Optimal age at first calving in pasture-based dairy systems

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Abstract

The age at first calving (AFC) is one of the most used indicators to evaluate the efficiency of rearing systems in dairy cattle herds. The objective of the present study was to evaluate the association between AFC and different parameters of productive and reproductive efficiency in dairy cows of Holstein and Jersey breeds and their crosses. A retrospective longitudinal study was carried out with information on the performance of 77,311 cows with birth and culling dates between 1990 and 2016 from 633 specialized dairy herds from mid and high-altitude regions of Costa Rica. Cows were classified into five categories according to their age in months at first calving (≤ 24, 25–27, 28–30, 31–33, ≥ 34). A generalized linear mixed model was used to assess the effect of AFC and racial factors on milk production (first lactation, lifetime total, and per day of life), open period (first calving and lifetime total), and herd life. The mean AFC was 29.5, 29.1, and 28.0 months for Holstein, Holstein×Jersey, and Jersey, respectively. The AFC was significantly associated ($P < 0.01$) with all the variables evaluated. Cows with AFC ≤ 24 presented a higher ($P < 0.01$) milk production (total lifetime and per day of life), as well as a longer herd life, compared to cows in categories of AFC > 28 m. The reduction in AFC contributes to a significant increase in the efficiency of dairy herds in Costa Rica.

Introduction

The age at first calving (AFC) is one of the most used parameters to evaluate the efficiency of replacement rearing programs in dairy herds (Castillo-Badilla et al., 2019; Cooke et al., 2013). Optimal AFC promotes the reduction of breeding costs and the extension of the herd life of the dairy cow (Meyer et al., 2004).

In intensive milk production systems, the goal of breeding programs has generally been to get females to reach their first calving at an age no older than 24 months (Cook et al., 2013; Do et al., 2013; Le-Cozler et al., 2008; Sawa et al., 2019). However, another study reported that the best profitability rates were obtained when the AFC was between 24 and 26 months (Krpálková et al., 2014).

In specialized dairy herds, the AFC averages reported in different regions worldwide for Holstein or Jersey females range between 24 and 29 months (Atashi et al., 2021; Cook et al., 2013; Do et al., 2013; Eastham et al., 2018; Hare et al., 2006; Mohd-Nor et al., 2013; Pirlo et al., 2000). In Costa Rica, where pasture-based production systems prevail, AFC mean values of 29.9 and 28.6 months have been reported for Holstein and Jersey females, respectively (Vargas-Leitón, 2013). Another study reported an AFC greater than 30 months for Holsteins at the local level (Salazar-Carranza et al., 2013).

Several studies reported a reduction in milk production during the first lactation when AFC was below 24 months (Atashi et al., 2021; Castillo-Badilla et al., 2013; Castillo-Badilla et al., 2019; Le-Cozler et al., 2008; Meyer et al., 2004; Mohd-Nor et al., 2013). Likewise, AFC < 22 months have been associated with lower fertility rates, lower survival probability to second calving, and lower production, both in the first lactation and during the herd life of the dairy cow (Steele, 2020). In addition, an increased risk of dystocia has also been reported in females that calved for the first time at ages below or above the range between 23 and 26 months (Atashi et al., 2021).

On the other hand, several studies have shown that AFC lower or equal than 24 months contributes to a significant increase in the length of herd life (Cooke et al., 2013; Sawa and Bogucki, 2010; Zavadilová and Stipková, 2013) and lifetime cumulative milk production of the dairy cow (Adamczyk et al., 2016; Cooke et at.; 2013; Do et al., 2013; Eastham et al., 2018; Sawa et al., 2019). It has also been pointed out that there are no significant adverse effects of the reduction of the AFC on the immediate postpartum-conception interval (Atashi et al., 2021; Castillo-Badilla et al., 2015; Vargas-Leitón and Ulloa-Cruz, 2008b), nor on milk production in the following lactations (Adamczyk et al., 2016).

In Costa Rica, specialized dairy production is mainly based on grazing systems, with variable use of supplementary feeds such as concentrates and/or agricultural by-products (Vargas-Leitón et al., 2013). Dairy farms are mainly located in regions between 500 and 2,500 meters above sea level, with average temperatures between 18 and 30°C and rainfall ranging between 500 and 3500 mm per year (Vargas-Leitón et al., 2013). The predominant dairy breeds are Holstein, Jersey, and their crosses, with average milk production of 6750 and 5184 kg per lactation and calving-conception intervals of 143 and 132 days, respectively (Vargas-Leitón and Romero-Zúñiga, 2010; Vargas-Leitón, 2013).

The most frequently used grasses in Costa Rican dairies are African star grass (*Cynodon nlemfuensis*) and Kikuyu (*Cenchrus clandestinus*) (CRIPAS, 2020). The percentage of dry matter in the diet that comes from grass ranges between 19 and 71%, while that from the concentrate extends between 23 and 38% (Iñamagua-Uyaguari et al., 2016).

