Graduate Student Literature Review: The problem of calf mortality on dairy farms*

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ABSTRACT

Calf mortality can be used as an indicator of animal health and welfare on dairy farms. However, several challenges surround the estimation and reporting of this metric, specifically: (1) lack of records or reliable data, (2) methods of data collection, and (3) inconsistencies in calculation and definitions used. Therefore, despite its importance, the lack of consensus on a definition of calf mortality makes it difficult to compare mortality rates between dairy farms or studies. Monitoring factors associated with calf mortality is vital to create preventative strategies. Although common strategies have been set about how to raise dairy calves and manage dairy calves, discrepancies among studies evaluating factors associated with calf mortality still exist. This review summarizes research on the evaluation of calf mortality and associated risk factors, specifically, the lack of reliable data and standardization of the definition of calf mortality. In addition, current strategies to monitor and prevent calf mortality will be presented in this review.

Key words: stillbirth, preweaning, calves, health, management

INTRODUCTION

Calf mortality can be used as an indicator of animal health and welfare in dairy farms (Ortiz-Pelaez et al., 2008; Roche et al., 2020). In addition, high levels of calf mortality lead to economic losses as a result of delayed genetic progress from a decrease of replacement heifers and increased cost of developing these replacements. The incidence risk for dairy preweaning mortality ranges from 5 to 11% (1 d of life to weaning; Compton et al., 2017) and, for perinatal mortality, from 2 to 10% (full-term birth to 1 or 2 d of life; Cuttance and Laven, 2019). However, several challenges surround the estimation and reporting of these metrics, specifically: (1) lack of records or reliable data, (2) methods of data collection, and (3) inconsistencies in calculation and definitions used (Compton et al., 2017; Winder et al., 2018; Santman-Berends et al., 2019). These challenges complicate farmers’ perceptions of mortality and could misguide the industry (including veterinarians and other advisors) to pursue unnecessary interventions. In addition, inaccurate data could affect the validity and comparison of research estimations.

Monitoring factors associated with calf mortality is vital to create preventative strategies. Although common strategies have been set about how to raise dairy calves and manage dairy calves, discrepancies among studies evaluating factors associated with calf mortality still exist (Compton et al., 2017; Barry et al., 2019). These discrepancies may reflect contextual factors such as breed, housing, or geography, but may also be the result of differences in study methodology. Overall, calf mortality appears to have had less research devoted to it compared with other topics in dairy production. When searching for literature in PubMed (http://www.ncbi.nlm.nih.gov/pubmed) using the keywords (dairy AND calf AND mortality) only 400 results were found from 1973 to 2021. Conversely, in the same database, 2 other searches (dairy AND cow AND reproduction; dairy AND cow AND mastitis) yielded 37,760 results and 9,732 results, respectively.

This review summarizes research on the evaluation of calf mortality and associated risk factors. Specifically, this review will focus on the lack of reliable data and standardization of the definition of calf mortality. In addition, current strategies to monitor and prevent calf mortality will be presented in this review. The literature search strategy consisted of a web-based search through Medline (via PubMed; 1966 to present) using the following search terms: (calf AND mortality) OR (dairy AND perinatal AND mortality) OR (dairy AND neonatal AND mortality) as well as a search regarding health management and illness detection (Table 1). For consistency and to avoid confusion, throughout this literature review 3 terms will be used to describe dairy
calf mortality: (1) perinatal mortality (proportion of calves dead at birth or within the first 48 h of life), (2) preweaning mortality (proportion of calves dying after the perinatal period until weaning), and (3) dairy calf mortality (proportion of calves dying from birth until weaning, including both perinatal and preweaning mortality).

CHALLENGES IN REPORTING MORTALITY IN DAIRY CALF OPERATIONS

Time at Risk

When creating a definition of calf mortality, it is important to define the time at risk (Dohoo et al., 2014). However, this has been inconsistently defined in the literature (Compton et al., 2017). For example, an observational study evaluating mortality in female calves in Denmark considered 0 to 28 d, 29 to 90 d, and 91 to 180 d as separate periods (Reiten et al., 2018). Another observational study defined calf mortality as “female calves dead up to 3 months of age” (Wendel et al., 2014). In the case of perinatal mortality, discrepancies have also been described regarding the time at risk (Compton et al., 2017). Interestingly, in 21 peer-reviewed studies evaluating perinatal mortality, 3 time endpoints from birth for perinatal mortality were used: 1 h (1 study), 24 h (14 studies), and 48 h (6 studies; Cuttance and Laven, 2019). To critically evaluate and synthesize results across studies, it is necessary to improve estimates of the effect size of an intervention or association (Fagard et al., 1996). To complete synthesis methods such as meta-analyses, the studies must be comparable, and variation in the definition of calf mortality makes comparison among studies difficult. Therefore, it is critical to develop a consensus in the definitions of periods of evaluation for calf mortality.

