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TIME SERIES MODELING OF RETAINED PLACENTA, METRITIS, AND KETOSIS IN HOLSTEIN COWS AND HEIFERS AND ITS ASSOCIATION WITH CLIMATE VARIABLES IN A HOT-ARID ZONE

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Aim: To forecast the monthly percentage of Holstein cows and heifers at a high-input dairy farm experiencing retained placenta (RP), puerperal metritis (PM), and clinical ketosis (CK). **Methods:** An autoregressive integrated moving average (ARIMA) model was employed to predict future monthly cases of these diseases using time series data. These puerperal diseases were observed on a single dairy farm with 2560 to 3300 milking cows over seven years, from 2014 to 2020. **Results:** The highest predicted RP incidence in cows was in May (11.3%; 95% CI = 6.3–16.4), while the lowest was in November (5.4%; 95% CI = 0.5–10.4). For heifers, the peak predicted RP occurrence was in August (20.6%; 95% CI= 11.0–23.1), and the lowest was in December (10.5%; 95% CI= 7.9–13.0). The highest projected CK occurrence in cows was in June (3.0%; 95% CI = 1.8–4.3), and the lowest was in November (1.1%; 95% CI = –0.1–2.4). For heifers, CK was most likely in May (2.7%; 95% CI= 0.9–4.5) and least in December (0.7%; 95% CI= –1.1–2.5). **Conclusions:** Both cows and heifers showed an increasing trend in RP, PM, and CK during summer months; ARIMA models effectively tracked disease trends throughout the year and can aid in health management decisions for dairy cows.

Keywords: dairy cows, heat stress, periparturient diseases, temperature-humidity index, trend analysis.

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INTRODUCTION

Common diseases in postpartum dairy cows that hinder pregnancy establishment include periparturient disorders (such as dystocia and retained placenta) (Funnell and Hilton, 2016), metabolic conditions (like ketosis and fatty liver) (Overton et al, 2017), and uterine diseases (including metritis and endometritis) (Gilbert, 2019). Puerperal metritis (PM), in particular, poses a significant challenge for the dairy industry worldwide due to its high prevalence (around 20%; De Oliveira et al, 2020), along with reduced milk production, economic losses, and effects on animal welfare (Pérez-Báez et al, 2021). Moreover, uterine infections on dairy farms lead to lower profits because of increased health expenses and higher involuntary culling rates (De Oliveira et al, 2020).

Seasonality, marked by periodic increases in disease occurrence, is common among many infectious diseases in dairy cattle, including uterine infections, which show higher incidence and persistence during the hot season than during the cold season (Molinari et al, 2022). Similarly, a higher incidence of retained placenta (RP) has been reported in summer compared to other seasons (Kamel et al, 2022). Holstein cows calving in summer face a greater risk of severe ketosis than those calving in winter (Jeong et al, 2018; Ha et al, 2023). Therefore, seasonality affects not only uterine infectious diseases but also metabolic diseases postpartum in dairy cows and heifers, such as ketosis, which tend to flare up more consistently at certain times of the year, depending on geography. However, the pattern of periparturient diseases remains poorly understood and not fully explained.

Seasonal variation in the occurrence of some infectious diseases is attributable to seasonal changes in the immune system's response, which are reduced by thermal stress (Bagath et al., 2019; Dahl et al., 2020). Additionally, numerous direct and indirect pathways exist through which climate can influence diseases associated with calving (Pinedo et al, 2020). No literature has been reported on the time series relationship between periparturient diseases and month of the year in zones of intense and prolonged thermal stress. Therefore, we hypothesized that the occurrence of RP, PM, and clinical ketosis (CK) would fluctuate across calving months. In addition, it was hypothesized that the association between periparturient disease occurrence and climatic conditions is influenced by delays or prior heat-stress events. Therefore, this study aimed to analyze seasonal patterns of RP, PM, and CK in Holstein heifers and cows in an intensive dairy operation in a hot environment and to develop an appropriate ARIMA model to predict future periparturient disease cases. Another objective was to assess the time lag between the occurrence of periparturient diseases and the climatic conditions throughout the year.

MATERIAL AND METHODS

General herd information. The study was approved by the Animal Care Committee of the Autonomous Agrarian University Antonio Narro (project #3001-2419). For this retrospective study, a single commercial dairy herd (ranging from 2,560 to 3,300 milking Holstein cows over seven years) in Northern Mexico (Matamoros County; 25°31′43″N 103°13′51″W) was examined. The mean annual temperature is 22.7°C, and the average annual rainfall is 210 mm. The study site experiences an extreme, very dry climate, with hot summers and occasionally cold winters, where a lack of rain is the norm. It is classified as a predominantly Hot Desert (BWh) climate, with variations towards Cold Desert (BWk) in winter (Köppen-García climate classification method; García, 1981).