The predominant rearing system in Costa Rican dairy herds is the semi-intensive type (CRIPAS, 2020). Pre-weaning rearing is carried out in semi-stalled systems with restricted access to grazing, group management of calves, with daily supply of 4 liters of milk and 0.7 ± 0.7 kg of concentrate feed. The most frequent weaning age is three months. In the post-weaning period, females are generally managed in semi-stalled groups with free access to grazing and an average daily supply of 1.7 ± 0.7 kg of concentrate. Heifers are mostly served using AI, and once pregnant, they are kept in rotational grazing with an average supply of 1.8 ± 0.9 kg of concentrate per day (CRIPAS, 2020).

At local level, no study has been conducted evaluating the impact of AFC on performance parameters throughout the dairy cow's life. Therefore, the objective of the present study was to determine the optimal AFC of dairy cows of Holstein and Jersey breeds and their crosses under the prevailing production conditions and rearing systems in specialized dairy herds in Costa Rica.

Materials And Methods

Data source

A population-based, observational, retrospective, and longitudinal study was carried out. The information analyzed was obtained from the database of the Regional Center for Informatics for Sustainable Animal Production (CRIPAS, by Spanish acronym) attached to the School of Veterinary Medicine of the National University of Costa Rica (Sánchez et al., 2020). This database contains health and management information from over 2500 dairy herds distributed in different geographical zones of Costa Rica. The information is mainly collected by the herd´s owners themselves and entered in the VAMPP Bovino 3.0 computer program (Noordhuizen and Buurman, 1984). Those individual farm databases are periodically centralized and used for population analysis.

Inclusion Criteria

In order to fulfill the objective set for the study, selection criteria were defined both, at the herd and animal level. These criteria were as follows:

- Specialized dairy herds were selected based on the availability of productive records of females born between 1990 and 2016. A minimum of five cows with information available per herd was mandatory.
- The breeds included in the study were: Holstein, Jersey, and Holstein×Jersey crosses.
- Only cows with complete follow-up data from birth to culling were included in the study. Cows with incomplete records or that were still alive at the time of extracting the information were not included. In addition, the

availability of an estimate of total milk production for each of the lactations of all cows was required. This production was estimated from test-day records using the Test Interval Method (TIM) according to the procedure used in VAMPP (Noordhuizen and Buurman, 1984). The number of daily records available per lactation was highly variable between herds and cows, with an average of 15 records per lactation. Lactation length was also highly variable since culling could occur at any time during lactation.

- To reduce the effect of extreme values in the statistical analyses, restriction intervals were defined for variables analyzed in the study. These intervals were established based on the observed distribution of these variables in the entire population. The restriction intervals were: age at first calving between 18 and 60 months, days open between 20 and 500 days, herd life between 1 and 150 months, and age at culling between 20 and 180 months. In addition, maximum values were also established for cumulative days open (1500 d), lactation length (800 d), milk production per lactation (21000 kg), and cumultive milk production (100000 kg).
- Cows culled within 15 days after the first calving were also excluded from the study.

Cows fulfilling previous criteria were classified according to their age at first calving in one of the following five categories (in months, after rounding up to the nearest integer): 1) AFC ≤ 24 months, 2) AFC 25 to 27 months, 3) AFC 28 to 30 months, 4) AFC 31 to 33 months, 5) AFC ≥ 34 months.

Descriptive Statistical Analysis

For each racial group and AFC category, population parameters were obtained for the following variables:

- Age at First Calving (AFC): Months elapsed between birth and first calving.
- Open period after first calving (OPFC): Calving-conception interval (in months) after the first calving.
- Cumulative open period (COP): Sum (in months) of the calving-conception intervals of all calving registered for each cow.
- Age at Culling (ACU): Time elapsed (in months) between birth and culling.
- Herd Life (HLI): Time elapsed (in months) between first calving and culling.
- Lactations (LAC): Total number of lactations with reported production data.
- Milk production in the first lactation (PRF): Total milk production (in kg) during first lactation, estimated from test day records.
- Cumulative milk production (CPR): Sum (in kg) of the milk production of all lactations of each cow.
- Milk production per day of life (PRD): Obtained by dividing cumulative milk production (CPR, in kg) by the age at culling (ACU, in days).

Survival Curves By Race × Age At First Calving Strata

Fifteen strata were formed from the combinations of the three race groups (Holstein, Jersey, Holstein×Jersey) and the five AFC categories previously described. For each strata, Kaplan Meier curves (Daniel and Cross, 2013) were fitted using Lifetest procedure of the SAS Statistical Analysis Program (SAS Institute Inc., 2022). Survival probability estimates according to lactation number (1 to ≥ 10) were obtained. Survival curves for different AFC categories within each racial group were compared using the log-rank test (Daniel and Cross, 2013).

Inferential Statistical Analysis Using Glmm

The generalized linear mixed model (GLMM) technique (Gbur et al., 2012) was used, as implemented in the GLIMMIX procedure of the SAS program (SAS Institute Inc., 2022) to assess the effect of age at first calving on different productive and reproductive variables of interest, adjusting for racial and environmental factors.

The general model used is described below:

$$y_{ijklm} = \mu + R_i + AFC_j + (R \times AFC)_{ij} + v_k + \lambda_l + \epsilon_{ijklm}$$

where:

$y_{ijklm} =$ The response variables (Milk production (CPR and PRF), open period (COP and OPFC), herd life (HLI), age at culling (ACU) and production per day of life (PRD)).

