

Benchmarking productive and reproductive traits dynamics in tropical dairy cattle

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Research Article

Keywords: dairy, reproduction, tropical, genotypes, seasonality

Posted Date: September 15th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10693501/v1>

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Abstract

Dairy production in tropical regions faces particular challenges related to heat stress, management constraints, and seasonal changes on feeding quality and quantity, yet comprehensive benchmarks for productive and reproductive performance are scarce. This study aimed to characterize reproductive traits of dairy cattle under tropical conditions using long-term on-farm records from dairy production farms. The dataset comprised 21,147 calving records from 10,475 cows across 11 dairy farms in El Salvador collected between 2001 and 2024. Services per conception, days to first service, days open, gestation length, age at first breeding and age at first calving were analyzed using mixed models accounting for genotype, parity, and season. Additionally, seasonality of calvings and culling reasons were studied. Clear seasonal patterns in calving distribution were observed, with primiparous cows showing a more uniform distribution across the year than multiparous. Reproductive traits varied significantly across genotypes. Jersey × Holstein crosses generally exhibited more favorable fertility indicators, and minor differences between Holstein and Brown Swiss × Holstein crosses. Seasonal effects were evident in Holstein cows, with improved reproductive performance during cooler and drier months. Overall, the results highlight the combined influence of genotype, parity, and season on dairy cow performance and support the strategic use of crossbreeding and climate-adapted management practices to improve productivity and resilience in tropical dairy systems. The derived benchmarks generated provide a valuable reference for producers, advisors, researchers, and policymakers, supporting evidence-based reproductive management, informed breed selection, and the development of realistic performance targets for dairy systems operating under tropical conditions.

Introduction

Establishing a reliable baseline is a fundamental step in assessing the effectiveness of sectoral development, as it enables objective evaluation of progress and the definition of future scenarios. In Salvadoran dairy farming, farm-level record keeping is relatively common; however, the level of detail recorded and the extent to which these data are used for management and decision-making vary widely among producers. Moreover, the absence of national performance benchmarks limits farmers' ability to assess whether their herds perform above or below expectations under local conditions and restricts the capacity of stakeholders to identify best practices that could be transferred across herds.

Compiling consistent national statistics on dairy cattle reproduction remains challenging in many countries. Nevertheless, several nations have established robust livestock performance monitoring systems. For example, Dairy Herd Improvement (DHI) programs in Canada and the United States (CDCB 2023; USDA 2022), Meat & Livestock Australia (MLA 2022), and the German Livestock Association (ADR 2023) routinely collect detailed herd- and individual-cow-level data, generating valuable information that supports evidence-based decision-making at both farm and policy levels.

In contrast, where national benchmarks are lacking, reference values for productive and reproductive parameters are often derived from temperate production systems. These systems differ substantially in

both environmental and management conditions from tropical dairy systems, thereby limiting the generalizability of such benchmarks. Consequently, it remains unclear whether these reference values represent realistic or appropriate performance targets for dairy production under tropical conditions.

Even within region and production system, reproductive performance can vary substantially according to season and parity (Li et al. 2022). Marked differences exist among breeds, as previous studies have reported an inverse relationship between milk yield and reproductive efficiency, with Jersey cows generally exhibiting better reproductive performance than Brown Swiss, and Brown Swiss outperforming Holstein cows (Brown et al. 2012; Piccand et al. 2013; Toledo-Alvarado et al. 2017).

Under these conditions, locally derived benchmarks that account for differences in breed, parity, and season are essential to accurately characterize reproductive performance, guide management decisions, and support the sustainable development of the dairy sector. Accordingly, this study aimed to establish locally relevant benchmarks for reproductive performance in dairy cattle in El Salvador, providing reference values that support evidence-based management and realistic performance targets for tropical dairy systems.

Materials and methods

Dataset

The database used in this study consisted of records from 21,147 calvings between 2001 and 2024, from 10,475 cows (5,913 Holstein and 4,562 of other breeds and crosses) from existing records in 11 dairy farms in El Salvador. These herds are confined and fed on Total Mixed Ration all year around, where the diet is based on maize silage, Pennisetum grass and concentrate, the latter in a proportion varying between 40 and 55% of the dry matter. The data were available through the VAMPP Bovino program (Version 3.0) and the UniForm program (UNIFORM-Agri).

The dataset included information on farm and cow identification, date of birth, genotype (pure breeds and crosses), birth weight (kg), age at first service (months), age at first calving (months), calving date, number of services per conception (for the corresponding calving) (SPC), days to first service postpartum, days open, lactation number, and gestation length (days).

Records with age at first service < 12 or > 40 months and records with age at first calving < 20 or > 60 months were removed. Observations with days open < 45 or > 365 days and days to first service < 45 or > 150 days were also excluded. Additionally, gestation length records < 260 or > 300 days were removed. Moreover, calving events were classified according to lactation number into three parity groups: primiparous (1), secundiparous (2), and multiparous (≥ 3). A summary of the available data is presented in Supplementary Table S1.

Additionally, the dataset included 2,859 records of cows whose productive lives had ended due to either death or culling. Mortality by lactation was quantified, and culling reasons were categorized as follows:

fertility (n = 698), health problems (n = 266), lameness (n = 225), low productivity (n = 83), udder health (n = 182), and other reasons (n = 856).

Genotypes

A total of 98 distinct genotypes were identified in the dataset, including both pure breeds and crossbreds (Supplementary Table S2). For the analyses, only genotypes (pure breeds or crosses) represented by at least 70 calving records were retained as separate categories. The pure breeds included Holstein (H8, n = 11,895), Jersey (J8, n = 1,682), and Brown Swiss (BS8, n = 171). In addition, records were available for Brahman (BR), Ayrshire (AY), Simmental (SM), Swedish Red and White (SR), Gyr (GY), Shorthorn (SP), Milking Shorthorn (MS), Wagyu (WY), and Angus (A), as well as for their crosses, mainly involving Holstein, Jersey, and Brown Swiss.

The Holstein × Brown Swiss crosses included H7×BS1 (n = 171), H6×BS2 (n = 1,070), H5×BS3 (n = 290), H4×BS4 (n = 833), BS5×H3 (n = 349), BS6×H2 (n = 1,348), and BS7×H1 (n = 341). The Holstein × Jersey crosses included H6×J2 (n = 417), H4×J4 (n = 1,535), J6×H2 (n = 249), and Other J×H (n = 184). Additional genotype groups included Other Holstein (crosses with ≥ 50% Holstein composition; n = 184), Other Jersey (crosses with ≥ 50% Jersey composition; n = 133), H×BR (Holstein × Brahman crosses with at least 1/8 Brahman ancestry; n = 221), and Other genotypes (all remaining crosses not included in the previous categories; n = 74). Detailed information on the specific crosses and genotype composition of each category is provided in Supplementary Table S2.

Season

To explore potential seasonality effects, each record was assigned a corresponding month of calving. In addition, a cluster analysis was conducted using regional weather data obtained from <https://en.climate-data.org> for the farms' location. Based on this analysis, months were grouped into four climatic clusters:

Cluster 1: November through February, representing the dry season with the lowest temperatures and Temperate-humidity Index (THI) (Avg T = 24.8°C, THI = 76.9, Humidity = 65%, Precipitation = 19.1 mm);

Cluster 2: March-April, corresponding to the dry season with highest temperature and THI (Avg T = 26.1°C, THI = 79.2, Humidity = 66%, Precipitation = 35.3 mm); **Cluster 3:** May through August, representing the rainy season with highest temperature and THI (Avg T = 25.2°C, THI = 77.6, Humidity = 84%, Precipitation = 245.1 mm); and **Cluster 4:** September-October, corresponding to the rainy season with lowest temperatures and THI (Avg T = 24.2°C, THI = 75.9, Humidity = 87%, Precipitation = 322.1 mm).

In addition, month of birth of the cow and its corresponding climatic cluster was assigned to each record to assess potential seasonality effects on birth weight, age at first services, and age at first calving.

Statistical analysis

The differences in the monthly calving distribution between parity groups (1, 2, or ≥ 3) was assessed using a multinomial logistic regression model, with month of calving as the categorical response and parity group as a predictor in base R (version 4.4.1).

The significance of parity was evaluated by comparing the full and reduced (null) models using a likelihood ratio test (χ^2 test) and pairwise model comparisons (1 vs. 2, 1 vs. ≥ 3 , and 2 vs. ≥ 3) were conducted to identify which groups differed in their monthly calving distributions.

The discrete variable services per conception (≥ 1) was evaluated for goodness-of-fit to Poisson, negative binomial, and geometric distributions using maximum likelihood estimation in R (MASS package). Model comparison indicated that the negative binomial distribution provided the best fit. For continuous traits, distributional assumptions were assessed prior to analysis. Days open and days at first service were not normal, thus the analyses were conducted on the log-transformed data, while gestation length was normally distributed.

Services per conception were analysed using a generalized linear mixed model with a negative binomial error distribution (NB1; variance proportional to the mean), fitted with glmmTMB in R (glmmTMB package). Days at first service, days open, and gestation length were analysed using linear mixed models fitted with lmer (lme4 package). Fixed effects included genotype, parity, and their interaction (genotype $\times$ parity) to allow parity-specific trends. Random intercepts were fitted for animal ID and for year nested within farm to account for repeated measures and clustering. Statistical significance was declared at $P < 0.05$.

When a fixed-effect interaction was significant, pairwise comparisons were conducted using emmeans (emmeans package, R), contrasting each genotype with Holstein within parity groups and comparing parity levels within each genotype. Tukey's method was used to adjust for multiple testing. Additionally, orthogonal contrasts were performed to compare Holstein, H $\times$ BS (all Holstein $\times$ Brown Swiss crosses), and H $\times$ J (all Holstein $\times$ Jersey crosses).

