Journal of Science and Development, JSD Vol. 13 No. 2 **2025**

Original Research Article||

Monitoring Milk Yield and Composition Traits in Ethiopian Zebu x Holstein Friesian Crosses: Influence of Genotype, Location, Lactation Stage, and Parity in Urban Milk Production System of Southern Ethiopia

Eyerusalem Tesfaye[1,2], Aberra Melesse[1], Dereje Andualem[2], Simret Betsha[1]

[1]*Hawassa University, School of Animal and Range Sciences, P.O. Box 05, Hawassa, Ethiopia*
[2]*Dilla University Department of Animal Sciences, P.O. Box 490, Dilla, Ethiopia*

Abstract

This study evaluated the effects of genotype (G), parity (P), lactation stage (LS), and location (L) on milk yield and composition of Holstein Friesian (HF) crossbred dairy cows in the Shashemene–Dilla milkshed. A total of 117 lactating cows (39 per location: Shashemene, Hawassa, and Dilla) were included, comprising three genotype groups (50%, 75%, and 87.5% HF; 13 cows per genotype per location). Milk yield traits assessed were peak yield (PY), total yield (TY), lactation length (LL), peak day (PD), and average daily milk yield (ADMY). Milk composition traits; fat, protein, lactose, milk density (MD), salt, pH, freezing point (Fpt.), and total solids (TS) were determined using a Milkoscan FT2. Data were analyzed using a linear mixed-effects model in R (version 4.3.3). GraphPad Prism (10.4.0) was used to visualize milk production, while Origin software illustrated changes in ADMY across lactation stages by genotype. Results showed that 87.5% HF crosses outperformed 75% and 50% HF cows in ADMY, TY, PY, LL, and PD. In contrast, 50% HF cows exhibited higher MD, TS, protein, Fpt., and salt content, whereas 75% HF cows had the highest fat percentage. Location significantly affected MD, Fpt., and salt ($P < 0.05$), with significant genotype × location interactions observed for MD, TS, protein, and solids-not-fat. Lactation stage significantly influenced fat, MD, TS, protein, and salt ($P < 0.001$), while parity affected all yield traits except PD. ADMY was negatively correlated with fat ($r = -0.22$) and TS ($r = -0.22$). Protein showed strong positive correlations with density ($r = 0.86$) and lactose ($r = 0.63$), while solids-not-fat was strongly associated with density ($r = 0.76$). Overall, higher HF inheritance improved milk yield, although production was strongly influenced by location. Strategic selection based on performance records and improved management practices is recommended to enhance productivity under smallholder systems.

Key words: Genotype, Milk yield, Milk constituents, Lactation Length

Original submission: September 07, 2025; **Revised submission**: December 30, 2025; **Published online**: December 31, 2025

***Corresponding author's address:** Eyerusalem Tesfaye, Email: *tesfayeeyerusalem@gmail.com*
Authors: Aberra Melesse, Email: a_melesse@uni-hohenheim.de; Simret Betsha, Email: sbetsha@yahoo.com; Dereje Andualem, Email: a.dereje@yahoo.com

INTRODUCTION

Ethiopia is expecting a doubling of the number of middle-class consumers by the year 2030, with fast growth in terms of population (now exceeding 100 million), which will lead to higher demand for livestock products, including milk (Ndambi et al., 2017). In response to this growing demand, the Ethiopian government has set an ambitious goal of quadrupling national milk production by 2031 through targeted interventions aimed at improving the productivity of dairy cattle, camels, and goats (Leggesse et al., 2023).

Ethiopian cattle populations, known for their considerable genetic diversity and varying degrees of admixture, represent a valuable genetic resource for the development of context-specific dairy genotypes. This diversity holds promise for genetic improvement programs tailored to the country's wide range of agroecological zones (Goshme and Dadi, 2024). To capitalize on this potential, various breed improvement initiatives have been implemented, including the distribution of crossbred heifers, the provision of improved dairy stocks, and the expansion of artificial insemination (AI) and bull services (Kumar et al., 2014). In urban and peri-urban areas, dairy farmers typically raise Holstein–Zebu and Jersey–Zebu crossbred cows under zero- or semi-zero-grazing systems with minimal access to pasture (Deneke et al., 2022).

Genetic improvement efforts have led to the development of crossbred cattle, which are generally more productive than indigenous breeds (Gizaw et al., 2017). However, the success of these programs relies heavily on continuous performance monitoring under prevailing farm management conditions (Guadu and Demissie, 2016). Several studies have assessed the productive performance of crossbred and indigenous cattle, often focusing on exotic blood levels within research stations or government-owned farms, as well as selected urban and peri-urban dairies (Gizaw et al., 2017). Nonetheless, Ethiopia's dairy supply chain remains underdeveloped in terms of quality assurance, safety protocols, and organizational structure, with limited routine evaluations of herd performance and farm capacity (Feyisa et al., 2024).

Urban dairy systems in cities such as Hawassa, Shashemene, and Dilla play a critical role in bridging the national demand-supply gap. These systems maintain both improved (crossbred or high-grade) and indigenous cattle genotypes, contributing substantially to household income up to 43.6–79.7% of the gross annual income in the Shashemene–Dilla milkshed (Tegegne et al., 2013; Mengistie, 2016). Although several studies have examined the use of Holstein Friesian, crossbred dairy cows in Ethiopia, regarding region-specific insights into how blood level, environmental conditions, and cow-side factors affect milk production for On-farm periodical evaluation remains limited (Getahun et al., 2020; Beneberu and Alem, 2025).

Therefore, this study aims to address this gap by conducting a year-long, on-farm evaluation of the productive performance of crossbred dairy cows kept in farms across the Shashemene–Dilla milkshed. The study focuses on identifying both genetic and non-genetic factors influencing milk yield and assessing the physico-chemical properties of raw milk under real farm conditions.

MATERIALS AND METHODS

Study Area Description and Source of Sample

Data for this study were collected from 3 study locations (Shashemene, Hawassa, and Dilla) found in the Shashemene-Dilla milkshed, Ethiopia. The geographical location ranges from 6°24′30″N to 7° 12' N latitude and 38°28″E to 38° 36' E longitude (Figure 1). All selected sites are in the East African Great Rift Valley. According to Yigrem et al. (2008), two major dairy production systems were distinguished in the study milkshed: the mixed crop-livestock system characteristic of rural and peri-urban environments and the urban dairy system situated within urban centers. Study areas were selected based on the availability of Holstein Friesian crosses lactating dairy cows with the desired genotype (50%HF, 75%HF, 87.5% HF).

