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# Factors affecting the hourly distribution of calving in Holstein cows in a hot environment

## [ Fatores que afetam a distribuição horária do parto em vacas Holandesas em um ambiente quente ]

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**Abstract**: This study aimed to determine whether hourly calvings in Holstein cows vary with calf gender, dystocia, stillbirth, gestation length, and heat stress at calving. Additionally, the monthly calving time of cows was predicted using an autoregressive integrated moving average (ARIMA) model. The parturition times of 29,410 Holstein cows recorded over seven years from a single herd were analyzed. More cows/heifers calved during daylight hours (57.5 %) than in darkness (42.5 %). On the day of calving, cows experiencing severe heat stress (THI > 84) on average calved 30 minutes later (P < 0.001) than cows not experiencing heat stress (THI < 70). Cows with gestations <277 days gave birth 24 minutes later (P < 0.05) than cows with gestation lengths between 279-281 days. On average, calving occurred six minutes earlier (P < 0.05) in cows carrying female calves compared to male calves. Cows giving birth to stillborn calves calved, on average, one hour later (P < 0.001) than those giving birth to live calves. Cows experiencing calving difficulty calved, on average, one hour later (P < 0.001) than cows with eutocic deliveries. The ARIMA model showed that deviations of calving hour from the overall mean were greater in summer and lower in winter. It was concluded that weather strongly influences the monthly calving rhythms in cows and heifers, and the ARIMA models reliably estimated the timing of parturition. Although various factors significantly affected birth frequency, these variations were not substantial enough to be of practical importance for managing pregnant Holstein cows.

**Keywords:** ARIMA; dystocia; gestation length; heat stress; stillbirth.

**Resumo**: Este estudo teve como objetivo determinar se o número de partos por hora em vacas da raça Holandesa varia de acordo com o sexo do bezerro, distócia, natimorto, duração da gestação e estresse térmico no momento do parto. Além disso, avaliou-se a predição do horário mensal de parto das vacas por meio de um modelo autorregressivo integrado de médias móveis (ARIMA). Foram utilizados os dados de 29,410 vacas da raça Holandesa, registrados ao longo de sete anos em um único rebanho. Mais vacas/novilhas pariram durante o dia (57.5 %) do que à noite (42.5 %). Vacas submetidas a estresse térmico severo (Índice de Temperatura e Umidade [ITU] > 84) no dia do parto pariram, em média, 30 minutos mais tarde (P < 0,001) do que vacas sem estresse térmico (ITU < 70). Vacas com gestações < 277 dias pariram 24 minutos mais tarde (P < 0.05) do que vacas com



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gestações entre 279 e 281 dias. Em média, o parto ocorreu seis minutos mais cedo (P < 0.05) em vacas que pariram bezerros machos e bezerros fêmeas. Vacas que deram à luz bezerros natimortos pariram, em média, uma hora mais tarde (P < 0,001) do que aquelas que deram à luz bezerros vivos. Vacas que apresentaram dificuldades no parto pariram, em média, uma hora mais tarde (P < 0,001) do que vacas com parto normal. O modelo ARIMA indicou que o desvio da hora do parto em relação à média geral foi maior no verão e menor no inverno. Concluiu-se que o clima teve forte influência nos ritmos mensais de parto em vacas e novilhas, e que os modelos ARIMA estimaram de forma robusta a ocorrência de partos. Embora diversos fatores tenham afetado significativamente a frequência de nascimentos, essas alterações não foram substanciais o suficiente para serem relevantes e tiveram importância prática limitada para o manejo de vacas Holandesas gestantes.

**Palavras-chave**: ARIMA; distocia; duração da gestação; estresse térmico; natimorto.

## 1. Introduction

Parturition is a crucial stage in the life cycle of dairy cows. It is a stressful period for cows that can negatively affect their periparturient health, future milk production, and reproductive success [(1)]. Additionally, dystocic parturition may also increase neonatal mortality and health issues in calves [(2)] and is linked to postpartum health problems such as retained placenta, uterine infections, delayed return to estrus, and reduced fertility [(3,4)].

Therefore, proper maternal care during calving is essential for delivering a healthy, live calf and ensuring a smooth transition for the cow [(5)]. Dairy cows at parturition require continuous supervision to ensure successful calving, including recognizing and assisting with calving difficulties. Knowing the hourly distribution of calving times can help stockpersons focus their attention during specific hours to monitor calving. Since the timing of birth varies throughout the day, these patterns have implications for technician staffing, as adequate staffing is necessary in the evenings and at night.