To investigate seasonal effects, a second set of models was fitted using only Holstein data (11,895 observations). Services per conception, gestation length, days at first service and days open were analysed as above, except that fixed effects included month of calving, parity and their interaction. If a month $\times$ parity interaction was significant, mean differences between parities were estimated within each month; otherwise, overall parity means were reported with pairwise differences adjusted by Tukey's test. Additionally, orthogonal contrasts were performed to compared climatic clusters.

Furthermore, an additional dataset was derived from the original one including only unique records with the objective of exploring birth weight, age at first service, and age at first calving. All three traits were confirmed to be normally distributed. The effect of genotype on these traits was analysed using a linear mixed model using the lmer function (lme4 package), where genotype was included as a fixed effect, and year nested within farm was included as a random effect. Also, in this subset, total number of lactations in culled cows were analysed using a generalized linear mixed model with a negative binomial

error distribution (NB1; variance proportional to the mean), fitted with glmmTMB (glmmTMB) including genotype as fixed effect, and year nested within farm was as a random effect.

Additionally, a separate analysis was performed using only Holstein cows to assess the effect of month of birth on birth weight, age at first service, and age at first calving. In this model, month of birth was included as a fixed effect, while year nested within farm was included as a random effect using lmer (lme4 package). Moreover, for Holstein cows only, age at first service and age at first calving were regressed on birth weight using a mixed model (lmer function, lme4 package), with year nested within farm included as a random effect. Both linear and quadratic effects of birth weight were evaluated; however, the quadratic term was subsequently removed due to a lack of statistical significance.

Results

Calving distribution and seasonality of calvings

From the available calvings 36.0%, 25.6%, and 38.4% of those corresponded to first, second, and third or more calving, respectively. There is a clear seasonal pattern in calving among Salvadoran dairy cows; however, calving distribution also differs according to parity group (Fig. 1). Multinomial logistic models followed by likelihood ratio tests (χ^2) revealed that the month of calving distribution differed significantly between Parity 1 and both Parity 2 ($\chi^2_{(11)} = 78.2$, $P < 0.001$) and Parity ≥ 3 ($\chi^2_{(11)} = 127.5$, $P < 0.001$), but not between Parity 2 and ≥ 3 ($\chi^2_{(11)} = 10.6$, $P = 0.47$). Primiparous cows showed a more uniform pattern throughout the year, with the lowest calving frequencies observed in August. In contrast, cows in their second and third or higher parities exhibited a more pronounced seasonal pattern, with significantly more calvings between September and November and fewer between February and March (Fig. 1).

Genotype effects on services per conception

For Holstein, Jersey and Brown Swiss, as well as most of crosses involving Holstein or Jersey, SPC were lowest for the first pregnancy and increased thereafter, with no difference between the second and third or greater pregnancies. In contrast, in Brown Swiss $\times$ Holstein crosses (i.e., H6 $\times$ BS2, H4 $\times$ BS4, BS5 $\times$ H3, BS6 $\times$ H2, BS7 $\times$ H1) SPC were higher in the second pregnancy compared with third-or-greater.

There were no major differences in SPC for the first pregnancy between Holstein, Brown Swiss and Jersey with average ($\pm$ SE) SPC of 1.79 ± 0.04 , 1.63 ± 0.20 and 1.60 ± 0.07 , respectively (Table 1). Some of the Brown Swiss $\times$ Holstein crosses, “Other Jersey crosses” and “Other crosses” appeared to have lower SPC than Holstein in the first pregnancy, but only the BS7 $\times$ H1 was significantly different. For the second pregnancy, Holstein, Brown Swiss and Jersey averaged 2.91 ± 0.07 , 2.92 ± 0.32 and 2.70 ± 0.11 , respectively. Several Brown Swiss $\times$ Holstein crosses (H6 $\times$ BS2, H5 $\times$ BS3, H4 $\times$ BS4, BS5 $\times$ H3, BS6 $\times$ H2) had higher SPC than Holstein, whereas J6 $\times$ H2 had lower SPC (2.11 ± 0.18). For cows in third or greater pregnancy, no differences were observed between the genotypes (Table 1).

When using orthogonal contrasts to compare Holstein with Brown Swiss and their crosses, fewer SPC were required for the latter to achieve the first pregnancy ($P = 0.001$), with no differences between Holstein $\times$ Jersey and the pure Holstein group, nor between Holstein $\times$ Jersey and Brown Swiss $\times$ Holstein ($P > 0.05$). For the second pregnancy, differences were observed among all three genotypes: Brown Swiss $\times$ Holstein required more SPC than Holstein, and Holstein more than Jersey $\times$ Holstein ($P < 0.05$). For the third and later pregnancies, differences in SPC were no longer evident among genotypes ($P > 0.05$) (Table 1).

Genotype effects on gestation length

There was an interaction effect of genotype and pregnancy number where gestation length generally increased with pregnancy, although differences between pregnancies were not significant across all genotypes. Specifically, H6 $\times$ BS2, H4 $\times$ BS4, BS5 $\times$ H3, BS6 $\times$ H2, BS7 $\times$ H1 had longer gestation length than Holstein in the first pregnancy, while H5 $\times$ BS3, H4 $\times$ BS4, and BS6 $\times$ H2 exceeded Holstein in the third or greater pregnancy. In general, Brown Swiss $\times$ Holstein crosses tended to have longer gestation lengths than Holstein, whereas Holstein $\times$ Jersey crosses tended to be shorter (Table 1). Along that line, the contrast analysis showed that across all pregnancies, gestation length was significantly greater in genotypes containing Brown Swiss compared with those of Holstein or Jersey $\times$ Holstein ($P < 0.001$), while no differences were detected between Holstein and Jersey $\times$ Holstein cows ($P > 0.05$) (Table 1).

Genotype effects on days to first service and days open

For days to first service, no interaction effect between lactation and genotype was observed. Cows in their first lactation required a longer interval to first service (71.8 ± 1.03) compared with those in their second (69.2 ± 1.11) and later lactation (69.4 ± 1.12) ($P < 0.001$). Among genotypes, the lowest days to first service were observed in the J6 $\times$ H2 cross, significantly differing from Holstein ($P < 0.05$). According to the contrast analysis, Jersey $\times$ Holstein cows showed shorter days to first service than Holstein cows ($P < 0.001$), whereas no significant differences were detected between Brown Swiss $\times$ Holstein and either Holstein or Jersey $\times$ Holstein genotypes (Table 2).

For days open, the interval generally decreased with advancing lactation, although the pattern varied among genotypes. In Holstein cows, no significant difference was observed between cows in the first and second lactation, but a marked reduction in days open occurred for those in the third and later lactation. Similar trends were found for the Brown Swiss crosses. Conversely, some of the Jersey $\times$ Holstein crosses showed relatively short days open after the first calving, followed by a tendency to increase in subsequent ones. According to the contrast analysis, in the first lactation, days open were longest for the Brown Swiss $\times$ Holstein group, intermediate for Holstein, and shortest for Jersey $\times$ Holstein ($P < 0.01$). In the second lactation, only the Jersey $\times$ Holstein group differed from the other two, exhibiting shorter days open, whereas differences among genotypes disappeared in the third and later lactation ($P > 0.05$) (Table 2).

Table 1

Services per conception and gestation length by pregnancy for different breeds of dairy cows in a tropical environment (LSmeans $\pm$ standard error). Data between 2004 and 2024.

Genotype	Services per conception		Gestation length			
	Pregnancy number		Pregnancy number			
1	2	≥ 3	1	2	≥ 3	
Holstein	1.79 $\pm$ 0.04 ^a (n = 4220)	2.91 $\pm$ 0.07 ^b (n = 3157)	2.86 $\pm$ 0.07 ^b (n = 4518)	275.0 $\pm$ 0.21 ^a (n = 3218)	276.0 $\pm$ 0.22 ^b (n = 2384)	276.7 $\pm$ 0.21 ^c (n = 3321)
H7 $\times$ BS1	1.71 $\pm$ 0.15 ^a (n = 82)	3.48 $\pm$ 0.30 ^b (n = 49)	3.08 $\pm$ 0.32 ^b (n = 40)	276.5 $\pm$ 0.83 (n = 63)	278.7 $\pm$ 1.10 (n = 33)	277.9 $\pm$ 1.44 (n = 21)
H6 $\times$ BS2	1.69 $\pm$ 0.10 ^a (n = 249)	3.96 $\pm$ 0.22 ^{*c} (n = 210)	3.21 $\pm$ 0.16 ^b (n = 611)	277.2 $\pm$ 0.53 [*] (n = 198)	277.6 $\pm$ 0.55 (n = 185)	278.3 $\pm$ 0.46 (n = 514)
H5 $\times$ BS3	1.35 $\pm$ 0.11 ^a (n = 120)	3.86 $\pm$ 0.28 ^{*b} (n = 85)	3.35 $\pm$ 0.26 ^b (n = 85)	277.1 $\pm$ 0.70 ^a (n = 101)	277.8 $\pm$ 0.82 ^{ab} (n = 69)	280.4 $\pm$ 1.02 ^{*b} (n = 45)
H4 $\times$ BS4	1.73 $\pm$ 0.09 ^a (n = 279)	3.96 $\pm$ 0.21 ^{*c} (n = 200)	2.84 $\pm$ 0.15 ^b (n = 354)	278.1 $\pm$ 0.49 [*] (n = 230)	278.0 $\pm$ 0.54 (n = 180)	278.7 $\pm$ 0.51 [*] (n = 274)
BS5 $\times$ H3	1.38 $\pm$ 0.10 ^a (n = 171)	3.73 $\pm$ 0.26 ^{*c} (n = 99)	3.00 $\pm$ 0.25 ^b (n = 79)	277.8 $\pm$ 0.63 [*] (n = 138)	279.1 $\pm$ 0.83 (n = 66)	277.4 $\pm$ 1.03 (n = 50)
BS6 $\times$ H2	1.49 $\pm$ 0.08 ^a (n = 355)	3.61 $\pm$ 0.19 ^{*c} (n = 284)	3.10 $\pm$ 0.16 ^b (n = 709)	278.7 $\pm$ 0.49 [*] (n = 296)	278.8 $\pm$ 0.51 (n = 246)	278.5 $\pm$ 0.45 [*] (n = 595)
BS7 $\times$ H1	1.26 $\pm$ 0.09 ^{*a} (n = 173)	2.94 $\pm$ 0.21 ^c (n = 101)	2.19 $\pm$ 0.20 ^b (n = 67)	277.5 $\pm$ 0.64 [*] (n = 133)	278.9 $\pm$ 0.82 (n = 69)	279.3 $\pm$ 1.15 (n = 35)
* Means with a star indicate significant differences with Holstein within a column						

