

Challenges of Dairy Cattle Genetic Improvement Programs in Northwestern Ethiopia

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Abstract

Ethiopia possesses one of Africa's most diverse cattle gene pools and enjoys favorable agro-ecological conditions and strong cultural demand for dairy products; however, productivity remains constrained by persistent socioeconomic and technical bottlenecks. This study examined how farmer demographics, production goals, management strategies, and systemic constraints influenced the effectiveness of dairy cattle genetic improvement across two agro-ecological zones and major milk-shed areas in the Amhara region. A multistage sampling survey involving 355 smallholder dairy producers (253 mid and 102 highland areas) was conducted using semi-structured questionnaires. Respondents had, on average, 12.19 ± 6.50 years of dairy experience and were 48.19 years old. Breeding-related expenditures showed strong spatial variation: farmers in the midlands and Gondar milk-shed paid substantially higher costs for natural mating and informal AI services, whereas highland farmers benefitted from lower AI fees and shorter distances to service centers (1.40 ± 1.88 km). The Wilcoxon signed-rank test confirmed that milk production was the dominant objective for raising hybrid dairy cattle across both agro-ecologies (overall weighted index: 0.41), signaling a clear transition toward more specialized, market-oriented dairying. Major constraints limiting genetic improvement included security-related disruptions (top constraint, overall index = 0.30; $p = 0.002$), which restricted access to grazing and AI delivery. Additional challenges included shortages of AI technicians ($p = 0.04$), escalating feed costs and scarcity, and the inconsistent availability of quality semen. Collectively, these limitations contributed to poor conception outcomes and undermined the performance of AI-driven genetic improvement initiatives. The evaluation of breed and blood level effects demonstrated substantial genetic and economic differences. Holstein Friesian (HF) hybrids exhibited superior productivity, showing the highest average daily milk yields (13.52 ± 4.69 L/day) and significantly outperforming local dairy cows (1.99 ± 0.81 L/day). This translated directly to economic benefits, as HF hybrids generated the highest average Income Per Lactation (peaking at 275,693.93 ETB at > 75% blood level), far exceeding the income from local breeds (35,500 ETB). Furthermore, HF hybrids showed significantly earlier maturity, with a shorter Age at First Service Mating (AAFSM) (1.66 ± 2.10 years) compared to local breeds (3.35 years). Conversely, Jersey hybrids demonstrated better reproductive efficiency with a lower Number of Service Per Conception (NSPC) (1.40 ± 0.58) and higher Conception Rate (CR) ($81.29 \pm 24.01\%$), compared to HF hybrids (NSPC: 1.49 ± 0.57 ; CR: 76.03 ± 24.39). Notably, NSPC declined as the HF exotic blood level increased up to 75%, indicating a sweet spot for optimal crossbred performance. This variable performance across traits highlights an unstable performance paradox. Strengthening reproductive service delivery, improving feed and market systems, investing in breeding infrastructure, and addressing security barriers are essential for advancing sustainable dairy genetic improvement in Northwest Ethiopia.

Introduction

Ethiopia is a developing African country endowed with a vast and diverse cattle population, favorable agro-ecological conditions, a strong dairy consumption culture, and a rapidly growing demand for milk products that collectively offer substantial potential for dairy production (Nibo and Zewdu 2020). Among Ethiopia's agricultural activities, the livestock sector plays a central role in the socioeconomic and cultural livelihoods of rural communities (Girma and Fikru, 2023). Within this sector, local (indigenous) cattle comprise the majority of the national herd, particularly in the Amhara region, where they are kept across all agro-ecological zones. These cattle contributed significantly to rural livelihoods by providing cash income, nutrition, traction, and social value (Bekele, 2021). Despite their adaptability, indigenous breeds have limited genetic potential for milk production. To address this limitation, Ethiopia initiated dairy genetic improvement programs nearly 70 years ago (Yemane et al., 1993), focusing on eight national milk-shed areas: Adama–Asella, Ambo–Woliso, Addis Ababa, Hawassa–Shashemene, Gondar–Bahir Dar, Mekele, Dire Dawa–Harar, and Jimma. In the Amhara region, five major milk-sheds Bahir Dar, Gondar, Debre Markos, Dessie, and Debre Birhan have been the primary targeted areas for such interventions (Wytze et al., 2012). The combined effects of low milk yields from indigenous breeds, rapid population growth, and rising living standards of the population was created strong pressure to scale up genetic improvement initiatives and enhance dairy productivity (ELMP, 2015; Gondar Handling Study, 2016). Following that the breeding program was recommend to maintain exotic blood levels at between 50% and 62.5% to optimize performances while preserving adaptability under Ethiopia's diverse agro-ecological and management conditions (Aynalem, 2006; ELDMP, 2015)

