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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 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, reared under pasture-based conditions. 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 654 specialized dairy herds located in mid and high-altitude regions of Costa Rica. Cows were classified into five classes according to their age in months at first calving ($\leq$24, 25–27, 28–30, 31–33, $\geq$34). A generalized linear mixed model was used to assess the effect of AFC and breed 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 $\times$ Jersey, and Jersey, respectively. The AFC was significantly associated ($p < 0.01$) with all the variables evaluated. Cows with AFC $\leq$ 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 classes of AFC > 28 m. The reduction in AFC contributes to a significant increase in the production and reproduction efficiency of pasture-based dairy herds. This effect was consistent across the three breed groups.

Keywords: dairy cattle; herd life; milk yield; reproductive efficiency

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1. Introduction

The age at first calving (AFC) is one of the most frequently used parameters to evaluate the efficiency of replacement rearing programs in dairy herds [1,2]. Optimal AFC promotes the reduction of breeding costs and the extension of the herd life of the dairy cow [3]. In intensive milk production systems, the goal of breeding programs has generally been to get females to calve for the first time before 24 months [2,4–6]. Other studies reported that the best profitability rates were obtained when the AFC was between 24 and 26 months [7].

In specialized dairy herds, the AFC averages reported in different regions worldwide for Holstein or Jersey females range between 24 and 29 months [2,4,8–12]. In Costa Rica, where pasture-based production systems prevail, mean AFC of the order of 29.9 and 28.6 months have been reported for Holstein and Jersey females, respectively [13].

Several studies have found a reduction in milk production during the first lactation when AFC was below 24 months [1,3,5,8,11,14,15]. Likewise, AFC of < 22 months has been associated with lower fertility rates, survival probability to second calving and milk production [16]. In addition, an increased risk of dystocia has also been reported in females that calved for the first time at ages below or above an optimal age range, which has been proposed as the interval between 23 and 26 months [8].

On the other hand, several studies have shown that AFC lower than or equal to 24 months contributes to a significant increase in the length of herd life [2,14,17,18] and lifetime cumulative milk production of the dairy cow [2,4,6,9,19]. 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 [8,20,21], nor on milk production in the following lactations [19].

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 [22]. Dairy farms are mainly located in regions between 500 and 2500 m above sea level, with average temperatures between 18 and 30 °C and rainfall ranging between 500 and 3500 mm per year [22]. The most frequently used grasses in Costa Rican dairies are African star grass (*Cynodon nlemfuensis*) and Kikuyu (*Cenchrus clandestinus*) [23]. Between 19 and 71% of the dry matter consumed by the cows is provided by the grass, while the concentrate contributes between 23 and 38% [24].

In terms of breeding strategies, dairy farming in Costa Rica relies heavily on genetics imported mainly from North America, and to a lesser extent, from Europe and other regions in the world [13]. Currently, no official breeding programs or herd-testing recording schemes are being undertaken. The predominant dairy breeds are Holstein and Jersey with average milk production of 6750 and 5184 kg per lactation and calving-conception intervals of 143 and 132 days, respectively [22,25]. Crossbred Holstein × Jersey cattle constitutes more than 20% of specialized dairy cow population [25]. Analysis of centralized data coming from farm-owned production records suggests a consistent increase in average milk production per lactation, which has been estimated to be 60 and 72 kg/yr for Holstein and Jersey breeds for the period between 1985-2015 [26]. Conversely, a consistent decrease of 0.4% per year in first-service conception rate has also been observed for the same breeds [26].

Calf rearing systems in Costa Rican dairy herds are predominantly semi-intensive [23]. Pre-weaning rearing is carried out in semi-stalled systems with restricted access to grazing, and group management of calves, with daily supply of 4 L 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 [23]. Weight gains for Holsteins of 0.64 kg/day between birth and 12 months and 0.52 kg/day between 12 and 20 months have been reported, while for Jersey, the respective averages were 0.49 kg/day and 0.36 kg/day [21].

A large majority of studies on the effect of AFC on performance parameters throughout the dairy cow's life are from highly intensive dairy farms with the Holstein breed. Few studies have been conducted on pasture-based production systems, where management and environmental factors play a different role. Besides, pasture-based production systems in tropical and subtropical areas significantly differ from those located in temperate regions, where seasonal breeding and management practices are common. Optimal AFC for these production systems has not been clearly defined, nor investigated. 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 semi-intensive pasture-based production and rearing conditions prevailing in a tropical region.

