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Comparative productive performance of cows born through embryo transfer, artificial insemination and natural mating in dairy and dual-purpose herds raised in tropical conditions

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Abstract

A populational, observational and longitudinal-retrospective study with records of 28 dairy-specialized and dual-purpose farms was carried out to compare the productive performance of cows born by embryo transfer (ET), artificial insemination (AI) and natural mating (NM), using the database of Centro Regional de Investigación para la Producción Animal Sostenible (CRIPAS) of cattle herds in Costa Rica. Herds (system × altitude), conception method (ET, AI and NM), genetic background (DSpB: specialized dairy breeds [*Bos taurus*] and crosses, GYR × HOL: Gyr × Holstein Crossbred and DSpB × BI: crosses between dairy breeds and *Bos indicus*), year of birth (or at calving), lactation number and days in milk were evaluated for the productive parameters age at first calving (AFC), calving to conception interval (CCI) and lactation milk yield (LMY) using a GLIMMIX procedure on SAS. The AFC, CCI and LMY were affected ($p < .0001$) by all factors considered in each parameter. ET has lower ($p < .0001$) AFC in months (33.1) than AI (35.2) and NM (36.44). NM had lower ($p = .004$) CCI (110 days) than AI or ET (121 days) values which were similar ($p > .05$). The higher LMY ($p < .0001$) was observed in ET (4140 kg), compared to AI (3706 kg) and NM (3595 kg). There was no difference between AI and NM. In conclusion, the method of conception in calves affected their future reproduction and production during puberty, postpartum and lactation. The effects on management decisions will require a rigorous economical study to discern whether ET would be a cost-effective alternative to AI or NM.

KEYWORDS
calving, cattle, conception, dairy, embryo, tropical

1 | INTRODUCTION

Embryo transfer (ET) has been considered a helpful technique to advance genetic progress on a farm (Hernández-Castellano et al., 2019). It is argued that the contribution of the dam-bull (DB) path to selection intensity can be improved by ET, since only a small fraction of the female population is needed to produce the next generation of bulls, contrary to natural mating, in which the low number of progenies from bovine females leads to lower selection accuracy (Lohuis, 1995). On the other hand, the larger number of calves produced by multiple ovulation embryo transfers (MOET) is expected to have only a small impact on genetic diversity when the number of selected candidates is maintained (Contreras et al., 2021; Daetwyler et al., 2007). Traditionally, in tropical areas of the world, using natural mating (NM) with a bull of unknown genetic background is the most common breeding practice (Galina & Arthur, 1991; Gicheha et al., 2019). This policy brings the natural consequence of limited genetic progress in the farms. Because of this, several farmers have increasingly adopted artificial insemination (AI) as an alternative to eliminate the shortcomings of NM and assume valuable genetic progress by using proven bulls in their herds (Wahinya et al., 2022).

In an extensive review, Lamb et al. (2016) pointed out that the increasing benefits that AI has gained in the last few years, with the advent of numerous biotechnologies, facilitate the advancement of this technique in industrialized countries. According to Thibier and Wagner (2002), about 16% of the total number of inseminations in the world were carried out in North America, compared to only 2.2% that took place in South America, where most of the cattle are dual purpose. In apparent contrast, ET in cattle raised under tropical conditions has gained popularity in the last 15 years (Rodriguez-Martinez, 2012; Viana et al., 2018). Nonetheless, apart from selective programs in the more advanced countries in the region, the use of ET, at least in dual-purpose cattle, has been frequently applied with subsidies from different national and international organizations; when the subsidy finishes, the program comes to a halt (Contreras et al., 2021).

Therefore, the objective of this study was to evaluate differences in age at puberty, postpartum reproductive efficiency and lactational performance among herds using natural mating, artificial insemination and embryo transfer, using the database of Centro Regional de Informática para la Producción Animal Sostenible (CRIPAS) of cattle herds in Costa Rica.

2 | MATERIALS AND METHODS

2.1 | Location and herd characteristics

A populational, observational, longitudinal-retrospective study was carried out with records in 28 Costa Rican cattle herds. The country is located between 8°02′ and 11°13′ north latitude and 82°34′ and 85°58′ west longitude. It has a wide variety of ecological zones (Harris, 1973), with altitudes between 0 and 3820 m above sea level. Two climate seasons predominate: rainy and dry, with transitions between them. The duration of each season and total rainfall vary according to the region. Most territory has temperatures between 16°C and 28°C throughout the year.