$\mu =$ Population mean

$R_i =$ ith Fixed effect linked to racial group (three categories: Holstein, Jersey, and Holstein×Jersey crosses).

$AFC_j =$ jth fixed effect linked to category of age at first calving (five categories: ≤24m, 25-27m, 28-30m, 31-33m, ≥ 34m).

$(R \times AFC)_{ij} =$ fixed effect linked to the ijth interaction of racial group by AFC category (3x5=15 categories).

$v_k =$ random effect linked to the kth herd of origin of each cow (633 herds).

$\lambda_l =$ random effect linked to the lth year of birth (1990–2016).

$\epsilon_{ijklm} =$ random residual error.

Appropriate probability distributions were selected for each dependent variable according to the dispersion observed in the histograms. For PRD and PRF variables a normal distribution was assumed. Variables HLI, ACU, CPR, COP, and OPFC showed marked positive skewness, therefore a lognormal distribution was assumed. An identity link function was used for all models. In cases where the statistical significance of the AFC fixed effect was found, the adjusted means (least-squares means) were calculated and compared with each other using the Tukey-Kramer test (Daniel and Cross, 2013).

Results

Descriptive parameters

After applying the selection criteria, 77311 cows from 654 herds were identified. The average follow-up period of the herds was 17.8 years, ranging from 1 to 26 years. The average number of females analyzed per herd was 116, with a median of 34. The Holstein group contributed 43.0% of the data, followed by Jersey (34.6%) and Holstein×Jersey (22.4%) (Table 1). The most frequent racial compositions within the crossbred group were: ½Holstein/½Jersey (41%), ¾Jersey/¼Holstein (20%), and ¾Holstein¼Jersey (13.3%).

The overall AFC mean was 28.9 months (median: 27.6 m) (Table 1). AFC mean for Jerseys was 1.1 and 1.5 months lower than the Holstein×Jersey and Holstein groups. In the three race groups, the AFC categories with the highest presence of animals were AFC 25–27 and AFC 28–30; however, a considerable number of animals was also observed in the extreme categories (Table 1). Average AFC in these extreme categories were 22.8 and 38.3 mo for AFC ≤ 24 and ≥ 34 months, respectively.

The culling age (ACU) presented an overall mean of 65.2 months, with differences lower than 1.2 month between the three compared race groups (Table 1). For the three race groups, a trend to higher ACU was observed as the AFC increased. The opposite trend was observed in herd life, where cows with AFC ≤ 24 months had 4.0 (Holstein), 5.5 (Holstein×Jersey), and 5.3 (Jersey) more months of herd life compared to those with higher AFC (AFC ≥ 34). Likewise, Jersey cows had an average of 0.3 and 1.6 months longer herd life compared to Holstein×Jersey and Holstein, respectively.

The average number of lactations per cow (LAC) was 3.1, 0.3 lactations higher for Jersey compared to the other two race groups (Table 1). Again, cows with the lowest AFC (≤ 24 m) within the Holstein, Holstein×Jersey, and Jersey race groups averaged 0.4, 0.5, and 0.5 more lactations than cows in the highest AFC category (AFC ≥ 34m).

Cumulative milk production (CPR) in the Holstein group was 4984 and 3528 kg higher than Holstein×Jersey and Jersey, respectively (Table 1). Cows with AFC ≤ 24 months within the Holstein, Holstein×Jersey, and Jersey groups produced 43%, 37.3%, and 46.1% more milk than cows with AFC ≥ 34 months, respectively. The differences in milk production per day of life (PRD) were 4.1, 2.8, and 3.2 kg, in the same order.

Cumulative open period (COP) for Holstein cows was 1.0 and 1.6 months longer than Holstein×Jersey and Jersey, respectively. The differences in COP between the different AFC categories within the three race groups were mostly lower than one month.

Table 1
Arithmetic means (± SEM) of age at first calving, age at culling, herd life, number of lactations, cumulative milk production, milk production per day of life, and cumulative open period in Holstein, Holstein×Jersey and Jersey cows categorized according to their AFC.