There are few studies on the timing of dairy cow parturition. In the USA, it was observed that more calves are born between 0600 and 1800 hours than from 1800 to 0600 hours (56 % vs. 44 %) [(6)]. In the UK, calvings are reported to be evenly spread throughout the 24-hour period, with no preference for day or night births and no link to feeding times [(7)]. Data have linked delivery times to feeding schedules, indicating that when spring-calving beef cows are fed in the morning, calving occurs at random times during the day [(8)]. However, when feed is provided in the evening, more cows calve during daylight hours. Since earlier studies are outdated and based on limited observations to quantify the hourly distribution of parturition throughout the 24-hour day, this study aimed to determine whether calving in Holstein cows in hot environments occurs uniformly throughout the day. Another goal was to analyze how the hourly distribution of calving varies by calf gender, calving difficulty, gestation length, and heat stress at calving. Additionally, this research sought to model the time series pattern of calving in Holstein cows and heifers to develop an accurate prediction model using ARIMA. The final objective was to assess the time lag between calving activity and climatic conditions throughout the year.

## 2. Materials and methods

The procedures involving cows and heifers in the present study adhered to the guidelines outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (https://www.adsa.org/Portals/_default/SiteContent/docs/AgGuide3rd/Chapter07.pdf). The animal experiment was conducted under ethics permit 38111-425203001-2116 at the Autonomous Agrarian University Antonio Narro.

## 2.1 Animals, feeding, and housing

This study used cow records from a single commercial dairy farm that milks about 4,600 Holstein cows over a seven-year period, from January 2017 to December 2023, in northeastern Mexico (25°N; mean annual temperature 22.2 °C; average annual precipitation 230 mm). A total of 29,410 Holstein cow records were collected from cows and heifers enrolled on the day of calving. Some records were excluded if circumstances appeared to affect the start of labor, such as twins, antenatal complications (like vaginal prolapse), and calves with congenital malformations.

Cows were housed in large outdoor pens with dry, uncompacted manure and were milked three times daily. The barns had fans in the central area, and soaker lines with nozzles (activated every 5 minutes) were positioned above the feed lane. The system was turned on when the ambient temperature reached 25 °C.

The average daily milk yield per cow was 33.7 kg. Cows were fed a total mixed ration formulated to meet or exceed the nutrient requirements for lactating Holstein cows weighing 680 kg and producing 38 kg of 3.5 % fat-corrected milk[9]. Cows were fed around 7:00 a.m. and 3:00 p.m. Cows calving from 19:00 to 06:00 were considered to have calved at night, while those calving between 07:00 and 18:00 were considered to have calved during the day.

## 2.2 Parturition recordings

Approximately one week before the cows were due to calve, the animals were moved into individual maternity pens measuring 3 × 4 meters, constructed of horizontal tubular metal bars and containing no bedding. The cows were fed a prepartum total mixed ration ad libitum, consisting of a dietary forage-to-concentrate ratio of 70:30 (20 % corn silage, 50 % alfalfa hay) and 30 % concentrate and mineral mix on a dry matter basis (CP: 15.0, NEL: 1.4 Mcal/kg). Farm staff continuously inspected the maternity pens and recorded the hours of parturition, specifically the culmination of stage 2 of labor, which is the delivery of the calf. The time of parturition was defined as the delivery of the calf after it was forced out of the cow’s body, the umbilical cord broke, and the calf started to breathe on its own. Personnel do not observe calving cows "permanently" in the sense of a single person watching one cow 24/7 without interruption. However, intensive, continuous, or near-continuous monitoring protocols were used. The time from the appearance of the amniotic sac or the calf's feet outside the vulva was used by the technicians as a guideline to determine their presence for registering the calving time.

When necessary, staff provided assistance to cows experiencing calving difficulties, such as a lack of progression in labor, cow distress, or calf’s tongue protrusion. Dystocia was defined as a difficult birth that results in a prolonged calving process or requires significant assistance to extract the calf. The level of assistance during parturition was classified on a scale from 1 to 3, where 1 indicates no assistance, 2 indicates slight assistance, and 3 indicates the need for assistance, including mechanical extraction.

