the model could contribute to this understudied area of research. Further research is needed to ascertain the motivations behind producers who routinely evaluate their bulls for breeding soundness and to identify which types of herd operations are more inclined to perform this evaluation.

From a welfare perspective, weaning is a major source of management stress for beef calves and can increase their risk of developing clinical conditions, such as respiratory diseases (Griebel et al., 2014; Smith, 2020). Traditional weaning methods involve the immediate and complete separation of the calf from its dam, causing stress for both the cow and the calf. This abrupt separation can also result in increased stress hormones and reduced cell-mediated immunity (Hickey et al., 2003). Hodgson et al. (2005) found that calves that had been subjected to sudden weaning and transportation before being infected with bovine herpesvirus-1 (BHV-1) experienced twice the mortality due to BRD compared to those that underwent transportation alone. On the other hand, non-traditional weaning approaches like fence line separation, which allows calves to maintain contact with cows across a fence, can reduce the behavioral signs of distress displayed by calves (Price et al., 2003; Taylor et al., 2020). Despite the potential advantages of non-traditional weaning methods, abrupt weaning remained the most prevalent method, with 51.6% of observations employing it, likely because most calves were sold at the time of weaning. Weaning method is a proxy for herd management practices related to animal welfare. Producers' choice of weaning methods can reflect their priorities concerning the welfare, health, and overall well-being of their calves. Choosing low stress weaning methods could lead to significant enhancements in animal welfare, health, and decreased pre-weaning mortality proportions.

Vaccinating breeding females for reproductive diseases and vaccinating calves for respiratory diseases are recommended practices. Our model results identified some statistical correlations between various vaccination practices and calf mortality proportions. Our findings indicate that vaccinating young heifer calves against reproductive diseases, heifers against clostridial diseases, and cows against BRD are negatively associated with calf mortality proportions. Conversely, vaccinating heifers against scours has shown a positive correlation with calf mortality proportions. Vaccination is widely considered an essential tool in beef farming. Industry evidence suggests that vaccinating young calves and dams for BRD can help prevent the disease (O'connor et al., 2019). Likewise, vaccinating young heifer calves may help reduce the impact of BVDV (Ellis et al., 2001). Administering vaccines to females against clostridial diseases about four months before calving can improve maternal antibody protection in suckling calves against such diseases (Troxel et al., 1997).

Although the statistical significance of the effect of scour vaccination on calf mortality is evident, the contradiction between the expected negative impact and the observed positive impact on mortality proportions is intriguing. Previous studies have identified similar associations between calf vaccinations for scours and scour treatment rates in dairy calves (Waltner-Toews et al., 1986, 1985). It is possible that vaccinating calves against scours was not random, which may suggest either vaccination-related stress or increased attention from producers towards disease control in vaccinated calves (Waltner-Toews et al., 1986). In addition, the identification of a positive but statistically insignificant relationship between heifer vaccination for scours and calf mortality proportions could indicate that producers experiencing frequent outbreaks of scours attempt to mitigate disease transmission by administering vaccinations to the dams (Bendali et al., 1999). However, it is important to note that the relationship between vaccination and mortality proportions at the herd level can be complex, influenced by various factors such as animal genetics, environment, and management practices (Waltner-Toews et al., 1986). Further research may be needed to comprehensively understand the intricate relationships between vaccination and calf mortality proportions in cow-calf operations.

Producer and operational demographics have been found to be significantly associated with calf mortality proportions. Herd operations with more experienced primary decision-makers tend to have lower calf mortality proportions. This could be because experienced cattle producers are more likely to have developed effective management strategies and are better at identifying and addressing health issues in their animals. Age was excluded from the model due to collinearity; our finding is consistent with previous studies showing that older cattle producers typically report fewer calf health challenges compared to their younger counterparts (Martin et al., 2019).

Herd operations with primary decision makers who hold part-time, or full-time off-farm jobs are associated with lower mortality proportions. This finding aligns with previous research, which indicates that cow-calf operations viewed as secondary income sources have lower rates of bovine respiratory disease complex (BRDC) compared to those considered as primary income sources (Hanzlicek et al., 2013). Full-time and part-time cow-calf operations have different management objectives and utilize distinct management practices. Commercial full-time farming aims to maximize the production of weaned calves (Hanzlicek et al., 2013), while part-time or hobby farming tends to prioritize the health and welfare of young calves (Holloway, 2001).

