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Incidence and recurrence of bovine abortion in dairy cattle from Costa Rica

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ABSTRACT

The reproductive efficiency and milk yield of cows are crucial factors in a dairy farm's profitability. However, abortions can have a negative impact on these factors. While the morbidity of abortion has been estimated in many countries, information on the burden on dairy cattle in tropical conditions is limited, and Costa Rica is a good example. This study aims to assess the incidence and recurrence of bovine abortion in dairy cattle from Costa Rica. The study analysed the morbidity of abortion in Costa Rican dairy herds between 2010 and 2022. The incidence rate (IR) and the recurrence rate (ReR) were calculated per 100 cow-months at risk using data from the Veterinary Automated Management and Production Control Programme (VAMPP). The dataset comprised 1032,457 lactations from 330,265 cows in 1134 specialized dairy herds. Abortions were classified either as early foetal mortality (EFM) or late foetal mortality (LFM). Rates were estimated based on cow breed, lactation number, and ecological zone to which the farm belongs. The IR of general abortion, EFM, and LFM cases were 0.98, 0.41, and 0.57 per 100 cow-months at risk, respectively. No statistically significant differences were found in the IR between cow breed, lactation number, and ecological zone, nor for the trend of abortions over calving years. The first ReR (for cows that had one previous abortion during the lactation) was 0.95, and the second ReR (for cows that had two previous abortions during the lactation) was 1.41 per 100 cow-months at risk. These results suggest that bovine abortions are an important ongoing problem in dairy farms in Costa Rica with potentially detrimental effects on the reproductive and productive performance of cows and may be representative of other specialized tropical dairy systems in Latin America.

1. Introduction

The cows' reproductive efficiency and milk production are among the most critical aspects of a dairy farm's profitability. However, this profitability can be negatively impacted by bovine abortions, which have various causes and can reduce milk yield and the number of potential replacements for the herd. Furthermore, bovine abortions result in increased treatment costs, feeding expenses, the number of services per effective conception, and involuntary culling of cows (El-Tarabany, 2015; Gädicke et al., 2010; Lee and Kim, 2007).

Abortion in cattle is defined as the death of the foetus between days 42 and 260 of gestation (Markusfeld-Nir, 1997; Mee, 2020). However, different definitions of bovine abortion have been used in various studies, resulting in variable frequencies of occurrence of the abortion cases, which confounds their comparison. Furthermore, studies use different measures to evaluate the occurrence of abortion cases, mainly the cumulative incidence risk (CIR) and incidence rate (IR) (El-Tarabany, 2015; Forar et al., 1995; Gädicke and Monti, 2013; Markusfeld-Nir, 1997; Norman et al., 2012; Thobokwe and Heuer, 2004; Zobel et al., 2011). The IR of abortion in dairy cattle has been estimated in several countries, including Chile, Israel, and the USA, and ranges from 1.17 to 1.75 per 100 cow-months at risk (Forar et al., 1996; Gädicke and Monti, 2013; Markusfeld-Nir, 1997). However, information about the burden and impact of bovine abortion in dairy cattle from tropical productive conditions, such as Costa Rica, is scarce.

The causes of abortion are diverse and include infectious diseases such as infectious bovine rhinotracheitis (IBR), pathogenic *Leptospira* spp., and *Neospora caninum* (Anderson et al., 1990; Clothier and Anderson, 2016; Jamaluddin et al., 1996; Wolf-Jäckel et al., 2020), metabolic disorders, and genetic predisposition, among many others

Abbreviations: CIR, Cumulative incidence; EFM, Early foetal mortality; IR, Incidence rate; LFM, Late foetal mortality; ReR, Recurrence rate.

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(Hovingh, 2009). However, the precise cause of abortion often remains undetermined (Anderson et al., 1990; Campero et al., 2003; Clothier and Anderson, 2016; Jamaluddin et al., 1996; Khodakaram-Tafti and Ikede, 2005; Kirkbride, 1992).

In Costa Rica, dairy farms are typically located at altitudes between 500 and 2500 m above sea level (Vargas-Leitón et al., 2013). Furthermore, 79.4 % of cattle dairy production systems in Costa Rica are based on pasture (INEC, 2022), and an average of 4.5 kg of concentrate is offered daily to each lactating cow (Vargas-Leitón et al., 2013). However, being a tropical country, the climate can have a negative impact on cows' milk production, for example due to heat stress. In addition, several infectious diseases are endemic, but the infectious and vaccine status (if available for a particular disease) of all dairy herds in the country is not well recorded. Nevertheless, bovine vaccines available in Costa Rica include those against bacteria like *Brucella abortus*, *Clostridium* spp., pathogenic *Leptospira* spp., or viruses like bovine respiratory syncytial, bovine viral diarrhoea (BVD), IBR, and bovine parainfluenza-3 (Castillo-Badilla et al., 2019).

Estimating the frequency of overall abortion, regardless of the cause, can alert the farmer to the importance and impact of abortions in their dairy production systems. However, it is important to note that the incidence of abortion in dairy cattle from temperate countries cannot be extrapolated to tropical countries due to differences in conditions, characteristics, and management practices of dairy production systems. Therefore, the main objective of this study is to estimate the incidence and recurrence of abortion in dairy cattle from Costa Rica.