Inconsistency in Reporting

Inconsistent reporting of calves’ deaths on dairy farms is a concern reported in multiple studies (Compton et al., 2017; Lombard et al., 2019; Santman-Berends et al., 2019; Hyde et al., 2020b). Moreover, many farms’ management programs calculate calf mortality rates or risks; however, they often do not include a precise definition of mortality (Santman-Berends et al., 2019). As a result, calf mortality calculations may vary among veterinarians, farmers, researchers, and agricultural companies. A study in the Netherlands highlighted this disagreement between how farmers and a panel of expert consultants (veterinarians and epidemiologists) calculated calf mortality (5% mortality risk vs. 16.5% mortality rate, respectively; Santman-Berends et al., 2019). In the 2015 Canadian National Dairy Study (Winder et al., 2018), 251 of 762 participants reported zero annual preweaning mortality. The large number of zero values could have resulted in an estimate of preweaning mortality that likely does not reflect the true population value. Although an investigation focusing on the aspects of inconsistent data reporting of calf losses in dairy farms has not been addressed, possible explanations about why lack of reporting is a persistent challenge have been suggested. For instance, perinatal and early preweaning mortality might not be registered due to animal identification legislation (Hyde et al., 2020b). Specifically, in countries such as the Netherlands and Great Britain, proper ear tagging identification must be done within 3 and 20 d after birth, respectively, and it is likely that deaths within these periods

Table 1. Search categories and terms for the sections of risk factors associated with perinatal and preweaning mortality and strategies to reduce mortality in dairy calves

<table>
<thead>
<tr>
<th>Search category</th>
<th>Search term</th>
</tr>
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<tbody>
<tr>
<td>Risk factors associated with perinatal and preweaning mortality in dairy calves</td>
<td>dairy AND calf* OR calves AND “perinatal mortality” OR stillbirth AND dystocia</td>
</tr>
<tr>
<td>Perinatal mortality</td>
<td>dairy AND calf* OR calves AND colostrum* AND “failed transfer passive immunity”</td>
</tr>
<tr>
<td>Failed transfer of passive immunity</td>
<td>dairy AND calf* OR calves AND diarrhea OR nec AND pneumonia OR brd AND mortality</td>
</tr>
<tr>
<td>Common diseases associated with calf mortality</td>
<td>dairy AND calf* OR calves AND season AND summer AND winter AND mortality AND “heat stress” AND “thermoneutral zone”</td>
</tr>
<tr>
<td>Season</td>
<td>dairy AND heifer OR cow AND calving AND “calving intervention” AND “newborn care” AND “precision technology”</td>
</tr>
<tr>
<td>Strategies to reduce mortality in dairy calf operations</td>
<td>dairy AND calf* OR calves AND colostrum* AND “transition milk” AND hygiene</td>
</tr>
<tr>
<td>Perinatal mortality</td>
<td>dairy AND calf* OR calves AND housing* AND ventilation AND health AND hygiene AND bedding</td>
</tr>
<tr>
<td>Transfer of passive immunity</td>
<td>dairy AND calf* OR calves AND “high plane nutrition” AND waste milk AND pasteurization</td>
</tr>
<tr>
<td>Housing</td>
<td>calf* OR calves AND “oral antibodies” AND prebiotics AND probiotics AND health</td>
</tr>
</tbody>
</table>
are not recorded (Santman-Berends et al., 2019; Hyde et al., 2020b). In other countries, similar challenges have been identified. In France, it was suggested that farmers include abortions and deaths after the defined period (48 h after birth) for perinatal mortality, leading to overestimations of perinatal mortality and, in turn, underestimated preweaning mortality calculations (Robisson et al., 2013).

Finally, it is important to consider the recording of causes and circumstances surrounding calf deaths to better understand patterns of calf mortality and implement practices to prevent future deaths. An example of how to record these events was proposed by Lombard et al. (2019). In their article, a calf birth certificate was used to record health and management events individually, and a list of categories of causes of deaths was described (Lombard et al., 2019). Overall, not recording mortality events, including date and calf identification, could affect the farmer’s perception of performance when mortality is calculated. Within this framework, the improvement of recordkeeping is not only important for individual farm analyses; it also gives valuable information at the herd level for the validity of research estimations, and the opportunity for the industry and advisors to intervene (Sumner et al., 2018; Winder et al., 2018; Cuttance and Laven, 2019).

