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Effect of Genetic and Non-Genetic Factors on Productive and Reproductive Performances of Dairy Cattle at TALIRI–Tanga

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Authors' contributions

This work was carried out in collaboration among all authors. Author FC designed the study, collected data, performed the statistical analysis, and wrote the first draft of the manuscript. Authors SM and AN guided author a in designing the study, performed the statistical analysis, and read and approved the final manuscript. Author ZN participated on data collection read and corrected the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

In Tanzania, milk production demands the use of crossbreeding systems that include breeds adapted to harsh conditions with moderate productivity compared to pure exotic dairy breeds. In the present study, the data from 1013 cross-bred cows raised at TALIRI – Tanga, Tanzania grouped in

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three genotypes, pure Boran (BB), Boran x Friesian (BF), and Boran x Jersey (BJ) were used to determine the effect of genotype, season of calving and parity on age at first calving (AFC), calving interval (CI), 305 days milk yield (MY) and lactation length (LL). The General Linear Models (GLM) procedure of SAS software 2020 was used to estimate the least square means of the traits while the MANOVA procedure in SAS 2020 was used to establish partial correlation coefficients between traits. The VARCOMP of RStudio-2023 was used to estimate variance components to calculate the heritability of the traits. The results revealed that at ($P<0.05$), BJ heifers had significantly shorter AFC, BF had higher MY, and BB with longer CI compared to other genotypes. The dry season calving resulted in significantly shorter LL while the fourth parity had higher MY compared to the early lactations. Cows in the fourth parity had significantly shorter CI for about 41 fewer days than those in the first parity. Heritability estimated for AFC, LL, and CI were 0.19,0.28,0.32 respectively. While phenotypic correlations (Rp) between AFC and MY were negative and weak and that between LL versus MY was moderately positive. From these findings, it is concluded that crossing of Boran cattle with Jersey or Friesian cattle can significantly improve AFC and milk yield. However, the low to moderate heritability, for reproductive and productive traits under this study, improvement of crossbred cows in hot and humid areas like Tanga should be accompanied by the improvement of the animal husbandry practices to achieve the desired output.

Keywords: Age at first calving; calving interval; heritability; lactation length; milk yield.

1. INTRODUCTION

Tanzania has an annual human population growth of 1.3% [1] and requires more than 8 billion liters of milk annually compared to the current average milk yield of 3.6 billion liters per year [2]. Per-capital consumption of milk in the country is below the WHO recommendation of 200 liters per person per year [3]. This is partly because about 70 percent of the total milk produced in the country is from indigenous cattle breeds [4] and the remaining 30% comes from improved crossbred who contribute less than four percent of the country's cattle population [1]. However, the indigenous cattle breeds predominantly comprised of strains of the Tanzania short horn zebu have low genetic potential for milk yield which is not enough to meet the demand in the country. Some efforts have been made to address the challenge including the introduction of exotic dairy breeds, such as Holstein-Friesian, Jersey, and Ayrshire to be crossed with indigenous cattle. Such efforts have led to the establishment of government farms such as the livestock multiplication units (LMUs), and Tanzania Livestock Research Institute (TALIRI) farms in different parts of the country. These farms are strategically located in different ago-ecological zones with specific breeding goals according to such environments. In those centers, F1 crossbred heifers of exotic dairy/beef bulls and indigenous female cattle are produced and distributed to smallholder farmers and private commercial farms.

TALIRI Tanga is one of the farms in Tanzania where crossbreeding programs have been carried out to produce crossbred dairy animals that are adapted and suitable for milk yield in coastal areas which associated with hot and humid atmospheres. Evaluation of the performance of these cross-bred animals in terms of milk yield and reproductive performance traits is very important to understand the achievements due to these interventions.