Cattle herds are located at three altitudinal zones: low (0–800 m.a.s.l.), mid (801–1500 m.a.s.l) and highlands (above 1500 m.a.s.l.). The predominant pastures in the lowlands are *Cynodon nlemfuensis* (African star grass), *Paspalum* spp. and *Axonopus* spp., whereas in the highlands are *Lolium perenne* (ryegrass) and *Pennisetum clandestinum* (Kikuyu grass). In the midlands, there is a mixture of grasses existing in the low and highlands.

The nutritional management in >95% of the farms is mainly based on intensive rotational grazing and supplementation with concentrate feed and mineral salts. The farms predominantly use AI or NM, whereas ET has become popular during the last 10 years. Traditionally, cattle have been immunized against brucellosis (*Brucella abortus* Strain RB51, 3–8 months old), clostridial polyvalent vaccine (twice a year, total herd), leptospirosis polyvalent vaccine (twice a year, total herd), a polyvalent vaccine for infectious bovine rhinotracheitis, bovine viral diarrhoea, bovine parainfluenza type 3 and bovine respiratory syncytial virus (all the herd, cows and heifers before breeding). All farms have a milking parlour; cows are milked twice daily and receive veterinary assistance at least once a month.

2.2 | Data

The information analysed was obtained from the central database of the Centro Regional de Informática para la Producción Animal Sostenible (CRIPAS) at the Escuela de Medicina Veterinaria, Universidad National, Costa Rica (Romero-Zúñiga et al., 2019; Sánchez-Hernández et al., 2020). This database contains information on herds all over the country. Daily information is collected mainly through the owners, digitalized in the VAMPP Bovino software once a week (Noordhuizen & Buurman, 1984), and twice a year centralized for analysis.

The data set comprised 28 farms, 17 were dairy specialized (DSp) and 11 dual purpose (DPr). Twelve were in the midlands, and 16 were in the lowlands. Distributed in six ecozones, but almost 80% were in very humid forests (18% low mountain, 21% pre-mountain and 39% tropical). Fifty per cent of farms started keeping records in VAMPP Bovino software before 2005 and 80% before 2010.

2.2.1 | Inclusion and exclusion criteria

From the computerized records available in the database, the dairy-specialized (DSp) or dual-purpose (DPr) herds with at least 10 registered births of females born by ET since 2010 were considered. Also, farms located under high altitude conditions were not taken into consideration for not complying with the criteria indicated above. Within the selected herds, females contemporary to the ET group born from artificial insemination (AI) or natural mating (NM) were involved for comparative purposes. Females, whose provenance was reported as unknown, were excluded from the subsequent analysis. In addition, all historical information before the birth of the first female from ET was excluded from the subsequent analysis. Then, the final number of animals considered from the 28 farms ranged from 19 to 698 with an average of 153 cows.

2.2.2 | Genetic background

Due to the high racial variability, a classification was made into three main groups: (1) DSpB: dairy-specialized breeds (*Bos taurus*) and their crosses, (2) GYR×HOL: Gyr×Holstein crosses and (3) DSpB×BI: crosses between dairy-specialized breeds and *Bos indicus*. Due to

TABLE 1 General productive parameters according to the conception method of the females raised under field conditions in dairy farms of Costa Rica.

Variable	Embryo transfer				Artificial insemination				Natural mating			
	N	Mean	SD	P50	N	Mean	SD	P50	N	Mean	SD	P50
AFC (months)	615	31.0	4.0	30.6	1061	30.4	6.0	28.7	395	35.5	6.2	35.0
CCI (days)	512	133.0	80.5	105.5	2328	157.7	130.1	116.0	996	133.3	95.6	105.0
LMY (kilograms)	564	3134.4	2500.2	2574.0	2865	5007.2	3611.4	4460.0	1277	3191.0	2360.3	3026.0

Abbreviations: AFC, Age at first calving; CCI, Calving to conception interval; LMY, Lactation milk yield.

its higher frequency, the GYR × HOL group was segregated from the DSpB × BI group. Among the most frequent breeds included in the data set were Holstein, Jersey and Brown Swiss from the subspecies *Bos taurus* as dairy specialized, and Brahman and Gyr from the subspecies *Bos indicus*.

2.3 | Statistical analysis

2.3.1 | Descriptive statistics

A descriptive statistical analysis was performed to explore the behaviour of the following productive variables of interest:

a. Age at first calving (AFC): Months between the date of birth and the date of first calving, restricted to the interval between 18 and 60 months. The number of records considered was 615 for ET, 1061 for AI and 395 for NM.
b. Calving to conception interval (CCI): Days between calving and conception, restricted to the interval between 30 and 600 days. The number of records considered was 512 for ET, 2328 for AI and 996 for NM.
c. Lactation milk yield (LMY): LMY records between 100 and 15,000 kg were included. Accumulated milk yield (kg) up to the last daily production record available for each lactation. This calculation included completed or ongoing lactations with at least 100 days in production. The number of records considered was 564 for ET, 2865 for AI and 1277 for NM.