2. Materials and Methods

2.1. 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 [27]. This database contains health and management information from over 2500 dairy herds (mean number of cows 124, median 40) distributed in different geographical zones of Costa Rica [27]. The information is mainly collected by the herd's owners themselves and entered in the VAMPP Bovino 3.0 computer program [28]. At herd level, the personnel in charge upload to the VAMPP® system the different kinds of events (productive, reproductive, and health-related); this information is stored and sent periodically to the industry, to the local cattle associations, and to the Veterinary Medicine School (Universidad Nacional), on a voluntary basis. The central database is dynamic; therefore, the herds can enter or exit the system at any time. Likewise, the recording and sending of information to the central database is voluntary, so that not all herds have data updated to the last year, nor they have data on every type of event [27].

2.2. 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 those still alive at the time of extracting the information were not included in the study. 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 [28]. 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. Applied restriction intervals were: age at first calving between 18 and 60 months, days open between 30 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 (21,000 kg), and cumulative milk production (100,000 kg).
- Cows culled within 15 days after the first calving were also excluded from the study.
- Cows fulfilling the previous criteria were classified according to their age at first calving into one of the following five classes (in months, after rounding up to the nearest integer): (1) AFC $\leq$ 24 months, (2) AFC 25 to 27 months, (3) AFC 28 to 30 months, (4) AFC 31 to 33 months, (5) AFC $\geq$ 34 months.

2.3. Descriptive Statistical Analysis

For each breed group and AFC class, 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).

2.4. Survival Curves by Breed × Age at First Calving Strata

Cows were classified in fifteen strata based on the combinations of the three breed-groups (Holstein, Jersey, Holstein × Jersey) and the five AFC classes previously described. For each stratum, Kaplan Meier curves [29] were fitted using Lifetest procedure of the SAS Statistical Analysis Program [30]. Survival probability estimates according to lactation number (1 to ≥10) were obtained. Survival curves for different AFC classes within each breed group were compared using the log-rank test [29].

2.5. Inferential Statistical Analysis Using GLMM

A Generalized Linear Mixed Model (GLMM) [31], as implemented in the GLIMMIX procedure of the SAS program [30], was fitted to the data in order to assess the effect of age at first calving on different productive and reproductive variables of interest, adjusting for breed and environmental factors. The model is described in (1):

$$y_{ijklm} = \mu + B_i + AFC_j + (B \times AFC)_{ij} + v_k + \lambda_l + \varepsilon_{ijklm} \quad (1)$$

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)).
μ = Population mean
B_i = ith fixed effect linked to breed group (three classes: Holstein, Jersey, and Holstein × Jersey crosses).
AFC_j = jth fixed effect linked to class of age at first calving (five classes: ≤24 m, 25–27 m, 28–30 m, 31–33 m, ≥34 m).
$(B \times AFC)_{ij}$ = fixed effect linked to the ijth interaction of breed group by AFC class (3 × 5 = 15 classes).
v_k = random effect linked to the kth herd of origin of each cow (654 herds).
λ_l = random effect linked to the lth year of birth (1990–2016).
ε_{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, adjusted least-squares means were calculated and compared with each other using the Tukey-Kramer test [29].

3. Results

3.1. Descriptive Parameters

The initial number of cows with birth, first calving, and culling dates was 174,310. Having information for all lactations proved to be the most restrictive selection criterion, since this reduced the number of cows by 54.7%. An additional 1% was excluded as a result of applying restriction intervals for variables under analysis. The final number of cows included in the analysis was 77,311, distributed among 654 herds.

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 breed compositions within the crossbred group were: $\frac{1}{2}$Holstein/$\frac{1}{2}$Jersey (41%), $\frac{3}{4}$Jersey/$\frac{1}{4}$Holstein (20%), and $\frac{3}{4}$Holstein$\frac{1}{4}$Jersey (13.3%).

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 Class 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	33,207	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	17,307	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	26,797	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)
Overall	77,311	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)

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

The culling age (ACU) presented an overall mean of 65.2 months, with differences of less than 1.2 months between the three compared breed groups (Table 1). For the three breed 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 highest 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.

