J. Dairy Sci. 107:1592–1602
https://doi.org/10.3168/jds.2023-23439

Association between genomic daughter pregnancy rate and expected milk production on the resumption of estrus behavior in Holstein cattle

A. M. L. Madureira,[1] J. L. Plenio,[2] J. L. M. Vasconcelos,[3] T. G. Guida,[3] R. L. A. Cerri,[4] and S. Borchardt[5*]
[1]University of Guelph, Ridgetown Campus, Ridgetown, ON, Canada N0P 2C0
[2]Institute for Veterinary Epidemiology and Biostatistics, Freie Universität Berlin, 14163, Berlin, Germany
[3]Department of Animal Production, São Paulo State University, Botucatu, Brazil 18168-000
[4]Applied Animal Biology, Faculty of Land and Food Systems, University of British Columbia, Vancouver, BC, Canada V6T 1Z4
[5]Clinic of Animal Reproduction, Freie Universität Berlin, 14163, Berlin, Germany

ABSTRACT

The objective of this observational study was to evaluate estrous expression at the first estrus occurring between 7 to 30 d in milk (DIM), as detected by an automated activity monitor (AAM), and its association with genomic daughter pregnancy rate (GDPR) and genomic expected milk production (GEM) in lactating dairy cows. A total of 4,119 lactations from 2,602 Holstein cows were included. Cows were enrolled as first lactation (n = 1,168), second lactation (n = 1,525) and third and greater lactation (n = 1,426). Hair samples were collected from the tail switch, and cows were genotyped using an SNP platform (Clarifide, Zoetis, São Paulo, SP, Brazil). Postpartum cows were examined daily by the farm personnel from calving until 10 DIM. Calving was classified as assisted (forced calf extraction) and unassisted (normal calving). Retained fetal membranes (RFM), hyperketonemia (KET), and left displaced abomasum (LDA) were also recorded. Mean GDPR (± SD) was −0.29 ± 1.4, and the intensity and duration of the first estrus event was 15.9 ± 13.1 x-factor (intensity unit measurement) and 11.1 ± 3.8 h, respectively. Cows that had greater GDPR had greater intensity and longer duration of estrus at the alert, independent of parity. Overall resumption of estrous expression, between 7 to 30 DIM, was 41.2% (1,695/4,119), where 58.8% (2,424/4,119) did not have an estrus event, 31.0% (1,274/4,119) of cows had one event of estrus, and 10.2% (421/4,119) of cows had 2 or more events of estrus early postpartum. Mean DIM (± SD) at first estrus event, detected by the AAM, was 19.4 ± 4.4 d. Days in milk at first event for cows with one event was 20.7 ± 1.6 d and 15.9 ± 3.1 d for cows with 2 or more events of estrus. First lactation cows were more likely to have an estrus event early postpartum when compared with second and third and greater lactation cows (45.2 ± 1.4% [530/1168] vs. 41.6 ± 1.3% [636/1525] vs. 37.2 ± 1.3% [529/1426], respectively). There was an interaction of parity and GDPR on the proportion of cows demonstrating an early postpartum estrus. There was no difference in the proportion of cows with an early postpartum estrus between those with assisted or unassisted calving, RFM, or LDA. However, cows that had KET were less likely to have an alert early postpartum when compared with cows that did not have KET. Mean genomic expected milk production (± SD) was 256.8 ± 600.1 kg. There was no interaction between GEM and parity on estrous expression (i.e., intensity and duration). There was no interaction between GEM and GDPR on the proportion of estrus early postpartum.
Key words: daughter pregnancy rate, estrous behavior, expected milk production

INTRODUCTION

The transition period in lactating dairy cows is critically important, as 75% of diseases in dairy cows typically occur within the first 3 wk postpartum (LeBlanc et al., 2006). Postpartum health disorders can impair milk production, reduce fertility outcomes, and increase the risk of involuntary culling (Walsh et al., 2007a; Probo et al., 2018; Stevenson et al., 2020). During this period, cows experience a negative energy balance (**NEB**) due to the high energy demands for milk production, which could lead to metabolic disorders such as ketosis (Mann et al., 2015). Increased NEB is associated with greater circulating concentrations of nonesterified fatty acid and BHB and has been associated with reduced reproductive performance in some studies (Walsh et al., 2007b; Ospina et al., 2010).

Early resumption of cyclicity within the voluntary waiting period (**VWP**) has been associated with better reproductive performance (Chebel et al., 2006; Santos et al., 2009). Anovulation is associated with longer

Received March 1, 2023.
Accepted September 20, 2023.
*Corresponding author: Stefan.Borchardt@fu-berlin.de

calving intervals (Darwash et al., 1997), lower fertility at first service (Gümen and Seguin, 2003; Chebel et al., 2006), increasing days to conception, and as a consequence, reduced profitability (Galvão et al., 2010). The mechanisms leading to ovulation early postpartum are complex and multifactorial and dependent on cow health status and metabolic condition (Santos et al., 2016). The gold standard for identifying anovulatory cows before the VWP is either by transrectal ultrasound (for visualization of corpus luteum) or by blood or milk progesterone concentrations early postpartum. These methods are time consuming, but automated activity monitoring (**AAM**) systems provide the opportunity to recognize cows with poor reproductive performance without further effort. Two recent studies have reported that cows that did not have estrous activity (detected by a neck-mounted AAM system) between 7 to 40 DIM (Borchardt et al., 2021) or 7 to 60 DIM (Bretzinger et al., 2023) had reduced reproductive performance compared with cows that displayed estrous activity. Cows with transition disorders (i.e., stillbirth, retained fetal membrane [**RFM**], puerperal metritis, or subclinical ketosis) had a greater chance for being anestrus compared with healthy cows (Bretzinger et al., 2023), emphasizing the importance of transition cow health for estrous expression in early lactation.

Genomic merit for genomic daughter pregnancy rate **(GDPR)** is calculated using the risk of pregnancy of a bull's daughters and predicts the genetic improvement in pregnancy rates for a future daughter of a specific bull. Genomic daughter pregnancy rate can be used as a criterion to enhance selection for fertility of lactating dairy cows due to the advancements in genetic prediction. Norman et al. (2009) reported that using GDPR in reproductive programs reversed the phenotypic decline in fertility in dairy cows. A recent study by Madureira et al. (2022), reported that greater GDPR was positively associated with pregnancy per AI at first AI had increased pregnancy per AI for all inseminations, and had decreased risk for pregnancy loss. Similarly, Lima et al. (2020) reported a positive association between GDPR and pregnancy per AI at first AI and for all inseminations, for both multiparous and primiparous. The positive association between fertility and GDPR suggests that this trait can be used to improve fertility in dairy cattle.

Using AAM with genomic data might be an opportunity for the dairy industry to improve reproductive performance, optimize herd management practices, and increase profitability. This concept has been described as targeted reproductive management (**TRM;** Giordano et al., 2022). Major steps in the development and implementation of TRM programs for dairy cattle include identification and validation of robust predictors of reproductive outcomes and overall cow performance. Failure of estrous behavior within the VWP has been shown to be an important predictor of cows with poor reproductive performance (Borchardt et al., 2021; Rial et al., 2022; Bretzinger et al., 2023). Thus, our objectives were to provide insights on the first estrous activity postpartum detected by an AAM and its association with GDPR and GEM in lactating dairy cows.