2.3.2 | Inferential statistical analysis

To evaluate the effect of the conception method of the cows on the different productive and reproductive variables mentioned above, data were adjusted for racial and environmental factors. Generalized linear mixed models (GLMM) were used (Gbur et al., 2012) and executed with a GLIMMIX procedure of the SAS software (SAS Institute Inc., 2022).

Then, three very representative stages of the females were covered. Age at first calving (AFC), calving to conception interval (CCI) and lactation milk yield (LMY). The AFC assesses the effectiveness of the growing period, the CCI measures the reproductive ability after parturition, and LMY assesses the capability of milk production.

$$y_{ijklmnop} = \mu + O_i + R_j + A_k + E_l + Z_m + H_n(E \times Z)_{lm} + P_o + D_p + p(c) + \varepsilon_{ijklmnop},$$

where, $y_{ijklmnop}$ is the Dependent variables: AFC, CCI, and LMY; μ is the Population average; C_i is the ith fixed effect of the conception method of the female: ET, AI and NM; R_j is the jth fixed effect of the genetic background: DSpB, DSpB × BI and GYR × HOL; A_k is the kth fixed effect of the year of birth (for AFC) or year of calving (for CCI and LMY); E_l is the lth fixed effect of the farm type: specialized dairy/dual purpose; Z_m is the mth fixed effect of the altitudinal zone: lowland (0–800 masl) and midland (801–1500 masl); $H_n(E \times Z)_{lm}$ is the *n*th fixed effect of the herd, nested within the farm type and altitudinal zone; P_o is the *o*th fixed effect of the lactation number (evaluated only for CCI- and LMY-dependent variables); D_p is the *p*th fixed effect of the covariable of days in milk (only evaluated for LMY); *p*(*c*) is the Random effect accounting for correlation between repeated measures in different parities of the same cow (evaluated only for CCI- and LMY-dependent variables) and; $\varepsilon_{ijklmno}$ is the Random residual error.

Appropriate probability distributions were selected for each dependent variable according to the dispersion observed in the histograms. A normal distribution with identity link function was assumed for AFC and LMY. A lognormal distribution with identity link function was assumed for CCI due to the marked positive asymmetry observed in the study population. When the statistical significance of the fixed effect of the conception method was evidenced, the adjusted means were calculated and compared using the Tukey–Kramer test (Daniel & Cross, 2019).

3 | RESULTS

3.1 | Descriptive statistics

Some general characteristics (central tendency and position statistics) of the productive performance of females born by ET, AI and NM are shown in Table 1.

3.2 | Factors associated with productive performance

Results of the GLMMIX analyses for AFC, CCI and LMY are shown in Table 2. Remarkably, the conception method of the cows (ET, AI and NM) is strongly associated with the three productive variables selected for this adjusted study. Also, other intrinsic variables, such as genetic background and year of birth (or year of calving), were associated. Days in milk and lactation number were also related to LMY.

3.2.1 | Age at first calving (months)

Conception method, genetic background and year of birth affected significantly ($p < .0001$) the age at first calving (AFC, in months) at their different levels. Also, the effect of herd, nested into farm system and altitude, affected the AFC. When comparing the conception method, ET cows had significantly ($p < .0001$) lower AFC (33.1) than AI (35.2) and NM (36.4) (Table 3). On the other hand, the AFC was significantly different ($p < .0001$) when comparing GYR × HOL crosses (36.4) against DSpB (34.0) and DSpB × BI (34.5); however, there was no significant difference between DSpPB and DSpPB × BI ($p = .1912$) (Table 3). Furthermore, the year of birth showed a double trend of reducing the AFC year by year; so, there was a temporal cycle between 2010 (39.4) and 2014 (33.9) and another between 2015 (37.7) and 2020 (30.9) (Figure 1, panel a). There was a trend of lower AFC when the farms were in the midlands or were dairy-specialized (Figure 1, panel b).

3.2.2 | Calving to conception interval (days)

Conception method, genetic background, year of calving and herd, nested into farm system and altitude, significantly affected the CCI (in days, back-transformed from the log scale) at their different levels ($p < .001$). Thus, NM had a significantly ($p < .01$) lower CCI (110) than AI (121); however, comparisons against ET (121) were not statistically significant. Additionally, the CCI was significantly different ($p < .0001$) when comparing DSpB (140) against GYR × HOL (113) and DSpB × BI (103); however, there was not a significant difference ($p = .1912$) between GYR × HOL and DSpB × BI (Table 4).

