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A Genetic Study on Lifetime Traits for Experimental Herds of Friesian Cattle

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Abstract: This study analyzed data from 5,518 lactations involving 1,749 Friesian cows raised in two experimental herds between 1992 and 2022. The study aim was to estimate the genetic parameters for longevity traits using a multiple-trait animal model, including age at first calving (AFC), lifetime (LT), lifetime days in milk (LTDIM), total lactations (TL) and lifetime milk yield (LTMY). On average, cows lived for 80.4 months, with 41% of their lifetime spent in milk production. They averaged 3.2 lactations, starting at 32.7 months. Heritability estimates for longevity traits were 0.09 to 0.12 suggesting limited direct selection potential. Strong genetic and phenotypic correlations (0.88–0.96) were observed between lifespan traits and total milk production. Similar correlations were found between partial lifetime milk yield traits for the first three lactations and total lifetime milk yield (0.44 to 0.97). Genetic correlations between lifetime traits were consistently high (0.88 to 0.99), mirroring phenotypic correlations. Notably, heritability estimates for partial performance traits increased with more lactations considered, and correlations between partial and lifetime traits were improved with additional data. These findings suggest the feasibility of early indirect selection for longevity through correlated responses in early performance traits, particularly early lactation milk production, to enhance overall lifetime productivity.

1 Introduction

Longevity, often described as the herd life, is a pivotal trait in dairy cattle breeding, holding significant economic importance (Jairath et al 1994). It can be seen as a multifaceted characteristic encompassing elements of production, health and fertility (El-Saied et al 2005). Longevity is influenced by a multitude of factors, both inherent e.g., conformation traits, lactation, health and reproductive performance (Ferris et al 2014); as well as external factors e.g., feeding costs, milk price, nutrition, policies, replacement heifers and management practices (Grandl et al 2019, De Vries and Marcondes 2020).

Longevity can be evaluated through lifetime traits or stayability traits. Lifetime traits gauge the age at which a cow is culled or measure the productive life length; whereas stayability traits assess whether a cow remains alive at specific points of time, such as a fixed number of months from birth or up to a certain parity. As Dekkers (1993) emphasized, most decisions regarding the disposal of cows are economically driven and often involve replacement to maximize profit. Disposal decisions can be voluntary, contingent upon a cow's production level, or involuntary, resulting from health issues (e.g., mastitis, lameness), poor reproductive performance, or death (El-Saied et al 2005).

The main objective of raising dairy cattle is maximizing profits over the cows' lifetimes (Van Arendonk et al 1989), with increasing milk yield being just one part of this overarching goal (Jairath et al 1994). However, enhancing genetic improvement in longevity is challenging for several reasons. Longevity is measured solely in females and often at a later age, requiring complete documentation that is only available post-mortem; besides, this trait typically exhibits low heritability (Seeker et al 2018). Alternative approaches to direct lifetime selection include utilizing continuous measurements gathered relatively early in a cow's life (Jairath et al 1994) or indirect selection based on information about survival-related traits genetically linked to herd longevity (El-Saied et al 2005). Including productive longevity traits in animal breeding programs may extend the generation period due to the delayed availability of longevity information after a cow's exclusion (Vollema and Groen 1998). Nonetheless, over the past two decades, these traits have found utility in genetic evaluations.

Female fertility ranks among the most economically vital characteristics in dairy cattle, where reduced fertility leads primarily to extending calving intervals (Olori et al 2002). Factors such as lifespan, first calving age, and productive lifespan play pivotal roles in shaping genetic improvement and the dairy cow's economic performance (Caetano et al 2017). Particularly important is the age at first calving, which influences fertility, parturition frequency, total milk production, and productive lifespan (Zavadilova and Štipkova 2013, Cooke et al 2013). For instance, in the case of Holstein Friesian cows, achieving an optimal age at first birth of ≤24 months is crucial to maximize production efficiency and minimize heifer rearing costs (Krpálková et al 2017). Notably, Sawa et al (2019) highlighted that commencing too late (>30 months) or too early (≤22 months) milk production significantly shortens the herd life of cows and raises rates of culling as a result of increasing susceptibility to udder diseases and decreasing milk production.

The objectives of this study encompass characterizing lifetime performance traits in Friesian cows within two experimental herds of the Animal Production Research Institute (APRI), assessing the phenotypic correlations between total and partial lifetime traits, particularly during the first three parties, as well as examining potential avenues for improving Friesian cattle.