Surveillance for RP, PM, and CK in cows and heifers was conducted from January 1, 2014, through December 31, 2020, in a high-input dairy herd. RP was defined as fetal membranes not being ejected within 24 hours after parturition. PM was defined as cows with an enlarged uterus, a fetid, watery, mucopurulent, red-brown uterine discharge, depression, anorexia, and reduced milk yield within 21 days after calving. Cows with PM were treated with 50 mg/mL of ceftiofur (Zoetis, Mexico City, CDMX) for three days. CK was defined as cows displaying anorexia, nervousness, decreased milk production, severe loss of body condition, and a blood BHBA level of ≥3.0 mmol/L measured from a small blood sample from the tail vein using the Novavet blood ketone meter (Woodley Veterinary Diagnostics, Lancashire, UK) with a 22-gauge needle and vacuum tube.

Cows were kept in open pens with a dry manure substrate. They had shade structures in the middle of the pens and feed bunks. The shaded feed bunk was equipped with sprinkler nozzles and fans, which activated at air temperatures ≥25°C. Lactating cows were fed as a group a total mixed ration (TMR) based on corn silage, alfalfa hay, and grain concentrate twice daily at approximately 08:00 and 16:00 hours, with about 3% feed refusals daily. Throughout the study, diets contained at least 18% CP, 31% NDF, and an NEL of 1.67 Mcal/kg, adjusted for 23 kg of DMI. The forage-to-concentrate ratio was 50:50, and the ration was formulated to meet the nutrient requirements of 650 kg Holstein cows producing around 33 kg of 3.5% fat-corrected milk (NRC, 2001). Cows had free access to water at all times. Milking was performed three times daily at 01:00, 09:00, and 17:00 hours. The herd's annual daily milk yield ranged from 27.6 kg in summer to 33.0 kg in winter. For dry cows, the diet was designed to meet NRC (2001) nutrient requirements. Dry-off time was 60 days before the expected calving date or when daily milk yield was less than 18 kg.

Meteorological data. Seven years of climatic data (2014–2020) were collected from an official meteorological station located about 2 kilometers from the dairy farm (Experimental Station La Laguna, INIFAP, Matamoros, Mexico; 25°32′03″N 103°14′27″W). The data included hourly measurements of ambient temperature (°C) and relative humidity (%). This information was used to calculate the THI using the following formula:

$$\textit{Temperature-Humidity Index}\ (\text{THI}) = (0.8 \times \text{ambient temperature}) + [\%\ \text{relative humidity}/100 \times (\text{ambient temperature} - 14.4)] + 46.4.$$

Statistical analyses. We established a back-testing framework for one year of forecasting using a time series approach to predict the occurrence of RP, PM, and CK in cows and heifers. Statgraphics Centurion XV software (StatPoint Technologies Inc., Warrenton, VA, USA) was used to select a forecasting model by comparing multiple models and choosing the one with the lowest values for the Akaike Information Criterion (AIC) and the lowest Mean Absolute Percentage Error (MAPE); the level of significance was set at 5%. A common practice for this process is to choose an autoregressive integrated moving average (ARIMA) model (Luo et al, 2023). The final automatic model selection was based on the lowest Akaike information criterion value. The autocorrelation function (ACF; relationship between observations at different time lags) and partial autocorrelation function (PACF; direct correlation between a variable and its lagged values after removing the effects of intermediary time steps) were used to identify the order of moving average and autoregressive terms in the ARIMA model and to evaluate the goodness of fit. Cycles of 30 days were selected as the measurement unit to analyze the monthly occurrence of RP, PM, and CK.

ARIMA is a combination of auto-regressive and moving average components, represented by p (the order of autoregression), d (the degree of difference), and q (the order of moving average). The general multiplicative seasonal ARIMA model was:

$$Xt = \Phi_1 X_{t-1} + \ldots + \Phi_p X_{t-p} + a_t - \theta_1 a_{t-1} - \ldots - \theta_q a_{t-q}.$$

Where Φ (phis) represent the autoregressive parameters to be estimated, θ's (thetas) are the moving average parameters to be determined; the original series is denoted by X's, and a's are unknown random errors presumed to follow a normal probability distribution. The Box-Jenkins method was used to estimate p, d, and q values (Jere and Moyo, 2016), which define the structure of the ARIMA model and identify trends, seasonality, or other systematic patterns that change over time.

