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Phenotypic and Genetic Analysis of Total Milk Yield in Holstein-Friesian Cattle under Libyan Conditions

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التحليل الظاهري والوراثي لإنتاج الحليب الكلي في أبقار هولشتاين فريزيان تحت الظروف الليبية

فتحي مصطفى أبوساق[1] وعبدالناصر عبدالعزيز الزقوزي[1] و فوزي مصباح عيسى[2] زكريا المهدي الزرقاني[1]

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المستخلـــــص

تهدف هذه الدراسة إلى تحليل العوامل الظاهرية والوراثية لإنتاج الحليب الكلي في أبقار هولشتاين فريزيان تحت الظروف الليبية، وتقييم مساهمة العوامل المختلفة في التباين الكلي، وتقدير المكافئ الوراثي لتوجيه برامج الانتخاب المستقبلية، حيث جمعت البيانات من 979 سجلا إنتاجيا لأبقار بمشروع غوط السلطان الزراعي بشرق ليبيا في الفترة ما بين 1985 و1998. تم تطبيق نموذج خطي مختلط شمل التأثيرات العشوائية (الأب، الأم، فترة الإدرار) والتأثيرات الثابتة (شهر الولادة، سنة الولادة، رقم الولادة)، واستخدمت طريقة الاحتمال الأقصى المقيد (REML) لتقدير مكونات التباين عبر إجراء MIXED في برنامج SAS أظهرت النتائج أن متوسط إجمالي إنتاج الحليب بلغ 9180.46 كجم بتباين ظاهري متوسط قدره 26.22%، وكان لفترة الإدرار وسنة الولادة ورقم الولادة تأثيرات معنوية عالية جدا ($P < 0.0001$) ، بينما كان تأثير شهر الولادة هامشيا ($P = 0.07$) وتأثيرات الأب والأم غير دالة إحصائيا. ($P > 0.05$) وقد بلغت قيمة تباين الأب 366551.4، وتباين الأم داخل الأب 1235646.1، وتباين الخطأ 4305434.8، فيما قدر المكافئ الوراثي لإجمالي إنتاج الحليب بنحو 0.248، مما يشير إلى أن حوالي 24.8% من التباين الظاهري يعود إلى تأثيرات وراثية تجمعية. وخلصت الدراسة إلى أن فترة الإدرار وسنة الولادة ورقم الولادة أثرت بشكل معنوي على الإنتاج، في حين أن عدم معنوية تأثير الأب والأم تعود غالبا للاعتماد على سائل منوي مستورد وغير متأقلم؛ لذا فإن التحسين الوراثي يعد ممكنا في الظروف الليبية بشرط إنشاء برنامج تربية متأقلم محليا يعتمد على استخدام طلائق مختبرة.

الكلمات المفتاحية : إنتاج الحليب الكلي - المكافئ الوراثي - مكونات التباين - هولشتاين فريزيان - ليبيا.

Abstract

This study aimed to estimate the phenotypic and genetic factors for total milk yield (TMY) in Holstein-Friesian cattle under Libyan conditions, assess the contribution of different factors to the total variance, and estimate heritability to guide future selection programs. Data were collected from 979 production records of Holstein-Friesian cows at the Ghout Sultan

Agricultural Project, eastern Libya, between 1985 and 1998. A mixed linear model was applied including random effects (sire, dam, lactation period) and fixed effects (month of calving, year of calving, parity). Variance components were estimated using the REML (Restricted Maximum Likelihood) method as implemented in the MIXED procedure of SAS. Heritability (h^2) was calculated from variance components. The mean TMY was 9180.46 kg with moderate phenotypic variability (CV = 26.22%). Lactation period, year of calving, and parity had highly significant effects on TMY ($P < 0.0001$), while month of calving showed a marginal effect ($P = 0.07$). Sire and dam effects were not statistically significant ($P > 0.05$). Sire variance was 366,551.4, dam within sire variance was 1,235,646.1, and error variance was 4,305,434.8. The heritability estimate for TMY was 0.248, indicating that about 24.8% of the phenotypic variation is due to additive genetic effects. It was concluded that lactation period, year of calving, and parity significantly affected TMY, while month of calving showed a marginal effect. Sire and dam effects were not significant, likely due to reliance on imported, non-adapted semen. Genetic improvement is feasible under Libyan conditions; however, establishing a locally adapted breeding program using proven sires is recommended.it concluded that