Genotype	Services per conception		Gestation length			
	Pregnancy number		Pregnancy number			
1	2	≥ 3	1	2	≥ 3	
Brown Swiss	1.63 ± 0.20 ^a (n = 41)	2.92 ± 0.32 ^b (n = 37)	2.08 ± 0.19 ^a (n = 93)	276.1 ± 1.13 (n = 30)	279.6 ± 1.23 (n = 25)	277.6 ± 0.82 (n = 76)
H6×J2	1.55 ± 0.09 ^a (n = 204)	2.85 ± 0.18 ^b (n = 122)	2.57 ± 0.20 ^b (n = 91)	275.2 ± 0.57 (n = 139)	275.4 ± 0.79 (n = 63)	275.3 ± 0.97 (n = 44)
H4×J4	1.77 ± 0.07 ^a (n = 478)	2.75 ± 0.11 ^b (n = 367)	2.87 ± 0.10 ^b (n = 690)	275.4 ± 0.40 (n = 296)	276.0 ± 0.43 (n = 258)	276.0 ± 0.38 (n = 425)
J6×H2	1.61 ± 0.12 ^a (n = 112)	2.11 ± 0.18 ^{*b} (n = 68)	2.74 ± 0.23 ^b (n = 69)	274.4 ± 0.79 (n = 64)	275.6 ± 0.98 (n = 40)	276.6 ± 1.02 (n = 40)
Jersey	1.60 ± 0.07 ^a (n = 490)	2.70 ± 0.11 ^b (n = 401)	2.70 ± 0.10 ^b (n = 791)	274.7 ± 0.41 ^a (n = 299)	276.5 ± 0.42 ^b (n = 279)	276.4 ± 0.35 ^b (n = 558)
Other J×H	1.87 ± 0.15 ^a (n = 92)	3.15 ± 0.28 ^b (n = 53)	3.01 ± 0.32 ^b (n = 39)	274.1 ± 0.84 (n = 56)	276.2 ± 1.06 (n = 34)	275.5 ± 1.55 (n = 16)
Other Holstein	2.05 ± 0.18 ^a (n = 78)	3.08 ± 0.29 ^b (n = 51)	2.90 ± 0.29 ^b (n = 55)	276.5 ± 0.82 (n = 59)	276.0 ± 1.02 (n = 37)	277.5 ± 1.13 (n = 32)
Other Jersey	1.34 ± 0.17 ^a (n = 45)	2.78 ± 0.32 ^b (n = 31)	2.39 ± 0.24 ^b (n = 57)	276.6 ± 1.10 (n = 32)	277.3 ± 1.37 (n = 20)	277.5 ± 1.14 (n = 35)
H×BR	1.75 ± 0.16 ^a (n = 76)	2.52 ± 0.24 ^b (n = 55)	2.74 ± 0.23 ^b (n = 90)	274.7 ± 1.02 (n = 38)	275.1 ± 1.14 (n = 30)	276.8 ± 0.97 (n = 49)
* Means with a star indicate significant differences with Holstein within a column						

Genotype	Services per conception			Gestation length		
	Pregnancy number			Pregnancy number		
1	2	≥ 3	1	2	≥ 3	
Other crosses	1.45 ± 0.27 ^a (n = 18)	2.79 ± 0.41 ^b (n = 19)	3.34 ± 0.39 ^b (n = 37)	276.9 ± 1.93 (n = 10)	274.6 ± 1.64 (n = 14)	274.0 ± 1.27 (n = 27)
<i>P-values</i>						
Pregnancy	< 0.001			< 0.001		
Genotype	< 0.001			< 0.001		
Pregnancy × Genotype	< 0.001			0.04		
<i>Contrasts</i>						
H8 vs. H×BS	0.001	< 0.001	0.98	< 0.001	< 0.001	< 0.001
H8 vs. H×J	0.10	0.04	0.74	0.75	0.99	0.29
H×BS vs. H×J	0.18	< 0.001	0.99	< 0.001	< 0.001	< 0.001
* Means with a star indicate significant differences with Holstein within a column						

Different superscripts within a row for a specific parameter indicate significant differences (P < 0.05)

Table 2

Days to first service and days open for different breeds of dairy cows in a tropical environment (LSmeans $\pm$ standard error). Data between 2004 and 2024.

Genotype	Days to first service		Days open			
	Lactation number ¹		Lactation number ¹			
1	2	≥ 3	1	2	≥ 3	
H8	75.1 $\pm$ 0.87 (n = 2648)	72.4 $\pm$ 0.89 (n = 1763)	72.4 $\pm$ 0.87 (n = 2044)	136.0 $\pm$ 1.88 ^a (n = 2728)	133.7 $\pm$ 2.08 ^{ab} (n = 1864)	129.4 $\pm$ 1.96 ^b (n = 2207)
H7 $\times$ BS1	72.5 $\pm$ 3.48 (n = 37)	71.1 $\pm$ 4.61 (n = 19)	65.0 $\pm$ 5.01 (n = 14)	148.4 $\pm$ 13.4 (n = 38)	141.4 $\pm$ 17.3 (n = 20)	126.8 $\pm$ 18.2 (n = 16)
H6 $\times$ BS2	74.6 $\pm$ 2.02 (n = 163)	68.1 $\pm$ 1.95 (n = 141)	71.7 $\pm$ 1.67 (n = 365)	160.1 $\pm$ 7.46 ^a (n = 165)	146.4 $\pm$ 7.25 ^{ab} (n = 145)	136.3 $\pm$ 5.11 ^b (n = 389)
H5 $\times$ BS3	75.5 $\pm$ 2.97 (n = 64)	70.6 $\pm$ 3.27 (n = 42)	67.9 $\pm$ 3.99 (n = 25)	161.1 $\pm$ 11.3 (n = 68)	142.8 $\pm$ 12.0 (n = 45)	140.5 $\pm$ 15.1 (n = 27)
H4 $\times$ BS4	74.3 $\pm$ 1.94 (n = 167)	71.2 $\pm$ 2.03 (n = 132)	72.8 $\pm$ 1.99 (n = 171)	156.4 $\pm$ 7.34 ^a (n = 156)	136.8 $\pm$ 7.05 ^{ab} (n = 128)	126.7 $\pm$ 6.02 ^b (n = 185)
BS5 $\times$ H3	75.5 $\pm$ 2.66 (n = 85)	73.3 $\pm$ 3.91 (n = 30)	70.5 $\pm$ 4.15 (n = 26)	170.7 $\pm$ 11.0 ^a (n = 84)	159.9 $\pm$ 14.4 ^a (n = 39)	110.3 $\pm$ 11.8 ^b (n = 32)
BS6 $\times$ H2	72.0 $\pm$ 1.79 (n = 237)	70.2 $\pm$ 1.86 (n = 193)	70.8 $\pm$ 1.64 (n = 390)	155.3 $\pm$ 6.41 (n = 235)	147.5 $\pm$ 6.53 (n = 198)	140.7 $\pm$ 5.15 (n = 431)
BS7 $\times$ H1	67.6 $\pm$ 2.39 (n = 87)	71.0 $\pm$ 3.39 (n = 39)	69.5 $\pm$ 4.94 (n = 17)	142.7 $\pm$ 9.04 ^a (n = 90)	111.3 $\pm$ 9.96 ^b (n = 40)	104.6 $\pm$ 13.6 ^b (n = 19)
BS8	71.9 $\pm$ 3.79 (n = 29)	68.4 $\pm$ 4.40 (n = 19)	70.1 $\pm$ 2.75 (n = 61)	118.9 $\pm$ 11.9 (n = 30)	108.4 $\pm$ 13.5 (n = 19)	115.0 $\pm$ 8.52 (n = 67)
H6 $\times$ J2	74.3 $\pm$ 2.23	73.1 $\pm$ 3.40	72.1 $\pm$ 3.82	122.4 $\pm$ 6.60	116.6 $\pm$ 9.84	127.9 $\pm$ 11.7