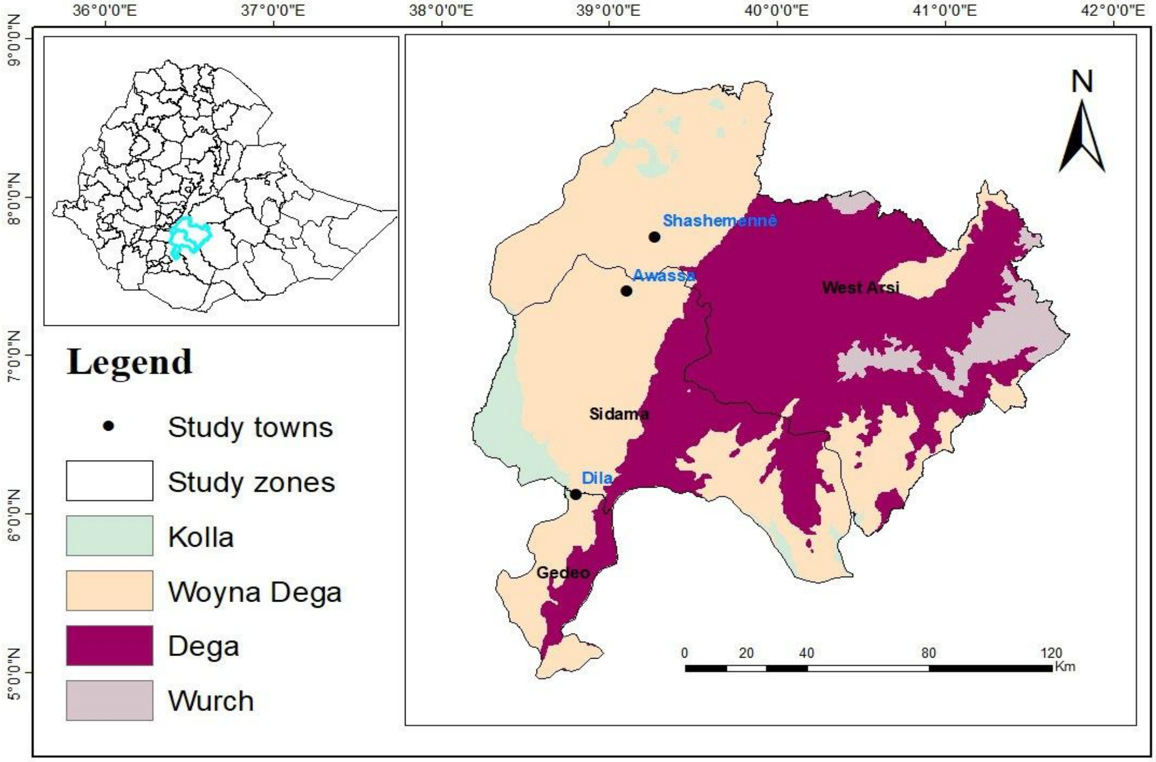

Figure 1. Map illustrating the three-milkshed locations where the study has been conducted

Agro-ecological conditions of milkshed locations: Kolla = lowland, Woynadega =Middle altitude; Dega = Temperate; Wurch = Frost

Sampling and Source of Milk Samples

Three study locations, namely Shashemene, Hawassa, and Dilla (SHA, HAW, and DIL), and nine farms, of which three from each location, were purposively selected based on the availability of the Ethiopian Zebu x HF crossbred dairy cattle (50%HF, 75%HF, and 87.5%HF) in the respective farms. The recorded data sheet from selected farms was used to determine the desired genotype, level of parity, and lactation stage. A total of 117 HF crosses (39 from each location) were used for on-farm evaluation of genetic and non-genetic factors affecting milk yield and composition traits. For each genotype (50%HF, 75%HF, and 87.5%HF), 13 Animals were selected from each location. Again, individual lactating cows were purposively selected at their 1-month postpartum (early lactation) and were grouped into three parities: primiparous (P), multiparous in the second (M2), and in the third (M3). Raw milk samples for milk constituents' determination were collected periodically from a total of 117 cows (13 cows from 9 farms) in the study locations during their early, mid, and late lactation stages.

All genotype groups within each participating farm were maintained under similar management practices, including feeding, housing, and milking routines. Management differences were applied only according to physiological needs such as lactation stage, pregnancy, or age class rather than genotype category.

Milk Yield Characteristics Data Collection

Milk yield data, of 117 lactating cows (grouped under primiparous and multiparous in the second and third lactation) were collected from the dairy producers' milk record cards for the whole lactation period once in a week manner. The milk yield of these dairy cows was monitored for the whole lactation period starting at the first week of December 2022-2023.

Raw Milk Composition Determination

The Raw milk sample for composition and quality analysis was aseptically collected from each cow during the three lactation stages and immediately taken to the HU (Hawassa University) dairy technology laboratory. The raw milk collection was done after discarding the first three to five milk strands, and about 40ml of morning or evening milk was aseptically stored in sterile sample bottles. The milk composition traits (fat, total protein, lactose, milk density, salt, pH, freezing point, and total solids) of the raw milk samples were determined using a Milkoscan FT2 (Foss Electric at HU dairy technology laboratory) apparatus. The measurement was done following the manufacturer's protocol for the consecutive three lactation stages (Souhassou *et al.,* 2018).

Data Management and Analysis

Data were processed using a linear mixed-effect model in R 4.3.3 by taking genotype (50%HF, 75%HF, and 87.5%HF), parity (primiparous, second, and third parity), lactation stage (early, mid, and late), and location (Shashemene, Hawassa, and Dilla) as fixed effects and the cows' ID as random effect. Means between fixed effects were separated using Tukey's range test. The effect of class variables was expressed as Least Squares Means (LSM). The milk production trends and illustrating the pattern of changes across lactation stage varying by genotype on the other hand were visualized with GraphPad Prism 10.4.0 and Origin software, respectively. SAS 9.4 was used for milk production traits correlation analysis.

A linear mixed-effects model was fitted including two interaction terms to investigate whether the effect of Genotype differs across Location, and the effect of the lactation stages parity across the lactation stages. The model was specified as:

$$Yijklm=\mu + L_i + G_j + (L \times G)_{ij} + P_k + LS + (P \times LS)_{kl} + u_m + \varepsilon_{ijklm}$$

Where:

- Y_{ijklm} is the response variable (fat percentage, Milk density, lactose percentage, total solid percentage, protein percentage, freezing point (° C), salt percentage, solid not fat percentage, Average daily milk yield (litters/day)), total yield, lactation length, peak yield, peak day.
- μ is the overall intercept,
- L_i is the fixed effect of the ith location,
- G_j is the fixed effect of the jth genotype category,
- $(L \times G)_{ij}$ is the fixed interaction effect between location and genotype,
- P_k is the fixed effect of parity category,
- LS_l is the fixed effect of lactation stage,
- $(P \times L)_{kl}$ is the fixed interaction effect between Parity and, Lactation Stage
- u_m is the random intercept for cow identity m, ($u_m \sim N(0,\sigma^2_u)$ accounting for correlation among repeated measurements from the same animal
- $\varepsilon ijklm$ is the residual error ($\varepsilon ijklm \sim N(0,\sigma 2)$).