2. Materials and methods

2.1. Herds and management

This study used a retrospective design with data from 01/01/2010–31/12/2022, encompassing all lactations from the cows present during these years. The study population comprised 330,265 cows from 1134 specialized dairy cattle herds from Costa Rica. The specialized dairy herds were located throughout the whole country in different ecological zones (ecozones) classified according to Holdridge's habitats classification. The ecozones are classified based on altitude, latitude, temperature, and rainfall (Holdridge et al., 1978). Management practices, grazing pastures, cow breeds, and endemic diseases tend to be similar in farms from the same ecozone. It is worth noting that a given ecozone may be present in different regions of the country.

2.2. Data collection

The inclusion criteria for a farm to be considered in this study were to have regular veterinary visits, to use the Veterinary Automated Management and Production Control Programme (VAMPP) (Noordhuizen and Buurman, 1984) herd management information system, and to have complete records of at least four years within the study period. Additionally, pregnancy had to be confirmed by any method (transrectal palpation or ultrasonography) between 35 and 60 days after artificial insemination/mating. During the routine visits, the veterinarians collected the reproductive information to be entered into the system, and the information regarding the abortions was collected by the farmers/farm workers or calculated by VAMPP software as half of the interval between the last positive pregnancy diagnosis and the registration of a new service or a non-pregnancy diagnosis by the veterinarian.

Inclusion criteria for the lactation of cows on each farm were that it started between 01/01/2010 until 30/09/2022 and that complete lactation data is available. Additionally, lactations in progress at the start of the record collection must have at least three months of records. The database was created by retrieving information from the VAMPP database, which belongs to the Centro Regional de Informática para la Producción Animal Sostenible (CRIPAS). The project is affiliated with the Escuela de Medicina Veterinaria of the Universidad Nacional de Costa Rica and includes data recorded since 1986 from almost 1800 Costa Rican farms.

2.3. Case definitions

A case of abortion was defined as the disruption of pregnancy between 42 and 260 days after conception (Markusfeld-Nir, 1997; Mee, 2020). The abortion could be observed by the farmer or inferred when a cow was inseminated or diagnosed as non-pregnant after a previously confirmed pregnancy (Markusfeld-Nir, 1997). Abortions were classified as early foetal mortality (EFM) if the abortion occurred between 42 and 120 days of pregnancy (Mee, 2020) and late foetal mortality (LFM) if they occurred between 121 and 260 days of pregnancy. The time-at-risk was calculated from 42 days post-conception, for cows confirmed pregnant, until:

(1) 260 days after the last service (end of the foetal period) for those lactations without abortion, (2) to the date of the observed abortion for those lactations with an observed abortion, (3) half of the interval between day 42 post-conception and half the interval between the last positive pregnancy diagnosis and the registration of a new service or a non-pregnancy diagnosis (as the exact date of the abortion was unknown) for those lactations with an unobserved abortion (noticed by a new service or a non-pregnancy diagnosis after a previously confirmed pregnancy), or (4) the last day present in the herd for those lactations that the cow left the herd due to being sold, death, or culling.

The first trimester of gestation was defined as the period between days 42–90 of pregnancy, the second trimester included the period between days 91–180, and the third trimester had the period between 181 and 260 days.

2.4. Statistical analysis

All retrieved records were edited and validated for biological plausibility. First, a descriptive analysis was performed, including general characteristics of the farms and animals. The morbidity of bovine abortion cases was estimated using crude and specific indicators such as IR, CIR, and recurrence rate (ReR). The overall IR was calculated as the number of new abortion cases over the population at risk (expressed as 100 cow-months at risk) for all the pregnant cows in the population (Henken et al., 2017). In addition, specific IR was calculated for EFM and LFM, and the CIR of abortion was calculated as the number of new abortion cases over the total number of cows at risk. Additionally, the study estimated specific rates for overall abortions and foetal mortality rates, considering cow breed, lactation number, and ecozone.

A set of models was used to determine if cow breed, lactation number, and ecozone were significantly associated with the abortion IR per farm. The different IR by cow breed, lactation number, and ecozone were statistically evaluated using a generalized linear mixed model with a Poisson distribution for each variable. These three models were adjusted for herd size and calving year, and with farm as a random effect. Another model was used to determine if calving year was significantly associated with the abortion IR per farm. The model used was a generalized linear mixed model with a Poisson distribution, adjusted for herd size and farm as a random effect. A $P<0.05$ was considered statistically significant.

The ReR of abortion in each lactation was calculated as follows: (1) single ReR: new abortion cases over the population at risk (expressed in 100 cow-months at risk) for cows that had previously aborted during the same lactation; (2) second ReR: new abortion cases over the population at risk (expressed in cow-months at risk) for cows that previously had two abortions during the same lactation (Glynn and Buring, 1996).

Finally, a descriptive analysis was conducted on the cows with recurrent abortions in different lactations, categorized by their respective farm and ecozone. Data processing and statistical analysis were performed using the Statistical Analysis System OnDemand for

Academics (SAS ODA).