AFC Category by Breed	Cows (n)	Age at First Calving (mo)	Age at Culling (mo)	Herd Life (mo)	Number of Lactations (n)	Cumulative Milk Production (kg)	Milk Production per Day of Life (kg)	Cumulative Open Period (mo)
Holstein	33207	29.5 (0.03)	65.4 (0.15)	35.9 (0.15)	3.0 (0.01)	19354 (94.1)	8.2 (0.03)	14.3 (0.06)
≤ 24	3726	22.8 (0.02)	59.2 (0.46)	36.4 (0.46)	3.1 (0.03)	21848 (309.6)	10.1 (0.09)	13.8 (0.17)
25–27	9432	25.6 (0.01)	63.5 (0.29)	37.9 (0.29)	3.2 (0.02)	21928 (189.8)	9.5 (0.05)	14.5 (0.11)
28–30	8220	28.4 (0.01)	65.3 (0.31)	36.8 (0.31)	3.1 (0.02)	19720 (186.3)	8.3 (0.05)	14.5 (0.12)
31–33	5060	31.4 (0.01)	66.1 (0.38)	34.7 (0.38)	2.9 (0.03)	17544 (218.2)	7.3 (0.06)	14.2 (0.15)
≥ 34	6769	38.4 (0.07)	71.0 (0.33)	32.4 (0.33)	2.7 (0.02)	15304 (178.6)	5.9 (0.05)	13.8 (0.13)
Holstein×Jersey	17307	29.1 (0.04)	64.4 (0.22)	35.2 (0.22)	3.0 (0.02)	14371 (102.8)	6.1 (0.03)	13.3 (0.08)
≤ 24	2214	22.5 (0.03)	58.6 (0.62)	36.1 (0.61)	3.2 (0.05)	15587 (302.0)	7.2 (0.09)	12.6 (0.21)
25–27	4916	25.6 (0.01)	62.4 (0.41)	36.8 (0.41)	3.2 (0.03)	15974 (204.6)	7.0 (0.06)	13.4 (0.15)
28–30	4310	28.5 (0.01)	65.0 (0.44)	36.5 (0.44)	3.1 (0.03)	14939 (206.9)	6.3 (0.06)	13.8 (0.16)
31–33	2678	31.4 (0.02)	66.4 (0.57)	35.0 (0.57)	3.0 (0.04)	13106 (240.8)	5.3 (0.07)	13.4 (0.21)
≥ 34	3189	38.1 (0.09)	69.0 (0.49)	30.6 (0.48)	2.7 (0.04)	11350 (210.1)	4.4 (0.06)	12.7 (0.19)
Jersey	26797	28.0 (0.03)	65.6 (0.17)	37.5 (0.17)	3.3 (0.01)	15826 (83.7)	6.7 (0.02)	12.6 (0.06)
≤ 24	4510	22.9 (0.02)	61.2 (0.43)	38.3 (0.42)	3.4 (0.03)	17711 (224.3)	7.9 (0.06)	12.3 (0.13)
25–27	9825	25.5 (0.01)	64.6 (0.29)	39.1 (0.29)	3.4 (0.02)	17391 (145.6)	7.4 (0.04)	12.9 (0.10)
28–30	6002	28.4 (0.01)	65.7 (0.36)	37.3 (0.36)	3.2 (0.03)	14867 (165.7)	6.3 (0.05)	12.6 (0.12)
31–33	3117	31.4 (0.02)	68.3 (0.50)	36.9 (0.50)	3.1 (0.04)	13981 (217.4)	5.7 (0.06)	13.0 (0.18)
≥ 34	3343	38.1 (0.10)	71.7 (0.48)	33.0 (0.46)	2.9 (0.03)	12123 (192.2)	4.7 (0.05)	12.1 (0.17)

AFC Category by Breed	Cows (n)	Age at First Calving (mo)	Age at Culling (mo)	Herd Life (mo)	Number of Lactations (n)	Cumulative Milk Production (kg)	Milk Production per Day of Life (kg)	Cumulative Open Period (mo)
Overall	77311	28.9 (0.02)	65.2 (0.10)	36.3 (0.10)	3.1 (0.01)	17016 (55.4)	7.2 (0.02)	13.5 (0.04)

Kaplan Meier Survival Curves

Survival curves for AFC categories showed similar patterns in the different race groups (Fig. 1). Survival curve for category AFC ≥ 34 was always lower than the other groups, which means that the cows that calved for the first time at late ages had consistently lower probabilities of remaining in the herd throughout all lactations. On the contrary, in the three race groups, the cows with AFC ≤ 24 tended to present higher survival curves than the other groups, though not always significantly different from AFC 25–27 and AFC 28–30.

In Holstein, the survival curve of the AFC ≤ 24 category was significantly higher ($P < 0.001$) than the other strata, except for the AFC 28–30 stratum. In Holstein×Jersey, the survival curve of the AFC ≤ 24 category was significantly higher ($P < 0.001$) than the two categories with the highest AFC. In Jersey, the survival curve of the AFC ≤ 24 category was significantly higher ($P < 0.001$) than the others, apart from the AFC 25–27 stratum. In the Jersey breed, a clear separation was also observed into three groups: those with the highest survival rate (AFC ≤ 27), those with the lowest survival rate (AFC ≥ 34), and an intermediate group conformed by the AFC categories from 28 to 33 months (Fig. 1).

Effect Of The Afc On Performance Variables

The effects of AFC on performance variables were generally consistent and similar across the three race groups. A significant effect ($P < 0.01$) of the AFC and race group was observed on all response variables. In contrast, the Race×AFC interaction was only significant on the variable production per day of life (PRD).

In all race groups, the adjusted mean for age at culling (ACU) for cows with AFC ≤ 24 was significantly lower ($P < 0.01$) compared to the other AFC categories (Table 2). Likewise, an increase in ACU was consistently linked to a higher AFC. The differences in ACU (backtransformed from the logarithmic scale) between the highest and lowest AFC categories were 8.9, 9.7 and 9.4 months for Holstein, Holstein×Jersey, and Jersey, respectively.

In contrast, the adjusted herd life (APR) of cows with AFC ≤ 24 was significantly higher ($P < 0.01$) than other AFC categories for all race groups, except for AFC 25–28 (Table 2). The increase in HLI (backtransformed from the logarithmic scale) between the lowest and highest AFC categories was 4.2, 4.0, and 3.9 months for Holstein, Holstein×Jersey, and Jersey, respectively.