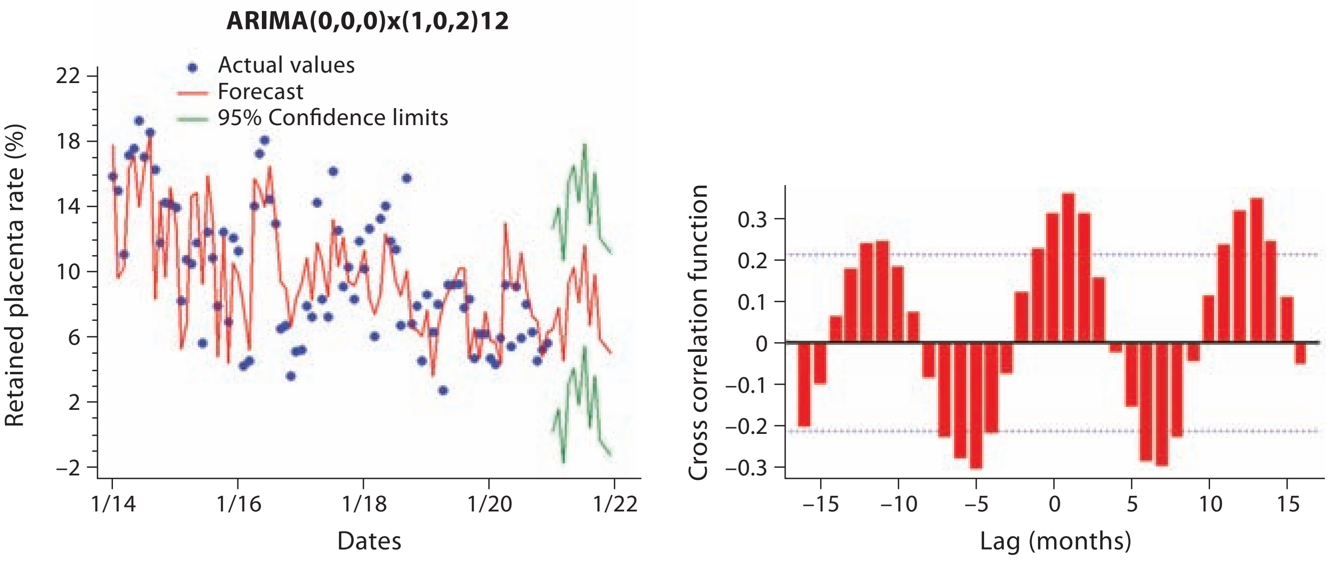
The Wessa software (2025) was used to calculate the cross-correlation between reproductive variables and THI over time for univariate time series. For all statistical analyses, $P < 0.05$ was considered statistically significant.

RESULTS

Retained placenta. The average prevalence of RP (7 years) observed in the present study was 11.1% in cows and 13.2% in heifers. The autocorrelation function (ACF) and the partial autocorrelation function (PACF) indicated that RP in cows was stationary over time, and the model fit the data reasonably well (**Fig. 1A**). Predicted RP in cows was highest in May (11.3%; 95% CI = 6.3–16.4) and lowest in November (5.4%; 95% CI = 0.5–10.4).

For cows, THI (input variable) and RP (%) (output variable) were significantly positively correlated within the same month (**Fig. 1B**). Correlations were significant and positive at lags +1, +2, and –1, indicating that THI and monthly RP in cows were positively correlated 2.5 and 5 months before parturition, as well as 2.5 months after parturition, demonstrating the strong and lasting positive effect of heat stress before calving on RP.

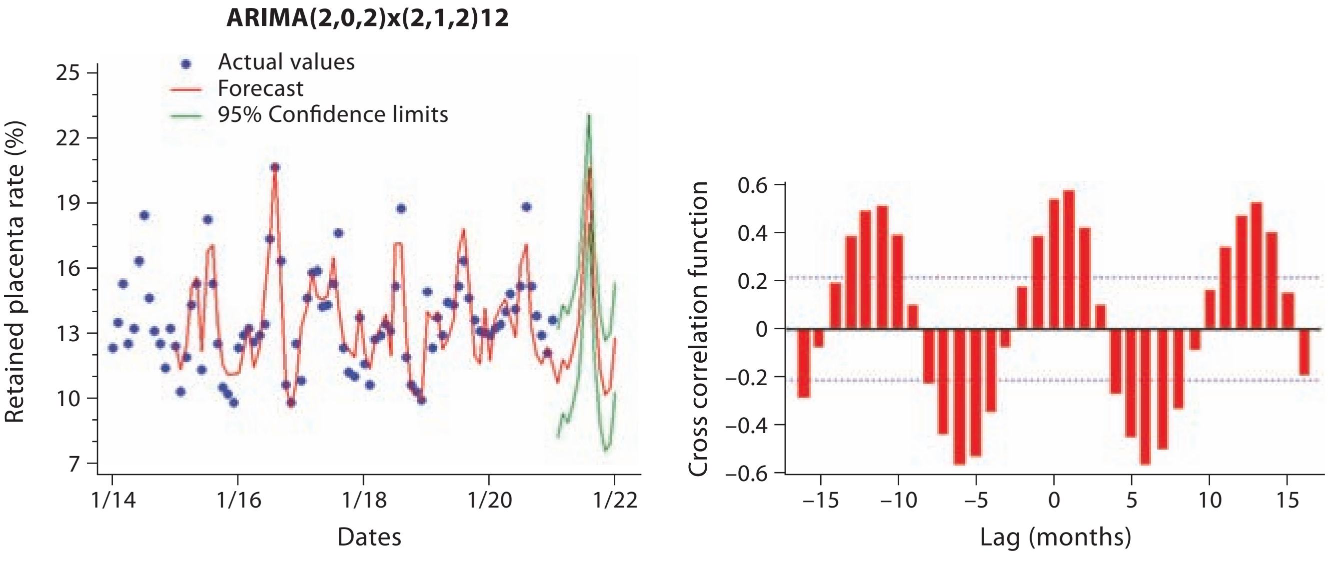
Time series plot of monthly RP cases in heifers during the period of this study is illustrated in **Fig. 2A**. The monthly predicted RP cases was highest in August (20.6%; 95% CI = 11.0–23.1) and lowest in December (10.5%; 95% CI = 7.9–13.0). For heifers, the cross-correlation function analysis between monthly THI and RP showed a significant positive relationship in the same month and 2.5 and 5 months prior (lags +1, +2; **Fig. 2B**). There was a significant positive relationship between THI and RP 2.5 months after calving, suggesting a delayed and persistent impact of warmer months on increased RP.