2 Material and Methods

2.1 Data Collection and Preparation

A comprehensive dataset consisting of 5,518 lactation records was meticulously assembled from two experimental herds, namely Sakha and El-Karada, located in Khafr El Sheikh province, Egypt. These herds belong to Animal Production Research Institute (APRI) research stations under the purview of the Ministry of Agriculture and Land Reclamation. These records spanned the extensive period between 1992 and 2022. Before analysis, the data underwent rigorous screening, excluding cows exhibiting aberrant phenotypic trait values.

The analytical framework adopted in this study employed an animal model that effectively captured all documented relationships among the individuals under investigation. The composition of the analyzed dataset is concisely presented in **Table 1**. The distribution of the surviving animals across different parities is visually depicted in **Fig 1**.

Table 1. Summary of data set for total lifetime performance traits

Item	Numbers
Number of Animals in the Pedigree	2,236
Number of Animals with Records	1,749
Number of Lactation Records	5,518
Number of Sires with Progeny	171
Number of Dams with Progeny	1,165

2.2 Feeding System

The dietary regimen for the animals in the study was characterized by a combination of rice straw and meticulously formulated integrated concentrate mixtures. This concentrated mixture consisted of decorticated cottonseed cake (48%), wheat bran (21%), maize (20%), rice polish (5%), molasses (3%), limestone (2%) and sodium chloride (1%), supplemented with berseem (*Trifolium alexandrinum*). During the summer season, berseem hay was substituted for fresh berseem.

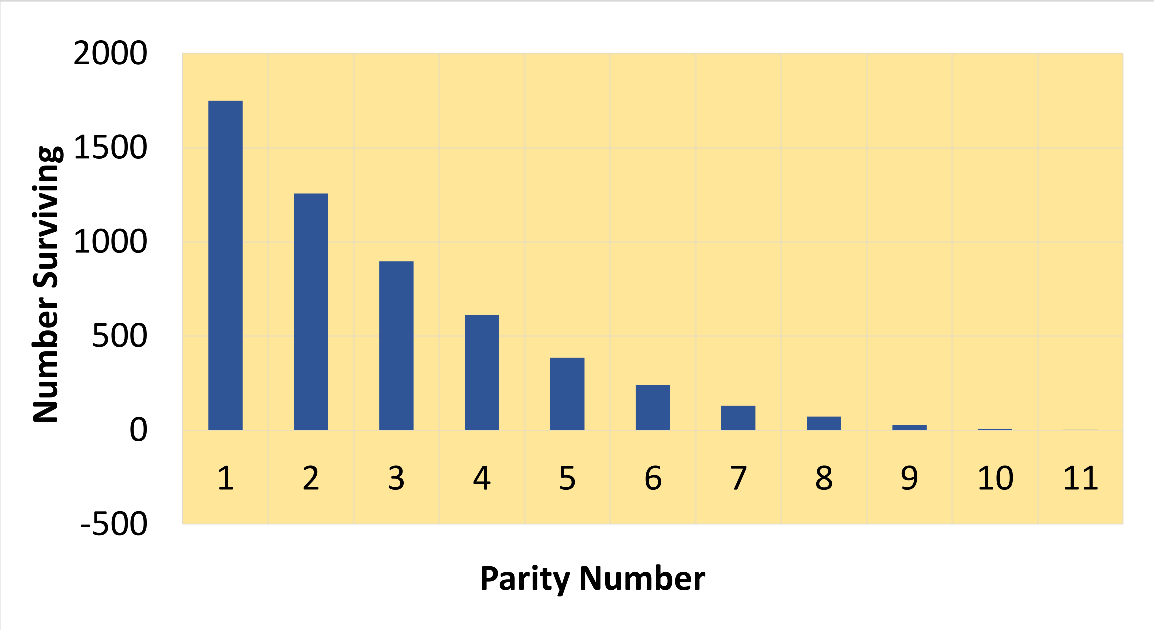

Fig 1. Number of Survived Animals at Each Parity

The quantity of feed allocated to each animal was judiciously determined, taking into account the individual animal's weight and the level of milk production it was generating. Feeding occurred twice daily, ensuring a consistent and balanced supply of rations, with a perpetual source of clean water accessible to the animals at all times.