Genotype	Days to first service		Days open			
	Lactation number ¹		Lactation number ¹			
1	2	≥ 3	1	2	≥ 3	
	(n = 98)	(n = 37)	(n = 29)	(n = 108)	(n = 42)	(n = 37)
H4×J4	71.5 ± 1.40 (n = 293)	69.7 ± 1.52 (n = 216)	68.7 ± 1.33 (n = 327)	127.1 ± 4.09 (n = 326)	126.0 ± 4.53 (n = 255)	119.2 ± 3.79 (n = 367)
J6×H2	65.0 ± 2.47* (n = 58)	65.7 ± 3.85 (n = 23)	73.2 ± 4.22 (n = 24)	101.7 ± 7.07* ^a (n = 64)	121.4 ± 11.7 ^{ab} (n = 32)	141.6 ± 15.6 ^b (n = 25)
J8	69.5 ± 1.37* (n = 294)	68.9 ± 1.48 (n = 227)	69.7 ± 1.30 (n = 355)	119.7 ± 3.83 (n = 342)	115.5 ± 4.08 (n = 269)	119.3 ± 3.65 (n = 422)
Other J×H	67.7 ± 3.01 (n = 41)	62.1 ± 3.88 (n = 20)	71.0 ± 5.69 (n = 12)	128.8 ± 10.5* (n = 45)	105.2 ± 12.5 (n = 21)	147.5 ± 21.5 (n = 14)
Other Holstein	74.9 ± 3.19 (n = 45)	66.2 ± 4.03 (n = 21)	65.6 ± 3.97 (n = 22)	135.7 ± 10.9 (n = 47)	144.9 ± 14.9 (n = 28)	111.4 ± 12.3 (n = 25)
Other Jersey	70.5 ± 4.21 (n = 22)	67.8 ± 4.88 (n = 15)	68.9 ± 3.90 (n = 26)	119.8 ± 12.8 (n = 26)	103.2 ± 12.9 (n = 19)	114.1 ± 11.3 (n = 33)
H×BR	69.9 ± 3.14 (n = 41)	66.5 ± 3.32 (n = 33)	62.5 ± 2.92 (n = 39)	119.3 ± 9.43 (n = 50)	119.2 ± 11.0 (n = 36)	107.7 ± 9.19 (n = 45)
Other	70.0 ± 5.21 (n = 14)	69.7 ± 5.83 (n = 11)	67.4 ± 4.96 (n = 15)	129.6 ± 18.2 (n = 15)	135.8 ± 23.3 (n = 10)	114.9 ± 13.8 (n = 22)
Mean Parity	71.8 ± 1.03 ^a	69.2 ± 1.11 ^b	69.4 ± 1.12 ^b	135.2 ± 2.73	128.7 ± 3.11	124.4 ± 3.01
<i>P-values</i>						
Parity	< 0.001			< 0.001		
Genotype	< 0.001			< 0.001		

Genotype	Days to first service			Days open		
	Lactation number ¹			Lactation number ¹		
1	2	≥ 3	1	2	≥ 3	
Parity × Genotype	0.84			0.02		
Contrasts						
H8 vs. H×BS	0.35	0.54	0.29	0.004	0.97	0.70
H8 vs. H×J	< 0.001	0.01	0.93	< 0.001	0.001	0.99
H×BS vs. H×J	0.11	0.46	0.77	< 0.001	0.01	0.78

¹ Lactation number represents the number of previous calvings. Thus, for cows in their first lactation, days open reflect the interval to the subsequent (second) conception.

* Means with a star indicate significant differences with Holstein within a column.

Different superscripts within a row for a specific parameter indicate significant differences between lactation number ($P < 0.05$).

Season effects for services per conception in Holstein cows

For Holstein cows, both month and pregnancy number significantly affected SPC ($P < 0.01$), but no interaction between these factors was detected ($P = 0.15$). More SPC were required to achieve the second (2.73 ± 0.13) and the third or greater (2.69 ± 0.12) pregnancies compared with the first (1.74 ± 0.08). The lowest SPC were observed for calvings occurring between December and February, while higher SPC were recorded from April through July. Consistently, the contrast analysis showed that cows calving in Cluster 1 (November–February) required fewer services per conception, whereas those in Cluster 3 (May–August) needed the most (Table 3).

Season effects for gestation length in Holstein cows

Gestation length was also influenced by month and pregnancy number ($P < 0.001$), with no interaction between them ($P = 0.34$). Cows in their first pregnancy had shorter gestation lengths (274.8 ± 0.22) than those in the second (276.0 ± 0.23) and third or greater (276.6 ± 0.22) pregnancies, with the latter being slightly but significantly longer than the former. According to the contrast analysis, the main differences were found between Cluster 1 and the other clusters: cows calving between November and February had longer gestation lengths than those in Clusters 3 and 4, and to a lesser extent, than those in Cluster 2 (Table 3).

Table 3

Services per conception and gestation length by parity of Holstein cows by month in a tropical environment (LSmeans $\pm$ standard error). Data between 2004 and 2024.

Month	Services per conception			Gestation length		
	Pregnancy			Pregnancy		
1	2	3+	1	2	3+	
February	1.53 $\pm$ 0.09 (n = 383)	2.43 $\pm$ 0.15 (n = 218)	2.64 $\pm$ 0.15 (n = 319)	276.1 $\pm$ 0.37 (n = 343)	277.2 $\pm$ 0.47 (n = 179)	277.6 $\pm$ 0.39 (n = 280)
February	1.69 $\pm$ 0.10 (n = 295)	2.30 $\pm$ 0.15 (n = 169)	2.67 $\pm$ 0.16 (n = 223)	276.2 $\pm$ 0.41 (n = 251)	277.4 $\pm$ 0.52 (n = 141)	278.2 $\pm$ 0.46 (n = 194)
March	1.73 $\pm$ 0.10 (n = 313)	2.69 $\pm$ 0.17 (n = 177)	2.66 $\pm$ 0.16 (n = 232)	275.2 $\pm$ 0.40 (n = 268)	275.4 $\pm$ 0.51 (n = 147)	276.9 $\pm$ 0.45 (n = 205)
April	1.74 $\pm$ 0.10 (n = 304)	2.90 $\pm$ 0.17 (n = 217)	2.62 $\pm$ 0.15 (n = 273)	275.1 $\pm$ 0.40 (n = 266)	275.2 $\pm$ 0.46 (n = 186)	276.0 $\pm$ 0.42 (n = 240)
May	1.73 $\pm$ 0.10 (n = 294)	2.87 $\pm$ 0.18 (n = 191)	2.76 $\pm$ 0.16 (n = 285)	274.1 $\pm$ 0.40 (n = 263)	276.6 $\pm$ 0.49 (n = 161)	275.9 $\pm$ 0.41 (n = 249)
June	1.88 $\pm$ 0.11 (n = 277)	2.67 $\pm$ 0.17 (n = 186)	2.85 $\pm$ 0.16 (n = 254)	273.5 $\pm$ 0.42 (n = 235)	275.8 $\pm$ 0.49 (n = 167)	276.3 $\pm$ 0.44 (n = 210)
July	1.81 $\pm$ 0.11 (n = 255)	2.89 $\pm$ 0.18 (n = 188)	2.64 $\pm$ 0.15 (n = 250)	274.3 $\pm$ 0.45 (n = 206)	275.8 $\pm$ 0.50 (n = 159)	276.1 $\pm$ 0.45 (n = 200)
August	1.81 $\pm$ 0.12 (n = 239)	2.88 $\pm$ 0.17 (n = 230)	2.94 $\pm$ 0.16 (n = 306)	274.8 $\pm$ 0.45 (n = 205)	275.4 $\pm$ 0.47 (n = 184)	276.6 $\pm$ 0.40 (n = 267)
September	1.71 $\pm$ 0.10 (n = 330)	2.89 $\pm$ 0.16 (n = 295)	2.72 $\pm$ 0.15 (n = 358)	274.8 $\pm$ 0.39 (n = 284)	275.3 $\pm$ 0.41 (n = 257)	276.4 $\pm$ 0.38 (n = 319)
¹ Cluster 1: November to February; Cluster 2: March to April; Cluster 3: May to August; Cluster 4: September to October						

Month	Services per conception			Gestation length		
	Pregnancy			Pregnancy		
1	2	3+	1	2	3+	
October	1.71 ± 0.10 (n = 358)	2.86 ± 0.15 (n = 343)	2.55 ± 0.13 (n = 519)	274.2 ± 0.39 (n = 294)	275.1 ± 0.38 (n = 300)	275.9 ± 0.33 (n = 457)
November	1.73 ± 0.10 (n = 355)	2.83 ± 0.16 (n = 297)	2.65 ± 0.14 (n = 442)	274.3 ± 0.38 (n = 310)	275.3 ± 0.41 (n = 255)	275.9 ± 0.35 (n = 395)
December	1.75 ± 0.10 (n = 336)	2.63 ± 0.15 (n = 284)	2.54 ± 0.14 (n = 337)	275.0 ± 0.39 (n = 293)	276.8 ± 0.41 (n = 248)	277.2 ± 0.38 (n = 305)
Means Parity	1.74 ± 0.08 ^a	2.73 ± 0.13 ^b	2.69 ± 0.12 ^b	274.8 ± 0.22 ^a	276.0 ± 0.23 ^b	276.6 ± 0.22 ^c
<i>P values</i>						
Month	0.002			< 0.001		
Parity	< 0.001			< 0.001		
Month×Parity	0.15			0.34		
<i>Contrasts</i> ¹						
Cluster 1 vs. 2	0.90	0.08	0.99	0.97	0.003	0.09
Cluster 1 vs. 3	0.10	0.004	0.12	< 0.001	0.08	< 0.001
Cluster 1 vs. 4	0.99	0.001	0.99	0.01	< 0.001	0.001
Cluster 2 vs. 3	0.90	0.99	0.48	0.01	0.61	0.99
Cluster 2 vs. 4	0.99	0.98	0.99	0.27	0.99	0.98
Cluster 3 vs. 4	0.63	0.99	0.24	0.92	0.20	0.99
¹ Cluster 1: November to February; Cluster 2: March to April; Cluster 3: May to August; Cluster 4: September to October						

Different superscripts within a row for a specific parameter indicate significant differences between pregnancy number ($P < 0.05$)

Table 4

Days to first service and days open by parity of Holstein cows by month in a tropical environment (LSmeans $\pm$ standard error). Data between 2004 and 2024.