During this study, assistance was required in 16 % of parturitions. Additionally, at calving, the gender of calves and those born dead were recorded. Gestation length was calculated as the interval between the last artificial insemination that resulted in pregnancy and the day of parturition. Stillbirth was defined as the death of a calf occurring after at least 260 days of pregnancy, just before (already dead in the uterus), during (due to a difficult calving), or within 24 hours after birth. Stillbirth was considered as a binary trait (1 = stillbirth and 0 = no stillbirth). The calving percentage varied by season, with the highest in September (10.1 %) and the lowest in April (3.4 %).

## 2.3 Temperature-humidity index (THI) calculation

The mean ambient temperature (Ta) in Celsius and the percentage of relative humidity (RH) on the day of calving were used to calculate the THI, according to the formula: THI= (0.8 × Ta) + [(RH / 100) × Ta – 14.3)] + 46.4 [10]. Although thermal radiation and airflow also influence total heat exchange [11], these variables were omitted because atmospheric temperature remains the primary factor driving heat exchange between the environment and the cows [12]. The THI for the study period is presented in Fig. 1.

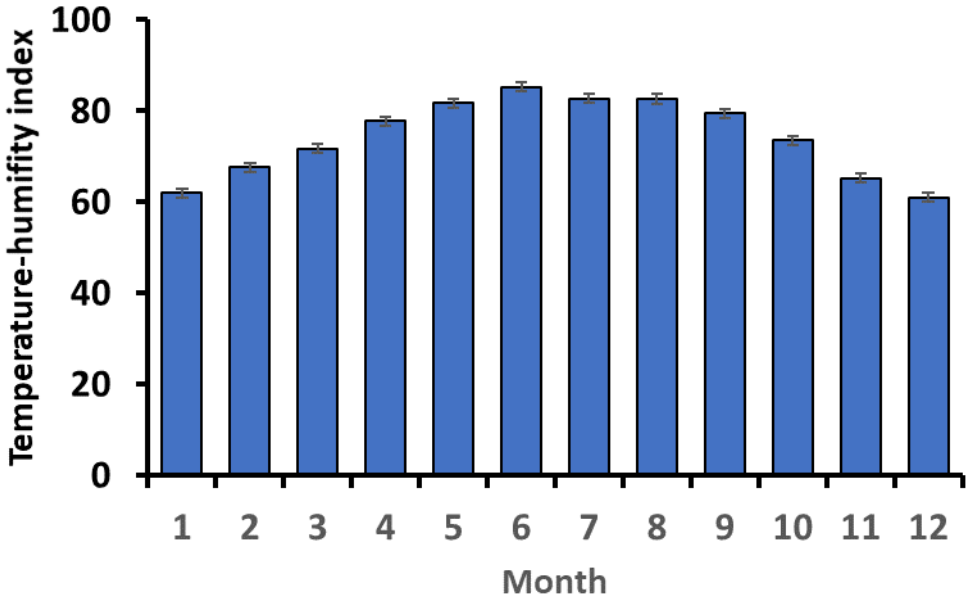


**Figure 1.** Monthly mean (± standard deviation) of the temperature-humidity index values during the study period (2017-2023) in the study site (25° N).

## 2.4 Statistical analyses

The PROC UNIVARIATE in SAS (SAS Institute Inc., Cary, NC, USA; version 9.4) was used to assess the normality of the time of parturition data. The Kolmogorov-Smirnov, Anderson-Darling, and Cramér-von Mises tests showed that data were normally distributed.

The hour of parturition was analyzed using the GLIMMIX procedure in SAS. The effects of THI, calf gender, gestation length, and stillbirth on the hour of calving (HC) were examined using a one-step procedure; HC was adjusted for a set of fixed and random effects, fitting the following mixed linear model.

$$HC_{ijklm} = \mu + cow_i + par_j + THI_k + calv_l + gen_m + still_n + diff_o + \epsilon_{ijklmno}$$

where $HC_{ijklm}$ is the calving time in one-hour intervals; μ= overall mean; $cow_i$ is the random effect of the *i*th cow (to account for the correlation between measurements recorded from the same cows); $par_j$ the fixed effect of the parity order*j* (confounding adjustment); $THI_k$ the fixed effect of the heat stress level *k*, classified based on no stress (THI <70), slight stress (THI =70-77), moderate stress (THI =77-84) and severe stress (THI >84); $calv_l$ the fixed effect of the year of calving (accounting for this confounding variable); $gen_m$ the effect of gender; $still_n$ the effect of stillbirths; $diff_o$ the effect of difficult parturition (yes or not) + $\epsilon_{ijklm}$ the random residual effect.