A

B

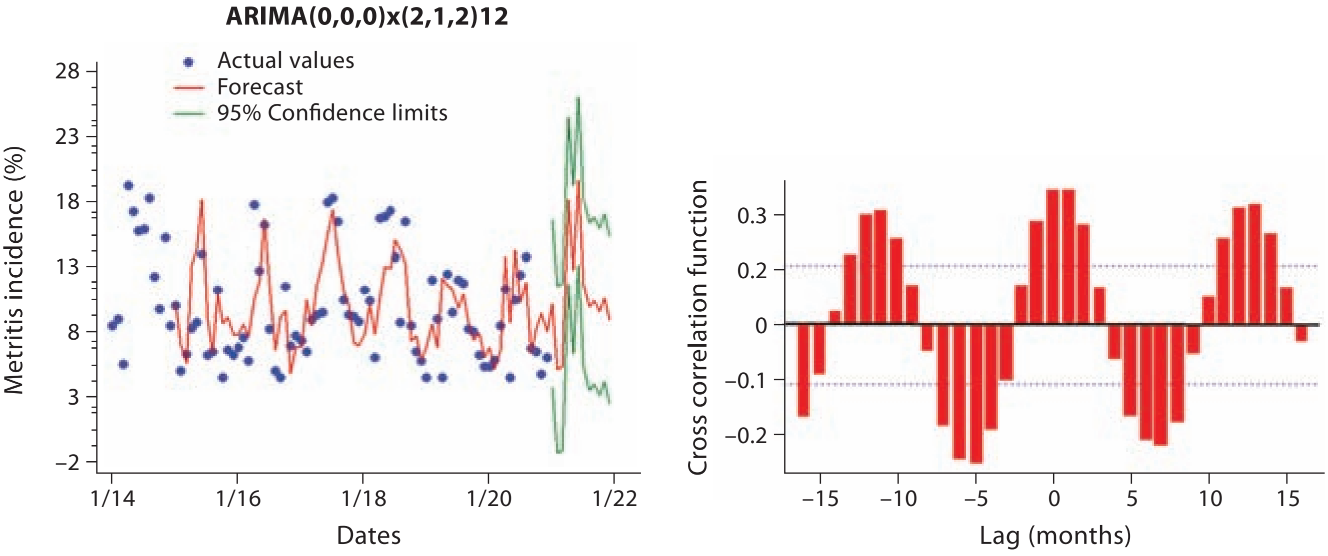
Fig. 1. **A:** The time series for monthly retained placenta rate in Holstein cows. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. **B:** Cross-correlation function of the time series of monthly temperature-humidity index and the proportion of monthly retained placenta in cows. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients



A

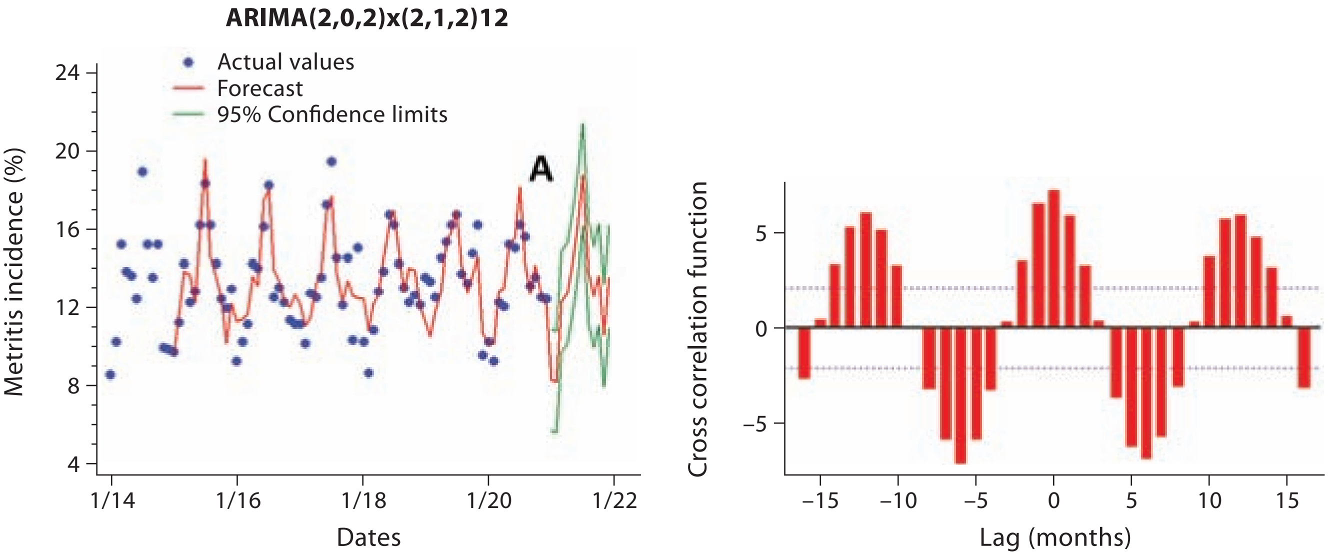
B

Fig. 2. **A:** The time series for monthly retained placenta rate in Holstein heifers. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. **B:** Cross-correlation function of the time series of monthly temperature-humidity index and proportion of monthly retained placenta in heifers. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients



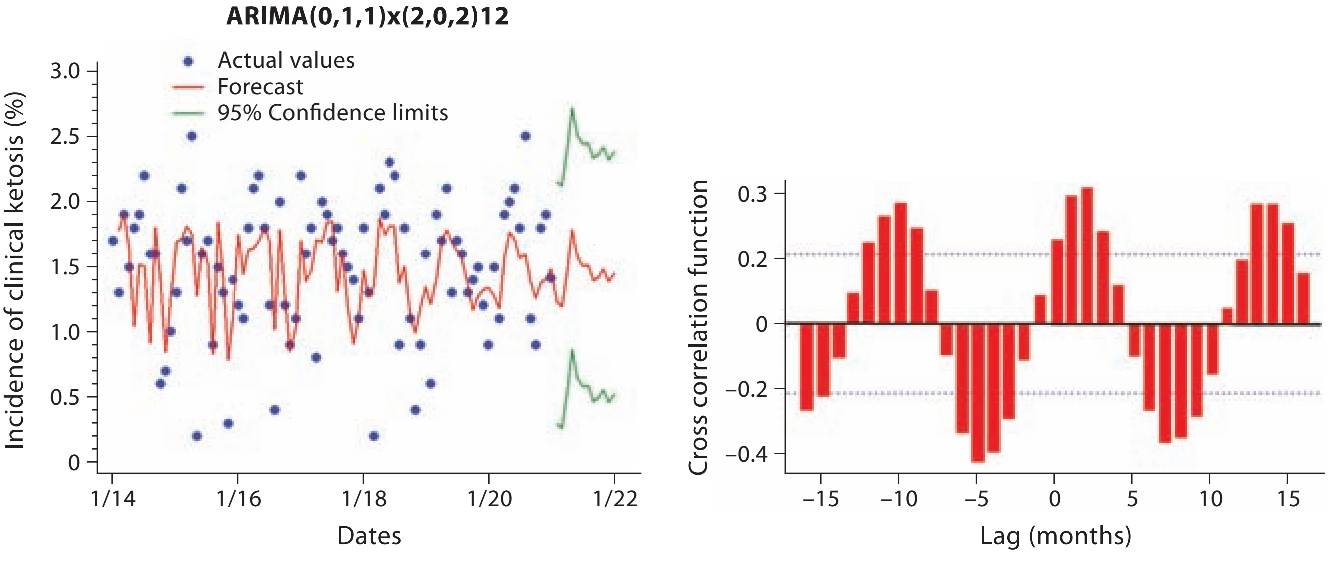
A B

Fig. 3. A: The time series for the monthly average incidence rate of puerperal metritis in Holstein cows. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. **B:** Cross-correlation function of the time series of monthly temperature-humidity index and monthly incidence of puerperal metritis in cows. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients



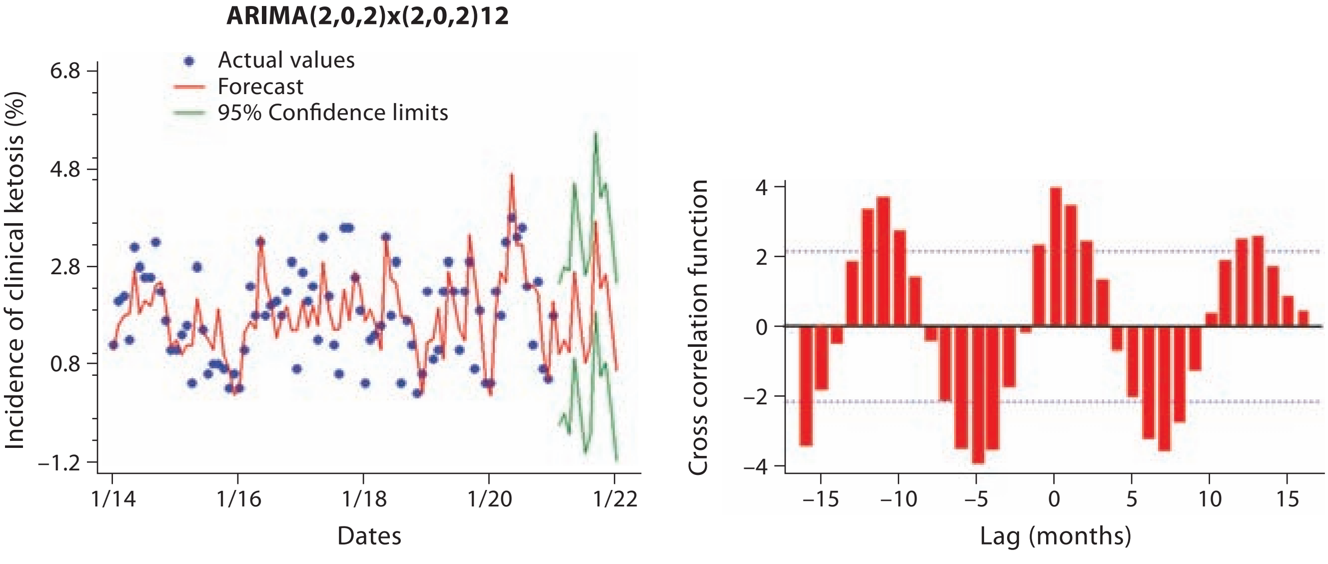
A B

Fig. 4. A: The time series for monthly puerperal metritis rate in Holstein heifers. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. **B:** Cross-correlation function of the time series of monthly temperature-humidity index and proportion of puerperal metritis rate in heifers. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients



A **B**

Fig. 5. **A:** The time series for the monthly average incidence rate of clinical ketosis in Holstein cows. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. B: Cross-correlation function of the time series of monthly temperature-humidity index and monthly incidence of clinical ketosis in cows. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients



A **B**

Fig. 6. **A:** The time series for the monthly average incidence rate of clinical ketosis in Holstein heifers. Each point denotes the mean value of a single herd (~2900 lactating cows) from 2014 to 2020. Values are fitted and predicted values. B: Cross-correlation function of the time series of monthly temperature-humidity index and monthly incidence of clinical ketosis in heifers. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95% confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients

Puerperal metritis. The overall incidence of PM was 11.3% in cows and 13.3% in heifers. Regarding the monthly incidence of PM in cows, **Fig. 3A** showed that the series were stationary. The predicted PM in cows was highest in July at 17.0% (95% CI = 12.1–21.8) and lowest in March at 7.3% (95% CI = 2.5–12.1). The cross-correlation plot between THI and the monthly incidence of PM in cows indicated that these variables were significantly correlated in the same month, as well as 2.5 and 5 months before calving, and 2.5 months after calving (**Fig. 3B**). The time series shape of the monthly RP incidence in heifers in this study showed a steady trend over the years (**Fig. 4A**). The forecasted peak monthly PM occurrence was in July at 18.8% (95% CI = 15.2–21.4), and the lowest was in February at 8.2% (95% CI = 5.7–10.8). The cross-correlation plot between THI and the monthly incidence of metritis in heifers showed significant correlations in the same month, 2.5, 5, and 7.5 months before calving, and 2.5 months after calving (**Fig. 4B**).

Clinical ketosis. The average incidence of CK for cows was 1.4%, and for heifers, 1.8%. CK in cows presented a manifest seasonal cyclicity, peaking in May and June (**Fig. 5A**). The predicted CK in cows was highest in May (1.8%; 95% CI = 0.9–2.7) and lowest in February (1.2%; 95% CI = 0.3–2.1). The cross-correlation plot between THI and CK in cows showed that these variables were significantly correlated in the same month and at 2.5, 5, and 7.5 months before parturition (**Fig. 5B**). These data indicated that warmer ambient temperatures in the months before parturition played a critical role in the occurrence of CK in a hot environment.