3. Results

3.1. Descriptive statistics

A total of 1032,457 lactations were analysed, representing 330,265 cows from 1134 specialized dairy cattle herds. The dairy herds studied were located in 10 ecozones: (1) moist low-mountain forest, (2) very moist low-mountain forest, (3) rainy low-mountain forest, (4) moist pre-mountain forest, (5) very moist pre-mountain forest, (6) very moist mountain forest, (7) rainy forest, (8) dry tropical forest, (9) moist tropical forest, and (10) very moist tropical forest.

This study included Holstein (28.8 %), Jersey (30.9 %), Holstein x Jersey crossbred cows (10.7 %), and other breeds (e.g., Gyr, Fleckvieh, Brown Swiss) and their crosses (29.6 %). The service of the cows included natural mating (46.2 %), artificial insemination (53.5 %), and embryo transfer (0.3 %). In this study, 20.0 % of the cows were in their first lactation, 21.9 % were in their second lactation, 17.7 % were in their third lactation, and 40.4 % were in their fourth lactation or more. The vaccines administered to the cows in this study were unknown as most farmers did not record this information in their system.

3.2. Frequency of overall and specific cases of abortion

Out of the 1032,457 lactations, 65,502 (6.3 %; 95 % CI 6.3–6.4 %) had at least one case of abortion. Among the 65,502 lactations with abortions, 27,416 (41.9 %) were classified as EFM, and 38,086 (58.1 %) were classified as LFM (Table 1).

3.3. Distribution of abortion by pregnancy time

In addition, there were 15,644 cases of pregnancy loss before 42 days of pregnancy and 860 cases of pregnancy loss that occurred after 260 days of pregnancy. These cases were excluded from further analysis. The cases of abortion were not evenly distributed between the 42–260 days of pregnancy, with the lowest number of cases (n=115) occurring on day 121 and the highest (n=775) occurring on day 259 (refer to Fig. 1).

3.4. Abortion cases and culling

Cows that experienced abortion during lactation were more likely to be culled (10 %) compared to those without abortion (3.8 %). From the lactations that ended with the cow's culling, 14.5 % presented an abortion, and this was distributed as 89.8 % of them had a single abortion, 9.2 % had two abortions, and 1.0 % had three or more abortions during the lactation. Finally, of the cows that underwent an abortion and were culled, 54.6 % had four or more calvings. The time elapsed between the last abortion in the lactation and the culling ranged from 23 to 2933 days, with 116 days being the most frequent (Fig. 2).

Table 1
Cumulative incidence risk (%) (CIR) and incidence rate (IR: number of new abortion cases per 100 cow-months at risk) for overall, early foetal mortality (EFM), late foetal mortality (LFM), per trimester of gestation, and recurrence rate (ReR) within a lactation, with their respective 95 % confidence interval (95 %CI).

Variable	Category	Abortions (n)	CIR	95 % CI	IR	95 % CI
Type of abortion	Overall	65,502	6.3	6.3–6.4	0.98	0.97–0.99
	EFM	27,416	2.7	2.5–2.8	0.41	0.40–0.41
	LFM	38,086	3.7	3.5–3.8	0.57	0.56–0.57
Pregnancy trimester	1	21,928	2.1	2.1–2.2	0.33	0.32–0.33
	2	17,808	1.7	1.7–1.7	0.27	0.26–0.27
	3	25,766	2.5	2.5–2.5	0.38	0.38–0.39
Recurrence	ReR1*	3488	5.3	5.2–5.5	0.95	0.92–0.98
	ReR2**	236	6.8	5.9–7.6	1.41	1.23–1.59

*Second abortion case in a single lactation. **Third abortion case in a single lactation.

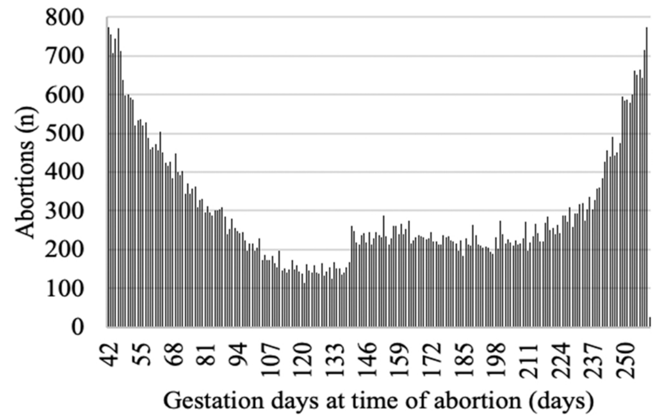

Fig. 1. Distribution of abortion cases according to the days of gestation at the time of the abortion diagnosis.

3.5. Abortion cases by cattle breed, lactation number, and ecozones

Holstein cows had the largest lactational CIR (7.5 %) and other crossbred cows had the lowest (4.7 %). Furthermore, the CIR ranged from 6.0 % to 7.0 % between lactation numbers, with a median of 6.3 %, being the largest for the second lactation. Finally, the CIR ranged from 5.0 % to 8.2 % between ecozones, with a median of 6.1 %, being the largest in the very moist mountain forest. Furthermore, the number of farms varied among ecozones, with a median of 79 farms per ecozone. The very moist mountain forest had the minimum number of farms (n=14), and the very moist pre-mountain forest ecozone had the maximum (n=388). The median number of cows with abortion per ecozone was 3684, ranging from 186 to 17,621 aborted cows per ecozone.