In dairy cattle production AFC, CI, and LL are the main indicators of productive and reproductive efficiency, herd fertility, and breeding heifer replacement rates on the farm. AFC reflects the time in which a particular cow calves for the first time, while CI refers to the period between two consecutive calvings the LL is a period during which a cow lactates in a single lactation. Early AFC can result in two additional calves compared to late AFC in the lifespan of the cows [5] and [6]. A shorter LL supports regular CI, while a longer LL minimizes the costs of maintaining cows on non-milking periods with optimal reproductive performance [7]. Despite the low to moderate heritability of these traits, effective animal husbandry management practices, including genotype, season of calving, and parity are essential for improving them [8] and [9]. It is also known that the total milk production adjusted in a 305-day serves as a valuable metric for assessing the performance of dairy cows as it aids farmers and breeders in achieving dairy breeding goals through selection due to its moderate to high heritability [10].

The objective of the current study is to assess the impact of both genetic factors (specifically breed/genotype) and non-genetic factors (such as season of calving and parity) on AFC, CI, LL, and milk production. Additionally, the study aims to estimate the heritability and phenotypic correlations of these parameters providing valuable insights for effective dairy cattle breeding practices.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out at the Tanzania Livestock Research Institute (TALIRI)- Tanga center which has the responsibility of producing dairy cattle adaptable in hot and humid coastal climates. The center is in Tanga city, located between 40 21' – 60 24' S, 360 11' -382 26' E with average ambient temperature ranging from 15 ^{0}C to 35 ^{0}C and is characterized by a hot - humid climate receiving an average annual rainfall between 500mm to 1500mm/year [11]. This zone has two distinct rain seasons which are a high rain season from March to May and a low rain season spreads from November to December [12].

2.2 Animal Management

Animals under this study are those kept at the TALIRI – Tanga center raised under a semi-intensive system, allowed to graze from 7:30 am to 1:00 pm. They are supplemented by 1.5kg concentrates during milking and thereafter continue to graze from 16:00 to 18:00 hrs. Breeding is done throughout the year using artificial insemination in which Boran cows/heifers are inseminated using Boran, Friesian, or Jersey semen to get F1 generation of three genotypes BB, BF and BJ which are studied under the present study. Routine disease control including vaccinations against foot and mouth disease (FMD), east coast fever (ECF), and other disease control measures are taken as happens.

2.3 Data Collection and Analysis

Records on age at first calving (AFC), 305-milk yields (MY), Lactation length (LL), and Calving interval (CI) were collected from 1,013 F1 and purebred Boran dams were used. The animals were categorized into three genotypes BB, BF, and BJ, and the season of calving was categorized into wet (December to June) and dry season (July to November). The records on MY, LL, and CI were taken in four consecutive parities one to four. The effect of genotype, calving season, and parity on AFC, MY, LL, and CI were analyzed using the General Linear Model (GLM) of the Statistical Analysis System (SAS, 2020, version 9.3) [13] using the model below.

2.4 Model

$$Y_{ijk} = \mu + G_i + S_j + P_k + GS_{ij} + GP_{ik} + E_{ijk}$$

Where**: -**

Y_{ijk} = Observations of the dependent variable/studied traits,
μ = Overall mean,
Gi = Effect ith genotype,
S_j = Effect of jth calving season**,**
Y_k = Effect of the kth parity,
GS_{ij} = Effect due to interaction of genotype by calving season;
GP_{ik} = Effect due to interaction of genotype by parity;
E_{ijk} = Random error term.

2.5 Partial Phenotypic Correlation Coefficients

The General Linear Models (GLM) procedure of SAS software (SAS 2020) with MANOVA option was used to analyze and establish partial correlation coefficients among the traits studied. Significance was declared at P ≤ 0.05.

2.6 Heritability Estimates

Narrow sense heritability was estimated based on the sire variance component using data on offspring, where by VARCOMP procedure of R-Studio-2023 was used to obtain estimates of variance components. The model used is similar to the one described above with the inclusion of the effect of the breed as random effects. Then, a narrow sense heritability estimate based on variance components was then calculated as δ^2_s/ δ^2_p where δ^2_s sire the variance component and δ^2_p is phenotypic variance.