Calf Mortality Metrics

Calf mortality can be calculated, over a defined time at risk, as an incidence risk or as an incidence rate estimation (Compton et al., 2017; Cuttance and Laven, 2019). Incidence risk measures the number of new cases per individual in the population over a defined period, whereas incidence rate measures the number of new cases per unit of animal-time (Dohoo et al., 2014). We consider that perinatal mortality can be calculated as incidence risk due to its short period of evaluation and can be divided in 2 calculations, namely stillbirth risk and perinatal mortality risk. By dividing the perinatal period, we can differentiate true stillbirths from perinatal mortality because risk factors for each are different. Stillbirth risk focuses on the calving process and can be defined as the proportion of calves dead at birth that are >260 d of gestation. In contrast, perinatal mortality risk focuses primarily on perinatal care and takes into consideration animals born alive that died within 48 h of life. The 48-h length is recommended due to carry-on effects at birth and immediate perinatal care that could cause mortality past 24 h of life. In addition, the calculation should include all animals present in the operation during the risk period as the denominator, including withdrawals if present (e.g., animals that left the farm and did not die).

For preweaning mortality, mortality risk is not ideal, as a dairy farm is an open population where animals are leaving (e.g., male calves) and entering (e.g., newborns) the calf population and are not commonly considered in the risk calculation (Santman-Berends et al., 2019). Therefore, incidence rate may be preferable to use when calculating a parameter in open populations. In addition, we suggest dividing preweaning mortality into a period from 2 d to 35 d of life (higher risk of digestive and respiratory diseases) and from 36 d until weaning (Figure 1). Although the weaning period could be different among dairy farms, therefore limiting comparison among peers, this period from 36 d to weaning might not be influenced by high mortality normally occurring during the first 4 wk of life (Uri et al., 2018). Thus, evaluating preweaning mortality in a sectorial manner will reduce the variation in age, and specific health interventions can be targeted if needed.

RISK FACTORS ASSOCIATED WITH PERINATAL AND PREWEANING MORTALITY IN DAIRY CALVES

To prevent losses, it is necessary to identify and monitor associated factors that influence the risk of mortality. Among the most common factors are failed transfer of passive immunity, the occurrence of health disorders (navel infection, neonatal calf diarrhea, and bovine respiratory disease), type of housing, season, nutrition, and perinatal mortality risk factors such as parity, calf sex, and dystocia score.

Risk Factors Associated With Perinatal Mortality

Perinatal mortality is often attributed to dystocia (Mee, 2008), with calves undergoing dystocia being 2 to 15 times more likely to die in the perinatal period (Lombard et al., 2007). Among the common causes of dystocia are abnormal fetal posture or position, fetal–maternal size mismatch, maternal-related causes, and birth weight (Silva Del Río et al., 2007). Specifically, for birth weight, the dystocia rate increases by 13% per additional kilogram above a birth weight of 40.3 kg for Holstein cows (Johanson and Berger, 2003). An additional risk factor is dam parity, where primiparous cows have higher perinatal mortality compared with multiparous cows (13% vs. 8%, respectively; Lombard et al., 2007). Twins are commonly associated as a cause of perinatal mortality in Holstein cows, as they are 3 times more likely to die in the perinatal period (Meyer et al., 2001; Lombard et al., 2007; Silva Del Río et al., 2007). It is speculated that shorter pregnancy length and increased incidence of dystocia are the causes of the decreased viability of twin calves (Meyer et al., 2001; Silva Del Río et al., 2007). Furthermore, male...
dairy calves have a higher risk of perinatal mortality compared with female dairy calves (10% vs. 6%, respectively; Silva Del Río et al., 2007). A possible explanation for the higher perinatal mortality in male calves is the elevated occurrence of dystocia attributed to longer gestation and greater birth weight compared with female calves (Johanson and Berger, 2003; Dhakal et al., 2013).

**Failed Transfer of Passive Immunity**

Colostrum is produced from the mammary gland during the 3 weeks before calving and provides immunoglobulin G (IgG), essential for transfer of passive immunity, and carbohydrates, fat, and proteins used as metabolic fuel for the newborn during the first hours of life.