2.3 Traits

The study examined four key traits related to lifespan in dairy cattle:

1. Total Lifetime (LT): This trait signifies the age at culling.
2. Lifetime Days in Milk (LTDIM): It represents the cumulative number of days a cow spends in milk production over its lifetime.
3. Total Lactations (TL): This trait indicates the number of lactations a cow successfully completes during its lifetime.
4. Total 305-Days Milk Yield throughout a Cow's Lifespan (LTMY): LTMY quantifies the cumulative milk yield a cow generates over its entire lifetime.

Additionally, partial lifetime traits were computed for the initial three calvings and included:

5. Lactation Length of the First Lactation (DIM1),
6. Cumulative Days in Milk for the $1^{st}$and 2^{nd} Lactations (DIM2),
7. Cumulative Days in Milk for the 1^{st}, 2^{nd} and 3^{rd} Lactations (DIM3),
8. Cumulative Milk Yield for the 1^{st}, 2^{nd} and 3^{rd} Lactations (MY1, MY2 and MY3),
9. Age at First Calving (AFC) a reproductive trait.

Fixed effects considered in this study are detailed in **Table 2**.

Table 2. Fixed Effects

Fixed Effect	Levels
Herd	Sakha and El-karada stations (2 herds)
Parity No.	1 to =>7
Year of Birth	1990-2019
Season of Birth	Divided into 3 levels (Season 1, Season 2, Season 3)
Year of Calving	1992-2022
Season of Calving	Divided into 3 levels (Season 1, Season 2, Season 3)

2.4 Statistical Analysis

2.4.1 Correction for Fixed Effects

The analysis encompassed two stages. Initially, a correction for fixed effects that influenced all traits. This correction addresses factors such as parity, calving year, and season of calving, to standardize animal performance across the dataset. Parity was utilized as an indicator of the cow's age and varied between lactations. The years of calving from 1992 to 2022 were divided into five levels, including three categories of seasons that categorized into three levels: (1) months 3, 4, 5 and 10, (2) months 6, 7, 8 and 9, and (3) months 11, 12, 1, and 2.

The following model was employed to rectify these fixed effects using SAS (2014):

$$Y_{ijkl} = \mu + P_i + YC_j + SC_k + e_{ijkl},$$

Where:

Y_{ijkl} represents the observation for the l^{th} cow of the i^{th} parity, j^{th} calving year, and k^{th} calving season for the various traits,

μ is the herd mean for productive traits and lifetime traits,

P_i is the fixed effect of the i^{th} parity (i = 1:11),

YC_j is the fixed effect of the j^{th} year of calving (j = 1992: 2022),

SC_k is the fixed effect of the k^{th} calving season (k = 1: 3),

e_{ijkl} signifies a random error associated with each individual observation distributed as N (0, $I\sigma^2e$).

The second stage of the analysis assessed the significance of herd, birth year and birth season using the General Linear Model (GLM) approach implemented in SAS (SAS 2014). The following statistical model was applied to analyze lifetime traits:

$$Y_{ijkl} = \mu + H_i + YB_j + SB_k + e_{ijkl},$$

Where:

Y_{ijkl} is the adjusted phenotype for the l^{th} cow of the i^{th} herd, j^{th} year of birth,

k^{th} season of birth for the various studied traits,

μ is the overall mean for LT, DIM, LTMY, AFC, and TL,

H_i is the fixed effect of the i^{th} herd, (i = 1 & 2),

YB_j is the fixed effect of the j^{th} year of birth, (j = 1990- 2019),

SB_k is the fixed effect of the k^{th} season of birth, (k = 1 – 3),

e_{ijkl} signifies a random error associated with each individual observation distributed as N (0, $I\sigma^2_e$).

2.4.2 Genetic analysis

Variance and covariance components, including genetic, phenotypic and environmental variances, as well as heritability, were estimated using a linear bivariate animal model within the VCE6 program (Groeneveld et al 2010). The model is expressed as follows:

$$Y = Xb + Za + e,$$

where:

Y is a combination of bivariate traits analyzed,

X represents the incidence matrix connecting fixed effects to y,

b is the vector comprising an overall mean and the herd fixed effects, birth year, and birth season,

Za denotes the incidence matrix connecting the direct additive genetic effects to y, where a signifies the vector of random direct additive genetic effects associated with the incidence matrix Zam, these effects are commonly assumed to follow a normal distribution with mean 0 and variance σ^2_a,

e represents the vector of random residual effects, distributed as N (0, $I\sigma^2_e$), where I is the identity matrix.