MATERIALS AND METHODS

Animals, Housing, and Management

This observational cohort study was conducted on one commercial farm in the state of Minas Gerais, Brazil (latitude 19°31′08″; longitude 46°04′90″) from January 2018 to December 2021. All animals that were previously genotyped on the farm (from 2015 to 2017) were enrolled in this study; there were not exclusion criteria for genotyping the animals in the herd. The local Institutional Animal Care Committee, following the requirements of the practices outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999), approved all experimental procedures. Lactating cows were housed in a naturally ventilated freestall barn, which contained stalls lined with rubber bedding and a layer of sawdust, and were fed thrice daily with a TMR that was formulated to meet or exceed the requirements of a 620-kg lactating Holstein cow producing 40 kg/d of 3.5% FCM (NRC, 2001). Feed was pushed 6 times daily and water and TMR were available ad libitum. Milking was performed thrice daily at approximately at 0500 h, 1300 h, and 2100 h.

Genotype

Hair samples were collected from the tail switch of every animal, with most samples being taken at approximately 2 mo of age. Samples were kept in a sample collector provided by the company, which was a specialized envelope, printed with the animal ID and individualized barcode. The hair sample, with the roots attached, was placed tight to the junction between the printed and sticky sides of the envelope, and the sticky side was then used to seal the sample. Samples were then genotyped using single nucleotide polymorphism genotyping platforms commercially available (Clarifide, Zoetis, São Paulo, SP, Brazil).

The results for GDPR and GEM were interpreted based on the Council on Dairy Cattle Breeding database that ranked the genotyped animal. Briefly, GDPR is an indicator of the animal′s genetic ability for better reproductive efficiency and is calculated using the risk

of pregnancy of a bull's daughters. The expected milk production is described as the genetic differences in total kg of milk produced during a 305-d lactation.

Health Event Diagnoses

Postpartum cows were examined daily by the farm personnel from parturition until 10 DIM, following standard operating procedures created by the herd manager, as described below. Cows were screened for health disorders based on visual observations performed by the farm personnel every morning. Calving assistance during parturition was carried out by farm personnel based off the discretion of farm management. Assisted calving was defined as forced extraction of a calf via manual pulling or use of calf chains from one or more farm personnel. Retained fetal membrane, hyperketonemia (**KET**), and left displaced abomasum (**LDA**) were recorded. Hyperketonemia was assessed at 3 and 7 d postpartum. Blood was harvested from the coccygeal vein and immediately tested using cow-side electronic handheld device (Freestyle Neo meter, Abbott Diabetes Care; validated by Kanz et al., 2015). Hyperketonemia was defined as whole blood BHB concentrations $\geq$1.2 mmol/L at one or more of the 2 postpartum blood samples (McArt et al., 2013). Cows with hyperketonemia were treated orally with 250 mL propylene glycol for 3 consecutive days. Cows were considered to suffer from LDA when percussion of the left flank resulted in tympanic resonance auscultated with a stethoscope. Treatment of choice was the "roll and toggle" method (Grymer and Sterner, 1982). In case of unsuccessful treatment, cows were surgically treated with abomasopexy. Cows with RFM after 24 h after calving were diagnosed as having an RFM. All treatments for RFM, KET, and LDA were based off farm management and made by the on-site herds veterinarian.

Automated Activity Monitor

All first calving cows were equipped with a neck-mounted AAM system (Smarttag Neck, Nedap Livestock Management, Groenlo, the Netherlands), validated by Roelofs and van Erp-van der Kooij, (2015). The sensor remained with the animals throughout their entire time within the herd. This accelerometer recorded activity data in real time and stored it as aggregated average activity blocks of 2-h time periods (12 blocks of 2 h/d). The relative change in activity was measured using a z-score transformation (Roelofs et al., 2005) and a proprietary algorithm. The z-score represents the deviation of the current activity from the mean activity within a certain period (i.e., comparing the number of neck movements within every 2-h period with the same 2-h period of the preceding 10 d for each cow individually). The z-score forms the basis for the intensity of an estrus event, quantified by the x-factor from 0 to 100 (0 = lowest index value, 100 = highest index value). When the x-factor exceeds a threshold for multiple consecutive periods, a cow is considered in estrus and an AAM alert (i.e., attention) is generated. Values for attention were either 0 (no estrus) or 1 (estrus). Onset of estrus was defined as the first 2-h period where the x-factor exceeds the threshold from at which the attention changed from 0 to 1. End of estrus was defined by the first instance at which the attention changed from 1 to 0. An estrus event was defined by the 2-h periods between onset and end of estrus. For each estrus early postpartum (7–30 DIM), estrous intensity and the duration of estrus were determined. The estrous intensity was defined as the maximum value of the x-factor within an estrus event during the observational period (i.e., 7–30 DIM). Estrous duration was defined as the interval, in hours, from the onset to end of an estrus event. A modified version of the software tool BovHEAT, written in open-source Python programming language (Python Software Foundation), was used to process all activity data (Plenio et al., 2021).

Statistical Analyses

Means, standard deviations, distributions and normality tests were obtained using the UNIVARIATE procedure of SAS University Edition (SAS Institute Inc., Cary, NC). Before all analyses, continuous dependent variables were checked for normality using the UNIVARIATE procedure and probability distribution plots. Parity was classified into first lactation, second lactation, and third and greater lactations. Genomic expected milk production (**GEM**) was classified by the median as lower milk production (<224 kg) or greater milk production ($\geq$224 kg).

The occurrence of estrus early postpartum was used as binomial dependent variables and tested for the effects of GDPR, GEM, calving month, parity, calving ease (0 = unassisted, 1 = calving assisted), RFM, KET, and LDA, using mixed-effects logistic regression using the GLIMMIX procedure by specifying the distribution as binary, cow as the experimental unit and as a random effect, lactation as the repeated measure and first-order antedependence as the covariance structure. Lactation was used as a repeated measure to account for the fact that observations from cows enrolled in different lactations were not independent from each other. Intensity and duration of estrus were used as continuous dependent variables assessed with ANOVA using

linear mixed regression models (GLIMMIX), where cow was specified as the experimental unit and as a random effect, lactation as the repeated measure and first-order antedependence as the covariance structure. All explanatory variables were checked for collinearity, where continuous variables were assessed using variance inflation factor by regression analysis, and categorical variables using contingency tables; no multicollinearity of explanatory variables was found. The correlation between the intensity and the duration of estrus detected by the AAM was determined by Pearson correlation using the Corr procedure of SAS. For all models, only variables with a P-value <0.15 were kept in final models, using manual backward elimination. Differences between groups with $P \leq 0.05$ were considered significant using Tukey's adjustments. All multivariable models were constructed using the variables as described, and manual backward stepwise elimination was used. Interactions were tested between all variables selected in the final model and kept if $P < 0.05$.

RESULTS

Data from 4,119 lactations from 2,602 lactating dairy cows were collected from January 2019 to September 2021. The GDPR and expected milk production was available for all lactating dairy cows. The number of estrus events detected by the AAM from 7 to 30 DIM for 4,119 lactations (e.g., first, second, and third and greater lactations) is described in Table 1.

Genomic Daughter Pregnancy Rate

Genomic daughter pregnancy rate (mean ± SD) was −0.29 ± 1.4 with the maximum of 5.5 and minimum of −5.2. Intensity and duration (mean ± SD) of the first estrus event was 15.9 ± 13.1 x-factor and 11.1 ± 3.8 h, respectively. Cows that had greater GDPR had greater intensity ($P = 0.02$) and longer duration ($P = 0.03$) of estrus at the alert, independent of parity, as shown in Figures 1 and 2, respectively. There was a correlation between the intensity and the duration of estrus detected by the AAM (r = 0.59). Overall resumption of estrous expression was 41.2% (1,695/4,119), where 58.8% (2,424/4,119) of the cows did not have an estrus event, 31.0% (1,274/4,119) had one event of estrus, and 10.2% (421/4,119) had 2 or more events of estrus early postpartum (7 to 30 DIM).