The relationship between the timing of parturition and the percentage of calvings in cows and heifers was analyzed using non-linear regression analysis with CurveExpert Professional 2.5.6 software (Hyams Development, Madison, AL, USA). Observations of calving hours collected

over seven years were used to develop a prediction model for the timing of parturition and to forecast the model's accuracy for the following year, with 95 % confidence intervals. For this purpose, Statgraphics Centurion XV software (Statpoint Technologies Inc., Warrenton, VA, USA) was employed to select the most suitable forecasting model by comparing multiple options and choosing the one that maximized the specified information criterion.

A common approach to this procedure is to select an autoregressive integrated moving-average (ARIMA) model of order (p, p-1). The final model was chosen based on the lowest Akaike information criterion value. The autocorrelation function (ACF) and partial autocorrelation function (PACF) of the residuals were used to confirm the autoregressive and moving-average parameters and to evaluate the model´s goodness of fit. 30-day cycles were used as the unit of measurement to analyze the monthly occurrence of parturitions.

ARIMA combines autoregressive and moving-average components, denoted by p, d, and q. Here, p is the number of lag observations included in the model, d indicates how many times raw observations are differenced, and q represents the degree of the moving average. The general ARIMA model was:

$$Xt= \Phi 1X\ t-1 + \ldots + \Phi pXt\text{-}p + at - \theta 1at\text{-}1\text{-}\ldots\text{-}\ \theta q\ at\text{-}q$$

Where Φ's (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 assumed to follow a normal distribution. The Box-Jenkins method was used to estimate p, d, and q values. The Wessa software [13] was used to calculate the cross-correlation between the time of parturition and THI over time for univariate time series. For all statistical analyses, P-values less than 0.05 were considered statistically significant.

The relationship between time of parturition (day or night), animal category (cows or heifers), and calving difficulty (three classes) was analyzed using response surface methodology with Statgraphics Centurion XV software.

## 3. Results

The mean (±SD) and median delivery times were 12:37 ± 6:23 and 12:33, respectively. The hourly calving frequencies showed a discrete unimodal pattern, with the lowest frequency during the dark hours and the highest during light hours (Fig. 2). The decline in parturition times began after 1200 h, while the peak in calving frequency occurred between 0600 and 1100 h over the seven-year period. When dividing the 24-hour day into 'darkness' (19:00-06:00) and "daylight" (07:00-18:00), the hourly percentage of calvings was 57.5 % during the day and 42.5 % at night (Fig. 2).

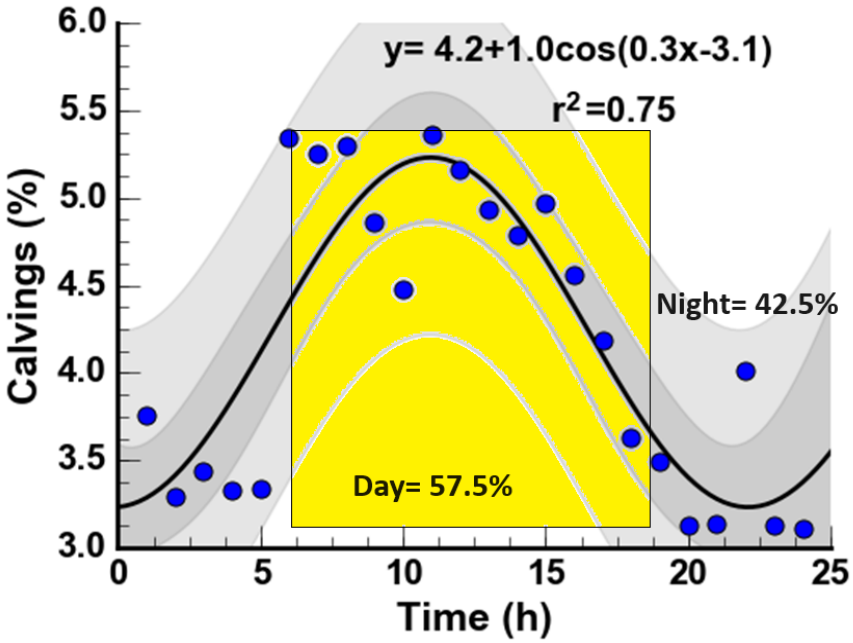


**Figure 2.** Relationship between calving frequency and parturition timing, expressed hourly over the 24-hour day in Holstein cows and heifers in a hot environment. Daytime hours (approximately sunrise to sunset) are marked in yellow. The darker bands correspond to the 95 % confidence interval for real data; the lighter bands correspond to the 95 % confidence interval for predicted data.