RESULTS

The range of the coefficient of variation for milk production traits was from 1.42% to 68.30%. The most variable trait was total yield (TY), while pH was the least variable**.** The mean values for the milk composition traits were milk fat (F) 4.17, density(D) 30.98, lactose(L) 4.64, total solid (TS) 10.73, protein(P) 3.27, freezing point (Fpt.) 0.54, salt (S) 0.70, pH 6.58, and solid not fat (SNF) 6.56. Whereas average daily milk yield (ADMY) 6.21, total yield (TY) 1448.73liters, lactation length (LL) 246.95 days, peak yield (PY) 11.01liters, and peak day (PD) 87.03 days were the mean values for milk yield characteristics.

Effect of Genotype, Parity, Location, and Lactation Stage on Milk Yield Characteristics

The crossbred dairy cows with 87.5% HF genotype had the highest average daily milk yield (9.97 liters/day/cow), Total Yield 2571 liters, and Peak Yield (PY) =16.64 liters/day/cow with longer Lactation Length (LL)=292days and Peak Day=93.63thday (Table 1). The 50% HF cows, on the other hand, were inferior for LL but had comparable TY and PY with 75% HF crosses and PD with 87.5% HF crosses.

The HF crossbred cows at the second(M2) and third (M3) parity had higher TY and PY, yet the longest lactation length was recorded for cows at the second parity as compared to the primiparous and the third parity cows. TY and LL, on the other hand, were affected significantly ($P<0.05$) by location, while PY and PD were the ones not affected by location. The HF crosses at Hawassa, Shashemene, and Dilla had higher, intermediate, and lower recorded TY, respectively (Table 1).

Table 1. Milk Yield Characteristics (LSM ± SE) as Affected by Genotype, Parity, and Location

Variables	TY	LL	PY	PD
Genotype (G)				
HF50%	821.58± 3.38^{b}	207.86±3.20^{c}	7.81±0.29^{b}	87.16±3.57^{ab}
HF75%	951.61±39.85^{b}	236.88±3.61 ^{b}	8.47±0.25^{b}	80.70±3.41^{b}
HF87.5%	2571.99±155.60^{a}	292.35±6.75^{a}	16.64±0.64^{a}	93.63±3.34^{a}
Parity (P)				
P	1034.35±74.29^{b}	225.59±4.42^{c}	8.59±0.44^{b}	82.82±3.24^{b}
M2	1540.24±159.04^{a}	253.91±8.45^{a}	11.87±0.82^{a}	85.32±3.86^{ab}
M3	1770.59±193.52^{a}	257.60± 7.89^{b}	12.47±0.86^{a}	93.35±3.21^{a}
Location (L)				
SHA	1440.96±146.35^{ab}	254.68±7.81^{a}	10.84±0.83ab	86.66±3.77
HAW	1565.68±128.28^{a}	239.74±8.12^{b}	11.41±0.87^{a}	88.95±3.16
DIL	1338.54±128.29^{b}	242.67± 6.56^{b}	10.67±0.67^{b}	85.87±3.62
Source of variation				
G	<0.00	<0.00	<0.00	0.04
P	<0.00	<0.00	<0.00	0.10
L	0.00	0.01	0.03	0.77

^{abc} means with different superscripts are significantly different (*$P<0.05$); **$P<0.01$; ***$P<0.001$)
Abbreviation: TY = total yield; LL= lactation length; PY= peak yield, PD = peak day

The interaction effect of genotype and lactation stage on the average daily milk yield of the HF crosses in the studied milkshed is presented in Figure 2. The 87.5% HF cows exhibited superiority over the remaining two genotypes (50% and 75%) regarding average daily milk yield throughout the three lactation stages. The average daily milk yield of the 87.5%, 75%, and 50% HF genotype cows in the current study was 5.54, 6.95, and 12.2 liters for early lactation, 4.86, 4.97, and 11.8 for mid-lactation, and 1.91, 2.28, and 5.87 liters for late lactation, respectively (Figure 2).

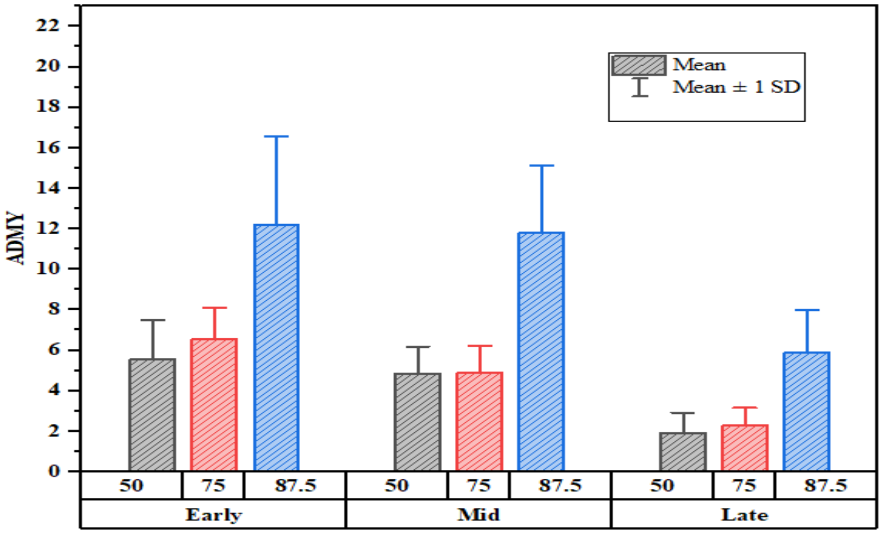

Figure 2. Effect of genotype and lactation stage on average daily milk yield of HF crosses

Milk Yield Patterns by Genotype, Location, and Parity

Graphs plotted using mean and standard error of average daily milk yield for the three genotypes, locations, and parity represented as a milk production graph in figures 3, 4, and 5. As presented in Figures 3, 4, and 5 genotype, location, and parity affected the average daily milk yield of HF crosses at the early, peak, mid, and late lactation. Average daily milk yield, milk yield peak, and lactation length were higher for HF 87.5% and lowest for HF 50% (Figure **3**). Holstein Friesian crosses at Hawassa had a higher peak and average daily milk yield than crossbreds at Shashemene and Dilla (***Figure*** **4**).

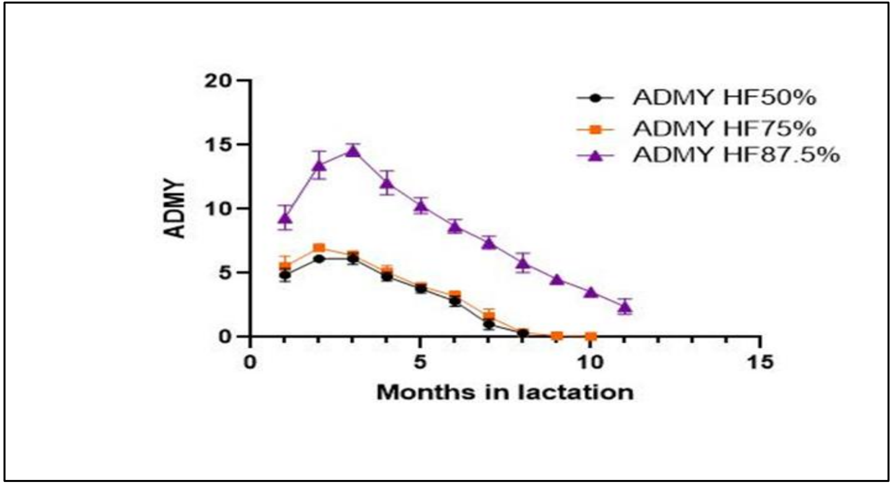

Figure 3. The mean and standard error for the average daily milk yield of three different genotypes of HF crosses