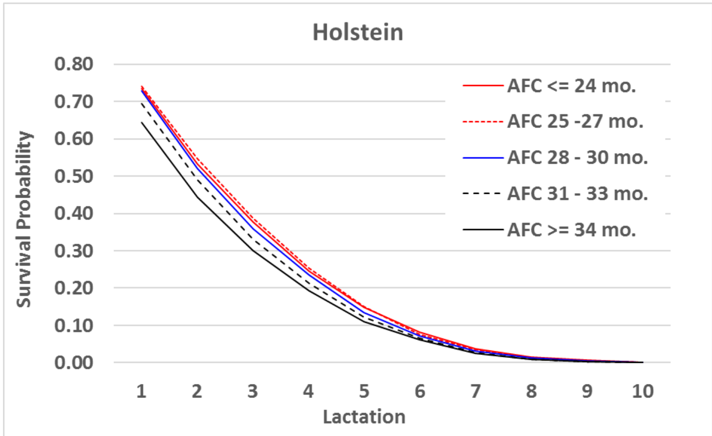
The average number of lactations per cow (LAC) was 3.1, 0.3 lactations higher for Jersey compared to the other two breed groups (Table 1). Again, cows with the lowest AFC (≤24 m) within the Holstein, Holstein × Jersey, and Jersey breed groups averaged 0.4, 0.5, and 0.5 more lactations than cows in the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

Cumulative milk production (CPR) in the Holstein group was 4984 and 3528 kg higher than for 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 for Holstein × Jersey and Jersey, respectively. The differences in COP between the different AFC classes within the three breed groups were mostly lower than one month. Average days open were 4.9, 4.4, and 4.0 months for Holstein, Holstein × Jersey and Jersey, respectively.

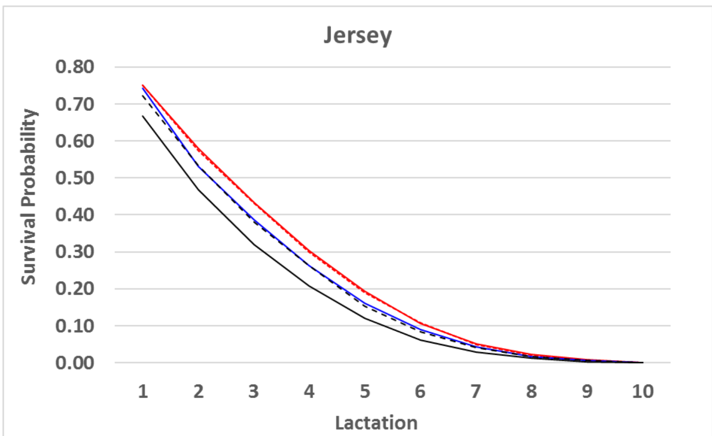
3.2. Kaplan Meier Survival Curves

Survival curves for AFC classes showed similar patterns in the different breed groups (Figure 1). Survival curve for class AFC $\geq$ 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 breed groups, the cows with AFC $\leq$ 24 tended to present higher survival curves than the other groups, though not always significantly different from AFC 25–27 and AFC 28–30.



(**a**)

(**b**)



(**c**)

Figure 1. Survival curves from lactations 1 to 10 for (**a**) Holstein; (**b**) Holstein × Jersey; (**c**) Jersey cows, categorized according to their age at first calving (AFC).

In Holstein, the survival curve of the AFC ≤ 24 class was significantly higher ($p < 0.001$) than that of the other strata, except for the AFC 28–30 stratum. In Holstein × Jersey, the survival curve of the AFC ≤ 24 class was significantly higher ($p < 0.001$) than those of the two classes with the highest AFC. In Jersey, the survival curve of the AFC ≤ 24 class was significantly higher ($p < 0.001$) than those of 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 formed by the AFC classes from 28 to 33 months (Figure 1).

3.3. *Effect of the AFC on Performance Variables*

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

In all breed 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 classes (Table 2). Likewise, an increase in ACU was consistently linked to a higher AFC. The differences in ACU (back-transformed from the logarithmic scale) between the highest and lowest AFC classes were 8.9, 9.7, and 9.4 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 Class by Breed	Age at Culling (log Month) *	Herd 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}
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 classes with equal superscripts within each breed group do not differ significantly ($p > 0.05$).