Month	Days to first service			Days open		
	Lactation number			Lactation number		
1	2	3+	1	2	3+	
January	74.2 $\pm$ 1.79 (n = 188)	71.2 $\pm$ 1.98 (n = 127)	71.1 $\pm$ 1.90 (n = 142)	127.3 $\pm$ 5.18 (n = 188)	130.1 $\pm$ 6.11 (n = 127)	134.4 $\pm$ 5.95 (n = 142)
February	73.0 $\pm$ 1.99 (n = 135)	72.6 $\pm$ 2.25 (n = 98)	72.0 $\pm$ 2.33 (n = 89)	128.8 $\pm$ 5.75 (n = 135)	135.3 $\pm$ 7.36 (n = 98)	150.4 $\pm$ 8.21 (n = 89)
March	73.0 $\pm$ 1.94 (n = 144)	76.4 $\pm$ 2.40 (n = 95)	71.8 $\pm$ 2.17 (n = 105)	127.4 $\pm$ 5.73 (n = 144)	140.2 $\pm$ 7.71 (n = 95)	129.0 $\pm$ 6.46 (n = 105)
April	76.9 $\pm$ 1.86 (n = 186)	73.2 $\pm$ 2.18 (n = 108)	70.8 $\pm$ 2.06 (n = 115)	138.7 $\pm$ 5.66 (n = 186)	137.8 $\pm$ 6.96 (n = 108)	132.4 $\pm$ 6.52 (n = 115)
May	74.3 $\pm$ 1.89 (n = 163)	74.8 $\pm$ 2.22 (n = 108)	73.3 $\pm$ 1.99 (n = 138)	143.2 $\pm$ 6.11 (n = 163)	143.9 $\pm$ 7.41 (n = 108)	135.5 $\pm$ 6.28 (n = 138)
June	77.7 $\pm$ 1.99 (n = 160)	76.0 $\pm$ 2.38 (n = 95)	73.9 $\pm$ 2.11 (n = 120)	140.3 $\pm$ 6.02 (n = 160)	142.6 $\pm$ 7.71 (n = 95)	142.4 $\pm$ 6.82 (n = 120)
July	74.5 $\pm$ 1.91 (n = 160)	72.0 $\pm$ 2.25 (n = 96)	72.7 $\pm$ 2.15 (n = 110)	136.9 $\pm$ 5.92 (n = 160)	133.3 $\pm$ 7.33 (n = 96)	133.9 $\pm$ 6.72 (n = 110)
August	72.9 $\pm$ 1.75 (n = 191)	69.2 $\pm$ 2.08 (n = 105)	69.6 $\pm$ 1.92 (n = 133)	144.1 $\pm$ 5.66 (n = 191)	131.1 $\pm$ 6.77 (n = 105)	134.3 $\pm$ 6.11 (n = 133)
September	73.1 $\pm$ 1.61 (n = 245)	66.2 $\pm$ 1.81 (n = 134)	71.3 $\pm$ 1.77 (n = 175)	137.4 $\pm$ 4.78 ^a (n = 245)	121.6 $\pm$ 5.67 ^{ab} (n = 134)	119.5 $\pm$ 4.96 ^b (n = 175)
¹ Cluster 1: November to February; Cluster 2: March to April; Cluster 3: May to August; Cluster 4: September to October						

Month	Days to first service			Days open		
	Lactation number			Lactation number		
1	2	3+	1	2	3+	
October	73.6 ± 1.54 (n = 285)	70.7 ± 1.67 (n = 200)	70.5 ± 1.56 (n = 249)	135.3 ± 4.47 ^a (n = 285)	126.8 ± 4.88 ^{ab} (n = 200)	113.0 ± 3.96 ^b (n = 249)
November	74.3 ± 1.62 (n = 253)	72.3 ± 1.77 (n = 179)	69.9 ± 1.65 (n = 202)	137.8 ± 4.83 ^a (n = 253)	133.2 ± 5.43 ^{ab} (n = 179)	122.2 ± 4.58 ^b (n = 202)
December	75.2 ± 1.66 (n = 242)	69.5 ± 1.85 (n = 143)	73.3 ± 1.97 (n = 139)	126.3 ± 4.52 (n = 242)	125.8 ± 5.58 (n = 143)	131.8 ± 5.77 (n = 139)
Mean Parity	74.4 ± 1.06 ^a	72.0 ± 1.08 ^b	71.7 ± 1.07 ^b	135.2 ± 2.04	133.1 ± 2.30	131.4 ± 2.23
<i>P values</i>						
Month	< 0.001			0.001		
Parity	< 0.001			0.02		
Month×Parity	0.52			0.03		
<i>Contrasts</i> ¹						
Cluster 1 vs. 2	0.99	0.24	0.99	0.99	0.68	0.98
Cluster 1 vs. 3	0.99	0.82	0.99	0.02	0.65	0.99
Cluster 1 vs. 4	0.98	0.18	0.99	0.50	0.62	< 0.001
Cluster 2 vs. 3	0.99	0.88	0.99	0.46	0.99	0.87
Cluster 2 vs. 4	0.85	0.002	0.99	0.98	0.09	0.04
Cluster 3 vs. 4	0.75	0.01	0.86	0.84	0.05	< 0.001
¹ Cluster 1: November to February; Cluster 2: March to April; Cluster 3: May to August; Cluster 4: September to October						

Different superscripts within a row for a specific parameter indicate significant differences between lactation number ($P < 0.05$)

Season effects for days to first service and days open in Holstein cows

Days to first services were affected by both, month of calving and lactation number ($P < 0.001$), with no interaction between these factors ($P = 0.52$). On average, cows in their first lactation had longer intervals to first service (74.4 ± 1.06) compared to those in their second (72.0 ± 1.08) and third or greater lactations (71.7 ± 1.07) (Table 4). Seasonally, the longest days to first service occurred around March and April, while the shortest intervals were observed in August and September.

For days open, there was an interaction between month and lactation number ($P = 0.03$). Generally, days open tended to decrease with increasing lactation, particularly evident from September through November. During these months, cows in their third or greater lactation showed a marked reduction in days open compared to lower lactation groups. This trend aligns with the contrast analysis, where cows calving in Cluster 4 (September – October) had significantly lower days open than those calving in any other time of the year, especially among cows in their third or greater lactation (Table 4).

Genotype effects for birth weight, age at first service, age at first calving and total number of lactations

An analysis of the effect of genotype on birth weight, age at first service, and age at first calving revealed differences among genotypes for all three traits ($P = 0.002$, $P < 0.001$, and $P < 0.001$, respectively). Birth weight was lower in genotypes involving Jersey crosses, particularly J6×H2 (25.7 ± 1.77 kg), J8 (29.8 ± 1.89 kg), and Other J×H (30.8 ± 1.03 kg), compared to Holstein or its crosses of Brown Swiss, which averaged around 34–35 kg, an effect confirmed by the contrast analysis ($P < 0.01$) (Table 5).

Age at first service varied slightly among genotypes, with most averaging 16.3–16.4 months. However, heifers from the H×BR and "Other" genotype groups had notably delayed first service ages (18.5 ± 0.37 and 18.4 ± 0.53 months, respectively) being both different than the age at first service of Holstein ($P < 0.05$). Moreover, contrasts between genotype groups showed no differences between the evaluated groups ($P > 0.05$). Along this line, age at first calving followed a similar trend, with most genotypes calving around 26.5–26.8 months. Earlier calving age was observed in Jersey crosses such as J6×H2 (25.8 ± 0.46 months) and H6×J2 (25.6 ± 0.40 months), while later calving age was recorded in H×BR (28.6 ± 0.46 months) and "Other" genotypes (29.0 ± 0.70 months), all different than the age at first calving of Holstein cows ($P < 0.05$). The contrast between H8 and H×J genotypes showed a difference in age at first calving ($P = 0.04$), while no differences were observed between H8 and H×BS ($P = 0.91$), or between H×BS and H×J ($P = 0.79$) (Table 5).

Table 5

Birth weight, age at first service, age at first calving, and total number of lactations by genotype in dairy cows in a tropical environment. (LSmeans $\pm$ standard error). Data between 2004 and 2024.

Genotype	Birth weight (kg)	Age at first service (months)	Age at first calving (months)	Total number of lactations per cow ¹
H8	33.9 $\pm$ 0.35 (n = 994)	16.4 $\pm$ 0.28 (n = 4646)	26.8 $\pm$ 0.31 (n = 5055)	3.10 $\pm$ 0.35 (n = 3181)
H7 $\times$ BS1	34.3 $\pm$ 1.29 (n = 18)	16.3 $\pm$ 0.41 (n = 98)	26.8 $\pm$ 0.53 (n = 100)	2.80 $\pm$ 0.50 (n = 37)
H6 $\times$ BS2	34.2 $\pm$ 1.37 (n = 16)	16.4 $\pm$ 0.36 (n = 295)	26.8 $\pm$ 0.44 (n = 298)	3.73 $\pm$ 0.48 (n = 154)
H5 $\times$ BS3	34.8 $\pm$ 1.48 (n = 16)	16.4 $\pm$ 0.40 (n = 146)	26.2 $\pm$ 0.51 (n = 148)	3.10 $\pm$ 0.53 (n = 45)
H4 $\times$ BS4	34.3 $\pm$ 1.58 (n = 11)	16.1 $\pm$ 0.34 (n = 302)	26.6 $\pm$ 0.42 (n = 309)	3.52 $\pm$ 0.46 (n = 136)
BS5 $\times$ H3	34.0 $\pm$ 1.17 (n = 47)	16.6 $\pm$ 0.39 (n = 201)	26.8 $\pm$ 0.49 (n = 203)	2.90 $\pm$ 0.52 (n = 41)
BS6 $\times$ H2	34.4 $\pm$ 1.15 (n = 51)	16.3 $\pm$ 0.36 (n = 425)	26.5 $\pm$ 0.44 (n = 423)	3.70 $\pm$ 0.48 (n = 184)
BS7 $\times$ H1	34.4 $\pm$ 1.12 (n = 65)	16.3 $\pm$ 0.39 (n = 191)	26.3 $\pm$ 0.50 (n = 191)	2.97 $\pm$ 0.53 (n = 40)
BS8	34.3 $\pm$ 1.85 (n = 8)	16.6 $\pm$ 0.50 (n = 37)	27.1 $\pm$ 0.63 (n = 48)	3.76 $\pm$ 0.53 (n = 38)
H6 $\times$ J2	33.2 $\pm$ 1.39 (n = 11)	15.8 $\pm$ 0.33 (n = 219)	25.6 $\pm$ 0.40* (n = 245)	3.23 $\pm$ 0.45 (n = 70)
H4 $\times$ J4	33.6 $\pm$ 1.86 (n = 6)	16.3 $\pm$ 0.30 (n = 545)	26.6 $\pm$ 0.34 (n = 608)	3.65 $\pm$ 0.43* (n = 358)
J6 $\times$ H2	25.7 $\pm$ 1.77* (n = 7)	15.9 $\pm$ 0.36 (n = 131)	25.8 $\pm$ 0.46 (n = 125)	3.12 $\pm$ 0.47 (n = 51)