Small-scale cattle farming or hobby farming is a prevalent activity in Canada (Boyd, 1998). Small-scale production can be viable for hobby farmers with off-farm employment, as a significant portion of the labor for these operations can be done during weekends or evenings (Basarir and Gillespie, 2006). In light of this, the Canadian beef industry would benefit from a comprehensive investigation into the professionalism and stress-management practices of part-time producers (Spooner et al., 2012).

Based on our model analysis, cow-calf operations with a backgrounding component tend to experience higher calf mortality proportions than those without. This is likely because purchased calves for backgrounding are often transported and mixed from different herds, which increases the risk of disease transmission and stress among young calves within the herd (Martin et al., 1981). As a result, this highlights the importance of implementing a robust preventive healthcare plan for a successful backgrounding program (Thomson and White, 2006).

We also examined the potential influence of herd size, represented by the total number of breeding females or calves, on calf mortality. Our model inherently captures herd size in the dependent variable, which is a proportion, with the denominator representing the number of calves and the numerator the number of preweaning calf deaths.

In further analyses, we incorporated the number of breeding females into fractional logit model as an independent variable. The coefficients associated with herd size were not statistically significant. In contrast, when implementing a Tobit model using the number of preweaning calf deaths as the dependent variable and the number of breeding females as an independent variable, herd size emerged as a significant factor.

The inclusion of herd size did not alter the significance of other variables, except for two: the occurrence of calves born in the same season, and BRD vaccination. These variables only achieved significance at the 10% level upon the inclusion of herd size. Crucially, the overall conclusions of our study remained consistent irrespective of the inclusion or the exclusion of herd size, justifying our decision to leave it out of the final model. Results from the Fractional Logit and Tobit models, including herd size, are available from the authors upon request.

5. Recommendations for future studies

Several limitations of this study should be acknowledged to inform future research. First, the risk factors identified are based on a cross-sectional survey, which constraints our ability to infer causal relationships from the observed associations. Second, our study relies on producer-reported data for calf mortality, instead of laboratory-confirmed data, potentially introducing reporting bias. This could lead to underreporting of calf deaths and an underestimation of the mortality proportion. Third, due to a limited sample size and missing data, some variables did not reach statistical significance despite showing expected trends. Moreover, our model did not account for potential confounders. For example, weather factors like heat, cold, and precipitation were not accounted for in the model despite that weather conditions were most identified as causes of calf mortality. Finally, we must consider potential response rate bias. Our respondents may not perfectly mirror all cow-calf operations, as there could be differences between those who chose to participate in the survey and those who did not. These limitations may affect the generalizability of our results.

For a more precise identification of risk factors, future studies should use comprehensive, multi-year herd management databases, and incorporate death rates defined epidemiologically that account for both temporal and spatial patterns. Integrating data on management practices and herd demographics would make such studies more insightful. Furthermore, for more robust insights and validation of our findings, future research should employ larger and more randomly selected sample sizes.

Special emphasis should be placed on creating distinct categories for calf death losses based on the age at death, rather than lumping all losses from birth to weaning. A targeted focus on data collection pertaining to high-risk periods for calf loss is also recommended, as understanding the timing of calf mortality is crucial for informed decision-making. Hence, future investigations should prioritize the timing of calf losses. Moreover, combining data-driven methodologies, such as adaptive LASSO, with theoretical approaches like directed acyclic graphs (DAGs), could be beneficial in future research. Such a combined approach would enable us to identify potential interactions among independent variables and elucidate complex causal relationships, thereby facilitating the development of more robust statistical models.

6. Conclusion

Calf mortality is a significant concern for cow-calf producers, until recently, assessing the link between herd-level factors and calf mortality proportions has been challenging due to difficulties in securing reliable data. Our study addresses this issue by utilizing producer-reported causes of calf mortality and corresponding death loss data from a survey conducted in Western Canada. Applying a fractional logit model, we identified several risk factors associated with management practices and herd demographics. These factors present promising opportunities for enhancing calf survival rates and reproductive efficiency. Although these factors may not be causative, implementing the identified practices can still enhance the overall health and productivity of cow herds. Overall, our findings highlight the need for continued research and the adoption of effective management practices to mitigate calf mortality and improve cow-calf production.

Declaration of Competing Interest

Authors of this research paper have no financial or personal interests that could have influenced the output of this paper.

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