The effect of THI was incorporated as a categorical variable with four classes to simplify the model. Results showed that cows experiencing severe heat stress (THI > 84) on the day of parturition calved, on average, 30 minutes later ($P < 0.001$) than cows not subjected to heat stress (THI < 70) (Table 1). It is worth noting that high standard deviations were observed, indicating that data points were widely dispersed around the mean; however, differences between THI categories were statistically significant, primarily driven by the large sample size. Therefore, in this study, statistical significance meant that the observed differences were unlikely to have been caused by chance, not that the differences were large, of practical importance, or consistent.

Cows with gestations <277 days gave birth, on average, 24 minutes later ($P < 0.05$) than cows with gestation lengths between 279-281 days (Table 1). Additionally, delivery time was, on average, 6 minutes earlier ($P < 0.05$) in cows carrying female calves compared to those carrying male calves (Table 1). Due to the large dataset, it is not surprising that this factor significantly influenced calving time, despite the small difference between the means.

**Table 1.** The effect of heat stress, gestation length, calf gender, stillbirth, and dystocia on the hour of birth of high-yielding Holstein cows in a hot environment.

| Variables | n | Average time of day, h | Standard deviation | *P*-value |
|---|---|---|---|---|
| **THI at calving** | | | | 0.0017 |
| <70 | 3498 | 11:42[c] | 06:12 | |
| 70 - 77 | 7796 | 11:54[bc] | 06:18 | |
| 77 - 84 | 12025 | 12:00[b] | 06:24 | |
| >84 | 6091 | 12:12[a] | 06:24 | |
| **Gestation length, days** | | | | 0.0243 |
| <277 | 1258 | 12:12[a] | 06:30 | |
| 277 -279 | 4520 | 11:54[ab] | 06:24 | |
| 279 -281 | 7010 | 11:48[b] | 06:18 | |
| 281 - 283 | 10946 | 12:06[ab] | 06:18 | |
| >283 | 5676 | 11:54[ab] | 06:24 | |
| **Gender** | | | | |
| Male | 14147 | 12:00[a] | 06:24 | 0.0430 |
| Female | 15263 | 11:54[b] | 06:18 | |
| **Stillbirth** | | | | 0.0010 |
| Yes | 1059 | 13:00[a] | 07:00 | |
| No | 28381 | 11:54[b] | 06:18 | |
| **Calving difficulty** | | | | |
| Yes | 1364 | 12:54[a] | 06:06 | <.0001 |
| No | 28046 | 11:54[b] | 06:24 | |

[a,b,c] Within column and variable, means with different superscripts differ (P < 0.05). Units are hours and minutes, in 24-hour format.

Cows that give birth to stillborn calves calved, on average, one hour later than those with healthy calves (Table 1), and cows experiencing calving difficulty calved, on average, one hour later (P < 0.001) than cows with eutocic delivery (Table 1). The relationship between X1 (animal category), X2 (parturition during dark and daylight hours), and Y (difficult parturition) is illustrated in Fig. 3. The highest incidence of dystocia occurred in heifers calving during daylight.

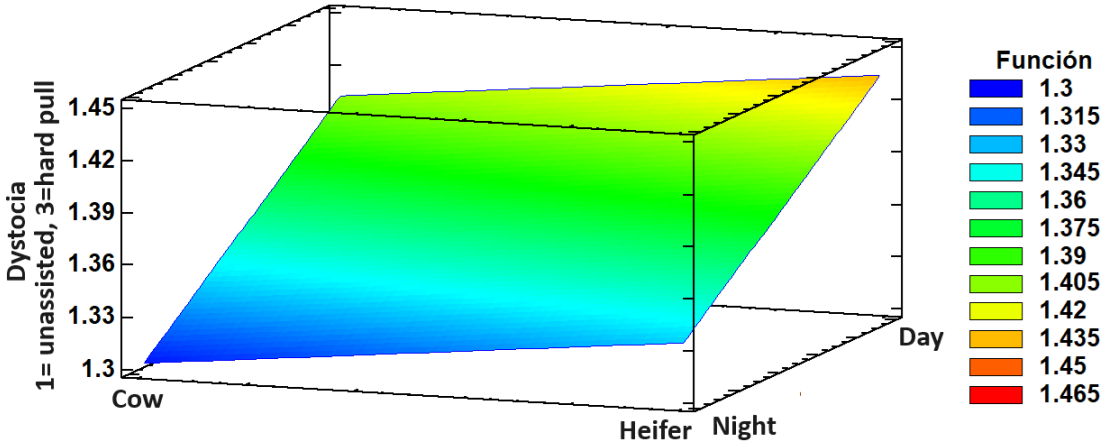


**Figure 3.** Response surface plot showing the occurrence of dystocia (scale 1-3) based on animal category (heifers or cows) and calving during daylight or darkness.