3. RESULTS

3.1 Effect of Genetic and Non-genetic Factors on Reproductive and Productive Performance

Table 1 shows the effect of genotype and non-genetic factors (season and parity) on AFC, CI, MY, and LL. It was revealed that BJ attained AFC significantly earlier compared to BB and BF.

The influence of genotype on CI was significant as the BB genotype had longer CI than the BF and BJ genotypes. However, the genotype did not affect the LL of the cows. On the other hand, the genotype significantly influenced MY whereby the BF genotype exhibits higher MY than both BB and BJ genotypes.

The season of calving significantly influenced LL, whereby cows calved in the wet season had significantly shorter LL compared to those calved during the dry season. Likewise, the parity of the cows significantly affected MY and CI but not AFC and LL (Table 1). Cows in their fourth lactation had 18% more MY than those in their first lactation and also exhibited significantly shorter CI of about 41 days less than those in the first parity.

There was a significant interaction effect between the season of calving and genotype on reproductive and productive parameters shown in Table 2. Season of calving by genotype interaction effect was only significant for Calving interval but not on Milk yield and Lactation length. This indicates that during the dry season, both genotypes exhibited no significant difference, whereas during the wet season, they displayed distinguishable variations.

On the other hand, an interaction effect between genotype and parity was observed for MY but no significant on both LL and CI as shown in Table 3.

3.2 Phenotypic Correlation of Reproductive and Productive Traits

Table 4. Shows that phenotypic correlation was significant only between MY and LL despite being weak 0.25. On the other hand, there is a weak negative phenotypic correlation between AFC and MY 0f -0.2.

Table 1. The effect of genetic and non-genetic factors on productive and reproductive traits

Source of Variation		AFC (Months)	CI (Days)	MY (Liters)	LL (Days)
Genotype	Boran X Boran	36.20±0.52^{A}	379.40±9.79^{A}	552.82±28.47^{B}	266.54±6.08
	Boran X Friesian	37.44±0.36^{A}	327.45±6.38^{B}	734.97±30.01^{A}	263.38±6.37
	Boran X Jersey	32.89±0.55^{B}	339.53±10.28^{B}	588.91±32.15^{B}	248.58±6.87
season of calving	Dry		340.97±7.99	620.53±26.66	249.48±5.69^{B}
	Wet		356.61±6.68	630.60±21.44	269.52±4.55^{A}
Parity	First	35.96±0.53	364.51±9.78^{B}	575.50±26.82^{B}	272.66±5.69
	Second	35.11±0.56	354.82±10.42^{B}	589.62±30.70^{B}	256.43±6.53
	Third	35.99±0.57	352.21±10.98^{AB}	636.94±35.76^{AB}	250.78±7.64
	Fourth	35.03±0.54	323.63±9.67^{A}	700.20±39.19^{A}	258.12±8.37

Note: AFC = age at first calving; MY = milk yield, LL = Lactation length, CI = Calving interval.
Means with different superscripts in the same column within the factor are significantly different (P≤0.05).

Table 2. Interaction effect of season of calving by genotype on a calving interval, milk yield, and lactation length

SEASON	GENOTYPE	PARAMETER		
		CI (DAYS)	MY (LITERS)	LL (DAYS)
DRY	BB	358.64±14.24^{B}	578.54±41.22^{A}	261.79±8.81^{AB}
	BF	344.17±9.61^{B}	722.15±38.99^{B}	252.41±8.33^{AB}
	BJ	320.11±16.67^{BC}	560.92±56.57^{A}	234.23±12.09^{A}
WET	BB	400.17±13.46^{A}	527.09±36.74^{A}	271.29±7.85^{B}
	BF	310.72±8.51^{C}	747.80±43.43^{B}	274.34±9.13^{B}
	BJ	358.94±12.10^{B}	616.89±29.51^{A}	262.93±6.29^{B}
P-VALUE		0.0007	0.388	0.5304

Note: CI = Calving interval, MY = milk yield, LL = Lactation length, BB = Boran pure, BF = Boran + Friesian crosses, and BJ = Boran + Jersey. Means with different superscripts in the same column within the factor are significantly different (P<0.05).