Table 2

Adjusted means (± SEM) for age at culling, productive life, first lactation milk yield, cumulative milk yield, open period after first calving and cumulative open period in Holstein, Holstein×Jersey, and Jersey, categorized according to their age at first calving (AFC).

AFC Category by Breed	Age at Culling (log month)*	Productive Life (log month)*	First Lactation Milk Yield (kg)*	Cumulative Milk Production (log-kg)*	Open Period First Calving (log month)*	Cumulative Open Period (log month)*
Holstein						
≤ 24	3.90 (0.03)[a]	2.96 (0.08)[a]	3848 (122)[a]	8.74 (0.09)[a]	4.77 (0.02)[a]	5.59 (0.06)[a]
25–27	3.95 (0.03)[b]	2.95 (0.08)[a]	4156 (119)[b]	8.77 (0.09)[ab]	4.82 (0.01)[b]	5.60 (0.06)[a]
28–30	3.97 (0.03)[bc]	2.88 (0.08)[b]	4271 (119)[c]	8.70 (0.09)[b]	4.82 (0.01)[b]	5.55 (0.06)[b]
31–33	4.00 (0.03)[c]	2.81 (0.08)[c]	4277 (120)[c]	8.63 (0.09)[c]	4.84 (0.01)[b]	5.54 (0.06)[c]
≥ 34	4.06 (0.03)[d]	2.71 (0.08)[d]	4255 (119)[c]	8.53 (0.09)[d]	4.81 (0.01)[b]	5.48 (0.06)[d]
Holstein×Jersey						
≤ 24	3.92 (0.03)[a]	2.99 (0.09)[a]	3245 (126)[a]	8.70 (0.09)[a]	4.59 (0.02)[a]	5.53 (0.06)[a]
25–27	3.98 (0.03)[b]	3.00 (0.08)[a]	3518 (120)[b]	8.74 (0.09)[a]	4.63 (0.01)[b]	5.53 (0.06)[a]
28–30	4.01 (0.03)[c]	2.95 (0.08)[b]	3676 (121)[c]	8.70 (0.09)[a]	4.65 (0.01)[b]	5.50 (0.06)[b]
31–33	4.03 (0.03)[c]	2.89 (0.08)[c]	3699 (124)[c]	8.64 (0.09)[a]	4.64 (0.02)[b]	5.47 (0.06)[c]
≥ 34	4.10 (0.03)[d]	2.77 (0.08)[d]	3748 (123)[c]	8.53 (0.09)[b]	4.69 (0.02)[c]	5.45 (0.06)[d]
Jersey						
≤ 24	3.93 (0.03)[a]	3.03 (0.08)[a]	2813 (122)[a]	8.63 (0.09)[a]	4.59 (0.02)[a]	5.52 (0.06)[a]
25–27	3.98 (0.03)[b]	3.01 (0.08)[a]	3006 (119)[b]	8.65 (0.09)[a]	4.61 (0.01)[ab]	5.51 (0.06)[a]
28–30	4.00 (0.03)[c]	2.96 (0.08)[b]	3158 (120)[c]	8.59 (0.09)[a]	4.63 (0.01)[b]	5.45 (0.06)[b]

*Group of homogeneous means according to the Tukey-Kramer test. Means of different AFC categories with equal superscripts within each racial group do not differ significantly ($P > 0.05$)

AFC Category by Breed	Age at Culling (log month)*	Productive Life (log month)*	First Lactation Milk Yield (kg)*	Cumulative Milk Production (log-kg)*	Open Period First Calving (log month)*	Cumulative Open Period (log month)*
31–33	4.04 (0.03)[d]	2.93 (0.08)[b]	3318 (123)[d]	8.59 (0.09)[a]	4.65 (0.02)[b]	5.48 (0.06)[b]
≥ 34	4.10 (0.03)[e]	2.82 (0.08)[c]	3388 (122)[d]	8.47 (0.09)[b]	4.64 (0.02)[b]	5.40 (0.06)[c]

*Group of homogeneous means according to the Tukey-Kramer test. Means of different AFC categories with equal superscripts within each racial group do not differ significantly ($P > 0.05$)

Regarding milk production during the first lactation (PRF), in the three race groups, there was a significantly lower production ($P < 0.01$) linked to the category of AFC ≤ 24 months and, to a lesser degree, to the following AFC 25–27 (Table 2). The differences in production per lactation between the lowest category of AFC and the highest were − 408, -503, and − 1408 kg for Holstein, Holstein×Jersey, and Jersey, respectively.

The opposite trend was observed for cumulative milk production (CPR) (Table 2). In the Jersey and Holstein×Jersey groups, the adjusted milk production in cows with AFC ≤ 24 was not significantly different ($P > 0.05$) than cows with AFC between 25 to 33 months, but it was significantly higher ($P < 0.001$) than production obtained for cows with AFC ≥ 34 months. For the Holstein group, the adjusted milk production of cows in AFC categories ≤ 27 was significantly higher ($P < 0.001$) than that obtained in cows with AFC ≥ 31 months. The adjusted difference in CPR (backtransformed from the logarithmic scale) between the lowest and highest AFC categories was 1197, 940, and 799 kg for Holstein, Holstein×Jersey, and Jersey, respectively.