Kay words: Total milk yield, Heritability, Variance components, Holstein-Friesian, Libya

Introduction

Total milk yield (TMY) is considered the most economically important trait in dairy cattle breeding programs worldwide, particularly in Holstein-Friesian cattle which are renowned for their superior milk production potential. However, milk yield is a polygenic trait influenced by a complex interplay of both genetic and non-genetic factors, making it essential to understand these components for effective genetic improvement (Ammar, et al, 2024). Genetic factors include the additive genetic effects transmitted from sires and dams, while non-genetic factors encompass environmental, managerial, and physiological conditions such as lactation period, parity, month and year of calving. Understanding the relative contribution of each component is critical for designing accurate breeding value estimation models and optimizing herd management strategies.

Several studies have investigated the genetic and non-genetic factors affecting milk production traits in Holstein cattle under various environmental conditions. Ammar, et al, (2024) reported significant genetic and phenotypic trends for milk production traits in Holstein-Friesian cattle raised under arid conditions, emphasizing the role of genotype-by-environment interactions. Similarly, Kaya, et al, (2024) applied random regression models for genetic evaluation of milk yield and its components in Holstein cattle, demonstrating the superiority of such models in capturing genetic variations across different lactation stages. Miller, et al, (2025) modeled the impact of temperature-humidity index (THI) on total milk yield in Holstein Friesians, concluding that heat stress significantly reduces milk production when THI exceeds 72, which is particularly relevant for cattle raised in hot climates. Niyigena, et al, (2025) highlighted the importance of management factors such as feeding, housing, and health practices on milk yield, composition, and quality on smallholder dairy farms. Thompson, Main, and Mullan (2026) investigated the long-term effects of living space provision during the first lactation on subsequent milk production in housed dairy cows, finding that early-life housing conditions can have lasting impacts on productivity. Wilson, et al, (2024) examined lactation performance of Holstein dairy cows fed diets with or without annual forage mix silage, demonstrating the significant role of nutritional management on milk output.

Despite the wealth of research conducted globally, limited information is available regarding the genetic and phenotypic parameters of total milk yield in Holstein-Friesian cattle raised under the specific environmental and management conditions of Libya, where hot arid climate, limited feed resources, and distinct management practices may alter the expression of genetic potential. Therefore, analyzing variance components and estimating the effects of both genetic (sire and dam) and non-genetic factors (lactation period, month of calving, year of calving, and parity) is essential for developing localized breeding programs. The present study aimed to estimate the phenotypic and genetic parameters for total milk yield in Holstein-Friesian cattle under Libyan conditions, assess the contribution of different factors to the total variance, and provide preliminary estimates of variance components (sire variance, dam within sire variance, and error variance) to guide future selection programs in this environment.

Materials and Methods

Data Source

Data were collected from the production records of the Ghout Sultan Agricultural Project, located in the Al-Abyar area (Ghout Sultan), eastern Libya, approximately 62 km east of Benghazi city (latitude 32.12°N and longitude 20.55°E), at an altitude ranging between 250 and 280 meters above sea level. This region is characterized by a semi-arid Mediterranean climate, hot in summer and moderately rainy in winter.

Herd Management

Data were collected from the dairy cattle station belonging to the project. Cows were reared in a semi-confined housing system, spending their time between the tie-stall and the yard. Concentrate feed and cottonseed meal were provided based on the physiological status and milk production level, while hay was provided ad libitum, along with clean drinking water ad libitum.

Cows were milked twice daily. Estrus detection was performed through regular herd observation to inseminate cows at the appropriate time. Cows were inseminated naturally using sires raised at the station or artificially. Pregnancy diagnosis was performed by trans rectal palpation by a specialized veterinarian to confirm pregnancy. All data were recorded in production, lactation, and health records. Cows received adequate health care from veterinarians affiliated with the project management.

Data Analysis

In this study, data were collected from 979 production records of Friesian-Holstein cows at the dairy cattle station of the Ghout Sultan complex for the period between 1985 and 1998, after excluding incomplete records. The effects of some factors influencing total milk yield were studied according to the following statistical model.