Abbreviation: ADMYHF50% = average daily milk yield of 50% Holstein Friesian crosses; ADMYHF75% = average daily milk yield of 75% Holstein Friesian crosses; ADMYHF75% = average daily milk yield of 87.5% Holstein Friesian crosses;

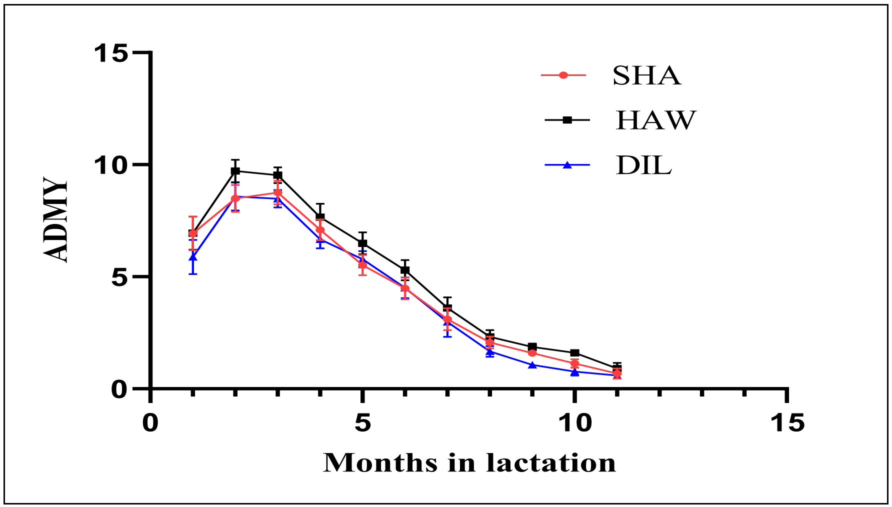

Figure 4. Mean and standard error for average daily milk yield of HF crosses at the three different location throughout lactation

Abbreviation: SHA = Shashemene; HAW = Hawassa; DIL= Dilla

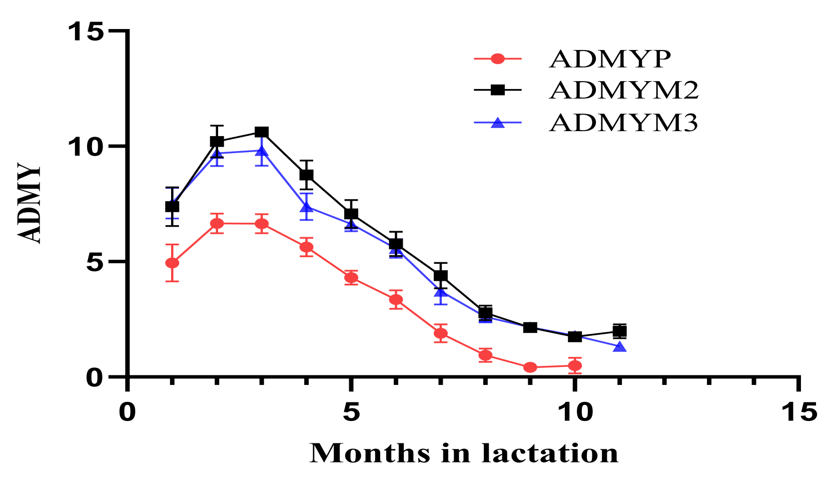

Figure 5. Mean and standard error for average daily milk yield of HF crosses grouped in three different numbers of parity throughout lactation

Abbreviation: ADMYP = average daily milk yield of the primiparous cows; ADMYM2 = average daily milk yield of multiparous cows in the second parity; ADMYM3 = average daily milk yield of multiparous cows in the third parity

The effect of Genotype and Location on milk composition traits

Genotype (genotype) affected almost all milk composition traits except L (Table 2). Crossbreds with 50% HF genotype have shown superiority over the other two genotypes for MD (32.16), TS (11.04), P (3.35), Fpt. (0.55), S (0.71), and SNF (6.84).

The 75% HF crosses also showed superiority for fat content (4.35) over the other genotypes and intermediate for milk pH value (6.58). The milk quality trait recorded higher for 87.5% HF crosses was milk pH value (6.60), and MY (Average daily milk yield) was also high for this genotype. Among the tested milk composition traits, L was not affected by genotype. From the tested milk quality traits, Milk-density (MD), Freezing Point (Fpt.), and Salt (S) were affected significantly ($P<0.05$) by the studied locations. The interaction effect of genotype and location was also significant for MD, TS, P, T, and SNF.

Table 2. Least squares mean of milk composition traits and average daily milk yield as affected by location and genotype

Variables	F	MD	L	TS	P	Fpt.	S	pH	SNF	ADMY
Location (L)										
Shashemene	4.11	31.6^{a}	4.68	10.8	3.32	0.55^{a}	0.70^{ab}	6.58	6.69	5.98
Hawassa	4.30	31.3^{ab}	4.64	10.8	3.27	0.55^{ab}	0.70^{a}	6.58	6.48	6.71
Dilla	4.10	30.1^{b}	4.60	10.6	3.23	0.53^{b}	0.68^{b}	6.60	6.50	5.94
Genotype (G)										
HF 50%	4.20^{ab}	32.2^{a}	4.69	11.0^{a}	3.35^{a}	0.55^{a}	0.71^{a}	6.57^{b}	6.84^{a}	4.10^{b}
HF 75%	4.35^{a}	30.1^{b}	4.59	10.6^{b}	3.19^{b}	0.53^{b}	0.69^{b}	6.58^{ab}	6.20^{b}	4.56^{b}
HF 87.5%	3.96^{b}	30.7^{b}	4.64	10.6^{b}	3.29^{ab}	0.54^{ab}	0.68^{b}	6.60^{a}	6.63^{a}	9.97^{a}
Sources of variation										
L	0.20	0.01	0.28	0.37	0.11	0.02	0.03	0.11	0.31	0.10
G	0.01	0.00	0.14	0.00	0.00	0.03	0.00	0.03	<0.00	<0.00
L x G	0.67	0.00	0.15	0.05	0.00	0.19	0.60	0.20	0.00	0.12

$^{a\,b\,c}$ means that with different superscripts are significantly different (*$P<0.05$); (**$P<0.01$): (***$P<0.001$)

Abbreviation: F = fat percentage; MD = Milk density; L = lactose percentage; TS = total solid percentage; P = protein percentage; FP = freezing point (^{o}C); S = salt percentage; SNF = solid not fat percentage; ADMY = Average daily milk yield (litters/day); HF =Holstein Friesian.