Predicted CK in heifers was highest in May (2.7%; 95% CI = 0.9–4.5) and lowest in December (0.7%; 95% CI = –1.1–2.5; **Fig. 6A**). Similarly, **Fig. 6B** showed that, for heifers, THI (input variable) and CK (output variable) were significantly positively correlated in the same month and at 2.5 and 5 months before parturition.

DISCUSSION

Retained placenta. The incidence of RP in this study falls within the normal range (9.4–22.6%) reported across various breeds, management systems, and countries (Chebel, 2021; Magata et al., 2021). One objective of this study was to analyze the seasonal patterns of RP in Holstein cows and heifers in a hot environment. The time plot showed recurring patterns at regular intervals, with RT increasing in summer and decreasing in winter. Similarly, Kamel et al. (2022), using extensive data from high-input Holstein dairy farms in a hot climate, observed higher RP rates in summer compared to other seasons. The peak RP rate during summer may be due to heat stress, which delays placenta expulsion, as seen in the study area where RP rose exponentially when THI exceeded 80 (Mellado et al, 2023). The influence of heat stress on PR cases may also stem from shorter gestation in heat-stressed cows in late gestation compared to those calving during cooler seasons (Tao and Dahl, 2013), since shorter gestations are linked with higher RP incidence (Mahnani et al, 2021). Additionally, heat stress affects the placenta of late-gestation dairy cows, resulting in fewer cotyledons and generally smaller cotyledon surface areas than cows cooled during the last two months of gestation (Casarotto et al, 2025).

The maximum THI in the current study was 89.6, indicating the severity of the heat load experienced by the heifers and cows. This stress could have triggered physiological changes such as increased evaporation, a higher heart rate, and an elevated respiratory rate in cows experiencing heat stress, which in turn affect oxidative stress, immune responses, and hormonal imbalances (Hashem and Amer, 2008; Chauhan et al, 2021). This response may impair the capacity of heifers and cows to detach the placenta after delivery from the uterine caruncle. Longer fetal membrane expulsion is more common in heat-stressed cows than in non-stressed cows (Seyed Almoosavi et al, 2021). High ambient temperatures in dairy cows limit oxygen metabolism (Zeng et al, 2023), and oxidative imbalance increases RP (Li et al, 2022).

This study reaffirms the importance of heat stress during late gestation and the occurrence of RP in heifers and cows (Mellado et al, 2023). Research on the effects of prolonged thermal stress prepartum on RP is limited. In this study, the increased RP in heifers and cows calving in the summer months compared to those calving in winter is probably related to greater THI exposure during the final stage of gestation, which could negatively affect immune function and the cows' ability to detach fetal membranes effectively (Menta et al, 2017).

Puerperal metritis. The occurrence of puerperal metritis in this study falls within the range of 10.8 to 34.4% in cows in high-input dairy systems (Benzaquen et al., 2007; Vieira-Neto et al., 2016; McNeel et al., 2017). Data from this research show that severe and prolonged heat stress is a key factor predisposing both cows and heifers to puerperal metritis, which is consistent with Gernand et al. (2019), who observed a positive correlation between PM and increased ambient temperature after parturition in dairy cows. Furthermore, the incidence of PM is higher in cows calving during the cool season compared to those calving in warmer seasons (Giuliodori et al., 2017; Jeong et al., 2018), regardless of differences in vaginal microbiome (Moliniari et al., 2022). Evidence suggests that rising temperature and humidity influence the host's response to the microbial pathogen, leading to uterine infections. High ambient temperatures weaken the immune system, raising the risk of disease (Lacetera, 2019) by encouraging the multiplication of pathogenic microorganisms (Quintana et al., 2020). Additionally, increased rates of metritis under hot and humid conditions may be due to higher pathogen carriers and dysbiosis of the uterine microbiota, characterized by decreased diversity and increased levels of Bacteroidetes and Fusobacteria (Galvão et al., 2019).

These findings suggest that warmer ambient temperatures in the months before and after parturition are crucial factors in preventing metritis in cows and heifers in hot environments. Mellado et al. (2023) indicated that a THI value above 85, indicating moderate to severe heat stress, marks a breakpoint for a significant increase in puerperal metritis incidence. These findings imply that high ambient temperatures reduce the number and activity of specific immune cells in dairy cows, and that prolonged thermal stress hampers their ability to fight uterine infections both before and after parturition, making them more vulnerable to uterine pathogens (Giannone et al, 2023).

Heifers showed a higher incidence of PM than multiparous herd mates (13.3% vs. 11.3%) due to greater calving difficulties in nulliparous cows (Ghavi Hossein-Zadeh and Ardalan, 2011), which increases the likelihood of puerperal pathogen contamination and uterine lesions (Galvão, 2013), or a dysbiosis of the uterine microbiota (Jeon and Galvão, 2018), leading to PM.