Days in milk (mean ± SD) at first estrus event, detected by the AAM, was 19.4 ± 4.4 d. Days in milk at first event for cows with one event was 20.7 ± 1.6 d and 15.9 ± 3.1 d for cows with 2 or more events of estrus. First lactation cows were more likely to have an estrus event early postpartum when compared with second and third and greater lactation cows (45.2 ± 1.4% [530/1168] vs. 41.6 ± 1.3% [636/1525] vs. 37.2 ± 1.3% [529/1426], respectively, $P < 0.01$). There was an interaction of parity and GDPR on the proportion of cows expressing estrus early postpartum ($P = 0.02$; Figure 3). There was no difference in the proportion of cows expressing estrus early postpartum in cows with assisted or unassisted calving ($P = 0.28$), RFM ($P = 0.69$), or LDA ($P = 0.44$). However, cows that had KET showed less alerts postpartum when compared with cows that did not have KET ($P < 0.01$), as shown in Table 2. There was an interaction of the incidence of KET (i.e., no KET vs. KET) and GDPR on the proportion of cows demonstrating estrus early postpartum ($P = 0.03$; Figure 4).

Genomic Expected Milk Production

Genomic expected milk production (mean ± SD) was 256.8 ± 600.1 kg, with a maximum of 2,177 kg and minimum of −2,029 kg. There was no effect of the GEM on the intensity ($P = 0.38$) nor the duration of estrus ($P = 0.12$). There was no interaction of parity and GEM on the duration of estrus ($P = 0.51$) nor the intensity of estrus and GEM ($P = 0.17$). There was no correlation between GEM and number of estrus events early postpartum (r = −0.02). There was no interaction between GEM and GDPR on the proportion of

Table 1. Number of estrus events[1] detected by an automated activity monitoring system[2] from 7 to 30 d postpartum for 4,119 lactations from the same herd

No. estrus events	All cows, n (%)	1st lactation, n (%)	2nd lactation, n (%)	≥3rd lactation, n (%)
0	2,424 (58.8)	638 (54.6)	889 (58.3)	897 (62.9)
1	1,274 (31.0)	385 (33.0)	458 (30.0)	431 (30.2)
≥2	421 (10.2)	145 (12.4)	178 (11.7)	98 (6.9)
Total	4,199	1,168	1,525	1,426

[1]An estrus event was defined when the attention variable indicated a value of 1 for at least 3 consecutive 2-h blocks.

[2]Smarttag Neck, Nedap Livestock Management, Groenlo, the Netherlands.

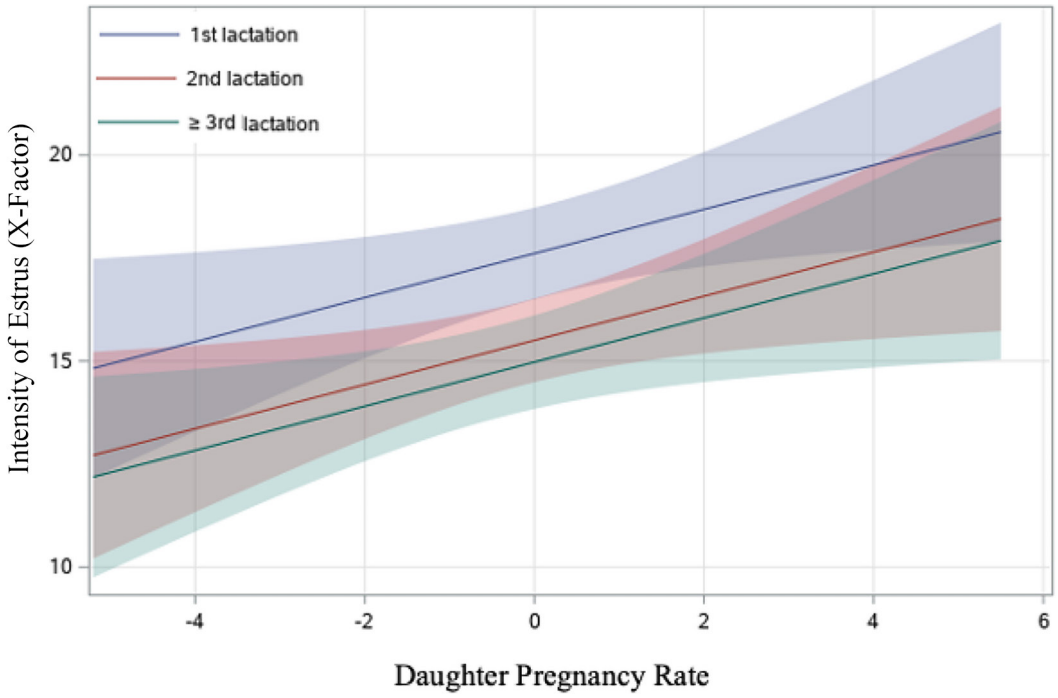

Figure 1. Association of genomic daughter pregnancy rate and intensity of estrus (shaded areas represent marginal means [proportion ± 95% CI]), detected by an automated activity monitor at first estrus event from 7 to 30 d postpartum using least square estimates from the linear mixed regression model stratified by parity.

cows expressing estrus early postpartum ($P = 0.63$), as shown in Figure 5.

DISCUSSION

The objective of this study was to evaluate the first estrus activity within 7 to 30 DIM, as detected by an AAM, and its association with GDPR and GEM in lactating dairy cows. Our results demonstrated that the proportion of cows expressing estrus early postpartum increased as GDPR increased. Greater intensity and duration of estrous expression were found in cows with greater GDPR. Genomic expected milk production did not affect the proportion of cows expressing estrus early postpartum.

Genomic daughter pregnancy rate is a trait that can be used as a tool to create enhanced decisions on fertility of lactating dairy cows. In a recent study, Madureira et al. (2022) reported that greater GDPR was associated with increased overall fertility and decreased pregnancy losses. Other studies have demonstrated the association with GDPR and fertility outcomes, in heifers and primiparous and multiparous cows (Veronese et al., 2019; Lima et al., 2020); however, this is the first study, to our knowledge, that evaluates the association of GDPR and GEM with the resumption of estrous behavior postpartum using an AAM.

In dairy cows, postpartum anestrus occurs when cows are not seen or reported to be in estrus for several weeks following calving. Resumption of cyclicity early postpartum has been associated with better fertility outcomes (Santos et al., 2009). Although frequency of postpartum cows that suffer from anestrus is herd specific, the average interval parturition until the return of cyclicity in dairy cows is approximately 24 d (Royal et al., 2000), even though it is quite common to identify cows that have not yet resumed cyclicity at 100 d postpartum. According to Stevenson et al. (2006), typical prevalence rates at the end of the VWP are between 10% and 30%, whereas higher rates of up to 59% have been documented in specific herds (Stevenson et al., 2006; Walsh et al., 2007a). In the current study, 58.8% of the cows had no estrous expression before 30 DIM. Studies that also used an AAM system to evaluate the prevalence of anestrus showed a similar prevalence of anestrus (Borchardt et al., 2021: 52.1%, 5 herds, 7 to 40 DIM; Chebel and Veronese, 2020: 52.7%, 1 herd, within 62 DIM). Comparisons among studies, however, are difficult because of differences in observational periods, AAM systems, herds, and definitions of anestrus.