The Effect of Lactation Stage and Parity on Milk Composition Traits

The lactation stage was significantly ($P<0.001$) affecting F, MD, TMS, P, and S of the HF crossbred dairy cows in the studied milk shed (Table 4). Higher F (4.60), MD (31.49), TMS (11.20), and P (3.34) content were recorded at the early and late lactation stages (Table 3). Milk was recorded as higher at early and mid-lactation compared to the late stage of lactation. The milk samples from mid and late lactation had low and intermediate salt content, respectively. The freezing point was high for early, intermediate for mid, and low for late lactation stage, respectively. The interaction effect of lactation stage and parity was also exhibited only on the protein content of the sampled milk.

Table 3. Least squares means of milk production traits as affected by lactation stage and parity

Variables	F	MD	L	TS	P	Fpt.	S	pH	SNF	ADMY
Lactation Stage(LS)										
Early	4.60^{a}	31.5^{a}	4.63	11.2^{a}	3.34^{a}	0.55	0.71^{a}	6.58	6.59	8.10^{a}
Mid	3.20^{b}	29.5^{b}	4.59	9.65^{b}	3.09^{b}	0.54	0.69^{b}	6.58	6.45	7.18^{a}
Late	4.71^{a}	32.0^{a}	4.69	11.4^{a}	3.39^{a}	0.55	0.69^{ab}	6.60	6.64	3.35^{b}
Parity (P)										
Pr.	4.09	31.5	4.66	10.8	3.32^{a}	0.54^{ab}	0.70	6.59	6.69	4.58^{b}
M2	4.28	31.0	4.68	10.8	3.30^{ab}	0.55^{a}	0.70	6.59	6.53	7.21^{a}
M3	4.14	30.5	4.58	10.6	3.21^{b}	0.53^{b}	0.69	6.57	6.46	6.84^{a}
Sources of variation										
LS	<0.00	<0.00	0.10	<0.00	<0.00	0.19	0.03	0.13	0.46	<0.00
P	0.13	0.22	0.12	0.17	0.02	0.02	0.81	0.09	0.33	<0.00
LS x P	0.97	0.98	1.00	0.98	0.98	0.89	0.98	0.73	0.99	0.44

$^{a\ b\ c}$ means that with different superscripts within a column are significantly different (*P<0.05); (**P<0.01); (***P<0.001)

Abbreviation: F = fat percentage; MD = Milk density; L = lactose percentage; TS = total solid percentage; P = protein percentage; FP = freezing point (° C); S = salt percentage; SNF = solid not fat percentage; ADMY = Average daily milk yield (litters/day); Pr. = Primiparous; M2 = Multiparous in the second lactation; M3 = multiparous in the third lactation.

Correlation between Milk Production Traits

Figure 6 presents the Pearson correlation coefficients among average daily milk yield (ADMY) and key milk composition traits, including fat percentage (F), protein percentage (P), lactose percentage (L), total solids percentage (TS), solids-not-fat percentage (SNF), density (D), freezing point (Fpt.), salt content (S), and pH (Figure 6). Statistical significance is indicated by $p < 0.05$ (*), $p < 0.01$ (), and $p < 0.001$ ()*, while NS denotes non-significance.

A notable negative association was observed between ADMY and most compositional parameters, particularly F ($r = -0.22$, $p < 0.001$), TS ($r = -0.22$, $p < 0.001$), and D ($r = -0.13$, $p < 0.05$). Fat percentage exhibited a positive correlation with TS ($r = 0.43$, $p < 0.001$) and a significant negative correlation with SNF ($r = -0.42$, $p < 0.001$).

Protein content was highly correlated with L ($r = 0.63$, $p < 0.001$), D ($r = 0.86$, $p < 0.001$), Fpt. ($r = 0.45$, $p < 0.001$), and S ($r = 0.48$, $p < 0.001$). Lactose content demonstrated strong positive associations with TS ($r = 0.52$, $p < 0.001$), SNF ($r = 0.47$, $p < 0.001$), and D ($r = 0.62$, $p < 0.001$). TS, SNF, and D were closely interrelated, with the strongest correlation observed between SNF and D ($r = 0.76$, $p < 0.001$).

Freezing point showed moderate positive associations with P ($r = 0.45$, $p < 0.001$), L ($r = 0.56$, $p < 0.001$), and S ($r = 0.45$, $p < 0.001$), while being negatively associated with pH ($r = -0.18$, $p < 0.01$). Salt content was moderately correlated with P, L, and SNF, and exhibited a significant positive correlation with pH ($r = 0.29$, $p < 0.001$). In contrast, pH generally showed weak relationships with other compositional parameters (Figure 6).

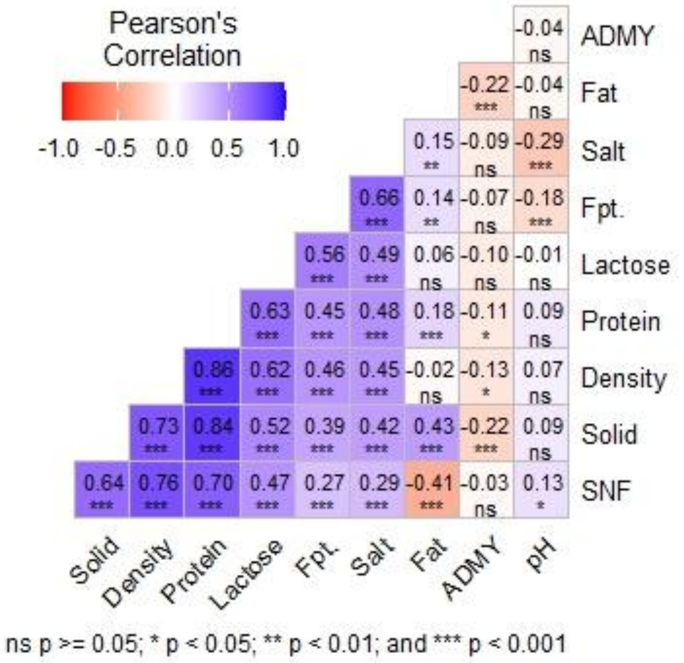

Figure 6. Pearson's correlation coefficient (r) for milk yield traits of Holstein Friesian crosses. The color intensity represents the strength of the correlations, with darker shades indicating a stronger association between traits and lighter shades a weaker association. Each square displays both the correlation coefficient (r) and the corresponding p-value, indicating the statistical significance of the association.