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

Regarding milk production during the first lactation (PRF), in the three breed groups, there was a significantly lower production ($p < 0.01$) for cows in the AFC classes ≤24 and 25–27 months, compared to the other classes (Table 2). The differences in production per lactation between the lowest class 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 ($p > 0.05$) from cows with AFC between 25 to 33 months, but it was significantly higher ($p < 0.001$) than production obtained from cows with AFC ≥ 34 months. For the Holstein group, the adjusted milk production of cows in AFC classes ≤27 was significantly higher ($p < 0.001$) than that obtained in cows with AFC ≥ 31 months. The adjusted difference in CPR (back-transformed from the logarithmic scale) between the lowest and highest AFC classes 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 in AFC was observed in the three breed groups (Figure 2). For Holsteins, all differences between AFC classes were significant ($p < 0.05$). The adjusted difference in PRD between the lowest and highest AFC classes was 2.4, 1.6, and 1.5 kg per day for Holstein, Holstein × Jersey, and Jersey, respectively.

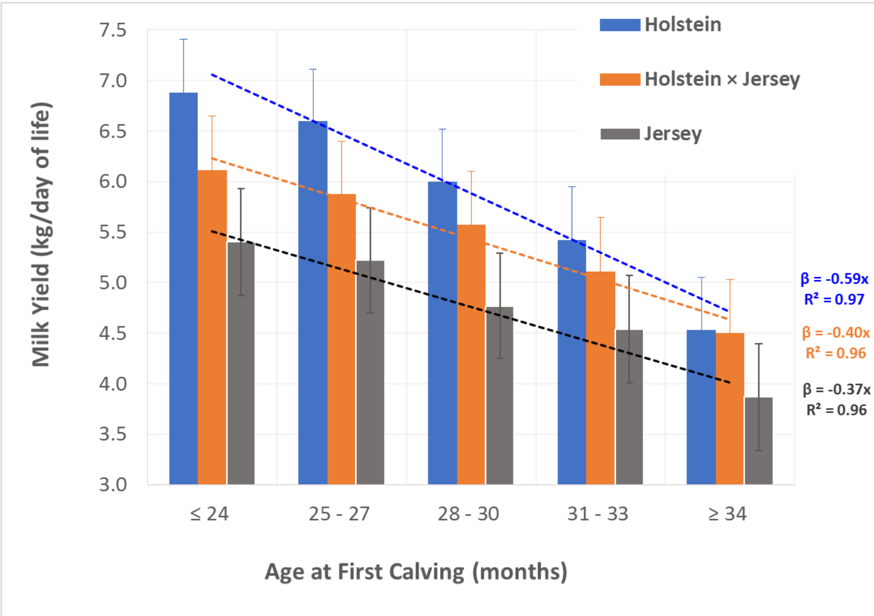


Figure 2. Adjusted milk yield per day of life (kg, mean ± 95% CI, with added linear trends, regression coefficient β, and R^2) in Holstein, Holstein × Jersey, and Jersey breeds, categorized according to their age at first calving.

A significant effect of AFC ($p < 0.01$), breed 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 class of AFC, with a lower open period, compared to the other classes. The differences between the highest class 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 classes in several cases were not significant ($p > 0.05$) nor showed a consistent pattern across the three breed groups.

The cumulative open period (COP) showed a slight tendency to decrease associated to the increase in AFC (Table 2). The reduction was significant ($p < 0.05$) only for AFC classes ≥28. The adjusted difference in COP between the lowest and highest AFC classes 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.

4. Discussion

The average age at first calving observed in this study tends to be higher than reported by other studies, which are generally in the range between 24 and 27 months [2,4,8,10–12] and mostly refer to the Holstein breed. Among the revised studies, only one reported an estimate of 29.1 months [9], which is 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 [22]. In addition, the greater dependence on grazing in these dairies is also associated with lower weight gains during the rearing period.

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 [32]. For a cow with an approximate adult weight of 450 kg (Jersey) or 600 kg (Holstein), average daily growth rates around 0.50 and 0.67 kg are required between birth and 15 months of age, respectively. In pasture-based systems included in the present study, weight gains for Holsteins of 0.64 kg/day between birth and 12 months and 0.52 kg/day between 12 and 20 months have been reported, while for Jersey, the respective averages were 0.49 kg/day and 0.36 kg/day [21]. 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 $\leq$ 24 months.