The IR of overall abortion cases per farm ranged from 0 to 4.97 cases with a median of 0.89 (Fig. 3). However, according to the first set of models, the IR per farm of overall, EFM, and LFM abortion cases did not differ (P>0.05) between cow breeds, lactation number, or ecozones. Finally, the abortion IR ranged from 0.67 to 0.78; the minimum corresponding to the year 2020 and the maximum to the year 2016. However, based on the year the abortion occurred, a trend of abortions was not observed over time (P>0.05).

3.6. Recurrence

Out of the 65,502 lactations with abortion, 5.3 % (n=3488) had two abortions within a lactation, and 0.3 % (n=236) had three or more

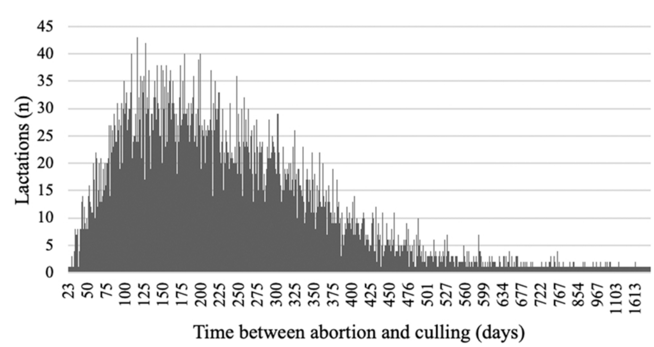

Fig. 2. Distribution of the time between the last abortion in lactation and culling.

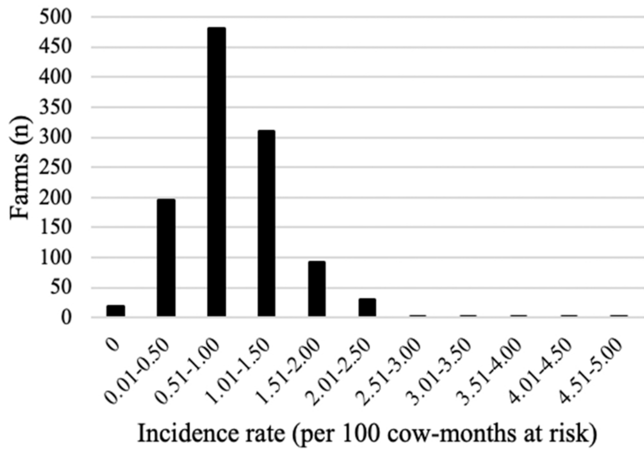

Fig. 3. Distribution of the abortion incidence rate (expressed per 100 cow-months at risk) per farm.

abortions in a given lactation. Therefore, the single abortion ReR was 0.95 (95 % CI 0.92–0.98) per 100 cow-months at risk for cows with one previous abortion during the lactation, while the second ReR was 1.41 (95 % CI 1.23–1.59) per 100 cow-months at risk for cows with two previous abortions during the lactation (Table 1).

In addition, 99.7 % (1112/1115) of the farms had cows with one abortion, and the proportion of farms with 1–6 recurrent abortions ranged from 75.6–0.1 %, respectively, indicating that cows with recurrent abortions were clustered in certain farms. However, 87.0 % (49,475/56,954) of the cows that experienced an abortion did not experience abortion in other lactations.

4. Discussion

The IR of overall abortion cases estimated in this study was 0.98 cases per 100 cow-months at risk, which is lower than that estimated in Israel (IR = 1.17) (Markusfeld-Nir, 1997), Washington, USA (IR = 1.41) (Forar et al., 1996), and Chile (IR = 1.74) (Gädicke and Monti, 2013). For the overall abortion cases, the definitions used in these studies were similar, considering that the gestational period used to calculate the time-at-risk was 45–260 days of pregnancy (Markusfeld-Nir, 1997), 31–260 (Forar et al., 1996) and 42–260 (Gädicke and Monti, 2013). Therefore, the difference in IR could be due to the definition of inferred and non-observed abortions, farm management practices, cow breeds used, endemic diseases, and climatic conditions (Forar et al., 1995). Furthermore, the CIR for overall abortion cases in this study was 6.3 %, which is lower than the estimated rates in Croatia (7.8 %) (Zobel et al., 2011), Spain (7.9–10.6 %) (Labèrnia et al., 1996; López-Gatius et al., 2004, 2002), the USA (10.8–12.5 %) (Chebel et al., 2004; Forar et al., 1996), and Iran (15.4 %) (Keshavarzi et al., 2017). However, the estimated morbidity rate in Costa Rican dairy farms is similar to that in Korea (6.9 %) (Lee and Kim, 2007), and the median of 12 studies from USA, Australia, and Canada (6.5 %) (Forar et al., 1995). This suggests that the morbidity of abortion in Costa Rican dairy farms is lower than in many other countries which could be caused by different factors, for example, differing farm management practices (Gädicke and Monti, 2013), different levels of intensification of the production systems, and the varying incidence of infectious diseases (Anderson, 2007), especially those that are considered as abortifacient. However, further research should be performed to determine whether these factors are associated with the IR of abortion in dairy cattle from Costa Rica.