DISCUSSION

Milk production and composition traits showed considerable variation, with coefficients of variation (CV) ranging from 1.47% (pH) to 68.30% (total yield). The reported CVs across the pooled population, reflecting both within and between population differences suggest that these traits are suitable for genetic improvement through selection, aligning with the earlier findings of Alphonsus et al. (2015). The ADMY of the sampled population observed in this study was higher than values reported by Demeke (2020) and Taju, (2018), who found 4.62 ± 0.35 L and 4.73 L/day for crossbred dairy cattle in different regions of Ethiopia. Conversely, it was lower than the results reported by Tegegne et al. (2013) and Getahun et al. (2020). Similarly, TY and LL in the current study were lower than the values reported by Getahun et al. (2020b). Kumar et al. (2014) reported a higher PY (12.15 ± 0.82 L) and mean lactation milk yield (2069.16 ± 78.44 L) for crossbred cows, while Bisrat and Nigussie, (2016) observed lower TY but longer LL compared to the present study. These variations between the current study and results reported by different researchers may be attributed to differences in management, nutrition, parity, age, lactation stage, and season (Zhang et al., 2024). The current study also demonstrated superior values compared to Bekele et al. (2023) and Yoseph et al. (2022) for fat (4.17%), density (30.98 kg/m³), lactose (4.64%), freezing point (-0.54°C), and salt (0.70%). The mean milk fat and protein contents exceeded the Ethiopian Standards (ES) of 3.50% and 3.20%, respectively (Table 1).

Effect of Genotype, Parity, Location, and Lactation Stage on Milk Yield Characteristics

Among the genotypes, cows with 87.5% Holstein-Friesian (HF) genotype produced the highest TY but had the shortest LL compared to Hago, (2020). Their PY was also higher than that reported by Gebreyohannes et al. (2013). The 50% HF crosses, although inferior in LL, had TY and PY comparable to 75% HF crosses, and PD to 87.5% HF crosses (Table 2). Beneberu, (2023) reported on-station lactation yields ranging from 1293.01 ± 23.70 L to 2957.46 ± 72.98 L, and LL ranging from 298.68 ± 5.17 to 374.05 ± 7.24 days, whereas on-farm yields ranged from 631.69 ± 222.98 L to 2705.43 L, and LL from 241.65 ± 26.22 to 310.91 ± 41.83 days. The TY and LL of the genotypes in the present study were lower than most on-station reports but comparable with some on-farm values.

The LL in this study was inconsistent with the standard 305-day lactation except for 87.5%HF inheritance, though extended lactations have been reported elsewhere (Beneberu, 2023). While extended LL may benefit cow health and fertility, low milk yield during this period raises concerns over excessive fattening. This highlights the need for individualized strategies for extended lactation management (Van *et al.,* 2022).

Parity significantly affected all milk yield traits, whereas location did not influence ADMY, PY, or PD. Yield generally increased with parity, consistent with Gebreyohannes *et al.* (2013), Worku *et al.* (2016), and Getahun *et al.* (2020b). TY was comparable between Shashemene and Hawassa, though LL was longer in Shashemene than in Hawassa and Dilla, likely due to environmental differences. Bedada *et al,* (2021) observed similar trends.

Milk Production Patterns by Genotype, Location, and Parity

Higher exotic genotypes were associated with greater ADMY across all lactation stages (Figure 2), consistent with Silva *et al.* (2019). Parity also influenced ADMY: primiparous cows had the lowest yields throughout lactation, likely because nutrients were still being partitioned toward growth (Marumo *et al.,* 2022). Evangelista *et al.* (2024) and Nalla *et al.* (2022) likewise reported lower PY in primiparous cows. Location-wise, Hawassa herds showed higher PY and ADMY than those in Shashemene and Dilla, echoing findings from Oloo *et al.* (2022) on the influence of agroecological variation. Since the farms in the current study exist under the urban production, differences in producer practices, such as feed quality, milking routines, and veterinary care, may have contributed significantly to the observed performance variation.

Effect of Genotype and Location on Milk Composition Traits

Genotype significantly influenced most milk composition traits ($p < 0.05$), except lactose (L) and temperature (T), in agreement with Kebede *et al.* (2018), who also found lactose to be unaffected by genotype. Milk constituent percentages generally declined with increasing exotic genotype. The 50% HF crosses were superior for most traits—milk density (32.16), total solids (11.04%), protein (3.35%), freezing point (0.55°C), salt (0.71%), and solids-not-fat (6.84%) aligning with Cheruiyot *et al.,* (2018) and Bekele *et al.* (2023).

Fat percentage was highest in 75% HF crosses (4.35%), contrasting with Chanda *et al.,* (2022), who found them inferior to 50% HF. The 87.5% HF crosses had the highest yields but the lowest composition values. Higher milk pH in high-yielding cows may be linked to increased rumen pH from greater rumination (Souza *et al.,* 2022). The inverse relationship between yield and constituent concentration has been well documented (Craig *et al.,* 2022; Brito *et al.,* 2021), reflecting selection emphasis on yield at the expense of fertility and health (Oltenacu *et al.,* 2023).

Location significantly affected milk density, freezing point, and salt ($p < 0.05$) but not fat, lactose, total solids, protein, pH, or solids-not-fat. Dilla, the warmest site, had the lowest milk density, salt, and freezing point. Most major milk constituents showed little variation across locations, likely because the sites share similar agroecological zones. Nonetheless, performance advantages in optimal temperature–humidity conditions have been noted (Bernabucci *et al.,* 2014; Zewdu *et al.,* 2014). Genotype × location (G × L) interactions were solids, protein, temperature, and solids-not-fat), reflecting differences in genotype performance across environments (Gebreyohannes *et al.,* 2014; Silva *et al.,* 2024).

Effect of Lactation Stage and Parity on Milk Composition Traits

Lactation stage significantly affected fat, milk density, total solids, protein, temperature, and salt ($p < 0.001$), but not lactose, freezing point, pH, or solids-not-fat. These results are consistent with Connolly *et al.* (2023) and Kumar *et al.* (2021), who found lactose, SNF, and pH to be stable across lactation stages. However, Sabek *et al.* (2021) reported that higher parity and longer days in milk negatively affected udder health and milk quality in tropical cows. Proper adjustment for parity and lactation stage allows more accurate estimation of true genetic potential of the cows and minimizes bias in selection decisions. This aligns with findings by Kumar et al. (2021), who reported strong phenotypic associations between lactation stage, parity, and performance traits. Therefore, recognizing these effects is particularly important in dairy systems where cows differ in reproductive status and stage of production, as failure to account for them could lead to inaccurate ranking and suboptimal genetic progress.

Correlation among Milk Production Traits

The strongest positive correlation was between milk density and protein content (r = 0.86), consistent with Suhendra *et al,* (2020). Protein and total solids were also highly correlated (r = 0.84). Fat content was positively correlated with total solids (r = 0.43), supporting Desye *et al.* (2023), who reported r = 0.88 for similar traits.

Freezing point was positively correlated with all major milk composition traits, reflecting its dependence on solute concentration, a colligative property rather than solute type (Khider *et al.* 2021). This aligns with its use in detecting milk adulteration or dilution, whether accidental or intentional (Kumar *et al.,* 2024). In contrast, pH was negatively correlated with freezing point (r = -0.18), consistent with Rai *et al.* (2022), who reported r = -0.31 for similar relationships in crossbred dairy cows.