However, adaptation and performance of dairy hybrids with varying exotic blood levels across Ethiopia's diverse agro-ecological and production systems have been challenged by multiple technical, institutional, and socioeconomic limitations. These included disparities among dairy producers, differing production objectives, and persistent technical gaps (Chencha and Kefyalew, 2012). Mohammed (2024) reported that inadequate artificial insemination (AI) management, the absence of a coordinated breeding policy, and risks of genetic erosion from uncontrolled crossbreeding continued to undermine genetic improvement efforts. Additional technical constraints such as insufficient training of AI technicians, low farmer awareness, limited access to liquid nitrogen and quality semen, and the high cost of AI services further reduced the efficiency of reproductive technologies (Oghaiki et al., 2017). Similarly, Moges et al. (2019) and Mohammed (2024) identified feed scarcity, land shortages; rising production costs, poor estrus detection, and weak technical capacity in semen handling were major obstacles. Transportation challenges, a shortage of dairy service centers, and inconsistent market access particularly during fasting periods further constrain dairy production in rural areas. In addition, fragmented reports were showed that persistent inefficiencies in genetic improvement programs were characterized by low conception rates (below 50%), unsatisfactory success of AI, and poor semen handling practices (Teweldemedhn and Berhe, 2023). Crossbred animals maintained by farmers frequently contain unoptimized and inconsistent exotic blood levels due to unsystematic mating practices, uncontrolled AI services, and unregulated bull distribution (Debir, 2016). Other recurring challenges include poor herd management, inadequate nutrition, limited technical capacity among inseminators, weak AI input supply chains, poor heat detection, incorrect insemination timing, and the resulting reduction in viable sperm cells (Tassew, 2024). Additional barriers—such as limited reproductive technologies, weak farmer knowledge, and management issues—have been reported across several regions, including Oromia's Walmera District, where environmental stress, poor health care, insufficient quality feed, the absence of a national breeding policy, and low use of advanced reproductive technologies contributed to crossbreeding inefficiencies (Ketema et al., 2018).

Although numerous studies have documented genetic improvement challenges across Ethiopia with a comprehensive assessments specific to the Amhara region remain limited, with only a few review works recommending national-level evaluation and strategic redesign of breeding programs (Chebo and

Alemayehu, 2012). These challenges highlight the urgent need for targeted interventions that support the development of locally adapted breeding strategies aligned with agro-ecological diversities to ensure economic viability and long-term sustainability (Abegaz et al., 2016). Therefore, this study aims to identify and evaluate the major gaps hindering current dairy cattle genetic improvement efficiencies affected milk production and lower per capita milk consumptions in different production areas of northeastern Ethiopia.

Specific Objectives

- To identify the technical, institutional, and socioeconomic factors limiting the efficiency of dairy cattle genetic improvement programs in the region.
- To assess the adaptation performance of dairy cattle hybrids with varying levels of exotic blood across different agro-ecological zones and milk-shed areas in Northwestern Ethiopia.
- To recommend targeted interventions and strategies

Materials and Methods

Description of the Study Area

The study was conducted in the northwestern part of Ethiopia, specifically in selected areas within the Gondar and Bahir Dar cities milk shed areas, which represent two target distinct agro-ecological zones. These milk/ water sheds are important dairy-producing regions characterized by diverse agro-ecological and climatic conditions. Differences in cattle population, number of dairy households and production systems ranging from milk shed areas and agro ecologies was associated to feed availability and demand differences which are influenced by variations in altitude, rainfall and temperature, all of which affect dairy productivity and management practices across these zones is detailed in Table 1.