The estimated IR expressed in this study was 0.41 and 0.57 per 100 cow-months at risk for EFM and LFM cases, respectively. In contrast to previous studies, a higher incidence rate (IR) was found for LFM cases than EFM cases. Previous studies have found a higher IR of abortion in the earlier stages of pregnancy. The IR of abortion cases in the first trimester varies from 1.39 (Gädicke and Monti, 2013) to 2.49 (Markusfeld-Nir, 1997) and in the third trimester from 0.81 (Gädicke and Monti, 2013) to 1.56 per 100 cow-months at risk (Markusfeld-Nir, 1997). This difference in IR could be explained by the burden of abortifacient infectious agents, which are specific to each trimester. Late-term abortions are generally associated with infectious agents such as *Brucella abortus*, IBR, and *Neospora caninum* (Anderson, 2007; Carpenter et al., 2006; Hall et al., 2005; Muylkens et al., 2007; Olsen and Tatum, 2010). A local study showed 94.7 % of Costa Rican dairy farms were seropositive for *N. caninum*. However, it cannot be concluded that *N. caninum* caused the abortion, as only 43.3 % of cows were seropositive (Romero et al., 2005). Furthermore, a local study reported a 4.2–4.4 % prevalence of *B. abortus*-infected Costa Rican dairy herds, estimated by indirect ELISA on Rosa Bengal-positive samples. However, the dairy industry is one of the main contributors to the control of bovine brucellosis in Costa Rica through the RB51 vaccine (Hernández-Mora et al., 2017). Therefore, further research is needed to determine whether *N. caninum* and *B. abortus* cause the high LFM IR in dairy cattle from Costa Rica.

Although the different ecozones in Costa Rica may represent diverse climatic conditions, farm management practices, pastures, and endemic diseases, the IR did not vary in this study. Further research is needed to understand this unexpected finding better. In addition, the IR was also similar among cow breeds. This contrasts with other studies where Holstein cows were found to have an increased abortion frequency, as reported in countries like Chile and Egypt (El-Tarabany, 2015; Gädicke and Monti, 2013). Holstein cows may have a higher milk yield, which puts them at a higher risk of experiencing a negative energy balance (NEB) due to an unbalanced and/or insufficient diet. It has been reported that cows in an NEB have poorer oocyte and embryo quality, which can result in embryo or foetal mortality (Leroy et al., 2008). This may also explain the higher incidence rate of EFM observed in other countries (Gädicke and Monti, 2013; Markusfeld-Nir, 1997).

This study found no difference in abortion IR between lactation, which is consistent with a study conducted in California, USA (Chebel et al., 2004). However, other studies reported higher IR in first (Gädicke and Monti, 2013) and second lactation cows (Markusfeld-Nir, 1997; Rafati et al., 2010), possibly due to differences in immunity to abortion-causing infectious agents. First and second-lactation cows may also be affected by the increased nutritional and metabolic demands caused by milk production and their growth.

Finally, no clear trend in abortion IR was observed during the study period. This suggests that there were no epidemic disease-induced abortions on the farms studied and no significant changes in management practices, climatic factors, or any other possible cause of abortion. However, it is possible that the minimum IR of 0.67 obtained in 2020 was influenced by the COVID-19 pandemic, which significantly altered working conditions and product availability. Similarly, the maximum IR of 0.78 obtained in 2016 may have been due to specific conditions that year, including the impact of Hurricane Otto on climatic conditions and temporary changes in farm management that may have favoured abortions. However, to arrive at a more definitive conclusion on the causes of the variation in abortion incidence rate over the years, it is necessary to conduct a detailed analysis of farm management practices and history, which was out of the scope of the present study.

The CIR of a single recurrent abortion during lactation was estimated to be 5.3 % in this study, which is lower than the rates found in Californian dairy farms (14.5 %) (Thurmond et al., 1990) and Israeli dairy farms (17.5 %) (Markusfeld-Nir, 1997). Additionally, 13 % of the cows in our study experienced recurrent abortions between lactations. There was evidence of clustering of cows with recurrent abortions, which could indicate deficient farm management, infectious diseases on specific farms, or even a genetic component (Hovingh, 2009; Wijma et al., 2022). Moreover, if the causes of abortion involve infectious agents, the abortion ReR can be influenced. For example, in some cases of *N. caninum*, the cow may have developed immunity after the abortion causing a decrease in the abortion ReR, as reported by Dubey et al., 2007. However, in many cases, cows infected with *N. caninum* can have repeated abortions increasing the abortion ReR (Dubey et al., 2007; Hovingh, 2009). Also, *N. caninum* seropositive herds could have an important role on the clustering of cows with recurrent abortions observed in this study. However, it is important to note that the farmer's culling policies for cows with repeated abortions within a lactation and between lactations can also influence the abortion ReR, and this can vary among farms and countries. In our study, we found that 9.6 % of lactations with miscarriages ended with the cow being culled, which was more than double the proportion of cows culled after a lactation without miscarriage (3.8 %). Although further research is needed, this may indicate that cows in Costa Rica that have abortions may be at a higher risk of being culled, which could ultimately reduce the risk of recurrence. Cows with abortions in Scotland and Iran had an increased risk of culling, according to Bell et al., 2010 and Keshavarzi et al., 2020. However, other factors can also lead to culling, such as increased age/parity, increased calving to conception interval, decreased milk yield and DIM, and health problems like mastitis, ketosis, lameness, retained placenta, ovarian cysts, among many others (Bell et al., 2010; Keshavarzi et al., 2020; Mõtus and Niine, 2022; Rilanto et al., 2020). However, our study found that 45.4 % of culled cows had fewer than four calvings, resulting in a significant economic loss for farmers. This is because maximum milk yield is typically not achieved until the third lactation (Rilanto et al., 2020; Vijayakumar et al., 2017).