CONCLUSIONS

The on-farm monitoring revealed that both genetic and non-genetic factors significantly affect milk yield and composition traits in Holstein Friesian crossbred cows. While higher exotic genotypes enhanced milk volume, 50% HF crosses exhibited superior total solid, milk density and salt content. These findings highlight that increased milk yield tends to reduce component concentrations. Considering the current structure of the Ethiopian dairy sector, where milk pricing is largely volume-based, milk yield continues to be the most economically relevant trait for selection. Although milk composition traits are biologically important, their expression is strongly affected by management, nutrition, and environmental conditions in addition to genetics. Therefore, improving management practices and monitoring quality parameters may provide more immediate benefit, while keeping the option open for future integration of composition-based selection as the industry evolves.

REFERENCES

Alphonsus, C., Essien, I. C., Gn, A., and P. P. Barje. 2011. Factors Influencing Milk Yield Characteristics in Bunaji and Friesian x Bunaji Cows in Northern Nigeria. In *Animal Production*, 13(3): 143-149. [Scholar Google]

Bedada, K. W., Kechero, Y., and G. P. J. Janssens. 2021. Seasonal and agro-ecological associations with feed resource use and milk production of ranging dairy cows in the Southern Ethiopian Rift Valley. *Tropical animal health and production*, *53*: 1-8. [Scholar Google]

Beneberu, N. 2023. Review on Milk Yield Performance of Crossbred Dairy Cows in Ethiopia. *Advances in Bioscience and Bioengineering*, 11(3). doi: 10.11648/j.abb.20231103.11. [Scholar Google]

Beneberu, N., and D. Alem. 2025. Meta-analysis for Milk Production Performance Traits of Jersey cross, 50% HF and 75% HF Cross Dairy Cattle in Ethiopia, *Meta Analysis*,U KR Journal of Agriculture and Veterinary Sciences, *1*(1): 14-25. [Scholar Google]

Bernabucci, U., Biffani, S., Buggiotti, L., Vitali, A., Lacetera, N., and A. Nardone. 2014. The effects of heat stress in Italian Holstein dairy cattle. *Journal of Dairy Science*, *97*(1), 471-486. doi: 10.3168/jds.2013-6611. [Scholar Google]

Bokharaeian, M., Toghdory, A., Ghoorchi, T., Ghassemi N. J., and I. J. Esfahani. 2023. Quantitative associations between season, month, and temperature-humidity index with milk yield, composition, somatic cell counts, and microbial load: A comprehensive study across ten dairy farms over an annual cycle. *Animals*, *13*(20): 3205. doi: 10.3390/ani13203205 [Scholar Google]

Brito, L. F., Bédère, N., Douhard, F., Oliveira, H. R., Arnal, M., Peñagaricano, F., and F. Miglior. 2021. Genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. *Animal*, *15*: 100292. doi: 10.1016/j.animal.2021.100292. [Scholar Google]

Chanda, T., Khan, M. K. I., Chanda, G. C., and G. K. Debnath. 2022. Effect of farm categories on quality and quantity of milk produced by different crosses of Holstein-Friesian cows. *Agricultural Reviews*, *43*(3): 389-393. doi: 10.18805/ag.RF-214. [Scholar Google]

Cheruiyot, E.K., Bett, R.C., Amimo, J.O., F.D.N. Mujibi. 2018. Milk composition for admixed dairy cattle in Tanzania. *Frontiers Genetics* 9: 142. doi: 10.3389/fgene.2018.00142. [Scholar Google]

Connolly, C., Yin, X., and L. Brennan. 2023. Impact of lactation stage on the metabolite composition of bovine milk. *Molecules*, *28*(18): 6608. doi: 10.3390/molecules28186608. [Scholar Google]

Craig, A. L., Gordon, A. W., Hamill, G., and C. P. Ferris. 2022. Milk composition and production efficiency within feed-to-yield systems on commercial dairy farms in Northern Ireland. *Animals*, *12*(14): 1771. doi: 10.3390/ani12141771. [Scholar Google]

Deneke, T. T., Bekele, A., Moore, H. L., Mamo, T., Almaw, G., Mekonnen, G. A., and S. Berg. 2022. Milk and meat consumption patterns and the potential risk of zoonotic disease transmission among urban and peri-urban dairy farmers in Ethiopia. *BMC Public Health*, *22*(1): 222. doi: 10.1186/s12889-022-12665-4. [Scholar Google]

Desye, B., Bitew, B. D., Amare, D. E., Birhan, T. A., Getaneh, A., and Z. H. Gufue. 2023. Quality assessment of raw and pasteurized milk in Gondar city, Northwest Ethiopia: A laboratory-based cross-sectional study. *Heliyon*, *9*(3): e14202. doi: 10.1016/j.heliyon.2023.e14202. [Scholar Google]

Evangelista, A. F., Martins, R., Valotto, A. A., Dias, L. T., and R. D. A. Teixeira. 2024. Environmental factors on the prediction of the lactation curve of Holstein cows. *Pesquisa Agropecuária Brasileira*, *59*. doi: 10.1590/S1678-3921.pab2024.v59.03366. [Scholar Google]

Feyisa, B. W., Haji, J., and A. Mirzabaev. 2024. Adoption of milk safety practices: evidence from dairy farmers in Ethiopia. *Agriculture and Food Security*, *13*(1). doi: 10.1186/s40066-024-00479-z. [Scholar Google]

Gebreyohannes, G., Koonawootrittriron, S., Elzo, M. A., and T. Suwanasopee. 2013. Variance components and genetic parameters for milk production and lactation pattern in an Ethiopian multi-breed dairy cattle population. *Asian-Australasian Journal of Animal Sciences*, *26*(9): 1237–1246. doi: 10.5713/ajas.2013.13040. [Scholar Google]

Gebreyohannes, G., Koonawootrittriron, S., Elzo, M. A., and T. Suwanasopee. 2014. Genotype by environment interaction effect on lactation pattern and milk production traits in an Ethiopian dairy cattle population. *Agriculture and Natural Resources*, *48*(1): 38-51. [Scholar Google]

Getahun, K., Hundie, D., and Y. Tadesse. 2020. Productive Performance of Crossbred Dairy Cattle. *International Journal of Agricultural. Science,* 30(2): 55-65. [Scholar Google]

Glória, J. R. D., Bergmann, J. A. G., Quirino, C. R., Ruas, J. R. M., Pereira, J. C. C., Reis, R. B., and S. G. Coelho. 2012. Environmental and genetic effects on the lactation curves of four genetic groups of crossbred Holstein-Zebu cows. *Revista Brasileira de Zootecnia*, *41(11)*: 2309-2315. doi: 10.1590/S1516-35982012001100002. [Scholar Google]

Goshme, S., and H. Dadi. 2024. Genetic diversity and footprint of the Ethiopian cattle population, and the application of molecular information on sustainable cattle genetic improvement: Opportunities, challenges, and future directions in Ethiopia. A comprehensive review. *Biological Diversity*, *1*(3-4): 147-157. doi: 10.1002/bod2.12026. [Scholar Google]

Kebede, E. 2018. Effect of cattle breed on milk composition in the same management conditions. *Ethiopian Journal of Agricultural Sciences*, *28*(2): 53-64. [Scholar Google]

Khider, M., Ahmed, N., and W. A. Metry. 2021. Functional ice cream with a coffee-related flavor. *Food and Nutrition Sciences*, *12*(8): 826-847. doi: 10.4236/fns.2021.128062.