Although the AFC averages observed in this study were higher than those reported by most studies, the results obtained with respect to the effect of AFC on the productive and reproductive performance of the adult cow reflect similar trends. In line with findings reported by several authors [1,3,5,8,11,14], 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 longer herd life, as has also been pointed out in numerous studies [2,4,6,9,17–19].

According to data from Table 1, average production per lactation for cows in the present study was 6454, 4795 and 4790 kg for Holstein, Jersey and Holstein × Jersey, respectively. There is also evidence that milk yield per lactation has increased for the past 30 years at a rate of 72 and 56 kg/yr for Holstein and Jersey breeds [26]. Local production level is low when compared to highly intensive production systems in USA, where average production is currently reported as 12,700 kg for Holstein and 9500 kg for Jersey [33]. However, it is higher than production reported for other pasture-based production systems in New Zealand, where average milk yield per lactation is currently reported as 4560 kg for Holstein-Friesian, 3298 kg for Jersey, and 4193 kg for Holstein × Jersey [34]. These last figures, however, are hardly comparable due to the seasonal breeding and management practices in New Zealand.

Results derived from the present study also indicate a long calving interval (419 days), for the Holstein breed, compared to 404 days for Holstein × Jersey and 392 days for Jersey. A consistent decrease of 0.4% per year in first-service conception rate during the last 30 years has been reported for both breeds [26]. For Holstein and Jersey cows in United States, calving interval close to 397 and 400 days, respectively, are currently reported [35]. Estimates from New Zealand pasture-based production are much lower, being around 369 days for both breeds [34]. In terms of herd life, results observed in the present study tend to be similar to values reported for high producing cows in intensive production systems, which fluctuate between 3 to 4 years [36].

The variable production per day of life has been used 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. [2] 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. [9] 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 with the 4.1 kg obtained in the present study, between Holstein cows with AFC $\leq$ 24 and $\geq$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 $\leq$24 months spends 39% of her life on production, compared to only 14% for a cow with AFC $\geq$ 34 months. The difference between the two cows in total milk production under local conditions would be approximately 9000 kg. In the study conducted by Cooke et al. [2], 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 [16]. Locally, the heifer rearing cost from birth to first calving was estimated at US$1474 [37], 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 [38]. 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 $2364 when the age at first calving decreased from 32.8 to 22.3 months [4]. In another study, the most profitable rearing system was obtained for intermediate AFC (26–28 months), and the highest milk production ($\geq$8500 kg) occurred for AFC earlier than 780 days (25.6 months) [7].

Some studies considered AFC $\leq$ 22 months as a separate class [2,14,17]. In the present study, heifers with AFC $\leq$ 22 months constituted less than 2% of the total, so their inclusion as a separate class was not justified. Our results strongly support the observations made by several studies regarding the superior lifetime performance observed for cows with AFC $\leq$ 24 months. In the present study, the average AFC for this class was 22.8 months; therefore, the results cannot be extrapolated to younger ages. Besides, it seems unrealistic for pasture-based dairy systems to pursue AFC lower than 22 months.

In general, results obtained in the present study show suboptimal performance, mainly in terms of high AFC, extended days open, and relatively low herd life. These were mainly associated with the Holstein breed. It must be taken into account that the performance of specialized dairy cattle reared under semi-intensive pasture-based production systems in tropical and subtropical regions is subject to a large number of unfavorable factors, such as high temperature and humidity, variability in diet composition, long walks on hilly roads, or high exposure to pests and infectious diseases, among others. These factors all together have an important effect on lowering growth rate, increasing calving interval, and decreasing survivability of the dairy cow. A major driver of short herd life observed in local production systems is involuntary culling. A former local study reported involuntary culling rates ranging from 51 up to 83 percent for a sample of herds in this population [39]. Reproduction failure was the main reason for culling, although events related to mastitis and lameness also played an important role.