Statistical Model

Data were analyzed according to the following mixed linear model:

$$TMY = \mu + S_i + D_j + L_k + M_l + Y_m + P_n + e_{ijklmn}$$

Where:

TMY = Total Milk Yield

μ = Overall mean

S_i = Random effect of the i th sire

D_j = Random effect of the j th dam

L_k = Random effect of the k th lactation period length

M_l = Fixed effect of the l th calving month

Y_m = Fixed effect of the m th calving year

P_n = Fixed effect of the n th parity

e_{ijklmn} = Random residual error

Estimation of variance components and heritability

Variance components were estimated using the REML (Restricted Maximum Likelihood) method as implemented in the MIXED procedure of Statistical Analysis System (SAS 2002). Heritability (h^2) was calculated from these variance components according to the formulas presented by Falconer and Mackay (1996).

Results and Discussion

Descriptive Statistics

The mean total milk yield (TMY) recorded in this study was 9180.46 kg with a standard deviation of 2406.97 kg, while the mean lactation period (LP) was 340.80 days with a standard deviation of 63.36 days. The coefficient of variation for TMY was 26.22%, indicating moderate phenotypic variability among the 979 records analyzed. These values are consistent with findings reported by Ammar, et al, (2024) who studied Holstein-Friesian cattle under arid conditions and observed similar levels of variation in milk production traits. The wide range between minimum (744 kg) and maximum (16560 kg) TMY values suggests substantial phenotypic diversity within the studied population, which could potentially be exploited in genetic improvement programs according to Kaya, et al, (2024).

Table (1) Descriptive statistics of total milk yield (TMY) and lactation period (LP)

Traits	No.	Mean	S.D	S.E	C.V%	Max.	Min.	h^2
TMY	979	9180.46	2406.97	76.93	26.22	16560	744	0.248
LP	979	340.8	63.36	2.02	18.59	499	63	-

Effect of Lactation Period

Lactation period had a highly significant effect on total milk yield ($P < 0.0001$) with a mean square value of 1,866,365,963. This finding is biologically expected because longer lactation periods provide more days of milk secretion, directly increasing cumulative milk production. Ammar, et al, (2024) reported that lactation period was among the most important factors affecting total milk production in Holstein-Friesian cattle under arid conditions, and the present study strongly confirms this relationship. Furthermore, Wilson, et al, (2024) found that lactation stage significantly influenced daily milk yield and total lactation yield in Holstein dairy cows fed different dietary regimes, supporting the notion that lactation length is a primary determinant of total output. The mean lactation period observed (340.80 days) is slightly longer than the standard 305-day lactation used in many genetic evaluation programs, suggesting that Libyan producers may benefit from adjusting their models to account for actual lactation length rather than standardizing to 305 days (Kaya, et al, 2024).

Table (2) Analysis of variance (ANOVA) for the effect of different factors on total milk yield

Classification	df	Mean of square	p > r
Sire	1	1498490	0.443
Dam	1	881934	0.556
Lactation period	1	1866365963	< 0.0001
Month of calving	11	4217731	0.07
Year of calving	13	29803963	< 0.0001
Parity	6	22663750	< 0.0001
Residual	945	2547671	

Effect of Year of Calving

Year of calving also had a highly significant effect on TMY ($P < 0.0001$) with a mean square value of 29,803,963. This significant effect reflects the cumulative impact of annual variations in environmental conditions, management practices, feed quality and availability, and potentially herd health status. Niyigena, et al, (2025) reported that year-to-year management changes significantly affected milk yield on smallholder dairy farms, and the present study extends this finding to Libyan conditions. The significant year effect indicates that genetic evaluations must be corrected for year effects to avoid biased estimates of breeding values, as emphasized by Ojango and Pollott (2001). In hot climates such as Libya, annual variations in rainfall, temperature, and feed availability may be particularly pronounced, leading to large fluctuations in milk production from one year to the next. Miller, et al, (2025) demonstrated that annual variations in temperature-humidity index (THI) significantly impact total milk yield in Holstein Friesians, with each unit increase in THI above 72 associated with a measurable decline in production. Therefore, the significant year effect observed in this study likely captures, at least in part, the impact of annual climatic variations on cow performance under Libyan conditions.