The inadequate ingestion of colostrum and transfer of immunoglobulins into the blood of the calf is defined as failed transfer of passive immunity (FTPI), which, in turn, is associated with higher risk of calf mortality (Urie et al., 2018; Lombard et al., 2020). Traditional thresholds used to define FTPI are a concentration of serum total protein (STP) below 5.2 g/dL or a concentration of IgG below 10 g/L (Lombard et al., 2020). However, some have suggested that these thresholds may need to be adjusted (Urie et al., 2018; Barry et al., 2019). For example, Barry et al. (2019) found no difference in calf mortality using a cutoff value of 10 g/L IgG, whereas Robison et al. (1988) reported a 2-fold increase in mortality among calves with serum IgG concentration <12 g/L. Therefore, a dichotomous classification for FTPI (<10 vs. >10 g/L IgG) seems to be simplistic to indicate the magnitude of the effect of IgG on calf health and mortality, since it fails to capture differences in risk of mortality with differences in serum IgG concentrations. A study proposed 4 categories for FTPI (poor, ≤10.0 g/L; fair, 10.0–17.9 g/L; good, 18.0–24.9 g/L; and excellent, ≥25.0 g/L IgG) based on a consensus recommendation of calf health experts (Lombard et al., 2020; Table 2). Hence, based on the available scientific evidence, a vision of achieving greater concentrations of IgG in serum should be emphasized to reduce calf mortality, instead of relying on the traditional dichotomous values to determine FTPI.

**Common Diseases Associated With Calf Mortality**

The most common cause of calf mortality is neonatal calf diarrhea (NCD; Donovan et al., 1998; Windeyer et al., 2014), which accounts for the highest percentage of preweaning heifer deaths (56.5%) in the United States (NAHMS, 2021). Affected calves suffer from dehydration, electrolyte imbalances, and metabolic acidosis (Foster and Smith, 2009), which contribute to a case of fatality risk between 5 to 9% (Windeyer et
Beyond mortality, other long-term effects of NCD include reduced weight gain, increased time to first calving, and reduced milk production in the first lactation, which result in significant economic losses to dairy producers (Virtala et al., 1996; Aghakeshmiri et al., 2017).

Bovine respiratory disease (BRD) is considered the second most common cause of mortality in dairy calves, being responsible for 24% of preweaning deaths (NAHMS, 2021). Bovine respiratory disease can be caused by environmental stressors, viral infection, or a combination of these, which debilitates the defense mechanism of the bronchopulmonary system, allowing bacterial colonization (Grissett et al., 2015). Affected animals generally present with mucopurulent nasal secretion, dyspnea, coughing, lack of appetite, dullness, and fever (>39.4°C). Case fatality risk for BRD is reported to be between 5 and 6% in the United States and Canada (Windeyer et al., 2014; Urie et al., 2018). Similar to NCD, long-term consequences of BRD include decreased body weight, reduced survival to first calving, and reduced first-lactation milk production (Stanton et al., 2012).

Finally, although less frequent than respiratory and digestive disorders, navel infections increase mortality risk (Renaud et al., 2018a). Between 5 and 20% of dairy calves in the United States develop umbilical infections (Virtala et al., 1996; Mee, 2008), and 3% of calf mortality is due to umbilical infections (NAHMS, 2021). Although the infection is often localized, hematogenous dissemination into joints, lungs, kidneys, and other organs, can cause severe complications leading to mortality (Virtala et al., 1996; Renaud et al., 2018b).

**Season**

Fluctuations in temperature affect the prevalence of health disorders and mortality risk (Windeyer et al., 2014). The lower critical temperature for dairy calves decreases with age, from 13°C at 1 d of age to 6.4°C at 30 d old (Silva and Bittar, 2019). Temperatures below the critical limit increase metabolic demands, and, when low temperatures are combined with restricted planes of nutrition, calves can be at risk to have impaired immune function (Nonnecke et al., 2009; Roland et al., 2016). Hence, producers should be encouraged to increase the amount of nutrients delivered to calves in cold months; however, according to the 2015 National Dairy Study in Canada, 33% of the respondents fed a maximum of ≤6 L/d of milk or milk replacer (Winder et al., 2018), which may not match the energy requirements for dairy calves during Canadian winter.