From a breeding perspective, specialized dairy farming in Costa Rica and similar countries in the region, relies mainly on genetics imported from North America, with no official breeding program functioning locally. It is true that breeding goals for dairy cattle in North America have changed substantially during the last decades [40]. The first USDA selection index included only milk and fat yield, whereas the latest version of the lifetime net merit index includes 13 traits and composites [40]. Current breeding objectives seek for a better balance between production, reproduction, health, feed efficiency, and longevity. However, these breeding goals have been designed for intensive production systems, where exposure to harsh conditions found in tropical areas are minimal. Traits such as heat tolerance, grazing ability, or resistance to parasites, which are key for production in the tropics, are not considered in such breeding schemes.

5. Conclusions

The average age at first calving in the local dairy cattle population is higher than reported in similar studies conducted in other latitudes, while the length of herd life is similar. The results indicate that cows with AFC $\leq$ 24 months consistently showed better performance in herd life, lifetime milk production, and milk production per day of life. This tendency was consistent across all three breed groups tested. Therefore, it is possible to assert that under predominantly pasture-based conditions, such as those found locally, 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.

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 breed groups.

In general, dairy cattle under local conditions, and mainly the Holstein breed, show relatively high age at first calving, low herd life and extended days open. Relying on breeding objectives which do not consider adaptation traits to tropical production environments is a major constraint for faster improvement in these production systems.

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References

1. Castillo-Badilla, G.; Vargas-Leitón, B.; Hueckmann-Voss, F.; Romero-Zúñiga, J. Factores que afectan la producción en primera lactancia de vacas lecheras de Costa Rica. *Agron. Mesoam.* **2019**, *30*, 209–227. [CrossRef]
2. Cooke, J.S.; Cheng, Z.; Bourne, N.E.; Wathes, D.C. Association between growth rates, age at first calving and subsequent fertility, milk production and survival in Holstein-Friesian heifers. *Open J. Anim. Sci.* **2013**, *3*, 1–12. [CrossRef]
3. Meyer, M.J.; Everett, R.W.; van Amburgh, M.E. Reduced age at first calving: Effects on lifetime production, longevity, and profitability. *Kans. Agric. Exp. Stn. Res. Rep.* **2004**, *0*, 42–52. [CrossRef]
4. Do, C.; Wasana, N.; Cho, K.; Choi, Y.; Choi, T.; Park, B.; Lee, D. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. Asian-australas. *J. Anim. Sci.* **2013**, *26*, 1511–1517. [CrossRef]
5. Le-Cozler, Y.; Lollivier, V.; Lacasse, P.; Disenhaus, C. Rearing strategy and optimizing first-calving targets in dairy heifers: A review. *Animals* **2008**, *2*, 1393–1404. [CrossRef] [PubMed]
6. Sawa, A.; Siatka, K.; Krężel-Czopek, S. Effect of age at first calving on first lactation milk yield, lifetime milk production, and longevity of cows. *Ann. Anim. Sci.* **2019**, *19*, 189–200. [CrossRef]
7. Krpálková, L.; Cabrera, V.E.; Kvapilík, J.; Burdych, J.; Crump, P. Associations between age at first calving, rearing average daily weight gain, herd milk yield and herd dairy production, reproduction, and profitability. *J. Dairy Sci.* **2014**, *97*, 6573–6582. [CrossRef]