One objective of this study was to examine seasonal patterns of parturition in Holstein cows and heifers in a hot environment. The autocorrelation function (ACF) and the partial autocorrelation function (PACF) indicated that the timing of calving was stationary, and the model fit the data reasonably well (Fig. 4). This suggests that, although subtle, the month of calving influences the timing of parturition. The predicted average time of parturition for heifers and cows, relative to the overall mean, was highest in February (1:10; 95 % CI = 00:7-2:28) and lowest in September (00:03; 95 % CI = -01:18-01:24).

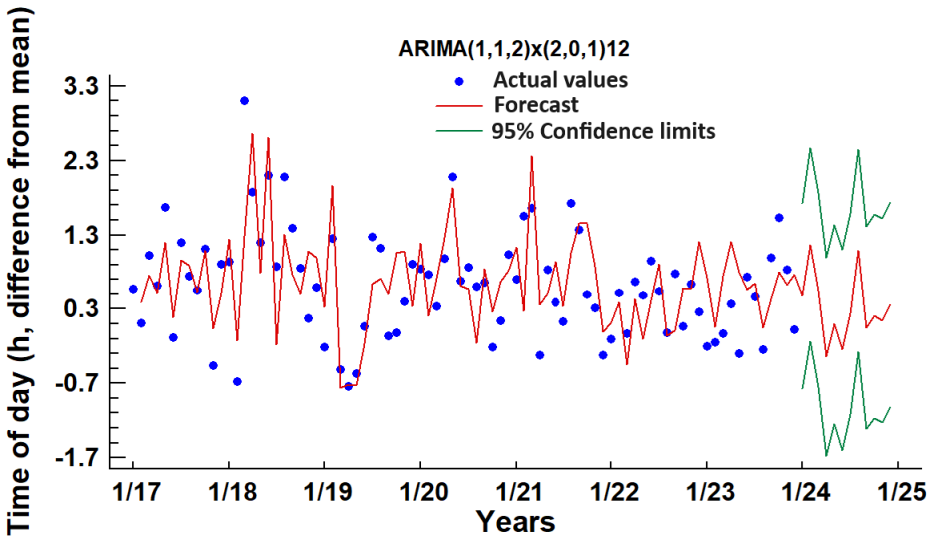


**Figure 4.** The time series of monthly calving hours for high-yielding Holstein cows in a hot environment. Each point represents the mean value of a single herd (~4600 lactating cows) from 2011 to 2023. Values are fitted and predicted values.

For cows/heifers, THI (input variable) and hour of parturition (output variable) were significantly positively correlated within the same month (Fig. 5). Correlations were also significant and positive at lag +1, indicating that THI and monthly calving in cows were positively related approximately 2.5 months earlier. This result suggests a moderate but lasting positive effect of thermal stress before calving on the timing of parturition.