This study estimated the incidence of abortion in dairy cattle in Costa Rica using a comprehensive dataset. However, this study has limitations. The farmers collected the records, but the periodicity and completeness of data collection varied. This variability affected the accuracy of abortion dates, especially for unobserved abortions. Additionally, different veterinarians carried out pregnancy diagnosis, introducing inter-operator variability. Furthermore, there was insufficient information regarding the vaccination and infection status of cows regarding *Brucella abortus*, IBR, BVD, and *Neospora caninum*. Additional research is required to determine the primary causes of abortion, estimate the reproductive and productive losses resulting from abortion, and assess its economic impact on dairy herds in tropical conditions.

5. Conclusions

This study is significant not only for dairy producers in Costa Rica but also for those in other Central American countries operating under similar conditions regarding climate, management, and production practices. Most available studies are based on temperate countries and focus on specific infectious agents. This study provides evidence to the dairy industries in Costa Rica and Latin America regarding the incidence of abortion in their productive systems which can have a significantly negative impact on their cows' productive and reproductive performance. It also highlights the importance of conducting regional-based studies to assess differences in the effects of health problems that may appear generalizable between production systems, climatic conditions, and management practices.

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CRediT authorship contribution statement

José Rojas-Campos: Resources, Data curation. **Emilia Vindas-van der Wielen:** Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Formal analysis, Data curation. **Gustavo Enrique Monti:** Writing – review & editing, Validation, Supervision, Project administration, Formal analysis, Data curation, Conceptualization. **Juan José Romero-Zúñiga:** Writing – review & editing, Validation, Resources, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declares not to have any conflict of interest.

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References

Anderson, M.L., 2007. Infectious causes of bovine abortion during mid- to late-gestation. Theriogenology 68, 474–486. https://doi.org/10.1016/j.theriogenology.2007.04.001.

Anderson, M.L., Blanchard, P.C., Barr, B.C., Hoffman, R.L., 1990. A survey of causes of bovine abortion occurring in the San Joaquin Valley, California. J. Vet. Diagn. Invest. 2, 283–287. https://doi.org/10.1177/104063879000200405.

Bell, M.J., Wall, E., Russell, G., Roberts, D.J., Simm, G., 2010. Risk factors for culling in Holstein-Friesian dairy cows. Vet. Rec. 167, 238–240. https://doi.org/10.1136/vr.c4267.

Campero, C.M., Moore, D.P., Odeón, A.C., Cipolla, A.L., Odriozola, E., 2003. Aetiology of bovine abortion in Argentina. Vet. Res. Commun. 27, 359–369. https://doi.org/10.1023/A:1024754003432.

Carpenter, T.E., Chrièl, M., Andersen, M.M., Wulfson, L., Jensen, A.M., Houe, H., Greiner, M., 2006. An epidemiologic study of late-term abortions in dairy cattle in Denmark, July 2000–August 2003. Prev. Vet. Med. 77, 215–229. https://doi.org/10.1016/j.prevetmed.2006.07.005.

Castillo-Badilla, G., Vargas-Leitón, B., Hueckmann-Voss, F., Romero-Zúñiga, J.J., Castillo-Badilla, G., Vargas-Leitón, B., Hueckmann-Voss, F., Romero-Zúñiga, J.J., 2019. Factores del animal y el manejo predestete que afectan la edad al primer parto en hatos de lechería especializada de Costa Rica. Agron. Costarric. 43, 9–24. https://doi.org/10.15517/rac.v43i2.37788.

Chebel, R.C., Santos, J.E.P., Reynolds, J.P., Cerri, R.L.A., Juchem, S.O., Overton, M., 2004. Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. Anim. Reprod. Sci. 84, 239–255. https://doi.org/10.1016/j.anireprosci.2003.12.012.

Clothier, K., Anderson, M., 2016. Evaluation of bovine abortion cases and tissue suitability for identification of infectious agents in California diagnostic laboratory cases from 2007 to 2012. Theriogenology 85, 933–938. https://doi.org/10.1016/j.theriogenology.2015.11.001.

Dubey, J.P., Schares, G., Ortega-Mora, L.M., 2007. Epidemiology and Control of Neosporosis and *Neospora caninum*. Clin. Microbiol. Rev. 20, 323–367. https://doi.org/10.1128/CMR.00031-06.

El-Tarabany, M.S., 2015. Impact of stillbirth and abortion on the subsequent fertility and productivity of Holstein, Brown Swiss and their crosses in subtropics. Trop. Anim. Health Prod. 47, 1351–1356. https://doi.org/10.1007/s11250-015-0870-z.