Parity was associated with the prevalence of anestrus (parity 1: 54.6%; parity 2: 58.3%; parity 3 or greater: 62.9%). These results correspond to the findings of Bruinjé et al. (2023; multiparous cows: 37% vs. primiparous

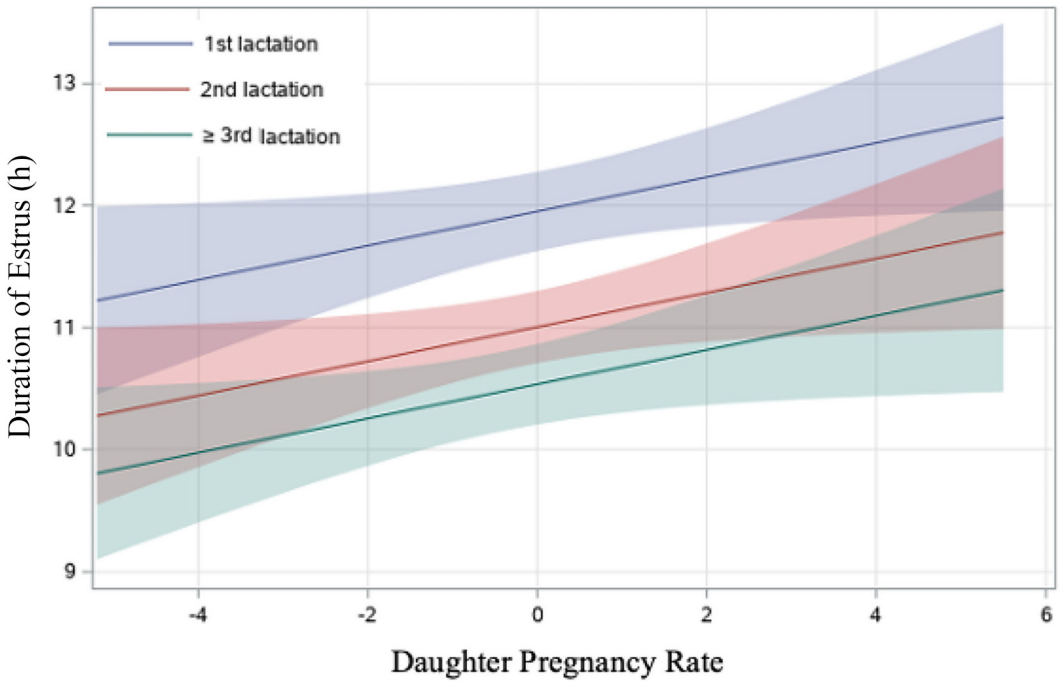

Figure 2. Association of genomic daughter pregnancy rate and duration of estrus (shaded areas represent marginal means [proportion ± 95% CI]), detected by an automated activity monitor at first estrus event from 7 to 30 d postpartum using least square estimates from the linear mixed regression model stratified by parity.

cows: 25%) and Bretzinger et al. (2023; multiparous cows: 23.1% vs. primiparous cows: 17.5%), whereas other studies have shown no association (Borchardt et al., 2021) or even a greater prevalence of anovulation in primiparous cows (Bamber et al., 2009; Vercouteren et al., 2015).

Efficient monitoring of cows during the transition period is crucial to maintain production and fertility per-

Table 2. Association of calving ease (i.e., unassisted vs. assisted), disease postpartum (i.e., retained fetal membrane, displaced abomasum, and hyperketonemia), and the proportion of cows expressing estrus prior to 30 DIM and characteristics of the first postpartum estrus event (i.e., DIM, estrous intensity and duration)

Variable[1]	Incidence of disease, %	Proportion of cows expressing estrus,[2] %	Odds ratio (95% CI)	DIM at 1st estrus event	Estrous intensity[3]	Estrous duration[4]
Calving ease						
Unassisted	—	40.8 ± 0.9	0.89 (0.67–1.12)	19.7 ± 1.8[a]	16.0 ± 0.4	9.8 ± 0.6
Assisted	8.3	37.5 ± 2.9		17.9 ± 6.3[b]	14.8 ± 1.3	9.2 ± 0.7
Retained fetal membrane						
No retained	—	40.7 ± 0.8	0.96 (0.77–1.19)	20.4 ± 5.1	12.1 ± 2.2	9.4 ± 0.6
Retained	10.4	39.7 ± 2.5		19.4 ± 1.7	9.7 ± 2.5	9.1 ± 0.7
Displaced abomasum						
No DA	—	40.9 ± 0.9	0.73 (0.32–1.65)	19.6 ± 1.8	15.0 ± 0.6[a]	10.8 ± 0.2[a]
DA	0.8	33.5 ± 9.6		20.5 ± 2.7	6.7 ± 3.9[b]	8.4 ± 1.2[b]
Hyperketonemia classification[4]						
No hyperketonemia	—	42.2 ± 0.9[a]	0.63 (0.50–0.78)	19.5 ± 1.8	16.2 ± 0.4	9.9 ± 0.6
Hyperketonemia	12.5	31.4 ± 2.3[b]		20.2 ± 5.6	14.6 ± 1.2	9.4 ± 0.7

[a,b]Different letters indicate differences between variables within the columns ($P < 0.05$).

[1]Calving ease: calving assisted was defined as forced extraction of a calf via manual pulling. Retained fetal membrane: cows with retained fetal membranes after 24 h after calving. Displaced abomasum (DA): cows were considered as having a displaced abomasum when percussion of the left flank resulted in tympanic resonance auscultated with a stethoscope. Hyperketonemia: whole blood BHB concentrations ≥1.2 mmol/L at 1 or more of the 2 postpartum blood samples (3 and 7 d postpartum).

[2]Marginal means ± SE obtained from mixed logistic regression model.

[3]Estrous intensity: the maximum value of the x-factor within an estrus event during the observational period detected by the automated activity monitor (Smarttag Neck, Nedap Livestock Management, Groenlo, the Netherlands).

[4]Duration: the interval, in hours, from the onset to the end of an estrus event.