Table 3. Interaction effect of parity by genotype on calving interval, milk yield, and lactation length

PARITY	GENOTYPE	PARAMETERS		
		CI (DAYS)	MY (LITERS)	LL (DAYS)
FIRST	BB	396.18±19.41^{CB}	366.67±48.65^{C}	273.54±10.40^{A}
	BF	354.62±11.66^{B}	754.74±38.91^{A}	276.50±8.29^{B}
	BJ	342.72±18.66^{AC}	605.11±50.93^{AB}	267.94±10.70^{A}
SECOND	BB	388.36±19.64^{CB}	603.29±53.43^{B}	265.52±11.42^{A}
	BF	336.02±13.72^{B}	633.83±54.35^{A}	252.51±11.25^{A}
	BJ	340.07±20.13^{AC}	531.73±51.95^{B}	251.26±11.26^{A}
THIRD	BB	361.50±21.51^{B}	510.85±74.32^{CB}	237.31±15.88^{A}
	BF	317.22±12.83^{A}	785.78±58.89^{A}	272.74±12.58^{B}
	BJ	377.92±21.31^{B}	614.19±50.12^{AB}	242.28±10.71^{A}
FOURTH	BB	371.58±17.79^{B}	730.46±46.06^{A}	289.76±9.84^{B}
	BF	301.92±12.67^{A}	765.54±82.44^{AB}	251.76±17.62^{A}
	BJ	297.39±19.08^{AC}	604.59±70.18^{AB}	232.85±14.99^{A}
P-VALUE		0.2688	0.001	0.0754

Note: CI = Calving interval, MY = milk yield, LL = Lactation length BB = Boran pure, BF = Boran + Friesian crosses, and BJ = Boran + Jersey. Mean with different superscripts in the same column within the factor are significantly different (P<0.05).

Table 4. Correlation coefficients of reproductive and productive parameters

PARAMETER	AFC	CI	MY	LL
AFC	-	0.02	-0.2**	-0.02
CI		-	0.01	0.06
MY			-	0.25***
LL				-

*AFC = age at first calving, MY = milk yield, LL = lactation length, CI = calving interval, significantly level P≤0.05*** and P≤0.01**.*

3.3 Heritability of Reproductive and Productive Traits

Table 5 shows the heritability estimates for age at first calving (AFC), milk yield (MY), lactation length (LL), and calving interval (CI). Narrow sense heritability estimates for AFC, MY, LL, and CI based on the sire variance component were 0.19, 5.15 x 10^{-9}, 0.28, and 0.32 respectively.

Table 5. Estimated variance components and heritability

Studied Trait	Heritability H^2
AGE AT FIRST CALVING (AFC)	0.19
CALVING INTERVAL (CI)	0.32
MILK YIELD (MY)	5.15X10^{-9}
LACTATION LENGTH (LL)	0.28

Where by: -
h^s = heritability,
$δ^2s$ = sire breed genetic variance,
$δ^2p$ = phenotypic variance Σ of all variance components,
AFC = age at first calving, MY = milk yield,
LL = lactation length and CI = calving interval.

4. DISCUSSION

4.1 Effect of Genotype on Reproductive and Productive Performance

In the present study, the F1 BJ heifers attained AFC almost 4 months before the BF and BB heifers similar to what was found in the following studies [14-20]. The AFC exhibits significant variation among individual animals within a population due to factors such as nutrition, health, and management practices, the discrepancies in AFC observed in this study are primarily influenced by genetic differences, particularly between the Jersey and Friesian breeds. This is also because both genotypes in this study shared Boran blood and were subjected to uniform management practices. Similarly, the difference attributed to the Jersey cattle purposefully selected for early maturity [21], in contrast to other dairy breeds such as Friesian and Ayrshire. Hence, the crosses of Boran and Jersey (BJ) in this study demonstrate a shorter age at first calving (AFC). On the other hand, Jersey cattle are known to adapt in hot-humid tropical climates as illustrated in the study by [22] due to their excellent feed conversion efficiency which makes them adaptable to various climates and management systems. This situation enables jersey cattle to thrive in a wide range of environments contributing to their ability to mature early in such environments. Selection for early calving age aims to have an animal with a long productive period with many lactations in a lifetime [6]. Although there are disadvantages of early AFC related to increased risk of calving difficult, reproductive challenges and may impair the longevity and milk yield mainly in the first lactation it is a desired parameter in the breeding aspect.