¹ Only for culled cows

* Means with a star indicate significant differences with Holstein within a column

Genotype	Birth weight (kg)	Age at first service (months)	Age at first calving (months)	Total number of lactations per cow¹
J8	29.8 ± 1.89 (n = 6)	16.3 ± 0.30 (n = 562)	26.7 ± 0.35 (n = 594)	3.58 ± 0.41* (n = 485)
Other J×H	30.8 ± 1.03 (n = 22)	16.2 ± 0.37 (n = 107)	26.5 ± 0.48 (n = 104)	2.89 ± 0.49 (n = 32)
Other Holstein	34.6 ± 1.11 (n = 18)	16.3 ± 0.37 (n = 101)	26.9 ± 0.48 (n = 101)	3.04 ± 0.47 (n = 38)
Other Jersey	32.0 ± 2.68 (n = 3)	15.7 ± 0.45 (n = 52)	26.1 ± 0.59 (n = 55)	4.20 ± 0.70 (n = 19)
H×BR	34.5 ± 3.38 (n = 2)	18.5 ± 0.37* (n = 116)	28.6 ± 0.46* (n = 123)	3.24 ± 0.49 (n = 40)
Other	35.0 ± 2.22 (n = 5)	18.4 ± 0.53* (n = 30)	29.0 ± 0.70* (n = 35)	3.88 ± 0.72 (n = 12)
<i>P-value</i>				
Genotype	0.002	< 0.001	< 0.001	< 0.001
<i>Contrasts</i>				
H8 vs. H×BS	0.66	0.57	0.91	0.03
H8 vs. H×J	< 0.001	0.19	0.04	< 0.001
H×BS vs. H×J	0.002	0.95	0.79	0.96
¹ Only for culled cows				
* Means with a star indicate significant differences with Holstein within a column				

Pure Jersey cows and the H4×J4 cross demonstrated greater longevity, as reflected by a higher number of total lactations at culling compared with Holsteins (Table 5). Although no other pairwise differences among individual genotypes reached significance, contrast analysis indicated that both the H×BS and H×J groups had more total lactations than pure Holsteins, with no difference between those crossbred groups.

Season effects for birth weight, age at first service and age at first calving in Holstein cows

No effect of month of birth on birth weight was observed for Holstein cows ($P = 0.41$). A significant, albeit very weak, association was observed between birth month and age at first service, with a statistical difference found only between heifers born in September (15.7 ± 0.30) and those born in October (16.4 ± 0.30) ($P = 0.02$), which represented the lowest and highest ages at first service, respectively. Similarly, a weak effect of birth month on age at first calving was detected, with differences observed only between heifers born in October (26.9 ± 0.40) and those born in March (26.1 ± 0.41) ($P = 0.04$) the highest and lowest ages at first calving, respectively (Table 6).

Effects of birth weight on age at first service and age at first calving

A regression analysis of age at first service on birth weight revealed a negative relationship, with a slope of -0.0367 ($P < 0.05$), indicating a decrease of approximately 1.12 days in age at first service for every additional kilogram of birth weight. Similarly, age at first calving was negatively associated with birth weight, with a slope of -0.061 ($P < 0.05$), corresponding to a reduction of about 1.84 days in age at first calving per additional kilogram of birth weight.

Table 6

Birth weight, age at first service and age at first calving depending on the birth month of Holstein cows.
(LSmeans $\pm$ standard error). Data between 2004 and 2024.

Month of birth	Birth weight (kg)	Age at first service (months)	Age at first calving (months)
January	34.4 $\pm$ 0.60 (n = 92)	16.1 $\pm$ 0.30 (n = 414)	26.6 $\pm$ 0.41 (n = 460)
February	34.6 $\pm$ 0.63 (n = 82)	15.9 $\pm$ 0.31 (n = 303)	26.6 $\pm$ 0.42 (n = 335)
March	33.4 $\pm$ 0.63 (n = 83)	16.1 $\pm$ 0.31 (n = 357)	26.1 $\pm$ 0.41 (n = 382)
April	34.4 $\pm$ 0.67 (n = 68)	16.3 $\pm$ 0.31 (n = 363)	26.7 $\pm$ 0.41 (n = 406)
May	34.5 $\pm$ 0.69 (n = 64)	16.0 $\pm$ 0.31 (n = 342)	26.2 $\pm$ 0.41 (n = 381)
June	33.1 $\pm$ 0.72 (n = 56)	16.3 $\pm$ 0.32 (n = 297)	26.6 $\pm$ 0.42 (n = 328)
July	33.9 $\pm$ 0.70 (n = 60)	16.2 $\pm$ 0.31 (n = 314)	26.3 $\pm$ 0.42 (n = 328)
August	33.4 $\pm$ 0.70 (n = 62)	16.1 $\pm$ 0.31 (n = 374)	26.4 $\pm$ 0.41 (n = 407)
September	33.1 $\pm$ 0.58 (n = 101)	15.7 $\pm$ 0.30 (n = 461)	26.3 $\pm$ 0.40 (n = 504)
October	34.3 $\pm$ 0.53 (n = 131)	16.4 $\pm$ 0.30 (n = 540)	26.9 $\pm$ 0.40 (n = 587)
November	34.1 $\pm$ 0.59 (n = 95)	16.3 $\pm$ 0.30 (n = 442)	26.8 $\pm$ 0.40 (n = 462)
December	34.0 $\pm$ 0.58 (n = 100)	16.3 $\pm$ 0.30 (n = 439)	26.5 $\pm$ 0.40 (n = 475)
<i>P-value</i>			
Month of birth	0.41	0.02	0.04

Mortality and culling reasons

In the dataset there was a 4.1% mortality rate (430 deaths out of 10,476 cows, the reason of death was not specified in the records), with the majority occurring in the first (25.3%) and second (26.3%) lactation and gradually decreasing with further lactations. The relative importance of culling reasons varied with the number of lactations as well (Fig. 2). Fertility problems were the most common cause of culling overall, accounting for 40% of removals in first-lactation cows and progressively declining to approximately 25% in older parities. Conversely, the proportion of cows culled due to health-related issues (including lameness, udder disorders, and general health problems) increased with parity, a trend particularly obvious for lameness and udder health. Low productivity was a minor reason for culling and, similar to “other reasons” showed only trivial variations across lactations.

*Other reasons included: low weight, age and other non-specified.

Figure 2. Number of cullings (in brackets) and the proportion of reason of culling by lactation number in dairy cows in a tropical environment.

Discussion

Overall, reproductive performance of dairy cattle from the dataset used for this study aligns with values reported for intensive dairy systems in tropical Latin America, although direct comparisons are challenging due to substantial variation in level of production, environments, and management practices. For instance, a study in Mexico evaluating grazing Brown Swiss and Holstein cows reported approximately 70 days to first service, 1.95 services per conception, and ~ 105 days open (Calderón-Robles et al. 2011) values slightly better than those observed in the present study. However, that work did not specify the parity structure of the herd, limiting comparability. Likewise, research from Brazil (Cruz et al. 2011) documented 2.1 services per conception, 146 days open, and 94 days to first service in a confined Holstein herd over a 10-year period, with an average lactation yield of 8,436 kg—substantially higher than the ~ 6,500 kg typical for El Salvador (Castro-Montoya et al. 2026a). Critically, both studies were conducted in regions with mean annual temperatures near 21°C, considerably lower than those experienced in Salvadoran dairy regions, which likely contributes to improved reproductive outcomes. Under more comparable climatic conditions, a study from Costa Rica using rotational grazing (Vargas-Leitón et al. 2024) reported ~ 123 days open for Holsteins, an age at first calving of 33.8 months (higher than in the present study), and milk yields of ~ 5,000 kg per lactation, lower than the Salvadoran average. These comparisons suggest that Salvadoran dairy systems achieve reproductive performance consistent with other tropical herds, and in some cases outperform herds under similar climatic constraints, highlighting the capacity of well-managed *Bos taurus* herds to reproduce efficiently even under high heat-load environments.