Kumar, A., Mandal, R. S., Bhatt, S., and A. Kumar. 2024. Physiological Edema. *Periparturient Diseases of Cattle*, 331-338. doi: 10.1002/9781394204007.ch30. [Scholar Google]

Kumar, N., Tkui, K., Tadesse Tegegne, D., and A. T. Mebratu. 2014. Productive Performance of Crossbred Dairy Cows and constraints faced by dairy farmers in Mekelle, Ethiopia. 7(1). www.iosrjournals.org. [Scholar Google]

Kumar, S., Gupta, I. D., Sharma, N., Deginal, R., Kumar, A., Chauhan, A., and A. Verma. 2021. Effect of season, parity, and stage of lactation on productive performance of Sahiwal cattle. *Indian Journal of Animal Research*, *55*(5): 597-602. [Scholar Google]

Leggesse, G., Gelmesa, U., Jembere, T., Degefa, T., Bediye, S., Teka, T., and S. Chemeda. 2023. Ethiopia National Dairy Development Strategy 2022–2031. https://hdl.handle.net/10568/135703.

Marumo, J. L., Lusseau, D., Speakman, J. R., Mackie, M., and C. Hambly. 2022. Influence of environmental factors and parity on milk yield dynamics in barn-housed dairy cattle. *Journal of Dairy Science*, *105*(2): 1225-1241. doi: 10.3168/jds.2021-20698. [Scholar Google]

Nalla, K., Manda, N. K., Dhillon, H. S., Kanade, S. R., Rokana, N., Hess, M., and A. K. Puniya. 2022. Impact of probiotics on dairy production efficiency. *Frontiers in microbiology*, *13*: 805963. [Scholar Google]

Ndambi, A., van der Lee, J., Endalemaw, T., Yigrem, S., Tefera, T., and K. Andeweg. 2017. Four important facts on opportunities in the Ethiopian dairy sector. *Practice brief DairyBISS project. Wageningen Livestock Research, Wageningen*.

Nyokabi, N. S., Phelan, L., Gemechu, G., Berg, S., Lindahl, J. F., Mihret, A., and H. L. Moore. 2023. From farm to table: exploring food handling and hygiene practices of meat and milk value chain actors in Ethiopia. *BMC Public Health*, *23*(1): 899. doi: 10.1186/s12889-023-15824-3. [Scholar Google]

Oloo, R. D., Ekine-Dzivenu, C. C., Ojango, J. M., Mrode, R. A., Chagunda, M., and A. O. Mwai. 2022. Effects of breed exoticness, agro-ecological zone, and their interaction on production and fertility traits of multibreed dairy cattle in Kenya. *ILRI Research Report*.

Oltenacu, P. A., and D. M. Broom. 2023. The impact of genetic selection for increased milk yield on the welfare of dairy cows. *Animal welfare*, *19*(S1): 39-49. doi: 10.1017/S0962728600002220. [Scholar Google]

Rai, P., and N. Adhikari. 2022. Study of the relationship among milk parameters in crossbred dairy cattle. doi: 10.21203/rs.3.rs-1920222/v1. [Scholar Google]

Sabek, A., Li, C., Du, C., Nan, L., Ni, J., Elgazzar, E., and S. Zhang. 2021. Effects of parity and days in milk on milk composition in correlation with β-hydroxybutyrate in tropic dairy cows. *Tropical Animal Health and Production*, *53*. [Scholar Google]

Shibru, D., Tamir, B., Kasa, F., and G. Goshu. 2019. Effect of season, parity, exotic gene level, and lactation stage in milk yield and composition of Holstein-Friesian crosses in the central highlands of Ethiopia. *European Journal of Experimental Biology*, *9*(4): 15. [Scholar Google]

Silva Neto, J. B., Mota, L. F., Londoño-Gil, M., Schmidt, P. I., Rodrigues, G. R., Ligori, V. A., and F. Baldi. 2024. Genotype-by-environment interactions in beef and dairy cattle populations: A review of methodologies and perspectives on research and applications. *Animal Genetics*, *55*(6): 871-892. doi: 10.1111/age.13483. [Scholar Google]

Silva, M. V. G. B., Carvalheiro, R., Santos, D. J. A., Tonhati, H., Albuquerque, L. G., and C. N. Costa. 2019. Heterosis in the lactation curves of Girolando cows with emphasis on variations of the individual curves. *Journal of Applied Animal Research*, 47(1): 85-95. doi: 10.1080/09712119.2019.1575223. [Scholar Google]

Souza, J. G., Ribeiro, C. V., and K. J. Harvatine. 2022. Meta-analysis of rumination behavior and its relationship with milk and milk fat production, rumen pH, and total-tract digestibility in lactating dairy cows. *Journal of Dairy Science*, *105*(1), 188-200. doi: 10.3168/jds.2021-20535. [Scholar Google]

Standard, E. 2009. Unprocessed whole/raw cow milk specification. *Ethiopian Standard*, *3460*, 2009.

Suhendra, D., Rahman, M. A., and M. Megawati. 2020. Correlation of protein contents and milk temperatures, with milk density of Friesian Holstein (fh) cow in Ngablak district of Magelang regency, Central Java. *Journal of Livestock Science and Production*, *4*(2): 289-294.

Taju H. 2018. Productive and Reproductive Performance of Indigenous Ethiopian Cow under Small Household Management in Dawro Zone, Southern Ethiopia. International Journal of Current Research and Academic Review, 6 (5). doi: 10.20546/ijcrar.2018.605.007.

Toghdory, A., Taghi G., Mohammad A., Mostafa B., Mojtaba N., and GN. Jalil. 2022. "Effects of Environmental Temperature and Humidity on Milk Composition, Microbial Load, and Somatic Cells in Milk of Holstein Dairy Cows in the Northeast Regions of Iran" *Animals* 12(18): 2484. doi: 10.3390/ani12182484. [Scholar Google]

Wondossen, A., Mohammed, A., and E. Negussie. 2015. Milk production performance of Holstein Friesian dairy cows at Holetta Bull Dam farm, Ethiopia.

Yigrem S, Beyene F, Tegegne A, and B. Gebremedhin. 2008. Dairy production, processing and marketing systems of Shashemene-Dilla area, South Ethiopia. IPMS Working Paper. https://cgspace.cgiar.org/items/cb6ec164-6aa9-4169-b774-751753fbfa40.

Zewdu, W., Thombre, B. M., and D. V. Bainwad. 2014. Effect of macroclimatic factors on milk production and reproductive efficiency of Holstein Friesian× Deoni crossbred cows. *Journal of Cell and Animal Bio*logy, *8*(4): 51-60. doi:10.5897/JCAB2014.0408. [Scholar Google]

Zhang, H., Gao, Q., Wang, A., Wang, Z., Liang, Y., Guo, M., and Y. Wang. 2024. Estimation of Genetic Parameters for Milk Production Rate and Its Stability in Holstein Population. *Animals*, *14*(19): 2761. doi: 10.3390/ani14192761. [Scholar Google]