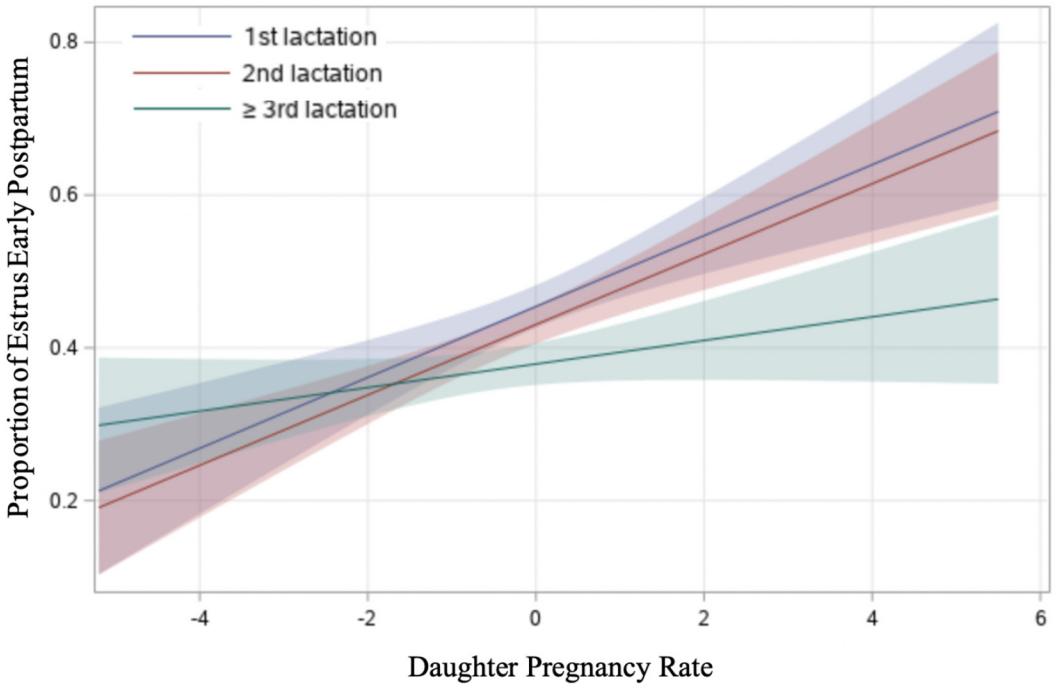

Figure 3. Association of genomic daughter pregnancy rate and the proportion of cows expressing estrus early postpartum (shaded areas represent marginal means [proportion ± 95% CI]), detected by an automated activity monitor, from 7 to 30 d postpartum using least square estimates from the linear mixed regression model stratified by parity.

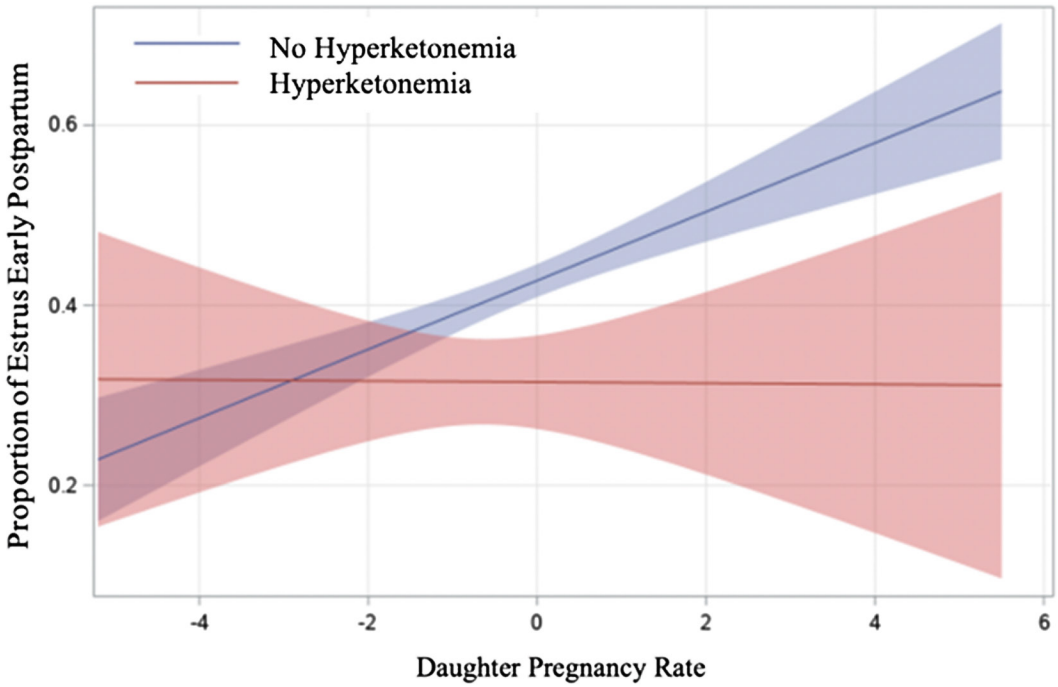

Figure 4. Association of genomic daughter pregnancy rate and the proportion of cows expressing estrus early postpartum (shaded areas represent marginal means [proportion ± 95% CI]), detected by an automated activity monitor, from 7 to 30 d postpartum using least square estimates from the linear mixed regression model stratified by the incidence of hyperketonemia (i.e., No Hyperketonemia (<1.2 mmol/L of BHB either at 3 or 7 d postpartum) and Hyperketonemia (≥1.2 mmol/L of BHB either at 3 or 7 d postpartum).

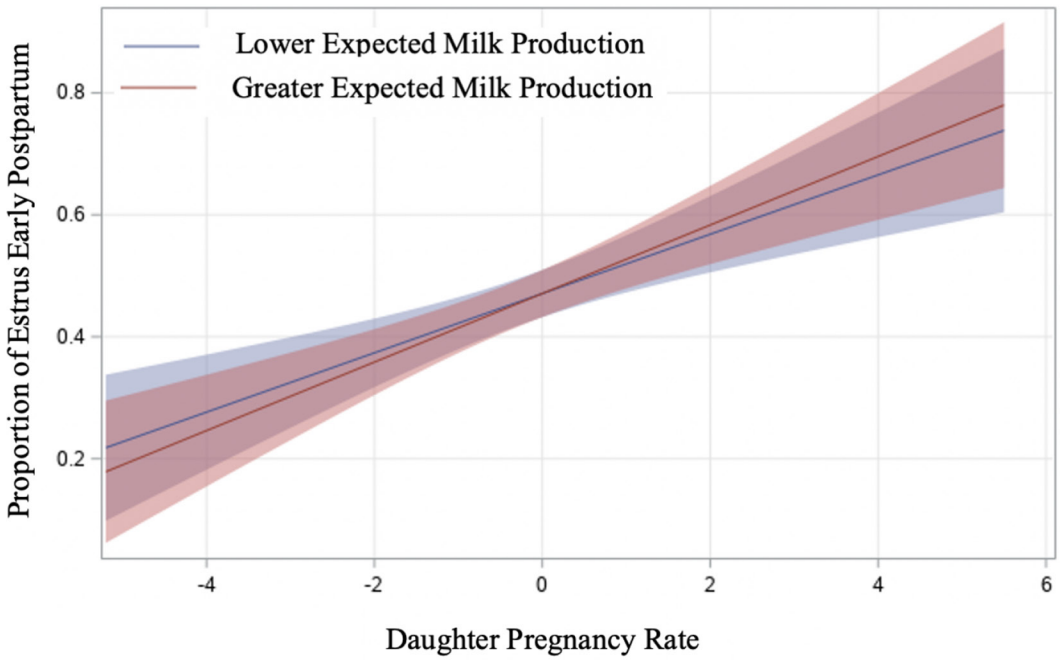

Figure 5. Association of genomic daughter pregnancy rate and the proportion of estrus early postpartum (shaded areas represent marginal means [proportion ± 95% CI]), detected by an automated activity monitor, from 7 to 30 d postpartum using least square estimates from the linear mixed regression model stratified by genomic expected milk production (i.e., <224 kg is categorized as lower expected milk production and ≥224 kg is categorized as greater expected milk production).

formance, but it can be laborious and time consuming. Therefore, implementing dairy monitoring technologies (e.g., automated activity monitors) early postpartum can be a tool to identify cows in anestrus (Borchardt et al., 2021; Rial et al., 2022; Bretzinger et al., 2023). Using AAM systems, it has been shown that cows with no estrous expression from 7 to 40 DIM had reduced estrous expression at first AI and had inferior reproductive performance compared with cows that displayed estrous activity within the VWP (Borchardt et al., 2021). Bretzinger et al. (2023), reported that cows with early postpartum disorders (e.g., RFM, metritis, and subclinical ketosis) were more likely to be in anestrus (i.e., lack of resumption of estrous expression detected by AAM) within the VWP and were more likely to have inferior reproductive performance compared with cows that displayed estrous activity detected by the AAM.