The longer CI of BJ and BF compared to BB declared under the present study is mainly caused by the lower reproductive and fertility performance of BB compared to the very specialized dairy breeds Jersey and Friesian cattle [19]. In addition, Boran cattle with an adaptive advantage to harsh climates and grazing conditions make them prioritize body resources for resilience and survival in such harsh environments while compromising their reproductive performance, leading to some reproductive failures like poor conception rate that result in longer calving intervals as shown here. On the other hand, Friesian and Jersey breeds are demonstrated to have optimal genes specific for improving fertility and reproductive performance as shown in the studies by [23] and [24] the traits also acquired in their crosses lead to good reproductive performances like shorter calving intervals compared to their purebred Boran as shown in the present study. The insignificant difference in CI between Jersey and Friesian cross is because, both sire breeds are dairy with closely related metabolic rates as concluded in some studies like [25], [26] and [19].

The observed interaction effect between season of calving and genotype in this study, in which BB cattle have a longer calving interval (CI) than their crosses during the wet season, could be attributed to the BB genotype's adaptation advantage during the dry season [16]. Boran cattle are typically well suited to the hurdles of the dry season, such as a shortage of food and water, so that their reproductive performance is unaffected when compared to their crosses [19]. Nonetheless, during the dry period, environmental stress may evenly affect all genotypes in the current study, resulting in equal calving periods.

However, because of the increased quantity and quality of feed, the wet season climate is suited for crossbred cattle. Because they utilize the available best nutrition sources more effectively than purebred animals in CI. Furthermore, heterosis, or hybrid vigor, is seen in crossbred cattle which contribute to superior CI performance. This suggests that genetic heterosis is the cause of the interaction effect found in present study.

The BB genotype in the fourth lactation exhibited significantly higher MY than other genotypes in subsequent lactations. The situation is attributed due to fully developed and efficient functioning of mammary glands in cows at the fourth parity, [25] and [26]. On the other hand, [10] reported increased in milk production with advancing parity due to an increased body condition loss which in candid with the present findings. It was also discovered that by the fourth lactation, cows become more familiar with pre-milking procedures, aiding milk letdown as opposed to cows in early lactations who are unfamiliar with such milking procedures, as described in [27]. The findings of this study are consistent with those published by [28] and [29], which support an increase in milk yield with greater parity due to a combination of larger body weight and full development of secretory tissues [30].

4.2 Effect of Non-Genetic Factors on Reproductive and Productive Traits

Cows calving during a wet season had comparatively extended lactation lengths (LL), as demonstrated by the current study and prior studies [31], [32], and [28]. This phenomenon arises because pasture growth is significantly higher during the rainy season, resulting in reduced fiber content, which leads to increased voluntary feed intake by animals and thus improved milk production [33]. Biologically, during the wet season, milk-secreting tissues in the mammary glands proliferate at a faster pace, resulting in persistent milk secretion throughout the lactation period and extending lactation lengths [34-36]. In contrast, during the wet season, the carotene content in pasture is higher, which is associated with climatic conditions influencing the growth and maturity stages of pastures, resulting in higher blood carotene concentration in milking cattle, contributing to prolonged milk synthesis in their mammary gland, as explained in the study by [37].