A gradual reduction in the production per day of life (PRD) linked to the increase of AFC was observed in the three race groups (Fig. 2). For Holsteins, all differences between AFC categories were significant ($P < 0.05$). The adjusted difference in PRD between the lowest and highest AFC categories was 2.4, 1.6, and 1.5 kg per day for Holstein, Holstein×Jersey, and Jersey, respectively.
A significant effect of AFC ($P < 0.01$), racial group ($P < 0.01$) and their interaction ($P < 0.05$) on the open period after the first calving was also observed (Table 2). In this case, the trend was favorable to the lowest category of AFC, with a lower open period, compared to the other categories. The differences between the highest category of AFC with the lowest were 5, 11, and 5 days open for Holstein, Holstein×Jersey, and Jersey, respectively. The differences between the other AFC categories in several cases were not significant ($P > 0.05$) nor showed a consistent pattern across the three race groups.

The cumulative open period (COP) showed a slight tendency to decrease with the increase in AFC (Table 2). The reduction was significant ($P < 0.05$) only for AFC categories ≥ 28. The adjusted difference in COP between the lowest and highest AFC categories was 29, 21, and 29 days open for Holstein, Holstein×Jersey, and Jersey, respectively. However, the higher COP for AFC ≤ 24 is directly linked to a larger number of parities.

Discussion

The average age at first calving observed in this study tends to be higher than that reported by other studies, which have been mostly associated with Holstein breed. Previous values are generally in the range between 24 and 27 months (Atashi et al., 2021; Cook et al., 2013; Do et al., 2013; Hare et al., 2006; Mohd-Nor et al., 2013; Pirlo et al. al., 2000). Only one study reported an estimate of 29.1 months (Eastham et al., 2018), similar to our study. The higher AFC found in the present study may be mainly linked to environmental and management circumstances prevailing in the country. A large part of the herds included in this study are located in areas of medium altitude (500–1500 masl) or even low altitude (< 500 masl), where average temperatures can exceed 30°C in some hours of the day. In addition, the greater dependence on grazing in these dairies implies inconsistency and irregularity in the availability of feed throughout the year, which results in lower weight gains during rearing,

Achieving AFC lower or equal to 24 months requires efficient rearing systems, so that the heifer reaches 60% of its adult weight at first service, at a target age close to 15 months (Roche et al., 2015). For a cow with an approximate adult weight of 450 kg (Jersey) or 600 kg (Holstein), average growth rates of around 0.50 and 0.67 kg day-1 are required before 15 months, respectively. In Costa Rica, weight gains for Holsteins of 0.64 kg day^{-1} between birth and 12 months and 0.52 kg day-1 between 12 and 20 months have been reported, while for Jersey, the respective averages were 0.49 kg day-1 and 0.36 kg day^{-1} (Vargas-Leitón and Ulloa-Cruz, 2008a). These growth rates suggest an expected weight of 280 kg at 15-months age for Holstein, equivalent to 47% of adult weight, and 223 kg for Jersey, equivalent to 49% of the adult weight. In both cases, this average growth rate is not high enough to achieve an AFC ≤ 24 months.

Although the AFC averages observed in this study were higher than those reported by most studies, the results obtained regarding the effect of AFC on the productive and reproductive performance of the adult cow reflect similar trends. In congruence with findings reported by several authors (Atashi et al., 2021; Castillo-Badilla et al., 2019; Le-Cozler et al., 2008; Meyer et al., 2004; Mohd-Nor et al., 2013), our study also found a lower milk production during the first lactation for cows calving at 24 months or less. However, this reduction in milk production in the first lactation is offset and outweighed by a significantly higher cumulative total production, which is primarily linked to a long herd life, as has also been pointed out in numerous studies (Adamczyk et al., 2016; Cooke et al., 2013; Do et al., 2013; Eastham et al., 2018; Sawa and Bogucki, 2010; Sawa et al., 2019; Zavadilová and Stipková, 2013).

The variable production per day of life has been reported in several studies, because it brings together in a single parameter the effects of AFC on production and reproduction throughout the dairy cow's life. Cooke et al. (2013) reported that the milk produced per day of life progressively decreased from 12 kg in the AFC group < 23 months to 9 kg in the AFC group > 30 months. Similarly, Eastham et al. (2018) found that 22-month-old AFC cows had a lifetime daily yield of 15.2 kg, while 36-month-old AFC cows had a lifetime mean daily yield of 12.8 kg. The differences reported in both studies are consistent to the 4.1 kg obtained in the present study, between Holstein cows with AFC ≤ 24 and ≥ 34 months.

This superior performance is mainly because females that calve at a younger age will dedicate more time to production. According to the results obtained in the present study, an average 5-year-old Holstein cow whose AFC was ≤ 24 months will have dedicated 39% of her life to production, compared to only 14% for a cow with AFC ≥ 34 months. The difference between the two cows in total milk production under local conditions would be approximately 9,000 kg. In the study conducted by Cooke et al. (2013), the corresponding values were 44% and 18%, consistent with the present analysis.