Several factors have been linked to anovulation or anestrus in lactating dairy cattle in the VWP (e.g., parity, ketosis, displaced abomasum, greater concentration of haptoglobin, NEB [Dubuc et al., 2012], dystocia, and twins [Walsh et al., 2007a; Vercouteren et al., 2015; Stevenson et al., 2020]). High milk yield and severe NEB in the postpartum period have been associated with delays in the resumption of cyclicity (Dubuc et al., 2012). Butler and Smith (1989) reported a close correlation between the interval to the first estrus and the degree of NEB.

It is known that NEB during early lactation affects later reproductive function (Butler, 2003). Negative energy balance has also been associated with postponing and diminishing the intensity of the LH surge, which delays the start of the luteal activity and has a detrimental effect on fertility performance (Ospina et al., 2010). Elevated concentration of BHB, as an indicator of NEB, and clinical and subclinical ketosis, during the first week postpartum has been associated with cows in anestrus (Walsh et al., 2007b). Ketosis has an economic impact in dairy herds due to increased premature culling of cows, impaired production and fertility performance, and increased risk of fresh cow diseases, such as displaced abomasum and mastitis (Berge and Vertenten, 2014; Steeneveldid et al., 2020). In the current study, the proportion of cows expressing estrus early postpartum, was reduced in cows diagnosed with hyperketonemia, which agrees with a recent study by Bretzinger et al., (2023) that reported the prevalence of anestrus was increased about 30% in cows with hyperketonemia. The intensity and duration of estrous expression was not affected by hyperketonemia. Studies have investigated the relationship between the concentration of BHB and fertility. The concentration and intensity of blood BHB were negatively associated with pregnancy at first AI in

large studies by Walsh et al. (2007b) and Ospina et al. (2010), whereas a smaller study by Kessel et al. (2008) reported no difference in the number of days from calving to conception or the rate of fertility at first AI in cows presenting elevated blood BHB.

An increase in GDPR was associated with greater intensity and duration of estrous expression postpartum. Madureira et al. (2022) reported, that the odds, in primiparous and multiparous cows, of occurrence of estrous expression increased as GDPR increased even though cows were induced with estradiol cypionate, where most cows demonstrate estrus at timed AI. Heifers with higher GDPR exhibited greater concentrations of estradiol during estrus (Veronese et al., 2019), suggesting that high GDPR is linked to better hormonal support for improving estrous behavior. There is evidence to support the idea that greater levels of estradiol during estrus may improve fertility (Buhi, 2002; Jinks et al., 2013; Pereira et al., 2016). Different studies have shown an association between GDPR and estrous expression in heifers and primiparous and multiparous cows, suggesting that additional physiological mechanisms that are linked to estrous expression may potentially be associated with GDPR. Although it seems that the genomic merit for GDPR is important for resumption of estrous expression in early lactation, in the current study, this association was offset in cows with hyperketonemia. Therefore, management of transition cows for the prevention of hyperketonemia (e.g., controlled energy diets, avoiding overweight cows, overcrowding) is needed for cows to demonstrate their genetic potential.

Improvements in management and intensive genetic selection has helped increase individual milk production, and it has coincided with a corresponding drop in fertility (Lucy, 2001). A negative genetic correlation has been shown between milk yield and fertility in dairy cattle (Roxström et al., 2010), although it has been argued that the low heritability of reproductive traits prevents conflicts between selection for milk production and reduction in reproduction (Hansen, 2000). According to Dobson et al. (2008), the severe genetic selection for high milk production has decreased fertility, mostly because of greater incidences of postpartum clinical diseases, uterine infections, and defective oocytes and embryos. Madureira et al. (2022) reported a mild negative correlation between GDPR and expected milk production, where some cows with greater fertility had high GDPR and high GEM. There was no interaction of GEM and GDPR on the proportion of cows expressing estrus early postpartum in the current study, suggesting that overall, the selection for GEM is not associated with the resumption of cyclicity postpartum.

Targeted reproductive management is a prospective strategy that is currently being investigated (Giordano et al., 2022; Rial et al., 2022). Using a variety of conventional and cutting-edge sources of biological (e.g., estrus [Madureira et al., 2015; Tippenhauer et al., 2021] and ovulation [Burnett et al., 2018]) management (e.g., creating strategies for better reproductive performance using AAM [Borchardt et al., 2021; Rial et al., 2022] and performance data), TRM is a method that involves identifying subgroups of cows with similar biological and performance traits (Berry et al., 2016; Zolini et al., 2019) and enrolling cows into different reproductive programs with a goal to enhance reproductive performance (Giordano et al., 2022). Combining sensor technologies and genomic data may be a novel reproductive strategy for the dairy industry to improve reproductive performance, optimize individual and herd management practices, and increase profitability.

One clear drawback of this study is a lack of measurements of milk or blood progesterone concentrations in the early postpartum period, as this is considered the gold standard to characterize estrus cyclicity patterns (Lucy, 2019). In addition, we did not confirm whether cows identified by the AAM system were truly in estrus using ultrasonography or other means. The observation period (7–30 DIM) was rather short, allowing only a limited number of cows to resume estrous expression. This observation period was chosen due to hormonal interventions within the VWP (after 30 DIM) that would have biased the results. Future studies should use observational periods that resemble more of the typical approach for VWP. The study was conducted in only one herd in Brazil. Therefore, results are difficult to extrapolate to the dairy industry, as cows were exposed to specific environmental conditions (e.g., high temperature-humidity index), which might have also affected the findings of this study.

CONCLUSIONS

An increase in GDPR was associated with a greater proportion of cows expressing estrus early postpartum. Greater GDPR was also associated with a greater intensity and longer duration of estrous expression early postpartum (7– 30 DIM). The current study reported that GEM was not associated with the proportion of cows with expressed estrus early postpartum and that GDPR could be the driver for resumption of cyclicity postpartum, suggesting that it is possible to select a cow for greater GDPR and greater GEM. The results from this study provide evidence that GDPR can be associated with resumption of estrous expression postpartum and can be used as a tool for better reproductive management.

ACKNOWLEDGMENTS

We are grateful to Fazenda Sekita (São Gotardo, Minas Gerais, Brazil) and farm personnel for contributing with this research project. The authors thank Nedap Livestock Management (Groenlo, the Netherlands), and in particular, Evine van Riemsdijk and Arnold Harbers, for providing the AAM data. The authors have not stated any conflicts of interest.

REFERENCES

Bamber, R. L., G. E. Shook, M. C. Wiltbank, J. E. P. Santos, and P. M. Fricke. 2009. Genetic parameters for anovulation and pregnancy loss in dairy cattle. J. Dairy Sci. 92:5739–5753. https://doi.org/10.3168/jds.2009-2226.

Berge, A. C., and G. Vertenten. 2014. A field study to determine the prevalence, dairy herd management systems, and fresh cow clinical conditions associated with ketosis in western European dairy herds. J. Dairy Sci. 97:2145–2154. https://doi.org/10.3168/jds.2013-7163.

Berry, D. P., N. C. Friggens, M. Lucy, and J. R. Roche. 2016. Milk production and fertility in cattle. Annu. Rev. Anim. Biosci. 4:269–290. https://doi.org/10.1146/annurev-animal-021815-111406.

Borchardt, S., C. M. Tippenhauer, J. L. Plenio, A. Bartel, A. M. L. Madureira, R. L. A. Cerri, and W. Heuwieser. 2021. Association of estrous expression detected by an automated activity monitoring system within 40 days in milk and reproductive performance of lactating Holstein cows. J. Dairy Sci. 104:9195–9204. https://doi.org/10.3168/jds.2020-19705.