TABLE 2 Adjusted effect of the conception method of the cows on productive parameters of females raised under field conditions in dairy farms of Costa Rica, assessed by GLMM procedures. Only the statistically significant independent variables are presented.

Dependent variable	Effect	DF	*F* value	Pr > F
Age at first calving (AFC)	Conception method	2	32.20	<.0001
	Herd (farm system*altitude)	26	28.32	<.0001
	Genetic background	2	18.93	<.0001
	Year of birth	10	36.84	<.0001
Calving to conception Interval (CCI)	Conception method	2	5.30	<.01
	Herd (farm system* altitude)	25	17.80	<.0001
	Genetic background	2	49.21	<.0001
	Year of calving	9	21.17	<.0001
Lactation milk yield (LMY)	Conception method	2	12.44	<.0001
	Herd (farm system* altitude)	22	162.46	<.0001
	Genetic background	2	7.02	<.001
	Year of calving	8	39.50	<.0001
	Days in milk	1	6828.57	<.0001
	Lactation number	7	73.77	<.0001

TABLE 3 Pairwise comparison of age at first calving (AFC) in months between least square means of conception method and genetic background factors of females raised under field conditions in dairy farms of Costa Rica.

Independent variable	Categories under comparison		Least square means		Difference LSM1–LSM2	SE	*t*-value	Adj. *p*
Conception method	ET	AI	33.1	35.2	−2.1	0.3	−6.1	<.0001
	ET	NM	33.1	36.4	−3.3	0.4	−8	<.0001
	AI	NM	35.2	36.4	−1.2	0.3	−4	<.0001
Genetic background	GYR×HOL	DSpB	36.4	34	2.5	0.5	5.4	<.0001
	GYR×HOL	DSpB×BI	36.4	34.5	1.9	0.4	5.5	<.0001
	DSpB	DSpB×BI	34	34.5	−0.5	0.4	−1.3	.3829

Abbreviations; Adj. *p*, adjusted *p* value; AI, Artificial insemination; DSpB, pure dairy breed and their crosses; DSpB×BI, dairy breeds×*Bos indicus*; ET, embryo transfer; GYR×HOL, Gyr×Holstein; NM, natural mating; SE, standard error.