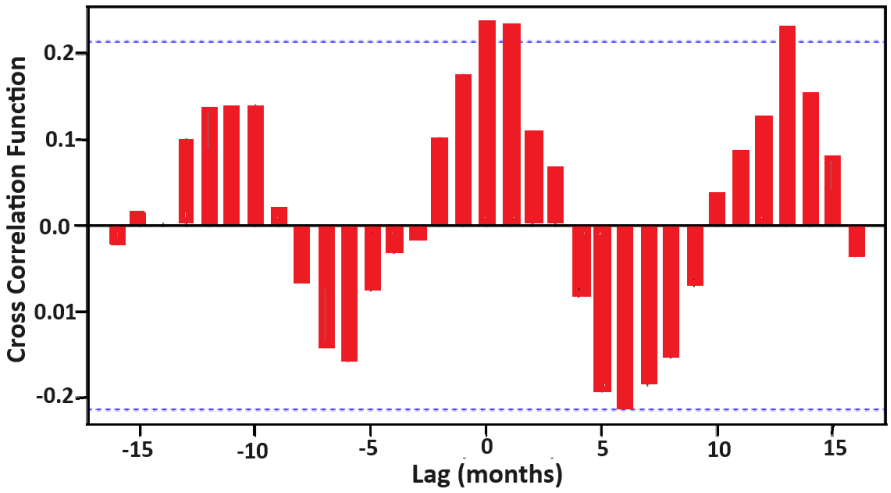


**Figure 5.** Cross-correlation function of the time-series of monthly temperature-humidity index and monthly hours of parturition in Holstein cows in a hot environment. The spikes denote the cross-correlation coefficients. The dashed lines represent the 95 % confidence limits (CL). Spikes outside the CL are significant cross-correlation coefficients.

## 4. Discussion

Despite variations in the hourly timing of parturition times, the overall frequency of births over the 24-hour period remained above 3 %. Cow births could occur at any time, but a general pattern was still observable. These findings are consistent with other studies [7], which showed more calvings from 0601 to 1800 h than from 1801 to 0600 h in Holstein cows. In this study, the hourly calving percentage over the 24-hour period ranged from 3.1 to 5.4 %, aligning with other data [14], in which calving percentages for beef cows ranged from 2.7 to 5.3 % over 24 hours. Therefore, the results suggest that calving times in Holstein cows fed in the morning and afternoon are fairly evenly spread over 24 hours, with a slight peak during the day. This pattern is observed regardless of calf gender, gestation length, stillbirth, dystocia, or heat stress at calving.

Extreme ambient temperatures at calving affected the distribution of births by hour of the day. However, this statistical significance does not translate into practical or economic advantages; thus, applying practices to alleviate heat stress around calving would not benefit dairy farmers seeking to modify birth distribution. The precise cause of this response is unknown. Still, late-gestation heat stress hampers fetal nutrient supply, as it reduces dams' feed intake and diverts maternal blood flow from the uterus to the periphery to maximize the dam´s radiant heat loss, thereby affecting fetal temperature [15]. Placental function is also reduced due to increased cotyledon mass and lower maternal circulating estrone sulfate, which exacerbates the reduced nutrient supply to the fetus and thereby reduces calf birth weight [16,17]. Additionally, heat exposure during late gestation in dams reduces gestation length compared to non-heat-stressed counterparts [18]. All these responses could alter the time of parturition in cows calving on hot days.

Gestation length in this study affected the timing of birth within 24 hours, although this difference was subtle and of limited practical significance. It indicates that gestation length may impact calving time. Several factors influence gestation length in cows, including breed, cow age, ambient temperature, season of mating and calving, milk production, cow parity, and the number and sex of the fetus [19,20]. In this study, it is believed that shorter gestation lengths were mainly due to hot weather at calving, as cows calving in summer tend to have shorter gestation lengths than those calving in winter [21]. Gestation length is 2.0 days shorter in Holstein cows conceiving in October compared to those conceiving in winter [22].

When calving time was examined in relation to calf gender, a slightly different pattern of hourly parturition distribution was observed. A potential effect of gender on the birth process may be linked to fetal morphology, ease of calving, and birth weight, as male calves in this study were 4.1 % heavier than females. Other researchers have noted that Holstein male calves are 8.5 % heavier than female calves [23]. Another physiological explanation for male calves being born slightly later than females is that they produce androgenic hormones during fetal life [24], which, besides promoting muscle tissue growth, could also stimulate the labor process, since testosterone concentrations in dams carrying a male fetus are higher than those carrying a female fetus [25]. As in humans, androgens may regulate parturition through cervical remodeling at term and myometrial relaxation [26].

The timing of delivery was affected by stillbirths. The causes of stillbirths that are not due to infectious reasons appear to be multifactorial, and dystocic calving might be responsible for about half of these stillbirths [27, 28]. Therefore, this factor could be confounded with the impact of difficult calving, especially in calves born to heifers. Disproportionate body conformation [29] and

lower birth weight [30,31] are linked to stillbirth independently of dystocia, implying that poor prenatal development is associated with fetal death shortly before, during, or after calving. This inadequate prenatal development could disrupt key regulatory pathways that control the shift from uterine quiescence to contractility during calving [32]. Additionally, dead calves may exhibit abnormal presentation and posture due to a lack of the righting reflex, which can take time to correct.