Forar, A.L., Gay, J.M., Hancock, D.D., 1995. The frequency of endemic fetal loss in dairy cattle: A review. Theriogenology 43, 989–1000. https://doi.org/10.1016/0093-691X(95)00063-E.

Forar, A.L., Gay, J.M., Hancock, D.D., Gay, C.C., 1996. Fetal loss frequency in ten Holstein dairy herds. Theriogenology 45, 1505–1513. https://doi.org/10.1016/0093-691X(96)00118-5.

Gädicke, P., Monti, G., 2013. Factors related to the level of occurrence of bovine abortion in Chilean dairy herds. Prev. Vet. Med. 110, 183–189. https://doi.org/10.1016/j.prevetmed.2012.11.022.

Gädicke, P., Vidal, R., Monti, G., 2010. Economic effect of bovine abortion syndrome in commercial dairy herds in Southern Chile. Prev. Vet. Med. 97, 9–19. https://doi.org/10.1016/j.prevetmed.2010.07.008.

Glynn, R.J., Buring, J.E., 1996. Ways of measuring rates of recurrent events. BMJ 312, 364–367. https://doi.org/10.1136/bmj.312.7027.364.

Hall, C.A., Reichel, M.P., Ellis, J.T., 2005. *Neospora* abortions in dairy cattle: diagnosis, mode of transmission and control. Vet. Parasitol. 128, 231–241. https://doi.org/10.1016/j.vetpar.2004.12.012.

Henken, A.M., Graat, E.A.M., Casal, J., 2017. Measurement of disease frequency. in: Application of Quantitative Methods in Veterinary Epidemiology. Wageningen Academic Publishers, The Netherlands, pp. 63–96.

Hernández-Mora, G., Ruiz-Villalobos, N., Bonilla-Montoya, R., Romero-Zúniga, J.-J., Jiménez-Arias, J., González-Barrientos, R., Barquero-Calvo, E., Chacón-Díaz, C., Rojas, N., Chaves-Olarte, E., Guzmán-Verri, C., Moreno, E., 2017. Epidemiology of bovine brucellosis in Costa Rica: Lessons learned from failures in the control of the disease. PLoS One 12, e0182380. https://doi.org/10.1371/journal.pone.0182380.

Holdridge, L., 1978. Ecología basada en zonas de vida. Instituto Interamericano de Ciencias Agrícolas (IICA), Costa Rica.

Hovingh, E., 2009. Abortions in dairy cattle I: Common causes of abortions. Virginia Tech.

INEC, 2022. Encuesta Nacional Agropecuaria 2021: Resultados generales de la actividad ganadera vacuna y porcina.

Jamaluddin, A.A., Case, J.T., Hird, D.W., Blanchard, P.C., Peauroi, J.R., Anderson, M.L., 1996. Dairy cattle abortion in California: evaluation of diagnostic laboratory data. J. Vet. Diagn. Invest. 8, 210–218. https://doi.org/10.1177/104063879600800211.

Keshavarzi, H., Sadeghi-Sefidmazgi, A., Ghorbani, G.R., Kowsar, R., Razmkabir, M., Amer, P., 2020. Effect of abortion on milk production, health, and reproductive performance of Holstein dairy cattle. Anim. Reprod. Sci. 217, 106458 https://doi.org/10.1016/j.anireprosci.2020.106458.

Keshavarzi, H., Sadeghi-Sefidmazgi, A., Kristensen, A.R., Stygar, A.H., 2017. Abortion studies in Iranian dairy herds: I. Risk factors for abortion. Livest. Sci. 195, 45–52. https://doi.org/10.1016/j.livsci.2016.11.004.

Khodakaram-Tafti, A., Ikede, B.O., 2005. A retrospective study of sporadic bovine abortions, stillbirths, and neonatal abnormalities in Atlantic Canada, from 1990 to 2001. Can. Vet. J. 46, 635–637.

Kirkbride, C.A., 1992. Etiologic agents detected in a 10-year study of bovine abortions and stillbirths. J. Vet. Diagn. Invest. 4, 175–180. https://doi.org/10.1177/104063879200400210.

Labèrnia, J., López-Gatius, F., Santolaria, P., López-Béjar, M., Rutllant, J., 1996. Influence of management factors on pregnancy attrition in dairy cattle. Theriogenology 45, 1247–1253. https://doi.org/10.1016/0093-691x(96)00079-9.

Lee, J.I., Kim, I.H., 2007. Pregnancy loss in dairy cows: the contributing factors, the effects on reproductive performance and the economic impact. J. Vet. Sci. 8, 283. https://doi.org/10.4142/jvs.2007.8.3.283.

Leroy, J., Opsomer, G., Van Soom, A., Goovaerts, I., Bols, P., 2008. Reduced fertility in high-yielding dairy cows: Are the oocyte and embryo in danger? Part I The importance of negative energy balance and altered corpus luteum function to the reduction of oocyte and embryo quality in high-yielding dairy cows. Reprod. Domest. Anim. 43, 612–622. https://doi.org/10.1111/j.1439-0531.2007.00960.x.

López-Gatius, F., Santolaria, P., Yániz, J., Rutllant, J., López-Béjar, M., 2002. Factors affecting pregnancy loss from gestation day 38 to 90 in lactating dairy cows from a single herd. Theriogenology 57, 1251–1261. https://doi.org/10.1016/s0093-691x(01)00715-4.