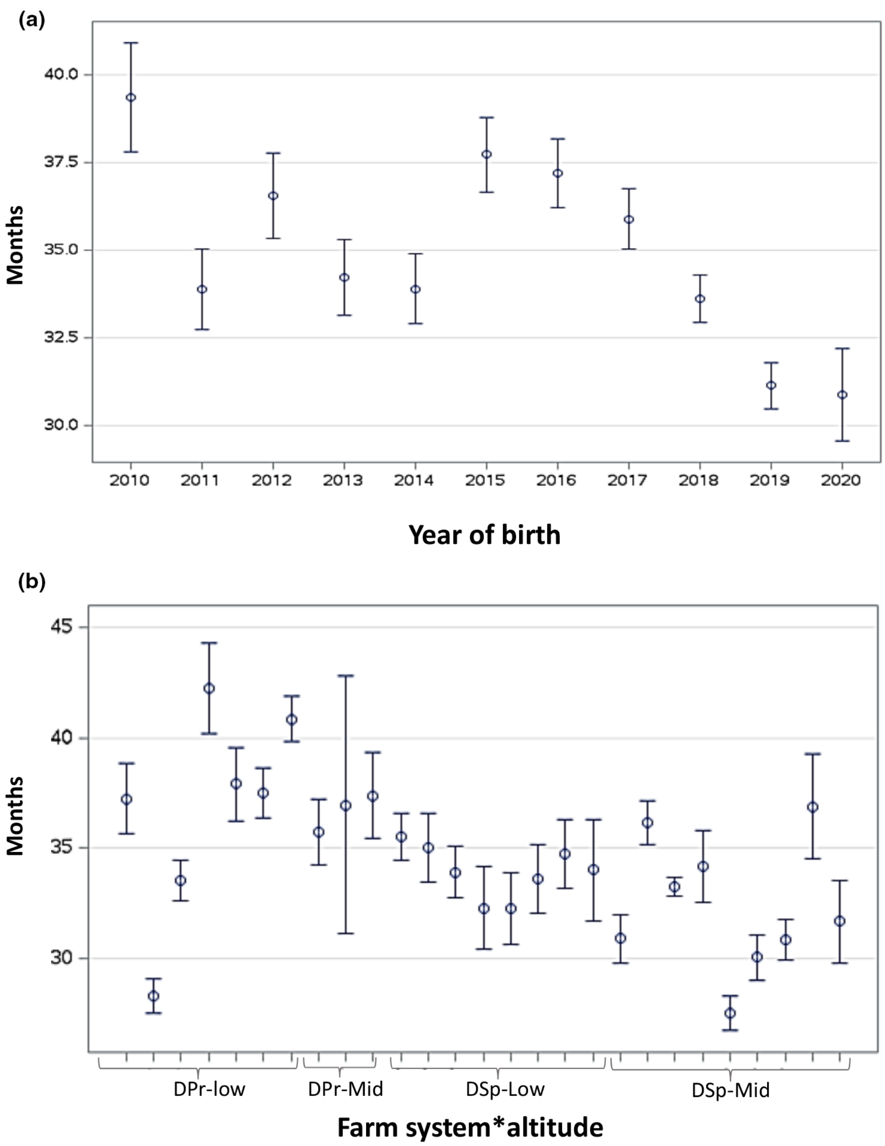

FIGURE 1 Age at first calving (months) least square means estimates with a 95% confidence interval for females raised under field conditions in dairy farms in Costa Rica. (a) Cow's year of birth; (b) Herd: Farm system (Dual purpose: DPr or dairy specialized: DSp) by altitude (lowlands: Low or midlands: Mid).

Likewise, there was a tendency for lower CCI as the years went by ($p<.0001$), with extreme values in 2013 (156) and 2022 (70) (Figure 2, panel a). Besides, a tendency for higher CCI in dual-purpose farms (130) compared to dairy specialized (106) (Figure 2; panel b).

3.2.3 | Lactation milk yield (kilograms)

Conception method, genetic background, year of calving, lactation number, days in milk and herd, nested into farm system and altitude, significantly affected the lactation milk yield least square means at their different levels ($p < .001$). The higher milk yield ($p < .0001$) was observed in ET (4140), compared to AI (3706) and NM (3595); however, there was no difference between AI and NM. The lower production was observed in the genetic background DSpB × BI (3661), which was different from DSpB (3849, $p = .005$) and GYR × HOL (3929, $p = .003$) (Table 5). No difference was assessed between DSpB and GYR × HOL. Cows with more than two parities showed significantly ($p < .0001$) higher milk yield (Figure 3; panel a). A tendency of increased milk production was determined as the year went by ($p < .0001$), with the lowest value in 2013 (3115) and the highest in 2021 (4585) (Figure 3; panel b). Also, a tendency of lower LMY was assessed in dual-purpose farms compared to dairy specialized, and the lowlands with respect to midlands (Figure 3; panel c).

4 | DISCUSSION

Age at first calving was affected by the method of conception, herd nested into farm system and altitude, genetic background and year of birth. The offspring born by ET had lower AFC than AI and NM. This effect could suggest that irrespectively of the breed used, location or type of farm, the calves born by ET would reach their puberty and deliver a calve earlier than AI and NM. In contrast, Bonilla et al. (2014) found that Holstein replacement heifers obtained by ET tended to have more birth weight but the age at first calving did not differ compared to those obtained by AI. Consequently, AFC was lower when the farms were in the midlands or in the group of dairy specialized. Similarly, Takele (2014) found in dairy and dual-purpose heifers located in the midlands had lower AFC compared to the lowlands but argued, that the main differences, were confounded by appropriate management practices. In contrast, Herold et al. (2011) found in the conditions of Vietnam, that the AFC was lower for those farms located in the lowlands with less technification than those in the highlands using specialized cattle. They claimed that cattle raised in the conditions of the uplands are not properly adapted. Altitude as a variable, is a good feature when used in the context of the geographical space that is being analysed. For example, in Costa Rica, the reason for achieving lower AFC in the midlands may be that the cattle are more comfortable and have better conditions for specialized cattle to express their genetic potential (Solano et al., 2006). Concerning the genetic background, AFC was lower for GYR × HOL crosses compared to DSpB and DSpB × BI. In Girolando cattle, Canaza-Cayo et al. (2018) demonstrated that lesser AFC was achieved in the genetic groups that had most the specialized breeds in their genetic composition. This effect was also documented for Holstein × Zebu cattle (Guimarães et al., 2002). Galina and Arthur (1989) in an old but comprehensive review considering publications detailing age at first calving from different breeds in different countries within the tropics, found 36.5–39.2 months with a 95% confidence interval. In our study, we found similar AFC regardless of the conception method from which the female was born.