Although less information exists about what the upper critical temperature in dairy calves is, it is likely 26°C (Silva and Bittar, 2019). However, the temperature–humidity index (THI) is considered the best environmental indicator of heat stress for dairy calves (Dado-Senn et al., 2020). The THI is the combination of the environmental temperature and relative humidity (Kovács et al., 2020). In subtropical conditions during the warmer months (July–October), a THI higher than 69 suggests heat stress in dairy calves in a shaded environment (Dado-Senn et al., 2020). Interestingly, in temperate climate conditions, a THI higher than 78 indicated heat stress in dairy calves, which could highlight that the threshold for heat stress based on THI varies according to the type of climate (Kovács et al., 2020).

### STRATEGIES TO REDUCE MORTALITY IN DAIRY CALF OPERATIONS

#### Perinatal Mortality

To reduce perinatal mortality, a focus should be placed on identifying and managing key mortality risk factors that are considered likely to occur in dairy farms and practical to solve.

Calving supervision and intervention are critical to minimize perinatal mortality. It is recommended to start monitoring cows every 3 to 5 h after the onset of parturition, which is indicated by behavioral changes such as elevation of the tail, switching of the tail, increased mucous discharge, and relaxation (softening) of the pelvic ligaments (Schuenemann et al., 2011). Maternity personnel should start assisting cows 70 min
after the amniotic sac appears (or 65 min after feet appearance) outside the vulva, as a dystocia is likely to be occurring (Schuenemann et al., 2011). Additionally, other approaches have been found to be successful. Specifically, intervening with only hand-pulling 15 min after the first sight of the calf’s 2 front hooves has the potential to prevent perinatal mortality and improve newborn vigor compared with late intervention in a normal calving (Villettaz Robichaud et al., 2017a). Such intervention did not affect the health and productive performance of the dam (M. Villettaz Robichaud, University of Montreal, Saint-Hyacinthe, QC, Canada, personal communication) or the calf (Villettaz Robichaud et al., 2017b). However, when checking for an abnormal fetal position, immediate correction should be performed. Thus, training personnel to recognize and manage difficult births are critical skills to intervene appropriately, thus reducing the risk of perinatal mortality (Schuenemann et al., 2013).

In dairy farms where constant calving surveillance is not guaranteed, the use of automatic devices for calving prediction could be an alternative. Data from animal behavioral and physiological parameters (e.g., vaginal temperature, rumination, tail movements) close to the moment of calving have contributed to the development of these technologies (Miller et al., 2020). Specifically, predicting calving at the beginning of the stage II of calving could be beneficial, as the time spent observing periparturient cows is reduced. Currently, intravaginal devices have been shown to determine the beginning of the stage II of calving (Crociati et al., 2022) but not to predict it, which might not be beneficial if a farm employee is not close to the calving area. Alternatively, other non-intravaginal sensors could be used; however, research has shown a low ability to predict the start of stage II of calving (Crociati et al., 2022). In the case of extensive pasture-based systems or where maternity pens are outdoors, the application of these technologies could be impaired by poor connection to a wireless base unit (Crociati et al., 2022). Thus, calving sensor devices can become a reliable tool for calving prediction in small or extensive pasture-based operations, but future efforts should be aimed to better predict calving within a reduced time window, decreasing the number of false-positive alarms and improving the ability to be adapted to any type of dairy operation.

Transfer of Passive Immunity

Newborn calves have an immature immune system because of the placental structure of the cow, which limits the transfer of serum IgG (Duhamel and Osburn, 1984; Peter, 2013). Thus, calves are born deficient in immunoglobulins and depend on the transfer of maternal antibodies through colostrum to improve their immune system (Duhamel and Osburn, 1984; Quigley et al., 2002).

Successful passive transfer of antibodies in neonatal calves can be achieved by feeding an adequate quantity and quality of maternal colostrum (MC) or colostrum replacer (CR). Although MC contains a myriad of important immune and nutritional components, IgG concentration has been considered the hallmark for evaluating colostrum quality (Godden, 2008). Traditionally, 50 g/L IgG is the concentration to define high-quality colostrum; however, this could be debatable because there is not clear evidence that this threshold classifies the quality of colostrum (Buczinski and Vandeweerd, 2016a). Because it is not practical to measure IgG concentrations in the farms, a validated cut point of ≥22% Brix is used on farm to indicate high-quality colostrum, whereas <18% Brix indicates poor-quality colostrum (Buczinski and Vandeweerd, 2016b).