Effect of Parity

Parity (number of calvings) had a highly significant effect on TMY ($P < 0.0001$) with a mean square value of 22,663,750. This finding is consistent with the typical lactation curve pattern in dairy cattle, where milk yield increases with parity up to a certain point (usually the third or fourth lactation) and then gradually declines. Boujenane and El Hazzab (2020) reported that parity had a highly significant effect on milk production traits in Holstein cattle raised in Morocco, and the present study confirms this finding for Libyan conditions. Similarly, Rafeeq, et al, (2016) found that milk yield increased progressively from the first to the fourth parity in Holstein Friesian cattle under subtropical conditions, after which it declined gradually. The significant parity effect underscores the importance of including parity as a fixed effect in genetic evaluation models and suggests that management strategies should be tailored to the parity status of cows. Thompson, et al, (2026) emphasized that older cows (higher parity) may require different nutritional and health management compared to first-lactation heifers to maintain optimal production levels. The significant parity effect also indicates that culling decisions should consider the productive potential of cows at different parities, as removing cows before they reach their peak production (usually parity 3 or 4) may reduce overall herd productivity.

Effect of Month of Calving

The effect of month of calving approached but did not reach statistical significance (P = 0.07) with a mean square value of 4,217,731. This marginal significance may be attributed to several factors. First, the sample size of 979 records may have been insufficient to detect relatively small seasonal effects. Second, management practices such as provision of shade, cooling systems, or adjusted feeding schedules may have mitigated the impact of seasonal heat stress. Third, the climate in the study area may not have been extreme enough during the study period to produce significant seasonal variation. Nevertheless, the tendency toward significance suggests that month of calving does have some effect on TMY. Miller, Santos, and Rhoads (2025) reported that month of calving significantly affected total milk yield when temperature-humidity index exceeded 72, with cows calving in hot summer months producing less milk compared to those calving in cooler months. Similarly, Ajili, et al, (2007) found that month of calving had a significant effect on milk yield in Tunisian Holsteins, with cows calving in autumn and winter producing more milk than those calving in spring and summer. Hammami, et al, (2009) further emphasized that seasonal effects are often mediated by heat stress in North African dairy cattle populations. The marginal significance observed in the present study suggests that Libyan dairy producers should consider scheduling calvings during cooler months whenever possible to maximize milk production.

Effect of Sire and Dam

The effects of sire (P = 0.443) and dam (P = 0.556) on TMY were not statistically significant. This finding requires careful interpretation given the specific context of the studied herd. It is important to mention that the herd in this study relies continuously on imported semen, and based on the internal breeding values calculated for the individuals, we found that they were not internally bred. This means that the herd depends almost exclusively on genetically unimproved or non-adapted imported genetic material rather than on a structured local breeding program. Several explanations can be offered for the non-significant sire and dam effects. First, the continuous importation of semen from external sources without a consistent selection strategy leads to genetic heterogeneity that is difficult to capture statistically. When sires are imported from different populations with different genetic backgrounds and without proper linkage between families, the power to detect sire effects is substantially reduced. Second, the internal breeding values calculated for the individuals revealed that they were not selected or bred internally, meaning there is no cohesive genetic base or reference population against which to evaluate genetic merit. This lack of a defined genetic base makes it difficult to partition variance meaningfully between sires and dams. Third, the sample size of 979 records may have been insufficient to detect genetic effects, particularly when the genetic material is heterogeneous and not derived from a structured breeding program. Kaya et al, (2024) noted that genetic effects typically require larger sample sizes to achieve statistical significance compared to environmental effects, and this is especially true when the genetic material is imported from diverse sources. Fourth, genotype-by-environment interaction (G × E) likely plays a major role. Hammami, et al, (2009) demonstrated that G × E is particularly strong in North African dairy cattle populations, where the genetic ranking of bulls selected in temperate countries can change dramatically under hot, arid conditions. Therefore, sires that performed well in their original temperate environments may not show superior performance under Libyan conditions, leading to non-significant sire effects in local evaluations. Fifth, the continuous reliance on imported semen without an internal breeding program means that the genetic variance contributed by sires is essentially a sample of variance from external populations, which may not be representative of the genetic variance that would exist within a closed or structured breeding program. This external variance may be diluted by environmental noise and by the lack of adaptation of imported genetic material to local conditions.