Calving to conception interval was affected by the breeding method, farm, genetic background and year of calving. The NM-delivered calves were found to have lower CCI than AI and ET. Lafontaine et al. (2023), found that the daughter fertility index (DF) displayed in MOET, IVF and AI daughters, were lower than the scores of their parents, but the lesser scores registered for AI. They claim that it is possible that as documented in mice, offspring derived from IVF could experience low fertility (Calle et al., 2012). There is still the need to investigate in future studies the effect of conception over reproduction and production in a long-term study (Hansen, 2020). No major differences were found in farms located at different altitudes; however, it seems that dairy-specialized farms display better CCI than those farmers raising cattle in dual-purpose systems. Roche Loaiza et al. (2019) found farms in three different ecozones located at altitudes below 1200 m.a.s.l. such as tropical dry forests, very humid premontane and very humid tropical forests, registered higher CCI compared to those located at higher altitudes. These environmental variables could potentially affect the animals living under these conditions and expose them to heat stress, thus affecting follicular and oocyte development and altering the animal's fertility (Dikmen & Hansen, 2009; West et al., 2003). The genetic background DSpB had a lower CCI than the other two. Temesgen et al. (2022), in crossbreed dairy cattle, found that CCI depends directly on the managemental practices and earlier services after calving mentioning, that having a higher fraction of dairy breeds could generate a confounding effect. The present study showed a tendency of reducing the CCI over the years in Costa Rica. Accurate record keeping in the tropics is a major factor for farms to reduce CCI over time (Banda et al., 2012).

The lactation milk yield (LMY, kg) was found to be affected by the conception method, farm, genetic background, year of calving, lactation number and days in milk. The ET-derived dams had higher milk yield compared to AI and NM. Lafontaine et al. (2023), speculate that a possible bias, is happening in terms of production, animals conceived by assisted reproductive techniques, are associated with a higher genetic potential, and the economic value expected from these animals leads the producers to offer better environmental conditions. Also, a trend of lower LMY was assessed in dual-purpose farms compared to dairy specialized, and the lowlands with respect to midlands. This effect could be explained as the altitude and the specialization in Costa Rica seems to go hand in hand (Solano et al., 2006). The higher milk yields were observed in those with the genetic background GYR × HOL and DSpB, with differences present with the group DSpB × BI, which could be explained as these animals are better adapted to the prevailing conditions. Girolando crossbreds have demonstrated that in the tropics, their potential for productiveness was better compared with other breeds or hybrids (Canaza-Cayo et al., 2018). A tendency for increased milk yield over the years was found in this study. It has been well documented that record keeping and data management in dairy farms are major determinants of being efficient and productive (Britt et al., 2018; Galukande et al., 2013).

Even though these parameters are affected by other factors not considered by this study, it is an approach trying to establish the advantages of using ET over AI and NM raised under tropical

TABLE 4 Pairwise comparison of calving to conception interval (CCI) in log days between least square means of conception method and genetic background factors of females raised under field conditions in dairy farms of Costa Rica.

Independent variable	Categories under comparison		Least square means		Difference LSM1–LSM2	SE	*t*-value	Adj. *p*
Conception method	ET	AI	4.8	4.8	0.0041	0.04	0.1	.993
	ET	NM	4.8	4.7	0.09	0.04	2.1	.089
	AI	NM	4.8	4.7	0.09	0.03	3.2	.004
Genetic background	GYR×HOL	DSpB	4.7	4.9	−0.2	0.04	−5.7	<.0001
	GYR×HOL	DSpB×BI	4.7	4.6	0.07	0.04	1.8	.1583
	DSpB	DSpB×BI	4.9	4.6	0.3	0.03	9.9	<.0001

Abbreviations: Adj. *p*, adjusted *p* value; AI, Artificial insemination; DSpB, pure dairy breed and their crosses; DSpB×BI, dairy breeds×*Bos indicus*; ET, embryo transfer; GYR×HOL, Gyr×Holstein; NM, natural mating; SE, standard error.