Bretzinger, L. F., C. M. Tippenhauer, J. L. Plenio, W. Heuwieser, and S. Borchardt. 2023. Effect of transition cow health and estrous expression detected by an automated activity monitoring system within 60 days in milk on reproductive performance of lactating Holstein cows. J. Dairy Sci. 106:4429–4442. https://doi.org/10.3168/jds.2022-22616.

Bruinjé, T. C., E. I. Morrison, E. S. Ribeiro, D. Renaud, R. C. Serrenho, and S. J. LeBlanc. 2023. Postpartum health is associated with detection of estrus by activity monitors and reproductive performance in dairy cows. J. Dairy Sci. https://doi.org/10.3168/jds.2023-23268.

Buhi, W. C. 2002. Characterization and biological roles of oviduct-specific, oestrogen-dependent glycoprotein. Reproduction 123:355–362. https://doi.org/10.1530/rep.0.1230355.

Burnett, T. A., L. Polsky, M. Kaur, and R. L. A. Cerri. 2018. Effect of estrous expression on timing and failure of ovulation of Holstein dairy cows using automated activity monitors. J. Dairy Sci. 101:11310–11320. https://doi.org/10.3168/jds.2018-15151.

Butler, W. R. 2003. Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. Livest. Prod. Sci. 83:211–218. https://doi.org/10.1016/S0301-6226(03)00112-X.

Butler, W. R., and R. D. Smith. 1989. Interrelationships between energy balance and postpartum reproductive function in dairy cattle. J. Dairy Sci. 72:767–783. https://doi.org/10.3168/jds.S0022-0302(89)79169-4.

Chebel, R. C., J. E. P. Santos, R. L. A. Cerri, H. M. Rutigliano, and R. G. S. Bruno. 2006. Reproduction in dairy cows following progesterone insert presynchronization and resynchronization protocols. J. Dairy Sci. 89:4205–4219. https://doi.org/10.3168/jds.S0022-0302(06)72466-3.

Chebel, R. C., and A. Veronese. 2020. Associations between genomic merit for daughter pregnancy rate of Holstein cows and metabolites postpartum and estrus characteristics. J. Dairy Sci. 103:10754–10768. https://doi.org/10.3168/jds.2020-18207.

Darwash, A. O., G. E. Lamming, and J. A. Woolliams. 1997. Estimation of genetic variation in the interval from calving to postpartum ovulation of dairy cows. J. Dairy Sci. 80:1227–1234. https://doi.org/10.3168/jds.S0022-0302(97)76051-X.

Dobson, H., S. L. Walker, M. J. Morris, J. E. Routly, and R. F. Smith. 2008. Why is it getting more difficult to successfully artificially inseminate dairy cows? Animal 2:1104–1111.

Dubuc, J., T. F. Duffield, K. E. Leslie, J. S. Walton, and S. J. LeBlanc. 2012. Risk factors and effects of postpartum anovulation in dairy cows. J. Dairy Sci. 95:1845–1854. https://doi.org/10.3168/jds.2011-4781.

FASS. 1999. Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching. FASS.

Galvão, K. N., M. Frajblat, W. R. Butler, S. B. Brittin, C. L. Guard, and R. O. Gilbert. 2010. Effect of early postpartum ovulation on fertility in dairy cows. Reprod. Domest. Anim. 45:e207–e211. 10.1111/j.1439-0531.2009.01517-X.

Giordano, J. O., E. M. Sitko, C. Rial, M. M. Pérez, and G. E. Granados. 2022. Symposium review: Use of multiple biological, management, and performance data for the design of targeted reproductive management strategies for dairy cows. J. Dairy Sci. 105:4669–4678. https://doi.org/10.3168/jds.2021-21476.

Grymer, J., and K. E. Sterner. 1982. Percutaneous fixation of left displaced abomasum, using a bar suture. J. Am. Vet. Med. Assoc. 180:1458–1461.

Gümen, A., and B. Seguin. 2003. Ovulation rate after GnRH or PGF2α administration in early postpartum dairy cows. Theriogenology 60:341–348. https://doi.org/10.1016/S0093-691X(02)01372-9.

Hansen, L. B. 2000. Consequences of selection for milk yield from a geneticist's viewpoint. J. Dairy Sci. 83:1145–1150. https://doi.org/10.3168/jds.S0022-0302(00)74980-0.

Jinks, E. M., M. F. Smith, J. A. Atkins, K. G. Pohler, G. A. Perry, M. D. MacNeil, A. J. Roberts, R. C. Waterman, L. J. Alexander, and T. W. Geary. 2013. Preovulatory estradiol and the establishment and maintenance of pregnancy in suckled beef cows. J. Anim. Sci. 91:1176–1185. https://doi.org/10.2527/jas.2012-5611.

Kanz, P., M. Drillich, D. Klein-Jöbstl, B. Mair, S. Borchardt, L. Meyer, I. Schwendenwein, and M. Iwersen. 2015. Suitability of capillary blood obtained by a minimally invasive lancet technique to detect subclinical ketosis in dairy cows by using 3 different electronic hand-held devices. J. Dairy Sci. 98:6108–6118. https://doi.org/10.3168/jds.2014-8957.

Kessel, S., M. Stroehl, H. H. D. Meyer, S. Hiss, H. Sauerwein, F. J. Schwarz, and R. M. Bruckmaier. 2008. Individual variability in physiological adaptation to metabolic stress during early lactation in dairy cows kept under equal conditions. J. Anim. Sci. 86:2903–2912. https://doi.org/10.2527/jas.2008-1016.

LeBlanc, S. J., K. D. Lissemore, D. F. Kelton, T. F. Duffield, and K. E. Leslie. 2006. Major advances in disease prevention in dairy cattle. J. Dairy Sci. 89:1267–1279. https://doi.org/10.3168/jds.S0022-0302(06)72195-6.

Lima, F. S., F. T. Silvestre, F. Peñagaricano, and W. W. Thatcher. 2020. Early genomic prediction of daughter pregnancy rate is associated with improved reproductive performance in Holstein dairy cows. J. Dairy Sci. 103:3312–3324. https://doi.org/10.3168/jds.2019-17488.

Lucy, M. C. 2001. Reproductive loss in high-producing dairy cattle: Where will it end? J. Dairy Sci. 84:1277–1293. https://doi.org/10.3168/jds.S0022-0302(01)70158-0.

Lucy, M. C. 2019. Symposium review: Selection for fertility in the modern dairy cow—Current status and future direction for genetic selection. J. Dairy Sci. 102:3706–3721. https://doi.org/10.3168/jds.2018-15544.

Madureira, A. M. L., J. Denis-Robichaud, T. G. Guida, R. L. A. Cerri, and J. L. M. Vasconcelos. 2022. Association between genomic daughter pregnancy rates and reproductive parameters in Holstein dairy cattle. J. Dairy Sci. 105:5534–5543. https://doi.org/10.3168/jds.2021-21766.

Madureira, A. M. L., B. F. Silper, T. A. Burnett, L. Polsky, L. H. Cruppe, D. M. Veira, J. L. M. Vasconcelos, and R. L. A. Cerri. 2015. Factors affecting expression of estrus measured by activity monitors and conception risk of lactating dairy cows. J. Dairy Sci. 98:7003–7014. https://doi.org/10.3168/jds.2015-9672.

Mann, S., F. A. L. Yepes, T. R. Overton, J. J. Wakshlag, A. L. Lock, C. M. Ryan, and D. V. Nydam. 2015. Dry period plane of energy: Effects on feed intake, energy balance, milk production, and composition in transition dairy cows. J. Dairy Sci. 98:3366–3382. https://doi.org/10.3168/jds.2014-9024.