Clinical ketosis. The incidence of CK in the current study falls within the range observed in high-input dairy herds in various countries (0.7–3.5%; Berge and Vertenten, 2014; Loiklung et al, 2022). The higher incidence of CK in cows and heifers during the warmest months aligns with a previous study showing that cows calving in summer tend to have a higher risk of ketosis than those calving in other seasons (Jeong et al, 2017). In fact, as thermal stress increases (THI > 80), the incidence of CK also rises (Mellado et al, 2023). However, other reports contradict these findings, showing a lower incidence of CK in summer months (Mellado et al, 2018; Pérez-Báez et al, 2019). These conflicting studies may be due to differences in detection methods for CK, sample sizes, environments, and data interpretation.

Heat stress decreases feed intake, which, in turn, alters energy metabolism, particularly during the transition period (Chang-Fung-Martel et al., 2021), a condition associated with ketosis (Pérez-Báez et al., 2019). The present study provides evidence that high ambient temperatures predispose heifers and cows to CK, highlighting the association between post-calving blood hyperketonemia and lower milk yield, poorer reproductive performance, and higher culling rates (Guliński, 2021).

In the present study, dry cows did not undergo cooling systems; therefore, the physiological effects of acute heat stress during late gestation became evident after calving, influencing the occurrence of CK. Thermal stress causes immunosuppression, increasing the influx of endotoxins and raising vulnerability to metabolic illnesses (Baumgard and Rhoads, 2013; Koch et al, 2019).

CONCLUSIONS

In the challenging, hot environment of this study, ARIMA modeling effectively identified seasonal patterns and accurately predicted future RP, PM, and CK peaks in Holstein heifers and cows, as validated by robust performance metrics, including the Mean Absolute Percentage Error (MAPE) and the Akaike Information Criterion (AIC). Moreover, the ARIMA models demonstrated the potential to forecast demand for veterinary interventions and preventive measures for RP, PM, and CK in cows and heifers during specific months, thereby helping anticipate administrative actions and timely veterinary care. Our study reaffirmed that heat stress before calving significantly affects the incidence of RP, PM, and CK in this hot setting. This research emphasizes the value of forecasting puerperal disorders to improve preparedness and enable early intervention, thereby reducing periparturient diseases in Holstein cows and heifers in hot environments.

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Data availability. The datasets used in the current study are available from Dr. M. Mellado (email: melladomiguel07@gmail.com) upon reasonable request.

Competing interests. The authors declare that there are no conflicts of interest regarding the publication of this article.

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МОДЕЛЮВАННЯ ЧАСОВИХ РЯДІВ ЗАТРИМКИ ПЛАЦЕНТИ, МЕТРИТУ ТА КЕТОЗУ В КОРІВ І ПЕРВІСТОК ГОЛШТИНСЬКОЇ ПОРОДИ ТА ЇХНІЙ ЗВ'ЯЗОК ІЗ КЛІМАТИЧНИМИ ПАРАМЕТРАМИ В ПОСУШЛИВІЙ ЗОНІ

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Мета. Спрогнозувати щомісячну частоту випадків затримки плаценти (ЗП), післяпологового метриту (ПМ) та клінічного кетозу (КК) у корів і первісток голштинської породи корів в умовах молочного комплексу інтенсивного типу. **Методи.** Для прогнозування майбутніх щомісячних випадків захворювань на основі даних часових рядів було застосовано модель авторегресії та інтегрованого ковзного середнього (ARIMA). Дослідження проводилися на базі одного молочного господарства (поголів'я від 2560 до 3300 корів) протягом семи років (2014–2020 рр.). **Результати.** Найвищу прогнозовану частоту ЗП у корів зафіксовано в травні (11,3%; 95% ДІ = 6,3–16,4), а найнижчу — у листопаді (5,4%; 95% ДІ = 0,5–10,4). У первісток пік захворюваності на ЗП припав на серпень (20,6%; 95% ДІ = 11,0–23,1), тоді як мінімум спостерігався у грудні (10,5%; 95% ДІ = 7,9–13,0). Найвищий прогнозований рівень КК серед корів відмічено в червні (ДІ = 1,8–4,3), найнижчий — у листопаді (1,1%; 95% ДІ = –0,1–2,4). Серед первісток імовірність виникнення КК була найвищою в травні (2,7%; 95% ДІ = 0,9–4,5) і найнижчою в грудні (0,7%; 95% ДІ = –1,1–2,5). **Висновки.** У літні місяці спостерігалася тенденція до зростання кількості випадків ЗП, ПМ та КК як у дорослих корів, так і у первісток. Моделі ARIMA продемонстрували ефективність у відстеженні сезонних тенденцій захворюваності й можуть бути використані як інструмент підтримки прийняття рішень в управлінні здоров'ям стада.

Ключові слова: молочні корови, тепловий стрес, навколопологові захворювання, температурно-вологісний індекс (THI), аналіз тенденцій, довірчий інтервал (ДІ).