3 Results and Discussion

3.1 Descriptive statistics

Table 3 provides an overview of the descriptive statistics of various lifetime performance traits, including minimum and maximum values, mean values, standard errors and standard deviations. The considered traits are Lifetime (LT), total life Days in Milk (LTDIM), first lactation length (DIM1), Cumulative Days in Milk of 1st and 2nd lactations (DIM2), Cumulative Days in Milk of 1st, 2nd and 3rd lactations (DIM3), Cumulative 305-Day Milk Yield for All Parities (LTMY), First Parity 305-Day Milk production (MY1), Cumulative 305-Day Milk production of 1st and 2nd Parities (MY2), Cumulative 305-Day Milk production of 1st, 2nd and 3rd Parities (MY3), Age at First Calving (AFC), and Total lactations (TL).

On average, these traits had the following values: LT: 2,452.55 days (approximately 80.4 months), LTDIM: 1,011.1 days (about 33.2 months), DIM1: 319.4 days. DIM2: 643.0 days, DIM3: 967.1 days. LTMY: 11,168 kg, MY1: 3,052.18 kg, MY2: 6,528.43 kg, MY3: 1,0231 kg, AFC: 32.7 months, TL: 3.2 lactations. These results are comparable to previous findings in the literature, with slight variations observed. For example, the mean LT in this study aligns with values reported for Holsteins in Egypt and Brazilian Holsteins, while there is a slight increase for Holstein cattle in the USA. LTDIM was lower than values reported for commercial herds of Holstein cows in Egypt but consistent with other countries. DIM1, DIM2 and DIM3 were similar to previous Egyptian studies but higher than estimates in the US. The cumulative milk yield traits (LTMY, MY1, MY2 and MY3) had lower mean values in this study compared to some previous research. The average TL of 3.2 was higher than that of Brazilian and US Holsteins (Musingi et al 2022).

The differences between these results and those of other studies can be attributed to variations in management practices, climatic conditions and differences in genetics among herds. The Holstein breed's primary focus is milk production, making it crucial to enhance

Table 3. Phenotypic means, minimum (Min), maximum (Max), standard deviations (SD) and standard errors (SE) for the whole and partial lifetime performance traits

Traits	N	Mean	Min.	Max.	SD	±SE
LT	1749	2,452.55	866.00	5,965.00	955	22.83
LTDIM	1749	1011.1	160	3,980	668.62	16
DIM1	1749	319.4	200	556	80.41	1.92
DIM2	1313	643.0	322	1,077	128.08	3.53
DIM3	922	967.1	555	1,575	172.20	5.67
LTMY	1749	11,168	1169	5,2817	8185	196
MY1	1749	3,052.18	191.00	8,158	934.26	22.35
MY2	1316	6,528.43	1,482.00	13,519	1,592.58	43.92
MY3	922	10,231	3,149.00	1,9012	2,225	73.28
AFC	1749	32.7	26	41.5	4.30	0.10
TL	1749	3.2	1	11	2.03	0.04

both productive and reproductive performance in these cattle. It is noted that earlier AFC, within the range of 24-30 months under arid conditions, can positively influence cumulative milk production in the first three lactations and total lifetime production.

The results showed that the LTDIM represents about 50.4 months which is approximately 43% of the LT of about 90 months. Additionally, the results of DIM1, DIM2 and DIM3 were close to the results obtained by (Alhammad et al 2008), which were 323, 662 and 1025 days respectively. These estimates are also higher than the estimates noted by Tsuruta et al (2005) on the Holsteins in the US which were 386, 665 and 935 days respectively.

Alhammad et al (2008) reported higher estimates than those obtained in this study for LTMY, MY1, MY2, and MY3 traits. Additionally, the average TL was 3.2, surpassing the reported values of Brazilian and US Holsteins, respectively, i.e. 2.7 and 2.8 (Kern et al 2015).

Building upon these findings, Almasri et al (2020) emphasized the impact of early calving under arid conditions, highlighting that first calving at an average age of 24-30 months affects cumulative milk production in the first three lactations and total lifetime production. Moreover, reproductive performance tends to decrease in younger cows compared to older ones. Consistently, Kučević et al (2019) demonstrated that cows calving for the first time at an age older than 29 months experienced a significant reduction in a productive life.