Calving distribution and longevity

The average productive lifespan of cows in this dataset was 3.25 lactations, which is consistent with the literature reporting that the productive lifespan of dairy cows in most developed dairy industries ranges between 2.5 and 4 years (De Vries and Marcondes 2020). Moreover, Holstein cows showed a shorter overall lifespan than Jersey and Brown Swiss genotypes, in line with previous studies, likely due to the negative correlation between higher milk yield and lifespan (De Vries and Marcondes 2020). Analysis of Salvadoran Holstein cows showed that the highest lactation milk yield occurred during the third lactation (7,133 kg per 305 days). Although production declined thereafter, yields remained higher than those observed in the second lactation up to the sixth lactation (Castro-Montoya et al. 2026b), indicating that the relatively short longevity of Salvadoran dairy cows may limit the economic potential of the farms.

Furthermore, the proportion of first-lactation cows in this dataset (36.1%) agrees with most reports in the literature. For example, the study of Li et al. (2022), with more than 8.5 million lactations in the United States, found that first-lactation cows accounted for 38.7% of the population. However, in high-performing herds, in Canada –such as those in the top 1%– the demographic structure differs markedly. These elite herds have a lower proportion of cows in first lactation (32.4%) and a substantially higher proportion of cows in third lactation or greater (45.9%) (Prince et al. 2021), indicating greater herd longevity and retention of older cows compared to typical herds, as well as with the average Salvadoran herd, in which 38.2% of cows are in third or greater lactation.

Genotype effects on reproductive parameters

A total of 98 different genotypes, including pure breeds and crossbreds, were identified in the dataset, representing a high level of genetic variability for a population drawn from 11 farms. In several cases, crosses involving three or even four breeds were recorded, including breeds with limited relevance to the national dairy sector. This wide diversity suggests a lack of standardized breeding strategies, reflecting a trial-and-error approach rather than a structured program aimed at maximizing productive performance.

In recent years, the incorporation of Jersey genetics into Holstein herds has become more common, primarily to increase milk solids concentration (farmers' personal communication). However, no consistent strategy has been observed regarding the proportion of Jersey animals within herds or the degree of crossbreeding implemented.

Overall, differences in reproductive performance among genotypes were modest. However, Jersey cows and Jersey × Holstein crosses consistently exhibited fewer days open and required fewer SPC than pure Holsteins. This advantage has been reported previously and is commonly attributed to the reduced metabolic stress of lactation in Jerseys, resulting in a less severe negative energy balance during early lactation (Smith et al. 2013). For instance, Brown et al. (2012) reported that Jersey cows and Jersey × Holstein crosses averaged ~ 30 fewer days open and required 0.2–0.4 fewer services per conception compared with Holsteins. Similarly, Norman et al. (2009) observed that Holsteins had 11 and 18.6 more days open than Jerseys for heifers and multiparous cows, respectively, along with an average increase of ~ 0.2 services per conception.

Conversely, Brown Swiss cows and their crosses showed slightly poorer reproductive performance than Holsteins in this dataset, averaging more SPC and longer days open, particularly in earlier lactations. This contrasts with several previous studies reporting similar or even superior fertility in Brown Swiss compared with Holsteins, both in temperate systems (Piccand et al. 2013; Toledo-Alvarado et al. 2017) and under subtropical conditions (El-Tarabany and Nsr 2015). In Mexico, Calderón-Robles et al. (2011) observed a small reduction in SPC (-0.21) for Brown Swiss compared with Holstein, but no differences in days open. It is important to note that in the present study, the less favourable performance of Brown Swiss may be partly attributable to herd-level effects, as approximately 80% of the Brown Swiss calvings originated from a single farm. Therefore, specific management practices on that farm likely influenced the observed outcomes.

Season effects on calving and reproduction

Heat stress is a major driver of seasonal variation in dairy performance (West, 2003). In tropical regions, however, seasonality reflects not only thermal stress but also fluctuations in forage quality and availability, which decline toward the end of the dry season (March–April) as stored feed resources are depleted. A clear seasonal effect on reproductive performance was observed in this study. Cows calving between September and October showed better fertility outcomes, particularly in second- and later-lactation animals. These cows had their last third of pregnancy during a period of relatively forage abundance and entered early lactation when feed supply remained adequate and climatic conditions were most favourable (October–January). In contrast, cows calving in February–March start the lactation, and reach peak yield, at the end of the dry season, when THI is highest (~ 79.2) and forage scarcity is most pronounced, with likely negative consequences on reproduction.

The stronger seasonal response in multiparous cows aligns with physiological expectations. Older and higher-producing cows generate more metabolic heat during lactation, increasing their susceptibility to thermal stress and its detrimental effects on fertility (Aguilar et al. 2009). In addition, heat stress reduces estrus expression and increases the incidence of anestrus and silent ovulation (De Rensis and Scaramuzzi 2003). Accordingly, Castro-Montoya et al. (2022) reported extended intervals between services (~ 42 days) in Salvadorian cattle, likely linked to silent estrus and early embryonic loss. Reduced voluntary dry matter intake during periods of heat stress further exacerbates negative energy balance and impairs reproductive performance, particularly in high-yielding cows and in seasons of low forage quality.

Seasonal calving patterns further support the biological response explained above. Multiparous cows exhibited the strongest seasonality, with a low-to-peak calving ratio of 0.428 (February to October), followed by second-lactation cows (0.475), both showing a consistent distribution. Primiparous cows displayed a much weaker pattern, with a low-to-peak ratio of 0.705 and a distinct nadir (August) and peak (November). For reference, Ferreira et al. (2020) reported low-to-peak ratios of 0.68 in Michigan (least seasonal U.S. state) and 0.18 in Louisiana (most seasonal). Based on this, it could be stated that heifers in the tropical environment of El Salvador exhibit weak seasonality, while multiparous cows show a moderate pattern. As expected, seasonal contrast in tropical environments is milder than in temperate

systems, explaining the more moderate ratios observed here. The similarity between the second and multiparous groups indicates that seasonal effects become consistent after the first lactation.

An additional factor to consider is the incidence of diseases. Castro-Montoya et al. (2022) reported that inflammatory disorders prior to breeding were more prevalent during hot and humid periods of the year, suggesting an amplification of seasonal reproductive challenges. The same study showed that intrauterine infections and mastitis increased days open by 25.7 and 12.1 days, respectively. Although these factors were not evaluated in the present study, they are likely to interact with heat stress, milk yield, and nutritional pressures in this production environment.

Genotype and season effects on birth weight, age at first service and age at first calving

Birth weight of Holstein and Brown Swiss cows was around 34 kg, both higher than Jersey, an expected outcome due to the smaller size of the latter. In general, the birth weight is lower than in most reports from the same breeds in temperate regions, a recognised phenomenon even when sired by the same bull (West 2003). There have been reports on the relationships between birth weight and puberty, age at first service and age at first calving, all mediated by the body weight relative to mature body weight (McNaughton et al. 2002; Wathes et al. 2014) but the relationship found here for Holstein heifers, even though significant, was almost negligible.

No effect of month of birth was found over birth weight, despite some reports suggesting an effect of heat stress on the development of the foetus (Reynolds et al. 2006). It appears that under the tropical humid conditions the differences in climate between seasons are not sufficient to elicit a significant effect on the weight of the calf, something also observed by Rezende et al. (2020) in Brazil.

Age at first calving was quite consistent between the genotypes, with some evidence of Jersey and its crosses with Holstein calving at a younger age than Holstein heifers. The age at first calving of Holstein cows in Brazil was 31 and 32.4 months (Cruz et al. 2011; Vargas –Leitón, et al. 2024)), higher than the average found in this study, however, the study in Brazil used rotational grazing, where growth rate is lower than in fully confined management (Roche et al. 2015). In agreement with our findings, a study of dairy heifers across seven regions in the United States reported a lower age at first calving in Jersey heifers compared with Holstein (García-Peniche 2004). However, that study also found higher ages at first calving in Brown Swiss compared with Holstein, an effect that was not observed in the present study. In general, Jersey heifers are biologically and reproductively more precocious than Holstein and Brown Swiss, due to their lower mature body weight, triggering an early puberty (Steele et al. 2023).

Similar to the seasonal effects on birth weight, month of birth had only a minor effect on age at first service and age at first calving. The difference between the month with the highest age at first service and at first calving (October) and the lowest was only 0.7 and 0.8 months, respectively, indicating a rather minimal biological effect.

Mortality rate and culling reason

For the dairy cows in the tropical environment included in the study, and in agreement with other studies (De Vries and Marcondes 2020; Wondatir Workie et al. 2021), fertility is the main cause for culling in dairy cows, especially in earlier lactations. Also udder and hoof health is a critical factor among culling reasons (De Vries and Marcondes 2020), which becomes more common at later lactations, as outlined by Yanga and Jaja (2022). These results indicate that reproductive inefficiency is the main culling factor in younger cows, while health and survival constraints become increasingly relevant as cows age. The observed mortality rate (4.1%) falls at the lower end of the range reported in studies from the United States, which estimate annual mortality between 4.8% and 7.7% (McConnel et al. 2008; Miller et al. 2008). Interestingly, among animals removed from the farm (culled or deceased), 17.7% were removed due to death, which is lower than the proportion reported for the U.S. Dairy Herd Improvement system (20.6%) (De Vries and Marcondes 2020).

Study Limitations

The farms included were those that maintained digital production records and were willing to share them, which reflects a certain level of management sophistication and openness and do not entirely correspond with less structured production systems. Nevertheless, these farms still represent commercial dairy operations under Salvadoran conditions. Also, the dataset was dominated by Holstein cows, and most farms managed mixed-breed herds under uniform management conditions rather than breed-specific strategies. This may introduce bias and obscure genotype-specific responses. In addition, the smaller number of observations for minor breeds and crossbreds reduced statistical power to detect meaningful patterns beyond those observed in Holsteins. Furthermore, no information was available on disease incidence or health events, neither on body condition score which may have acted as confounding factors affecting reproductive performance. Although the impact of such factors may be proportionally limited given the large dataset, their absence restricts causal interpretation. Although efforts were made to account for potential confounders in the statistical models, residual confounding cannot be excluded.