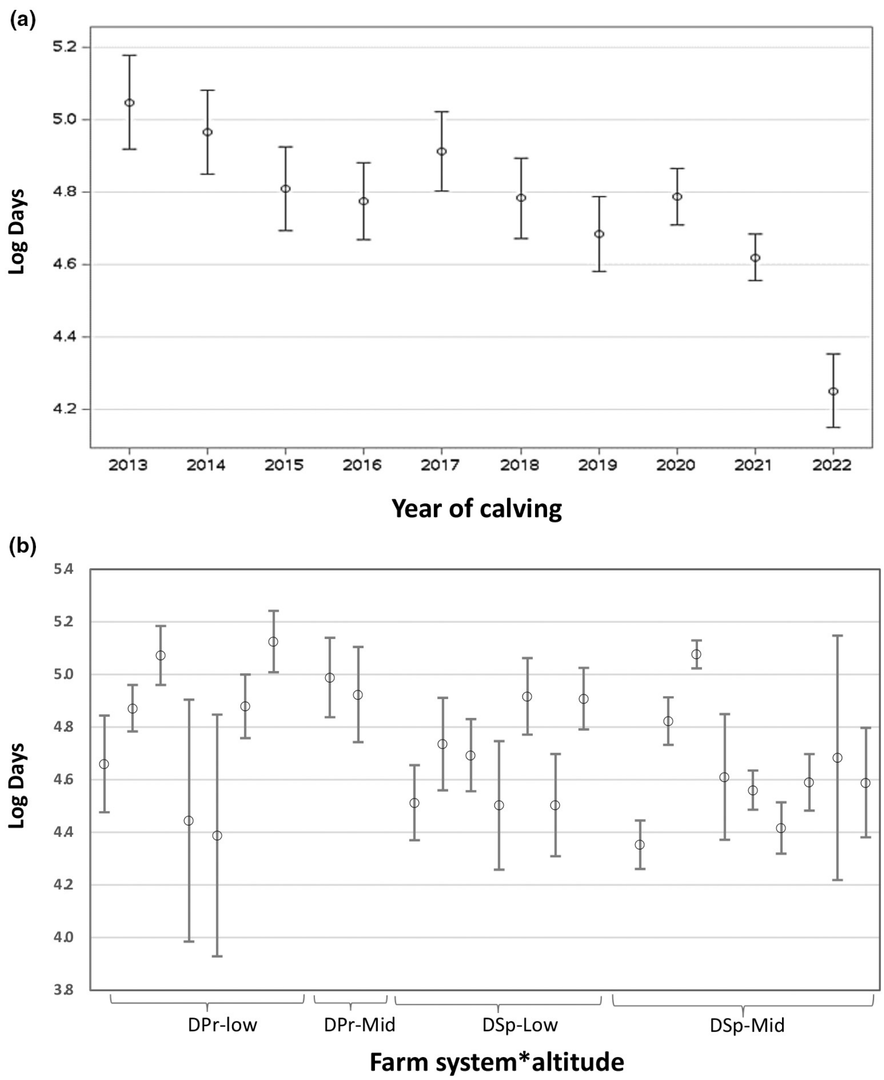

FIGURE 2 Calving to conception interval (log days) least square means estimates with a 95% confidence interval for females raised under field conditions in dairy farms of Costa Rica. (a) Year of calving; (b) Herd: Farm system (Dual purpose: DPr or dairy specialized: DSp) by altitude (lowlands: Low or midlands: Mid).

conditions. In our opinion, ET-delivered cattle must achieve greater efficiency to repay the investment and produce profits for the farm. One approach, by using ET in milk production in the tropics, could be the use of F1 hybrids of dairy-specialized cattle and zebu breeds (Madalena, 2005). This approach could benefit the producers in a short period but, had the disadvantage that optimal conditions, must be offered for cattle to display their productive capabilities.

This study offers some insight into the productive performance of cows born by ET, AI and NM in Costa Rican dairy and dual-purpose systems, but many questions remain to be answered, especially about the overall performance in their productive life span, as well as the improvement through the lifetime progeny. Future studies analysing several lactations and generations of offspring of animals born from these three methods of breeding, including more

TABLE 5 Pairwise comparison of lactation milk yield (LMY) in kilograms between least square means of conception method and genetic background factors of females raised under field conditions in dairy farms of Costa Rica.

Independent variable	Categories under comparison		Least square means		Difference LSM1-LSM2	SE	*t*-value	Adj. *p*
Conception method	ET	AI	4140	3706	434	99.3	4.4	<.0001
	ET	NM	4140	3595	545	109.9	5	<.0001
	AI	NM	3706	3595	111	61.1	1.8	.1549
Genetic background	GYR×HOL	DSpB	3929	3849	79	98.3	0.8	.6792
	GYR×HOL	DSpB×BI	3929	3661	269	88.9	3	.0079
	DSpB	DSpB×BI	3849	3661	189	66.7	2.8	.013

Abbreviations: Adj. *p*, adjusted *p* value; AI, Artificial insemination; DSpB, pure dairy breed and their crosses; DSpB×BI, dairy breeds×*Bos indicus*; ET, embryo transfer; GYR×HOL, Gyr×Holstein; NM, natural mating; SE, standard error.