Table 1
Summary of Key Characteristics of the study Areas

Feature	Gondar city water shed/ Milk Shed	Bihardar city Milk Shed/water shed	
		Bahir Dar	South Gondar zone
Cattle Population	1.15 million heads (CSA, 2020a)	120,000 heads (Tilahun et al., 2018)	1.18 million heads (CSA, 2020a)
No. of Dairy Households	1,300 households (BoARD, 2006)	1,900 households (Tilahun et al., 2018)	
Geographical Location	Northwest Ethiopia	565 km NW of Addis Ababa	660 km NW of Addis Ababa
Latitude and Longitude	12°36' N; 37°28' E	11°36' N; 37°23' E	11°02'–12°33' N; 37°25'–38°43' E
Elevation (masl)	1,780–2,700	1,700–1,840	1,500–3,200
Agro-Ecology	Moderate to cool climate	Suitable for intensive/semi-intensive systems	Highland and mid-altitude
Rainfall (mm/year)	700–1,530 mm	850–1,250 mm	800–1,400 mm
Temperature Range (°C)	10°C–32°C	10°C–32°C	10°C – 27°C

Table 1 Insert Here

Study Design and Data Collection

A multistage sampling approach combining purposive and systematic simple random sampling techniques was employed to select smallholder dairy owners from the highland and midland agro-ecological zones within the Bahir Dar and Gondar city milk shed areas.

Data Type and Collection Methods

Data Sources

Both primary and secondary data were collected through multiple follow-up surveys. Secondary data were gathered from comprehensive literature reviews, official reports, and online sources.

Primary Data Collection Methods

Primary data were primarily collected using semi-structured questionnaires. so, the survey instruments were designed to capture both quantitative and qualitative information relevant to dairy cattle genetic improvement programs.

The primary data collected were bifurcated into qualitative and quantitative sets. Qualitative data focused on capturing crucial respondent demographics (sex, religion, marital status, and educational level), as well as preferences regarding breeds and hybrids, and existing record-keeping practices. The quantitative data comprised two main areas: first, socioeconomic factors and constraints, which included respondent age, family size, years of dairy farming

involvement, land size, costs of bulls and AI services, distance to AI centers, and the stated purposes for keeping hybrid cattle (milk, meat, draft power, and breeding stock), alongside key constraints like lack of AI technicians, poor market linkage, security and high feed prices etc. Second, performance and productivity indicators were measured per lactation, including feed consumption, daily milk yield across lactation stages, milk and feed prices, expenses, income, and detailed reproductive performance indicators such as AAFSM (Age at First Service Mating), WA (Weaning Age), CR (Conception Rate), ANSPC (Annual Non-Service Period Cost), GI (Gestation Interval), CI (Calving Interval), and LL (Lactation Length). This quantitative information also encompassed daily grazing hours, and landholding per household was categorized by breed, blood level, agro-ecology, and milk shed.

Sample Size Determination

Multi-stage, purposive and systematic simple random sampling technique was delivered to select the study areas and dairy owners (who had a minimum of one hybrid dairy cow and more than 8 year of genetic improvement experience). Study areas were stratified based on agro ecologies and milk sheds with a total of 7 districts purposively selected. A total of 3 million dairy cows in the region, 90 dairy cooperatives and 6 dairy unions, 1,300 dairy HHs in Gondar and 1,900 HHs in Bahir Dar milk sheds were identified (ARSCPA, 2006; ARAIC, 2025). So, using Cochran, W.G. (1977) (Cochran, 1977) formula, a total of 3200 dairy owners from both Bihardar and Gondar milk sheds; the adjusted sample size from the known population was 355 dairy owners were selected from 7 districts. Proportionally, 102 dairy owners from Gondar (two districts) and 253 dairy owners from in Bahir Dar (five districts) were considered. About 311 HF, 166 Jersey and 51 locals with a total of 528 dairy hybrids were evaluated with the average hold of near to 1.5 hybrids. The sample size was determined using Yamane's (1967) simplified formula at a 95% confidence interval. So, respondents were proportionally allocated across seven purposively selected districts two from Gondar (102 owners) and five from Bahir Dar (253 owners). The formula was given as, $n = \frac{N}{1 + N(e)^2} = \frac{3,200}{1 + 3,200(0.05)^2} = 355$

Where n = is the sample size N = total population size; e = sampling error

Data Analysis

To evaluate differences and similarities across agro-ecologies and milk shed areas in the study, the Wilcoxon signed-rank test and χ^2 test significances (variation indicated to accept the alternative hypothesis) were employed for non-parametric paired ordinal and ranked data. This test was used to compare farmer responses between midland and highland areas regarding key variables, including socio-demographic characteristics, socioeconomic factors influencing genetic improvement, objectives of keeping hybrid dairy cattle and constraints to dairy production. Specifically, the test assessed whether statistically significant differences existed in the ranked purposes of hybrid cattle keeping such as milk, meat, breeding stock, traction and in the priority ranking of major production constraints like AI service access, feed shortage and market linkage.