Because the mammary gland secretion tissues in the fourth parity are fully matured [38] and more efficient in the synthesis, storage [39], and secretion of milk [40], which both favors milk productivity, cows in their fourth lactation showed significantly higher MY than in their earlier lactations, as illustrated in the current study. The results of this study are in line with those of [41], who hypothesizes that cows in their fourth lactation have optimal body condition scores, which raises their milk outputs compared to those in their first and second lactations. Additionally, [42]'s study found that cows in their fourth calving yield more milk every day. This conclusion is consistent with those of [43], [44], and [45], who observed lower milk yields following the fourth lactation as a result of a continual fall in body condition score.

4.3 Phenotypic Correlation of Reproductive and Productive Traits

A moderate positive correlation between lactation length (LL) and milk yield (MY) suggests that opting for a longer LL could moderately boost MY, thereby enhancing managerial practices such as feeding and significantly contributing to higher milk yield. These results align with previous research, such as that of [32]. However, other studies, such as [46] and [47], have noted a stronger positive correlation coefficient between LL and MY. Conversely, investigations like [48], [49], and [50] have observed a negative correlation between LL and MY, likely due to delayed breeding, which can result in increased annual milk yield. While achieving an optimal LL is crucial for cow health and welfare, studies by [51] and [52] recommend longer LLs. A lengthier LL provides adequate time for nutrient replenishment lost during lactation, supports reproductive recovery, and reduces metabolic stress associated with lactation.

In the current study, a low negative phenotypic correlation between age at first calving (AFC) and MY elucidates the antagonistic relationship between the two variables. This implies that selecting for a later AFC can improve the genetic potential for milk production in such animals [52]. There is ample evidence to explain the impact of early breeding on milk yield due to physical immaturity—animals are still growing—and negative nutritional status, as they may not have attained their full body size and weight, and their mammary glands may not be fully developed to support optimal milk yield [53]. These findings resonate with those reported for Girolando cattle in Brazil by [53].

4.4 Heritability of Reproductive and Productive Traits

The current study estimates a heritability of 0.19 for age at first calving (AFC), suggesting that genetic differences between individuals account for approximately 19% of the observed variation within the population, with the remaining 81% attributed to environmental factors and random effects. It also indicates that non-genetic factors, such as feeding, significantly influence an individual animal's AFC. Although the current estimates are higher than the 0.1 reported by [54], they are essentially equivalent to those reported by [55] and [56], but lower than those reported by [57], [58], and [59]. This discrepancy can be attributed to differences in computation formulas and population sizes.

The estimated heritability of 0.28 for calving interval (CI) in this study exceeds the optimal value of 0.1 reported in most tropical areas by [60] and [56]. The relatively small population size and the methodology employed for heritability estimation may contribute to the higher estimation in the present study. According to this research, selection alone is insufficient to achieve a suitable CI due to heritability being below 0.3; however, other managerial factors play a significant role in improving CI [61].

The study's estimated heritability of 0.32 for lactation length (LL) indicates that genetic factors modestly contribute to population variances, with environmental influences exerting a moderate influence. This suggests that selecting for LL can lead to a substantial improvement in the desired LL level. The study's findings are consistent with those reported by [61], [62], and [63], albeit lower than those reported by [56] and [64].

According to [65], the estimation of AFC, CI, and LL in tropical locations tends to be lower than in temperate areas due to environmental impacts. This implies that enhancing these qualities in tropical locations must be supplemented by better feeding and breeding management approaches.

5. CONCLUSION

This study illustrates that crossbreeding Boran cattle with exotic dairy breeds enhances performance in terms of age at first calving

(AFC), calving interval (CI), milk yield (MY), and lactation length (LL). The observed phenotypic correlations between those traits are weak to moderate, and the lower to moderate heritability of these traits is evident that selection and environment improvement should be taken together. In conclusion, to attain optimal performance in terms of AFC, CI, MY, and LL in the herd it is recommended that, the selection process for these traits should be coupled with improvements in animal husbandry practices.

ETHICAL APPROVAL

This work has received the Tanzania Livestock Research Institute's Livestock Research Ethical Clearance, offered with reference number TLRI/RCC.21/004 and dated November 1st, 2021.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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