Holstein cattle is a pasture breed that is basically used for the production of milk. The goal of their breeding program is to improve maternal performance of milk yield. **Table 3** shows that the average values for the studied traits are directly influenced by the Friesian cattle's reproductive and productive performance. Therefore, more attention should be paid to improving the reproductive and productive performance of the Friesian cattle. Enhancing reproductive performance would lead to an increase in farm profitability. The observed AFC was 32.7 months.

3.2 Analysis of variance

Table 4 lists the results of the analysis of variance for total lifetime performance traits (LT, LTDIM and LTMY) and partial lifetime traits (MY1, MY2, MY3, AFC and TL). The analysis revealed that birth year contributed to the variation in all traits significantly. There was a significant effect of the herd on all traits except MY2, where no significant effect was observed. The birth season did not affect significantly any of the lifespan traits.

3.3 Variance components, genetic parameters and genetic and phenotypic correlations

Table 5 provides estimates of direct genetic variance (σ^2_a), residual variance (σ^2_e), phenotypic variance (σ^2_p) and direct heritability (h^2) for various lifetime performance traits. Heritability estimates were generally low for traits such as LT, LTDIM, DIM1, LTMY, MY1, AFC and TL, ranging from 0.04 to 0.16. In contrast, moderate heritabilities were observed for DIM2, DIM3, MY2, and MY3, ranging from 0.20 to 0.24. The low heritability estimates suggest that direct selection for these traits may not be very effective, and improvements should be achieved indirectly through correlated responses in other related traits (El-Saied et al 2005).

Table 4. Analysis of variance of total and partial lifetime traits

	F-value and significance		
	Herd	**Birth year**	**Birth season**
LT	7.89 (0.0050)**	18.33 (<.0001)***	0.35 (0.7031)^{ns}
LTDIM	4.46 (0.0348)*	20.88 (<.0001)***	0.30 (0.7414) ^{ns}
LTMY	23.20 (<.0001)***	15.49 (<.0001 ***	0.75 (0.4745) ^{ns}
MY1	9.21 (0.0024) **	9.91(<.0001)***	1.73(0.0619) ^{ns}
MY2	0.00 (0.9729) ^{ns}	10.82(<.0001)***	1.26(0.2401) ^{ns}
MY3	5.66(0.0175)**	7.65(<.0001) ***	1.04(0.4092) ^{ns}
AFC	6.30 (0.0121)*	11.97 (<.0001)***	0.26 (0.7678) ^{ns}
TL	4.47 (0.0346)*	21.06 (<.0001)***	0.26 (0.7710) ^{ns}

Lifetime (LT); Cumulative Days in milk all parities (LTDIM); Age at first calving (AFC); Cumulative lifetime 305-milk yield (LTMY); 305-milk yield of first parity (MY1); Cumulative 305-milk yield of first 2 parities (MY2); Cumulative 305-milk yield of first 3 parities (MY3); Total lactations (TL). *P< 0.05, **P<0.01, ***P<0.001; ns= Not significant.

Table 5. The estimates of variances and heritability for lifetime performance traits

Traits	**σ^2_a**	**σ^2_e**	**σ^2_p**	**h^2**
LT	95,639.0	841,186.0	936,825.0	0.10 ± 0.03
LTDIM	39,097.0	409,855.0	448,953.0	0.09 ± 0.03
DIM1	792.0	5,700.0	6,492.0	0.12 ± 0.04
DIM2	3,286.0	13,308.0	16,594.0	0.20 ± 0.06
DIM3	6,875.0	22,787.0	29,661.0	0.23 ± 0.07
LTMY	7,385,505.0	51,104,495.00	58,490,000.0	0.13 ± 0.03
MY1	72,427.0	637,773.00	710,200.0	0.10 ± 0.03
MY2	334,560.0	1,331,440.00	1,666,000.0	0.20 ± 0.04
MY3	741,685.0	2,323,315.00	3,065,000.0	0.24 ± 0.04
AFC	3.0	15.0	18.0	0.16 ± 0.04
TL	0.46732	3.53268	4.0	0.12 ± 0.03

Table 6 presents genetic and phenotypic correlations among total lifetime performance traits. Strong positive correlations were observed among total lifetime, total lactation periods along the animal's life, total parties, and lifetime production, with genetic correlations ranging from 0.88 to 0.99 and phenotypic correlations ranging from 0.89 to 0.97. These strong correlations are attributed to shared genetic factors and the inherent relationship between these traits. In contrast, AFC exhibited weak and low correlations with other traits, both genetically and phenotypically.