8. Atashi, H.; Asaadi, A.; Hostens, E. Association between age at first calving and lactation performance, lactation curve, calving interval, calf birth weight, and dystocia in Holstein dairy cows. *PLoS ONE* **2021**, *16*, e0244825. [CrossRef]
9. Eastham, N.T.; Coates, A.; Cripps, P.; Richardson, H.; Smith, R.; Oikonomou, G. Associations between age at first calving and subsequent lactation performance in UK Holstein and Holstein-Friesian dairy cows. *PLoS ONE* **2018**, *13*, e0197764. [CrossRef]
10. Hare, E.; Norman, H.D.; Wright, J.R. Trends in calving ages and calving intervals for dairy cattle breeds in the United States. *J. Dairy Sci.* **2006**, *89*, 365–370. [CrossRef]
11. Mohd-Nor, N.; Steeneveld, W.; van Werven, T.; Mourits, M.C.M.; Hogeveen, H. First-calving age and first-lactation milk production on Dutch dairy farms. *J. Dairy Sci.* **2013**, *96*, 981–992. [CrossRef] [PubMed]
12. Pirlo, G.; Miglior, F.; Speroni, M. Effect of age at first calving on production traits and on difference between milk yield returns and rearing costs in Italian Holsteins. *J. Dairy Sci.* **2000**, *83*, 603–608. [CrossRef] [PubMed]
13. Vargas-Leitón, B. Mejoramiento genético: Herramienta para incrementar la productividad del hato lechero. *UTN-Inf.* **2013**, *66*, 6–14. Available online: https://www.utn.ac.cr/sites/default/files/attachments/revista%2066.pdf (accessed on 20 January 2022).
14. Berry, D.P.; Cromie, A.R. Associations between age at first calving and subsequent performance in Irish spring calving Holstein–Friesian dairy cows. *Livest. Sci.* **2009**, *123*, 44–54. [CrossRef]
15. Castillo-Badilla, G.; Salazar-Carranza, M.; Murillo-Herrera, J.; Romero-Zúñiga, J. Efecto de la edad al primer parto sobre parámetros productivos en vacas Jersey de Costa Rica. *Agron. Mesoam.* **2013**, *24*, 177–187. [CrossRef]
16. Steele, M. Age at first calving in dairy cows: Which months do you aim for to maximize productivity? *Vet. Evid.* **2020**, *5*. [CrossRef]
17. Sawa, A.; Bogucki, M. Effect of some factors on cow longevity. *Arch. Tierzucht.* **2010**, *53*, 403–414. [CrossRef]
18. Zavadilová, L.; Stípková, M. Effect of age at first calving on longevity and fertility traits for Holstein cattle. *Czech J. Anim. Sci.* **2013**, *58*, 47–57. [CrossRef]
19. Adamczyk, K.; Makulska, J.; Jagusiak, W.; Węglarz, A. Associations between strain, herd size, age at first calving, culling reason and lifetime performance characteristics in Holstein-Friesian cows. *Animal* **2016**, *11*, 327–334. [CrossRef]
20. Castillo-Badilla, G.; Salazar-Carranza, M.; Murillo-Herrera, J.; Hueckmann-Voss, F.; Romero-Zúñiga, J. Efecto de la edad al primer parto sobre parámetros reproductivos en la primera lactancia de vacas Holstein y Jersey de Costa Rica. *Rev. Cienc. Vet.* **2015**, *33*, 33–45. [CrossRef]
21. Vargas-Leitón, B.; Ulloa-Cruz, J. Relación entre curvas de crecimiento y parámetros reproductivos en grupos raciales lecheros de distintas zonas agroecológicas de Costa Rica. *Livest. Res. Rural Dev.* **2008**, *20*, 103. Available online: http://www.lrrd.org/lrrd20/7/varg20103.htm (accessed on 20 January 2022).
22. Vargas-Leitón, B.; Solís-Guzmán, O.; Saénz-Segura, F.; León-Hidalgo, H. Caracterización y clasificación de hatos lecheros en Costa Rica mediante análisis multivariado. *Agron. Mesoam.* **2013**, *24*, 257–275. [CrossRef]
23. CRIPAS-Centro Regional de Informática para la Producción Animal Sostenible. Resultados de Encuesta Diagnóstico. *Proyecto de Evaluación de la Genética Neozelandesa Basada en Pasturas. Cámara Nacional de Productores de Leche, Ministerio de Agricultura y Ganadería, Livestock Improvement Corporation, Centro Regional de Informática para la Producción Animal Sostenible.* 2020. Available online: http://www.egcrc.rf.gd/invest/NZLResultados_encuesta_Marzo2020.pdf (accessed on 20 January 2022).
24. Iñamagua-Uyaguari, J.P.; Jenet, A.; Alarcón-Guerra, L.G.; Vílchez-Mendoza, S.J.; Casasola-Coto, F.; Wattiaux, M.A. Impactos económicos y ambientales de las estrategias de alimentación en lecherías de Costa Rica. *Agron. Mesoam.* **2016**, *27*, 1–17. [CrossRef]
25. Vargas-Leitón, B.; Romero-Zúñiga, J. Efectos genéticos aditivos y no aditivos en cruces rotacionales entre razas lecheras. *Agron. Mesoam.* **2010**, *21*, 223–234. [CrossRef]
26. Vargas-Leitón, B. Aspectos Genéticos de la Fertilidad en Bovinos Lecheros. In Congreso Nacional Lechero, 1ra. Edición Virtual, San José, Costa Rica, 06/10/2020. 2020. Available online: https://www.youtube.com/watch?v=ssjt7BB664I&list=UU3SPT3-p8cWX5aiOyP8cKoA (accessed on 20 January 2022).
27. Sánchez-Hernández, Z.; Galina-Hidalgo, C.S.; Vargas-Leitón, B.; Rojas Campos, J.; Estrada-König, S. Herd management information systems to support cattle population research: The VAMPP® case. *Agron. Mesoam.* **2020**, *31*, 141–156. [CrossRef]
28. Noordhuizen, J.P.; Buurman, J. VAMPP: A veterinary automated management and production control program for dairy farms (the application of MUMPS for data processing). *Vet. Quart.* **1984**, *6*, 66–72. [CrossRef] [PubMed]
29. Daniel, W.W.; Cross, C.L. *Biostatistics. A Foundation for Analysis in the Health Sciences*, 10th ed.; John Wiley & Sons: Hoboken, NJ, USA, 2013.
30. SAS Institute Inc. *SAS/STAT®User's Guide*; SAS Institute Inc.: Singapore, 2022. Available online: https://documentation.sas.com/doc/es/pgmsascdc/v_023/statug/titlepage.htm (accessed on 20 January 2022).
31. Gbur, E.E.; Stroup, W.W.; McCarter, K.S.; Durham, S.; Young, L.J.; Christman, M.; West, M.; Kramer, M. *Analysis of Generalized Linear Mixed Models in the Agricultural and Natural Resources Sciences*; American Society of Agronomy, Soil Science Society of America, Crop Science Society of America: Madison, WI, USA, 2012. [CrossRef]
32. Roche, J.R.; Dennis, N.A.; MacDonald, K.A.; Phyn, C.V.C.; Amer, P.R.; White, R.R.; Drackley, J.K. Growth targets and rearing strategies for replacement heifers in pasture-based systems: A review. *Anim. Prod. Sci.* **2015**, *55*, 902–915. [CrossRef]
33. Norman, H.D.; Guinan, F.L.; Megonigal, J.H.; Dürr, J.W. State and National Standardized Lactation Averages by Breed for Cows Calving in 2020. CDCB Research Report K2-20,2-22. 2020. Available online: https://queries.uscdcb.com/publish/dhi/current/lax.html (accessed on 1 October 2023).