The later a heifer enters the milking herd, the higher feed and management costs during rearing (Steele, 2020). Locally, heifer rearing cost from birth to first calving was estimated at US$1,170 (Vargas-Leitón et al., 2012). Another study reported a cost of US$1474 (Elizondo-Salazar and Solís-Chaves, 2018), of which 79% corresponded to food and 7% to labor. In general, rearing costs in these systems represented between 9 and 16.5% of milk production costs (León-Hidalgo, 2015). These figures show the importance of reducing the AFC so that the productive days are maximized throughout the animal's life.

Several studies have estimated the economic benefit of the reduction in AFC. Lifetime profit of a Holstein dairy cow increased from $727 to $2364 when the age at first calving decreased from 32.8 to 22.3 months (Do et al., 2013). In another study, the most profitable rearing system was obtained for intermediate AFC (26–28 m), and the highest milk production (≥ 8500 kg) occurred for AFC earlier than 780 d (25.6 mo) (Krpálková et al.; 2014).

In the present study, heifers with AFC ≤ 22 months constituted less than 2% of the total, so their inclusion in a separate category was not justified. Our results strongly support the observations made by several studies regarding the superior lifetime performance observed for cows with AFC ≤ 24 months. However, it should be noted that the average AFC for this category was 22.8 months, thus the results cannot be extrapolated to younger ages.

Unlike most previous studies on the effect of AFC in dairy cattle, which were conducted almost exclusively on the Holstein breed, the present study provides valuable comparative information regarding the Jersey breed and crosses between these two breeds. As demonstrated, the effect of AFC on dairy cows' lifetime productive and reproductive performance is highly consistent across the three race groups.

In conclusion, the average age at first calving in the local dairy cattle population is higher than that reported in similar studies conducted in other latitudes, while the length of herd life is similar. The results indicate that cows with AFC ≤ 24 months consistently showed better performance in herd life, lifetime milk production, and milk production per day of life. This trend was consistent across all three race groups tested. Therefore, it is possible to assert that under local conditions, it is feasible and favorable to reduce AFC below 24 months, thereby increasing the dairy cow's herd life and total milk production per day of life.

Declarations

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Competing interests

The authors declare that they have no relevant financial or non-financial interests to disclose.

Ethics approval

Not applicable

Consent to participate

Not applicable

Written consent

Not applicable

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

Not applicable

Authors' contributions

All authors contributed to research design, analysis, interpretation of data, and drafting the manuscript. All authors read and approved the final manuscript.