To achieve successful transfer of passive immunity, it is commonly recommended to feed 3 to 4 L of MC, corresponding to 10 to 12% of body weight of a newborn calf weighing 43 kg (Morin et al., 1997; Godden, 2008). However, few studies provide evidence for this guideline (Uyama et al., 2022). Feeding large volumes of colostrum (e.g., ≥4 L) could decrease the efficiency of absorption of IgG. When calves are fed large volumes of colostrum in a single feeding, a mechanical distension of the abomasum and other forestomachs could occur, leading to a reduction in abomasal emptying (Mokhber-Dezfooli et al., 2012). Slower abomasal emptying may result in decreased absorption of colostral components (Russell Sakai et al., 2012). In addition, feeding colostrum volumes of 8.5% of body weight has been shown to be more efficient in IgG absorption compared with feeding colostrum at 10% of body weight (Conneely et al., 2014). Thus, although current guidelines of colostrum volume are well known, we suggest that more studies should be conducted to provide evidence on the support of current recommendations.

When concern for disease transmission exists (such as Mycobacterium avium ssp. paratuberculosis, bovine leukosis, or bacterial contamination of colostrum—total bacterial count >100,000 cfu/mL; Lago et al., 2018), CR can be used. Colostrum replacers offer an exogenous source of IgG, collected from dried bovine colostrum, dried bovine whey, or spray-dried bovine plasma or serum (Godden, 2008). Although studies have shown that CR can be successful in achieving serum concentrations >10 g/L IgG in dairy calves (Quigley et al., 2002, 2017; Lago et al., 2018; Lopez et al., 2020), others have reported the contrary (Swan et al., 2007; Godden et al., 2009). Such differences could be attributable to the variation of the nutritional composition due to...
different manufacturing procedures. The recommended apparent efficiency of absorption to obtain a minimum IgG serum concentration greater than 10 g/L ranges from 20 to 35% (Quigley et al., 2002). Based on this, it is suggested to feed CR with an IgG concentration between 150 and 200 g (Quigley et al., 2002).

Absorption of IgG is higher when colostrum is administered within the first 4 h of life, with highest levels of absorption seen when fed in the first hour of life (Stott et al., 1979; Fischer et al., 2018). Fischer et al. (2018) reported a faster absorption and greater concentrations of IgG in serum when heat-treated high-quality colostrum is administered during the first hour of life. In addition, delaying colostrum feeding tended to decrease the prevalence of beneficial bacteria associated with the colon mucosa, specifically *Bifidobacterium* and *Lactobacillus* spp., which are important for gut health (Fischer et al., 2018, 2019). Beyond the timing of the first feeding of colostrum, a second meal 5 to 6 h after the first colostrum meal may be important, as it has been shown to decrease FTPI and morbidity (Abuelo et al., 2021). Thus, we suggest that this practice should be implemented when possible.

Colostrum with bacterial counts of greater than 100,000 cfu/mL and coliform counts of greater than 10,000 cfu/mL (Lago et al., 2018) have been shown to impair IgG absorption (Godden et al., 2012). It is hypothesized that contaminated colostrum reduces Ig absorption by being bound and neutralized by bacteria. In addition, pathogenic bacteria could damage intestinal epithelial cells, leading to reduced permeability to Ig (Godden et al., 2012). It has been demonstrated that bacterial counts are lower when collected directly from the udder, and contamination is likely to occur during the harvesting process (Stewart et al., 2005; Hyde et al., 2020a). Hence, we suggest rinsing the colostrum harvesting equipment, nipples, bottles, and tube feeders with lukewarm water immediately after every use to prevent the drying of milk solids on surfaces, followed by disinfection and allowing to dry, to minimize bacterial contamination. These practices are advisable to maintain after colostrum feeding for buckets used for starter feed, milk, or water, as well as for automatic milkers and waterers (Berghund et al., 1987; Maunsell and Donovan, 2008).

Another important aspect of colostrum management is its storage. If the colostrum is not administered immediately, it is recommended to refrigerate it at 4°C (Stewart et al., 2005). Stewart et al. (2005) found that when colostrum is stored at 4°C for 96 h after collection, bacterial growth is reduced compared with colostrum storage at environmental temperature (23°C) for the same time interval. Finally, heat-treated colostrum could be an alternative to reduce bacterial contamination. For instance, heat-treated fresh colostrum reduced the presence of coliform bacteria, resulting in higher serum concentration of IgG (Godden et al., 2012; Malmuthuge et al., 2015). In addition, heat-treating colostrum reduces pathogens that causes acute or chronic disease, including *Mycoplasma bovis*, *Escherichia coli*, *Salmonella enteritidis*, and *Listeria monocytogenes* (Godden et al., 2012).