34. LIC-Dairy NZ. New Zealand Dairy Statistics 2021–2022. 2022. Available online: https://www.dairynz.co.nz/media/uzeekwgr/nz-dairy-statistics-2021-22-web.pdf (accessed on 1 October 2023).
35. Norman, H.D.; Guinan, F.L.; Megonigal, J.H.; Dürr, J.W. Reproductive Status of Cows in Dairy Herd Improvement Programs and Bred Using Artificial Insemination. 2020. Available online: https://queries.uscdcb.com/publish/dhi/current/reproall.html (accessed on 1 October 2023).
36. De Vries, A.; Marcondes, M.I. Review: Overview of factors affecting productive lifespan of dairy cows. *Animal* **2020**, *14*, 155–164. [CrossRef]
37. Elizondo-Salazar, J.; Solís-Chaves, H. Costo de criar una ternera lechera de reemplazo desde el nacimiento al parto. *Agron. Mesoam.* **2018**, *29*, 547–555. [CrossRef]
38. León-Hidalgo, H. Alternativas para la reducción de los principales costos de producción de leche en Costa Rica: Alimentación y mano de obra. In Proceedings of the XXI Congreso Nacional Lechero, Heredia, Costa Rica, 20–21 October 2015. Available online: http://proleche.com/recursos/documentos/congreso2015/produccion/Charla2.pdf (accessed on 20 January 2022).
39. Cedeño-Quevedo, D. Análisis de vida productiva y optimización de políticas de descarte en vacas lecheras de Costa Rica. Tesis Maestría, Producción Animal Sostenible, Posgrado Regional en Ciencias Veterinarias Tropicales Universidad Nacional, Lagunilla, Costa Rica, 2003. Available online: https://repositorio.una.ac.cr/handle/11056/22003 (accessed on 1 October 2023).
40. Cole, J.B.; VanRaden, P.M. Symposium review: Possibilities in an age of genomics: The future of selection indices. *J. Dairy Sci.* **2018**, *101*, 3686–3701. [CrossRef]