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Figures

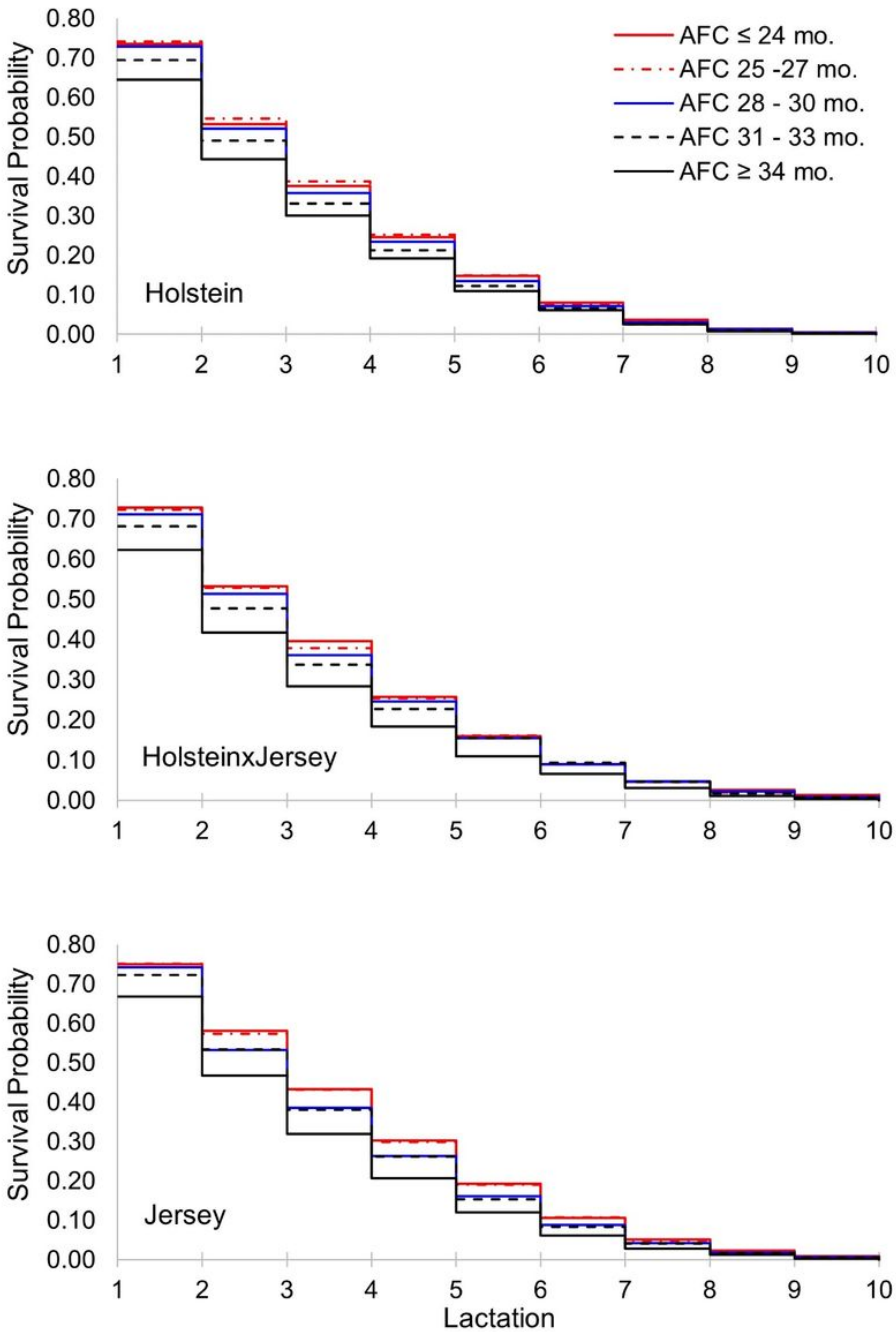

Figure 1

Kaplan Meier survival curves for Holstein, Holstein×Jersey, and Jersey cows, categorized according to their age at first calving.

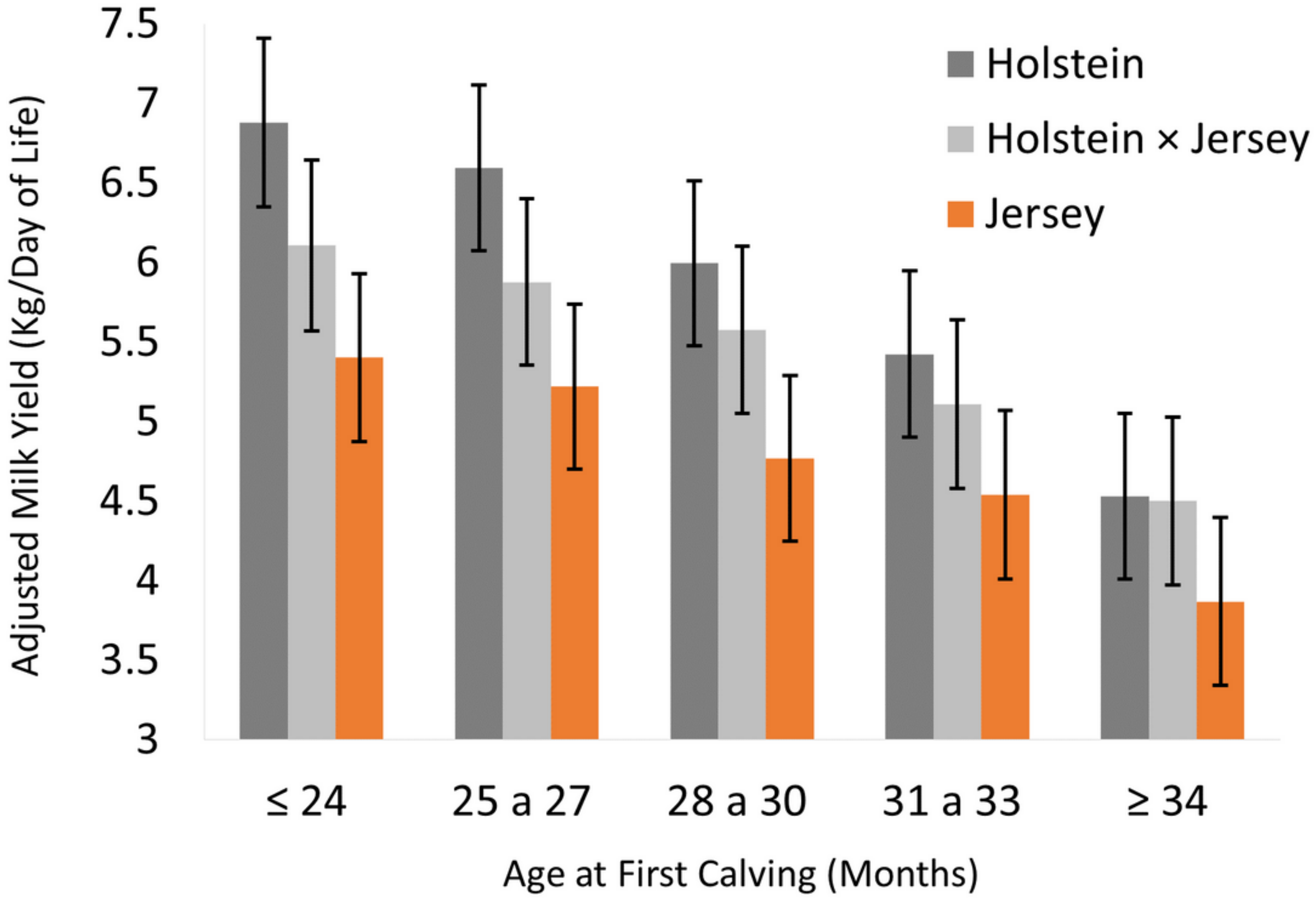

Figure 2

Adjusted milk yield per day of life (kg, mean ± 95% CI) in Holstein, Holstein×Jersey, and Jersey, categorized according to their age at first calving.