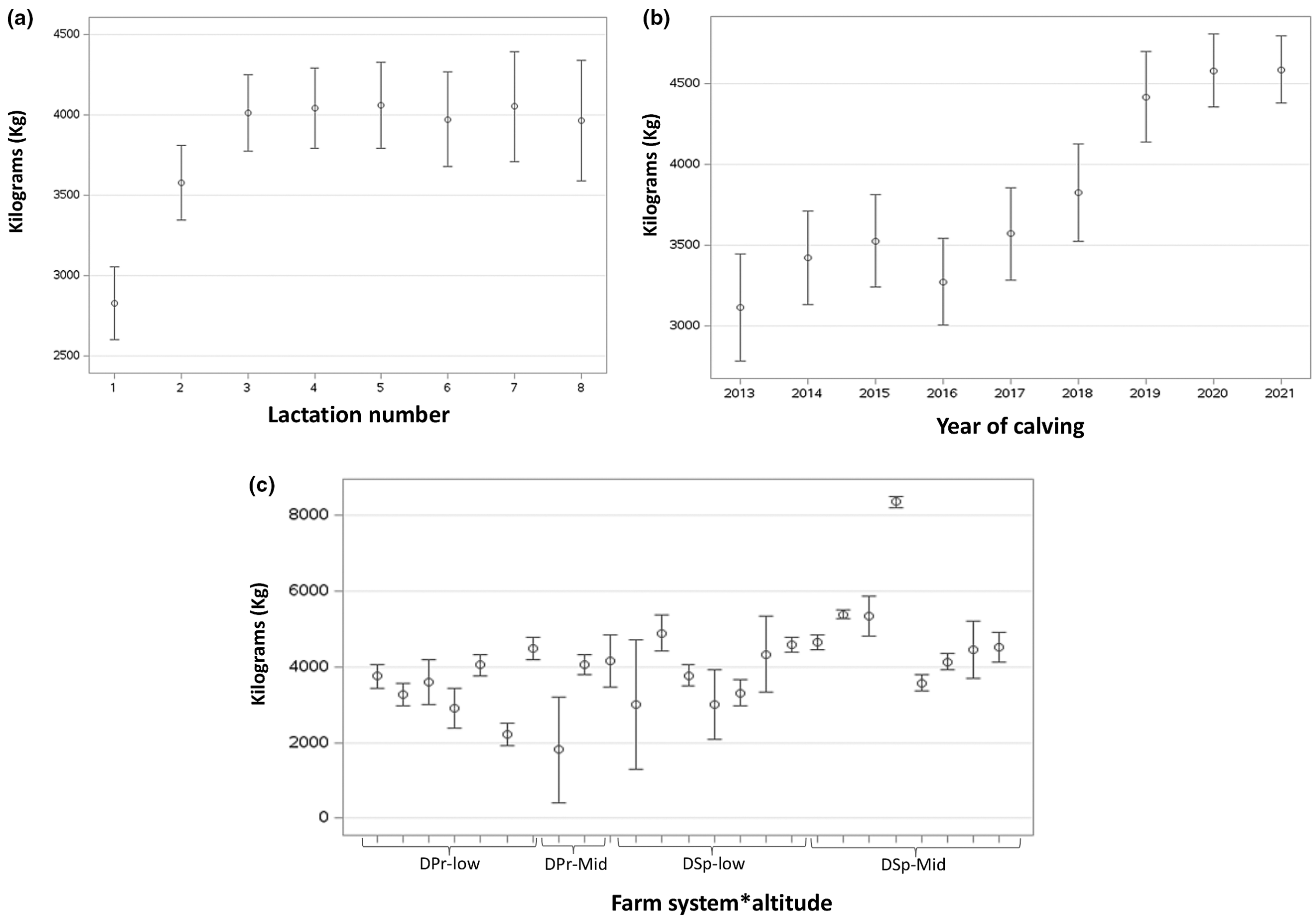

FIGURE 3 Lactation milk yield (kg) least square estimates with a 95% confidence interval for females raised under field conditions in dairy farms of Costa Rica. (a) Lactation number; (b) Year of calving; (c) Herd: Farm system (Dual purpose: DPr or dairy specialized: DSp) by altitude (lowlands: Low or midlands: Mid).

management variables and interactions will be necessary. In conclusion, the conception method affected the calf's future reproduction and production during puberty, postpartum and lactation. However, the effects on management decisions will require a rigorous economical study to discern whether a more expensive approach to breed cattle such as ET would be a returnable proposition.

AUTHOR CONTRIBUTIONS

J.F. Martínez: Conceptualization, Writing—review and editing, Funding. C.S. Galina: Conceptualization, Writing—review and editing. J. Rojas: Database preparation, Formal analysis, Writing—review and editing. B. Vargas: Database preparation, Formal analysis, Writing—review and editing. J.J. Romero-Zúñiga: Conceptualization, Database

preparation, Formal analysis, Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

None of the authors have any conflict of interest to declare.

DATA AVAILABILITY STATEMENT

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

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