McArt, J. A. A., D. V. Nydam, G. R. Oetzel, T. R. Overton, and P. A. Ospina. 2013. Elevated non-esterified fatty acids and β-hydroxybutyrate and their association with transition dairy cow performance. Vet. J. 198:560–570. https://doi.org/10.1016/j.tvjl.2013.08.011.

National Research Council (NRC). 2001. Nutrient Requirements of Dairy Cattle. 7th ed. Natl. Acad. Press.

Norman, H. D., J. R. Wright, S. M. Hubbard, R. H. Miller, and J. L. Hutchison. 2009. Reproductive status of Holstein and Jersey cows in the United States. J. Dairy Sci. 92:3517–3528. https://doi.org/10.3168/jds.2008-1768.

Ospina, P. A., D. V. Nydam, T. Stokol, and T. R. Overton. 2010. Associations of elevated nonesterified fatty acids and β-hydroxybutyrate concentrations with early lactation reproductive performance and milk production in transition dairy cattle in the northeastern United States. J. Dairy Sci. 93:1596–1603. https://doi.org/10.3168/jds.2009-2852.

Pereira, M. H. C., M. C. Wiltbank, and J. L. M. Vasconcelos. 2016. Expression of estrus improves fertility and decreases pregnancy losses in lactating dairy cows that receive artificial insemination or embryo transfer. J. Dairy Sci. 99:2237–2247. https://doi.org/10.3168/jds.2015-9903.

Plenio, J.-L., A. Bartel, A. M. L. Madureira, R. L. A. Cerri, W. Heuwieser, and S. Borchardt. 2021. Application note: Validation of BovHEAT—An open-source analysis tool to process data from automated activity monitoring systems in dairy cattle for estrus detection. Comput. Electron. Agric. 188:106323. https://doi.org/10.1016/j.compag.2021.106323.

Probo, M., O. B. Pascottini, S. LeBlanc, G. Opsomer, and M. Hostens. 2018. Association between metabolic diseases and the culling risk of high-yielding dairy cows in a transition management facility using survival and decision tree analysis. J. Dairy Sci. 101:9419–9429. https://doi.org/10.3168/jds.2018-14422.

Rial, C., A. Laplacette, and J. Giordano. 2022. Effect of a targeted reproductive management program designed to prioritize insemination at detected estrus and optimize time to insemination on the reproductive performance of lactating dairy cows. J. Dairy Sci. 105:8411–8425. https://doi.org/10.3168/jds.2022-22082.

Roelofs, J. B., F. J. C. M. Van Eerdenburg, N. M. Soede, and B. Kemp. 2005. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology 64:1690–1703. https://doi.org/10.1016/j.theriogenology.2005.04.004.

Roelofs, J. B., and E. van Erp-van der Kooij. 2015. Estrus detection tools and their applicability in cattle: Recent and perspectival situation. Anim. Reprod. 12:498–504.

Roxström, A., E. Strandberg, B. Berglund, U. Emanuelson, and J. Philipsson. 2010. Genetic and environmental correlations among female fertility traits, and between the ability to show oestrus and milk production in dairy cattle. Acta Agric. Scand. A Anim. Sci. 51:192–199. https://doi.org/10.1080/09064700118617.

Royal, M., G. E. Mann, and A. P. F. Flint. 2000. Strategies for reversing the trend towards subfertility in dairy cattle. Vet. J. 160:53–60. https://doi.org/10.1053/tvjl.1999.0450.

Santos, J. E. P., R. S. Bisinotto, and E. S. Ribeiro. 2016. Mechanisms underlying reduced fertility in anovular dairy cows. Theriogenology 86:254–262. https://doi.org/10.1016/j.theriogenology.2016.04.038.

Santos, J. E. P., H. M. Rutigliano, and M. F. S. Filho. 2009. Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. Anim. Reprod. Sci. 110:207–221. https://doi.org/10.1016/j.anireprosci.2008.01.014.

Steeneveld, W., P. Amuta, F. J. S. van Soest, R. Jorritsma, and H. Hogeveen. 2020. Estimating the combined costs of clinical and subclinical ketosis in dairy cows. PLoS One 15:e0230448. https://doi.org/10.1371/journal.pone.0230448.

Stevenson, J. S., S. Banuelos, and L. G. D. Mendonça. 2020. Transition dairy cow health is associated with first postpartum ovulation risk, metabolic status, milk production, rumination, and physical activity. J. Dairy Sci. 103:9573–9586. https://doi.org/10.3168/jds.2020-18636.

Stevenson, J. S., J. R. Pursley, H. A. Garverick, P. M. Fricke, D. J. Kesler, J. S. Ottobre, and M. C. Wiltbank. 2006. Treatment of cycling and noncycling lactating dairy cows with progesterone during Ovsynch. J. Dairy Sci. 89:2567–2578. https://doi.org/10.3168/jds.S0022-0302(06)72333-5.

Tippenhauer, C. M., J. L. Plenio, A. M. L. Madureira, R. L. A. Cerri, W. Heuwieser, and S. Borchardt. 2021. Factors associated with estrous expression and subsequent fertility in lactating dairy cows using automated activity monitoring. J. Dairy Sci. 104:6267–6282. https://doi.org/10.3168/jds.2020-19578.

Vercouteren, M. M. A. A., J. H. J. Bittar, P. J. Pinedo, C. A. Risco, J. E. P. Santos, A. Vieira-Neto, and K. N. Galvão. 2015. Factors associated with early cyclicity in postpartum dairy cows. J. Dairy Sci. 98:229–239. https://doi.org/10.3168/jds.2014-8460.

Veronese, A., O. Marques, R. Moreira, A. Belli, R. Bisinotto, T. Bilby, F. Peñagaricano, and R. Chebel. 2019. Genomic merit for reproductive traits. I: Estrous characteristics and fertility in Holstein heifers. J. Dairy Sci. 102:6624–6638. https://doi.org/10.3168/jds.2018-15205.

Walsh, R. B., D. F. Kelton, T. F. Duffield, K. E. Leslie, J. S. Walton, and S. J. LeBlanc. 2007a. Prevalence and risk factors for postpartum anovulatory condition in dairy cows. J. Dairy Sci. 90:315–324. https://doi.org/10.3168/jds.S0022-0302(07)72632-2.

Walsh, R. B., J. S. Walton, D. F. Kelton, S. J. LeBlanc, K. E. Leslie, and T. F. Duffield. 2007b. The effect of subclinical ketosis in early lactation on reproductive performance of postpartum dairy cows. J. Dairy Sci. 90:2788–2796. https://doi.org/10.3168/jds.2006-560.

Zolini, A. M., W. G. Ortiz, E. Estrada-Cortes, M. S. Ortega, S. Dikmen, F. Sosa, J. O. Giordano, and P. J. Hansen. 2019. Interactions of human chorionic gonadotropin with genotype and parity on fertility responses of lactating dairy cows. J. Dairy Sci. 102:846–856. https://doi.org/10.3168/jds.2018-15358.

ORCIDS

A. M. L. Madureira https://orcid.org/0000-0001-9696-8478
J. L. Plenio https://orcid.org/0000-0002-0809-0077
J. L. M. Vasconcelos https://orcid.org/0000-0001-6324-3614
R. L. A. Cerri https://orcid.org/0000-0002-8169-8900
S. Borchardt https://orcid.org/0000-0003-3937-5777