A practical way to evaluate the transfer of passive immunity in farms is the measurement of STP from calves with a refractometer or Brix refractometer (Lombard et al., 2020). Serum can be collected from 24 h up to 9 d after birth, as STP and IgG concentrations are highly correlated during that interval (Wilm et al., 2018). However, special consideration should be taken when evaluating STP among calves fed with CR, as the correlation between STP and IgG is low (Lopez et al., 2021). By monitoring this indicator, producers will obtain valuable information to compare with the current FTPI threshold recommendation and potentially present information to the herd veterinarian to look for modifications to establish the best colostrum management.

Finally, studies have demonstrated the potential benefits of prolonged colostrum feeding (Carter et al., 2021). Specifically, adding CR to the milk replacer or to whole milk during the first 14 d of life can improve growth and health and reduce antimicrobial use (Berge et al., 2009). Furthermore, feeding transition milk (milking 2 to 6 after parturition; Kargar et al., 2021) during the first 5 or 14 d of life resulted in higher body weight at weaning and improved health (Van Soest et al., 2020; Kargar et al., 2021). However, Carter et al. (2021) notes that it is difficult to distinguish whether the benefits of this type of strategy are due to the additional nutrients, bioactive molecules, or a combination of both, as energy and protein provisions are rarely balanced between treatments in many studies. Therefore, future research on feeding strategies with colostrum and transition milk should explore the mechanisms behind the beneficial effects reported.

**Housing**

Compared with individual calf housing, housing calves in groups helps develop social and cognitive skills, which are important to adapt to changes that occur on dairy farms such as diet changes, pen movements, and other new routines (Costa et al., 2016). However, negative behaviors such as cross-sucking and competition or aggression can also occur among grouped dairy calves (Keil et al., 2001; O’Driscoll et al., 2006). Solutions for these behaviors have been reviewed by Costa et al. (2016). Another common criticism of group housing is
increased transmission of pathogens, but only a small amount of literature demonstrates this (Costa et al., 2016; Knauer et al., 2021). Therefore, increased occurrence of health events due to the type of housing may be affected by other parameters (e.g., nutrition) and not by animals being grouped in the same pen.

Ventilation, temperature, ammonia, and humidity are all components that can modulate air quality and the prevalence of disease such as BRD. Appropriate ventilation and low stocking density decrease concentrations of airborne bacteria (Lago et al., 2006). Similarly, keeping the pen or hutch temperature within the thermoneutral zone and maintaining low levels of ammonia (i.e., <5.25 mg/m³; Kaufman et al., 2015) have contributed to reducing the prevalence of BRD (Buczinski et al., 2018; Louie et al., 2018). Regarding bedding, long wheat straw bedding has a higher capability to absorb water compared with other bedding materials and is associated with increasing the ideal nesting condition, which decreases heat loss (Paninivat et al., 2004; Lago et al., 2006). Therefore, it is recommended use bedding that allows calves to nest properly, and to remove soiled bedding and manure from pens and add fresh bedding as needed to keep calf housing clean and dry (Salfer and Broadwater, 2020).

**Plane of Nutrition and Hygiene**

Restricting milk or milk replacer consumption (i.e., 4 L of milk per day) was traditionally considered an optimal feeding strategy, as it increased the consumption of starter concentrate, which was associated with efficient ruminal development (Khan et al., 2011). However, this compromises preweaning growth and welfare (Khan et al., 2011; Eckert et al., 2015; Jafari et al., 2020). Concerning growth, multiple studies have reported that calves fed a more biologically normal quantity of milk (20% of total body weight daily) during the preweaning period have greater feed efficiency and higher body weight at weaning (Khan et al., 2007; Jafari et al., 2020). Restricted feeding has also been found to increase calf vocalization, which is considered a reflection of chronic hunger (Thomas et al., 2001). Therefore, based on the positive effects of feeding biologically normal amounts of milk to dairy calves, feeding biologically normal nutrition is recommended (Khan et al., 2011).

Beyond optimizing the growth and welfare of dairy calves, feeding a high plane of nutrition also benefits health. Decreased occurrence of diarrhea and reduced days with diarrhea were reported in dairy calves fed a biologically normal plane of milk nutrition (Khan et al., 2007; Ollivett et al., 2012). Such benefit to health could be attributed to a positive effect of nutrition on immune function (Obeidat et al., 2013; Ballou et al., 2015). Furthermore, weaned dairy calves fed with biologically normal levels of nutrition preweaning could have more tolerance to infections (Sharon et al., 2019). However, to garner the benefits of a high plane of milk nutrition, it is recommended to gradually wean calves by decreasing milk allowance beginning no earlier than 6 wk of age. Moreover, when stepping down milk consumption, calves should be eating >0.8 kg/d of starter concentrate to maintain average daily gain and support ruminal development (Eckert et al., 2015; Klopp et al., 2019).