Negative and weak correlations (-0.17, -0.25 and -0.04) were observed between AFC and each of LTDIM, LTMY and TL (**Table 6**). These results show that higher milk yields and TL can be expected from animals that calve at a younger age. The genetic correlation between age at first calving and length of life is positive and low (r = 0.03) (**Table 6**). Similar results (0.039 - 0.061) have been found by Do et al (2013). This study showed the impact of age at first calving on lifetime milk production considering the number of deliveries. A previous report by Sawa et al (2019) indicated that first calving at an earlier age contributes to more calves. Strapáková et al (2014) recognized that age at first calving is a factor that significantly influences the elimination rate of cows from the herd. Finally, worth mentioning are the research results of Curran et al (2013) and Krpálková et al (2017) who noted that due to different herd management strategies, it is difficult to determine an optimal time for the first calving of cows.

Table 6. Genetic correlations (rg above the diagonal), and phenotypic correlations (rp below the diagonal) among total lifetime performance traits

Trai ts	LT	LTDIM	LTMY	AFC	TL
LT		0.99	0.88	0.03	0.91
LTDIM	0.93		0.94	-0.17	0.96
TMY	0.91	0.89		-0.25	0.91
AFC	0.07	-0.10	-0.11		-0.04
TL	0.91	0.95	0.96	-0.13	

Table 7 shows the estimates of heritability for selected partial lifetime performance traits, DIM1, DIM2, DIM3, MY1, MY2 and MY3 as well as their genetic and phenotypic correlations with total lifetime performance traits, (LTDIM and LTMY). As more information was incorporated into the partial lifetime traits, the genetic and phenotypic correlations with full lifetime traits increased progressively.

Overall conclusion, these results suggest that indirect selection based on partial lifetime traits such as DIM2, DIM3, MY2, and MY3 could lead to improvements in lifetime milk production and other related traits. The study underscores the importance of early selection for these traits to enhance overall herd performance.

These findings align with previous research and emphasize the potential for genetic improvement in dairy cattle based on carefully selected lifetime performance traits. However, the study also highlights the complexity of genetic and environmental factors influencing these traits and the need for comprehensive breeding strategies in Friesian cattle management.

These results agree with the results of Jairath et al (1994), achieved for Holstein cows, who found that strong genetic correlations may be due to pleiotropy (the same gene that controls the same traits) and also to early childhood achievement being part of lifetime achievement (i.e. a part-whole relationship). Therefore, the associated response is favorable in DIM, 305-MY, AFC and TL; total lifetime income of milk is expected when early selection is made for the appropriate part of life traits. In the last years, there has been a growing interest in the genetic evaluation of longevity traits.

As with dairy cows, these traits could be exploited in the future as possible indirect selection traits. The currently available data are not sufficient for such a study. The highest estimate of heritability for a vital trait in this work was for MY2 and MY3 0.20 and 0.24, respectively. These traits are practical because they can be easily calculated at any point in the cattle's life. Both traits seem to be suitable as early intermediate selection traits to improve milk quality during shelf life (El-Saied et al 2005).

Table 7. Heritability estimates (± SE) for partial lifetime performance traits and their phenotypic and genetic correlations with total lifetime performance traits

Total lifetime traits	Partial Lifetime trait	$h^2 \pm$ SE of partial lifetime traits	Correlations	
			Phenotypic (rp)	Genetic (rg)
LTDIM	DIM1	0.12 ± 0.04	0.15	0.16
	DIM2	0.20 ± 0.06	0.19	0.18
	DIM3	0.23 ± 0.07	0.12	0.11
LTMY	MY1	0.10 ± 0.03	0.18	0.97
	MY2	0.20 ± 0.04	0.24	0.80
	MY3	0.24 ± 0.04	0.38	0.44

4 Conclusion

The findings of this study suggest that direct selection for improving total lifespan performance traits, such as total lactation length (LTDIM) and total lifetime production (LTMY), is not recommended due to their low heritability. Instead, it is more practical to consider early indirect selection for longevity by focusing on correlated responses in early performance traits, particularly milk production during early lactations. This study underscores the importance of looking beyond the immediate traits considering the long-term performance of dairy cattle. Selecting traits that positively impact longevity, such as early lactation milk production, can indirectly enhance the overall lifetime performance of Friesian cattle. This approach aligns to improve both the productive and reproductive aspects of Friesian cattle, ultimately contributing to farm profitability and sustainable dairy production.

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