López-Gatius, F., Santolaria, P., Yániz, J.L., Garbayo, J.M., Hunter, R.H.F., 2004. Timing of early foetal loss for single and twin pregnancies in dairy cattle. Reprod. Domest. Anim. 39, 429–433. https://doi.org/10.1111/j.1439-0531.2004.00533.x.

Markusfeld-Nir, O., 1997. Epidemiology of bovine abortions in Israeli dairy herds. Prev. Vet. Med. 31, 245–255. https://doi.org/10.1016/S0167-5877(96)01142-7.

Mee, J.F., 2020. Investigation of bovine abortion and stillbirth/perinatal mortality - similar diagnostic challenges, different approaches. Ir. Vet. J. 73, 20. https://doi.org/10.1186/s13620-020-00172-0.

Mõtus, K., Niine, T., 2022. Cow culling patterns in eight commercial Estonian dairy herds and farmers' behaviour in reporting culling reasons. Res. Vet. Sci. 152, 190–206. https://doi.org/10.1016/j.rvsc.2022.08.011.

Muylkens, B., Thiry, J., Kirten, P., Schynts, F., Thiry, E., 2007. Bovine herpesvirus 1 infection and infectious bovine rhinotracheitis. Vet. Res. 38, 181–209. https://doi.org/10.1051/vetres:2006059.

Noordhuizen, J.P., Buurman, J., 1984. VAMPP: A veterinary automated management and production control programme for dairy farms (the application of MUMPS for data processing). Vet. Q. 6, 66–72. https://doi.org/10.1080/01652176.1984.9693914.

Norman, H.D., Miller, R.H., Wright, J.R., Hutchison, J.L., Olson, K.M., 2012. Factors associated with frequency of abortions recorded through Dairy Herd Improvement test plans. J. Dairy Sci. 95, 4074–4084. https://doi.org/10.3168/jds.2011-4998.

Olsen, S., Tatum, F., 2010. Bovine Brucellosis. Vet. Clin. North Am. Food Anim. Pract. 26, 15–27. https://doi.org/10.1016/j.cvfa.2009.10.006.

Rafati, N., Mehrabani-Yeganeh, H., Hanson, T.E., 2010. Risk factors for abortion in dairy cows from commercial Holstein dairy herds in the Tehran region. Prev. Vet. Med. 96, 170–178. https://doi.org/10.1016/j.prevetmed.2010.05.008.

Rilanto, T., Reimus, K., Orro, T., Emanuelson, U., Viltrop, A., Mõtus, K., 2020. Culling reasons and risk factors in Estonian dairy cows. BMC Vet. Res. 16, 173. https://doi.org/10.1186/s12917-020-02384-6.

Romero, J.J., Breda, S.V., Vargas, B., Dolz, G., Frankena, K., 2005. Effect of neosporosis on productive and reproductive performance of dairy cattle in Costa Rica. Theriogenology 64, 1928–1939. https://doi.org/10.1016/j.theriogenology.2005.03.023.

Thobokwe, G., Heuer, C., 2004. Incidence of abortion and association with putative causes in dairy herds in New Zealand. N. Z. Vet. J. 52, 90–94. https://doi.org/10.1080/00480169.2004.36411.

Thurmond, M.C., Picanso, J.P., Jameson, C.M., 1990. Considerations for use of descriptive epidemiology to investigate fetal loss in dairy cows. J. Am. Vet. Med. Assoc. 197, 1305–1312.

Vargas-Leitón, B., Solís-Guzmán, O., Sáenz-Segura, F., León-Hidalgo, H., 2013. Caracterización y clasificación de hatos lecheros en Costa Rica mediante análisis multivariado. Agron. Mesoam. 24, 257–275.

Vijayakumar, M., Park, J.H., Ki, K.S., Lim, D.H., Kim, S.B., Park, S.M., Jeong, H.Y., Park, B.Y., Kim, T.I., 2017. The effect of lactation number, stage, length, and milking frequency on milk yield in Korean Holstein dairy cows using automatic milking system. Asian-Australas. J. Anim. Sci. 30, 1093–1098. https://doi.org/10.5713/ajas.16.0882.

Wijma, R., Weigel, D.J., Vukasinovic, N., Gonzalez-Peña, D., McGovern, S.P., Fessenden, B.C., McNeel, A.K., Di Croce, F.A., 2022. Genomic Prediction for Abortion in Lactating Holstein Dairy Cows. Animals 12, 2079. https://doi.org/10.3390/ani12162079.

Wolf-Jäckel, G.A., Hansen, M.S., Larsen, G., Holm, E., Agerholm, J.S., Jensen, T.K., 2020. Diagnostic studies of abortion in Danish cattle 2015-2017. Acta Vet. Scand. 62 (1) https://doi.org/10.1186/s13028-019-0499-4.

Zobel, R., Tkalčić, S., Pipal, I., Buić, V., 2011. Incidence and factors associated with early pregnancy losses in Simmental dairy cows. Anim. Reprod. Sci. 127, 121–125. https://doi.org/10.1016/j.anireprosci.2011.07.022.