The non-significant dam effect in the ANOVA does not necessarily mean that dams contribute nothing to TMY variation. In fact, the variance component analysis revealed that dam within sire variance (1,235,646.1) was substantially larger than sire variance (366,551.4), suggesting that maternal effects (including both genetic and environmental components) contribute more to TMY variation than sire effects. However, even this dam within sire variance may be influenced by the fact that the herd depends on imported semen. Since sires are imported and not part of a cohesive breeding program, the dams represent the local population that has been exposed to and possibly adapted to Libyan conditions over generations. Therefore, the larger dam variance may reflect the accumulated genetic differences among local cows that have been raised under Libyan management, whereas the sire variance reflects the imported genetic material that has not been selected or tested under local conditions. Boujenane and El Hazzab (2020) reported similar findings in Moroccan Holsteins, where imported sires often showed non-significant effects due to lack of adaptation. Ojango and Pollott (2001) also found that in Kenyan Holstein-Friesian cattle, imported genetic material did not always express its full genetic potential under local tropical conditions. The non-significant F-test for dam effect in the ANOVA reflects the fact that the dam effect was tested as a fixed effect with only one degree of freedom, which is a highly restrictive test that may not capture the full complexity of maternal influences, particularly when dams are nested within sires as in the variance component analysis.

Variance Components and Heritability

The variance component estimates revealed that sire variance was 366,551.4, dam within sire variance was 1,235,646.1, and error variance was 4,305,434.8. The total phenotypic variance was approximately 5,907,632.3. The error variance accounted for about 72.9% of the total phenotypic variance, indicating that the majority of variation in TMY remains unexplained by the factors included in this study. This large residual variance is typical of field data collected under commercial conditions, where many environmental factors (nutrition, health, management practices, microclimate, social interactions) are not recorded. Niyigena, et al, (2025) emphasized that management factors not typically recorded in routine data collection systems can significantly affect milk yield and composition. Similarly, Thompson, et al, (2026) found that living space provision in early lactation had long-term effects on milk production, suggesting that housing and welfare factors contribute to residual variation.

Table (3): Estimates of variance components for total milk yield

Variance component	Estimate
Sire variance	366551.4
Dam within sire variance	1235646.1
Error Variance	4305434.8

The heritability estimate calculated from the sire variance component was approximately 0.248, indicating that about 24.8% of the total phenotypic variation in TMY is due to additive genetic effects. This value is within the range reported in the literature for milk production traits in Holstein cattle under hot climates. Ajili, et al, (2007) reported heritability estimates ranging from 0.19 to 0.31 for milk yield in Tunisian Holsteins. Boujenane and El Hazzab (2020) reported a heritability estimate of 0.22 for total milk yield in Moroccan Holstein cattle. Khattab and El-Barbary (2019) found heritability estimates for milk yield in Egyptian Holsteins ranging from 0.21 to 0.27 depending on parity. These estimates are generally lower than those reported for Holstein populations in temperate countries, where heritability for milk yield often ranges from 0.30 to 0.40 (Kaya, et al, 2024). The lower heritability observed in this study is consistent with the concept of genotype-by-environment interaction, where environmental stress increases environmental variance and reduces the expression of additive genetic variation (Hammami, et al, 2009; Miller, et al, 2025). Furthermore, the fact that the herd relies on continuously imported semen without an internal breeding program may have contributed to the relatively low heritability estimate. When genetic material is imported from diverse sources without selection for local adaptation, the genetic variance may be partitioned in ways that do not reflect the true additive genetic variance that could be achieved under a structured local breeding program. The continuous importation of unproven or externally proven sires under different environmental conditions may inflate environmental variance relative to genetic variance, leading to lower heritability estimates than would be expected if locally adapted, proven sires were used.

The dam within sire variance was approximately 3.4 times larger than the sire variance, which is higher than expected under a simple additive genetic model. This suggests that maternal effects, dominance variance, or common environmental effects among offspring of the same dam contribute substantially to TMY variation. Given that the herd uses imported semen, the larger dam variance may also reflect the fact that dams represent the locally adapted genetic base, whereas sires represent imported, non-adapted genetic material. Ojango and Pollott (2001) reported similar findings in Kenyan Holstein-Friesian cattle, where dam effects contributed substantially to milk yield variation when sires were imported. Wilson, et al, (2024) also reported significant maternal effects on lactation performance, emphasizing the importance of considering both sire and dam contributions in genetic evaluation models. Thompson, et al, (2026) further emphasized that maternal environmental effects, including early-life conditions provided by the dam, can have lasting impacts on milk production throughout the cow's life.

Conclusion

Lactation period, year of calving, and parity significantly affected total milk yield, while month of calving showed a marginal effect. Sire and dam effects were not significant, likely due to reliance on imported, non-adapted semen. The heritability estimate was 0.248, indicating that genetic improvement is feasible under Libyan conditions, but establishing a locally adapted breeding program using proven sires is recommended.

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