Dystocia in this study influenced the distribution of births. Dystocia significantly affects the timing and progression of calving, prolonging the process. We acknowledge that time spent assisting the cows at calving may introduce bias related to calving timing, potentially confounding the interpretation of biological variables associated with parturition time.

Difficult labor has been extensively studied and is characterized by the interaction between fetal factors, such as large size, malposition, twinning, and malformations, and maternal factors, such as an abnormal birth canal and labor [33]. Prolonged labor in cows experiencing difficult calving, lasting more than one hour after rupture of the fetal membranes explains the later calving time compared with cows with eutocic parturition. Additionally, assisted calving with fetal extraction causes metabolic changes (i.e., increased maternal blood glucose and cortisol levels [34], which could affect calving time.

When calving difficulty was analyzed by animal category (primiparous and multiparous) and by calving time (day or night), clustering was observed among primiparous cows calving during the day. These findings partly agree with other studies, which have shown that Holstein cows fed only silage tended to have higher dystocia rates during the day (12 %) than at night (8 %) [35]. The reasons behind these results are not entirely clear. The increased rate of dystocia in cows and heifers might be due to more calvings occurring during daylight hours, when assistance is more accessible.

The extensive data in this study reveal patterns in calving distribution among Holstein cows, providing detailed insights into Holstein cattle behavior during parturition and the innate calving patterns exhibited by cows. The notable differences or associations observed are unlikely to have occurred by chance alone. However, considering the practical implications of these findings in real-world settings, the observed difference is of limited practical significance.

When examining delivery times throughout the year, the data revealed a subtle yet clear pattern recurring over seven years. This study thus demonstrates the link between heat stress during late gestation and the duration of parturition in cows and heifers. The literature on experiments evaluating the effects of prolonged prepartum heat stress on calving times is limited. The current observational study aimed to distinguish the effects of heat stress exposure on calving hours during key periods in gestation. Although observational studies have limitations, such as potential confounders beyond the variable of interest, the results indicate that heat stress earlier in pregnancy and during calving is associated with slight changes in birth timing.

THI is a reliable measure of thermal stress in dairy cows [36]. A high heat index a few days before parturition has been associated with a shortened gestation [37], which could alter calving timing. Although the effect of climatic factors on the onset of parturition has not been established [37], hormones released during periods of stress are also part of the hormonal cascade in bovine parturition, and these hormones may alter calving timing under heat stress [38,39]. In this study, it is crucial to consider both statistical and practical significance for intensive dairy herds; “significance” does not equate to “importance”. Thus, the study’s findings on forecasting future calving times are unlikely to influence current calving management practices, such as labor allocation, calving surveillance, and operational planning, in high-yield dairy herds.

## 5. Conclusion

In this hot environment, the timing of calving for Holstein cows was relatively evenly distributed over the 24-hour period. However, slight variations were evident over the 24-hour period, with more calving during the daytime than at night. Calf gender, warm weather at calving, the occurrence of stillbirths, and calving difficulties did influence the calving distribution during the 24 hours. However, these effects were not large enough to change management or improve animal welfare; thus, the significant effects detected were marginal and of barely practical relevance.

Assisted and unassisted parturitions were unevenly distributed, with higher proportions occurring in heifers giving birth during the daytime. The distribution of calving times across years in the current study showed that the ARIMA model accurately captured the subtle dynamics of parturition timing throughout the year in Holstein cows and heifers under prolonged and acute heat stress, with adequate predictive accuracy. The ARIMA models demonstrated the potential of time-series modeling of retrospective data to forecast parturition timing in dairy cows in herds in hot environments. Additionally, the study reaffirmed the important role of heat stress on the day of delivery and in the weeks leading up to parturition in determining calving time in Holstein cows.

### Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the findings reported in this study.

### Data availability statement

The data that support the findings of the present study are available from the corresponding author, (M. Mellado) upon reasonable request.

### Author contributions

Conceptualization: Mellado, M.; Mellado, J.; Methodology: Mellado, M.; Mellado, J.; Ávila, N. Y.; García, J. E.; Morales-Cruz, J. L.; Investigation: Mellado, M.; Ávila, N. Y.; Contreras, V.; Alvarado, M. G.; García, J. E.; Formal analysis: Mellado, J.; Review and editing: Mellado, J.; Morales-Cruz, J. L.; Contreras, V.; Writing (original draft): Mellado, M.

### Generative AI use statement

The authors did not use generative Artificial Inteligence tools or technologies in the creation or editing of any part of this manuscript.

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