A final consideration for this study is the limited availability of comparable data from other tropical herds. Consequently, much of the comparison and benchmarking in the discussion relies on values reported for temperate regions. As a result, several observed parameters appear to indicate comparatively poorer performance; however, it remains unclear whether this truly reflects suboptimal performance or differences that are typical for comparable tropical production systems. Addressing this knowledge gap is, in itself, a key motivation for the present study.

Overall, this study provides a comprehensive benchmarking of reproductive performance in commercial tropical dairy herds and it expands on the limited available information on tropical dairy. Clear seasonal effects on calving distribution were observed, with marked differences among parity groups, highlighting the importance of considering parity-specific reproductive management strategies. Genotype significantly influenced reproductive traits, particularly services per conception, gestation length, and days open, suggesting potential advantages of specific crossbreeding strategies for improving reproductive efficiency in tropical dairy systems.

Seasonal effects on reproductive performance in Holstein cows were evident, albeit with minor relative effects on fertility outcomes, which were better during cooler and drier months, emphasizing the role of climatic stress on reproductive efficiency. However, season of birth had only minor biological effects on age at first service and age at first calving.

These findings demonstrate that both genotype and seasonality play important roles in shaping reproductive performance and growth in tropical dairy herds. The results provide valuable reference values for producers and advisors and support the decision making to improve productivity and resilience of dairy cows under hot and humid tropical environments.

Declarations

Conflict of Interest Statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Statement of Animal Rights

This study was based exclusively on retrospective analysis of existing farm records. No animals were handled, subjected to experimental procedures, or otherwise directly involved in the study.

Acknowledgements

The authors thank all involved farmers for their openness to share their information for this study. Also, the authors thank UNIFORM-Agri for providing access to their software.

This work was supported by the SIC-UES Grant number 18.40

Data availability

The data generated from this study can be made available upon request.

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Figures

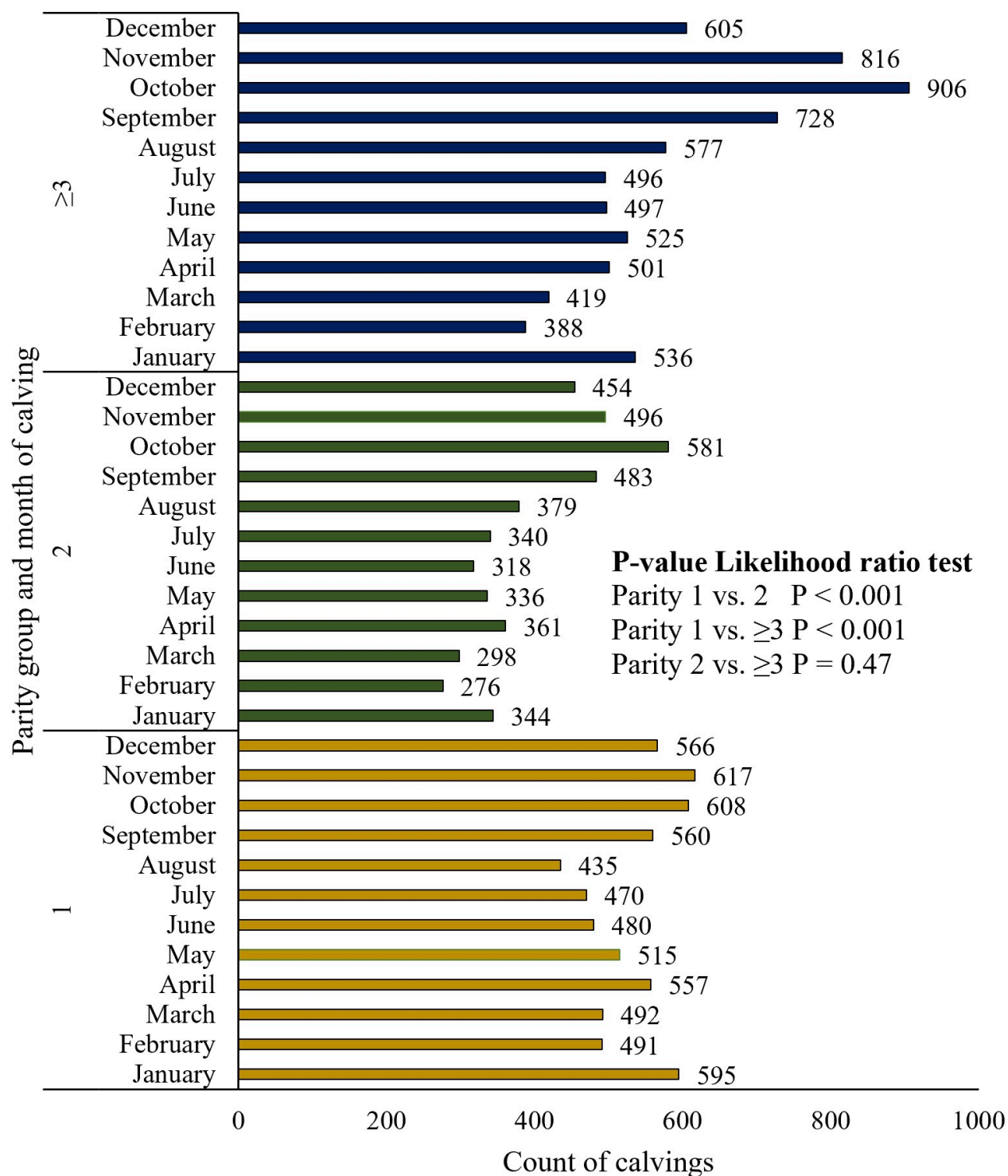


Figure 1

Number of calvings per month and parity group in dairy cows in a tropical environment. Data from 2004 to 2024

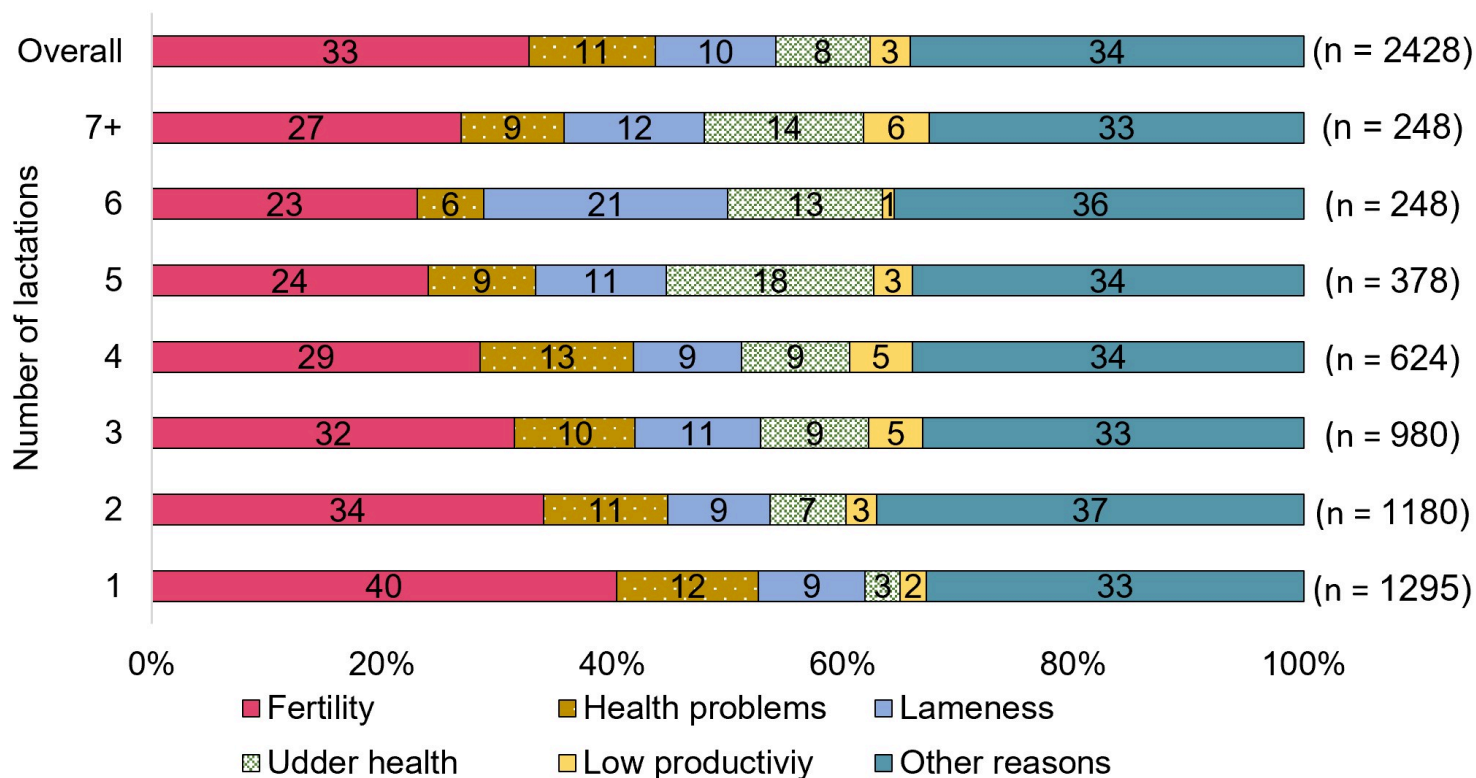


Figure 2

Number of cullings (in brackets) and the proportion of reason of culling by lactation number in dairy cows in a tropical environment.

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