Pathogens can be shed in the milk of infected cows and cause diarrhea, pneumonia, otitis media, or arthritis in calves (Maunsell and Donovan, 2008). The practice of pasteurization of bulk-tank or waste milk (e.g., mastitis milk, milk with antibiotic residuals) prior to feeding seems to be effective against *Mycoplasma* and *Salmonella* species and to decrease bacterial load in general (Butler et al., 2000; Edrington et al., 2018). It is important to highlight that it has been reported that dairy calves fed with pasteurized or non-pasteurized waste milk had changes in their fecal and nasal microbiota and foster the presence of antimicrobial-resistant bacteria (Maynou et al., 2017, 2019; Penati et al., 2021). In addition, waste milk can have variable nutritional composition compared with salable whole milk on a herd-level basis (Zhang et al., 2019; Vieira et al., 2021). However, no strong evidence shows negative effects of feeding waste milk on calf health (Zhang et al., 2019). Due to the possibility of the development of antimicrobial-resistant bacteria and the variability of the daily nutritional composition of waste milk, it is suggested not to feed calves with waste milk.

**Preventative Gut Health Interventions**

Traditionally, oral antimicrobials were added to milk or given in an oral bolus to prevent NCD (Buss et al., 2021). However, there is a scarcity of literature that has evaluated the use of oral antibiotics, with most reporting no or small differences in performance and health (Dennis et al., 2019; Buss et al., 2021). In addition, the gut microbiome may be affected by prolonged antibiotic feeding and may foster the presence of resistant bacteria (Maynou et al., 2017). Therefore, such practice needs to be reconsidered.

The use of microbial-based products such as pre- and probiotics has been researched as a strategy to prevent NCD. The most commonly used probiotics are live yeast, yeast cultures, and bacterial-based probiotics (Cangiano et al., 2020). Live yeast and yeast cultures of *Saccharomyces cerevisiae* possess immune modulatory properties involving anti-inflammatory effects and cell activation (Jensen et al., 2008). It has also been
reported that *Saccharomyces cerevisiae* has the capacity to support commensal bacterial colonization in the gut (Xiao et al., 2016) and increase the production of IgA (Villot et al., 2020). Similarly to live yeast and yeast cultures, bacterial probiotics based on *Lactobacillus* strains have been reported to modulate the gut commensal microbiota to maintain the homeostasis of gut microbial ecosystems (Fan et al., 2021; Fernández-Ciganda et al., 2022). These microbial-based probiotics have been demonstrated to reduce diarrhea, number of days with fever, pathogen fecal shedding, and risk of mortality (Magalhães et al., 2008; Brewer et al., 2014). According to a review by Cangiano et al. (2020), probiotics are useful when applied as a preventative measure, especially if the animals will face an stressful event (Alugongo et al., 2017; Fernández et al., 2020).

Regarding prebiotics, mannanooligosaccharides are the most researched (Cangiano et al., 2020) and have been shown to decrease fecal score and severity of diarrhea, and to improve fecal consistency (Heinrichs et al., 2003). Other prebiotics, such as fructooligosaccharides, galactooligosaccharides, β-glucans, and cellobiooligosaccharides, have shown no promising results in health, and to improve fecal consistency (Heinrichs et al., 2003). Prebiotics are useful when applied as a preventative measure, especially if the animals will face an stressful event (Alugongo et al., 2017; Fernández et al., 2020).

**CONCLUSIONS**

This narrative review highlights the importance of recording mortality events to calculate and interpret this relevant indicator for the dairy industry. Heterogeneous methodology reduces comparisons between studies, and more robust evidence is needed to establish the current occurrence of calf mortality in the dairy industry. Finally, although in this literature review, we have presented scientific evidence for predictors and strategies to prevent calf mortality, we believe that there is also a need for such scientific work to be communicated to dairy farmers, specifically through veterinarians. Veterinarians play a crucial role in opening channels of communication between researchers and dairy farmers to deliver updated information and to instruct and motivate changing practices that could be detrimental to the health and welfare of dairy calves.

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