Chi-square (χ^2) test was carried out to assess the statistical significance among categorical variables. An index was computed using weighed frequencies and indexes were ranked using auto ranking with R software. The following formula was used to compute index as employed by the following formula $\text{Index} = \frac{\sum (R_n \times C_1 + R_{n-1} \times C_2 \dots + R_1 \times C_n)}{\sum (R_n \times C_1 + R_{n-1} \times C_2 + \dots + R_1 \times C_n)}$ for individual criteria / $\sum (R_n \times C_1 + R_{n-1} \times C_2 + \dots + R_1 \times C_n)$ for overall criteria

Where, R_n = the last rank (example if the last rank is 7th, then $R_n = 7$, $R_{n-1} = 6$, $R_1 = 1$) C_n = number of respondents in the last rank, C_1 = number of respondents ranked first

So, the GLM model is $Y_{ijk} = \mu + X_i + Z_j + XZ_{ij} + e_{ijk}$

Where

Y = performance traits for individual, μ = overall mean of the trait, X_i = fixed effects of individual (blood level), Z_j = fixed effects of the environment (agro ecology) or agro-ecology/milk shed/ Gondar and Bihardar, XZ_{ij} = sub interaction effect, e_{ijk} = random error term

Results

Socio-Demographic and Management Practices of Dairy Farmers

Socio-demographic and management practices of dairy production were showed significant variation across agro ecological zone of the study area (Table 2). The analysis revealed significant differences in sex distribution and marital status between the mid and highland areas of the populations. In midland, males comprised 75.51%, higher than the expected frequency, while in highland, males accounted for only 44.90%, significantly lower than expected ($\chi^2=5.64$, $p = 0.02$). Conversely, females were underrepresented in midland (24.49%) but overrepresented in highland (55.10%), with a highly significant difference ($\chi^2= 14.06$, $p = 0.00$). Regarding marital status, the majority in both regions were married, with no significant difference observed ($p = 0.42$). However, the proportion of single individuals was significantly higher in midland (10.54%) compared to none in highland ($\chi^2= 4.59$, $p = 0.03$), suggesting potential socio-cultural or demographic influences affecting these variables. In contrast, religion, education level and record-keeping practices were relatively consistent between the two groups. Both populations were predominantly Orthodox Christians (96.94% in midland and 100% in highland), with negligible Muslim representation and no significant differences ($p > 0.05$). Education levels showed similar distributions across categories from illiterate to degree holders, with no statistical variation ($p > 0.05$). Record keeping was the critical and common problem in both agro ecologies. Breed preferences indicated a borderline significant higher preference for the HF breed in Highland ($p = 0.05$), while preferences for Jersey or mixed breeds were similar. Overall, these findings suggested that demographic factors such as sex and marital status, along with regional breed preferences, vary between midland and highland populations, whereas religion, education, and record keeping remain relatively uniform. These differences likely reflect underlying socio-cultural and environmental influences impacting livestock management and community dynamics.

Table 2
Socio-Demographic and Management Practices of Dairy Farmers

Variable	Level	Midland Observed (% of 294)	Midland Expected (% of 294)	Highland Observed (% of 49)	Highland Expected (% of 49)	Overall frequency (%)	X ²	p- value
Sex	Male	222 (76%)	209 (71%)	22 (45%)	35 (71%)	244(71%)	5.64	0.02*
	Female	72 (24%)	85 (29%)	27 (55%)	14 (29%)	99(29%)	14.06	0.00**
Religion	Orthodox	285 (97%)	286 (97%)	49 (100%)	48 (98%)	334(97%)	0.02	0.88
	Muslim	9 (3%)	8 (3%)	0 (0%)	1 (2%)	9(3%)	1.13	0.29
Marital Status	Married	262 (89%)	265 (90%)	49 (100%)	44 (90%)	311(91%)	0.66	0.42
	Single	31 (11%)	27 (9%)	0 (0%)	5 (10%)	31(9%)	4.59	0.03*
	Divorced	1 (0.3%)	(0%)	–	–	1(0.3%)	0.02	0.88
Education	Illiterate	34 (12%)	33 (11%)	5 (10%)	6 (12%)	39(11%)	0.20	0.66
	Read & Write	125 (43%)	121 (41%)	16 (33%)	20 (40%)	141(41%)	0.93	0.33
	Diploma	92 (31%)	94 (32%)	18 (37%)	16 (32%)	110(32%)	0.29	0.59
	Degree	43 (15%)	45 (15%)	10 (20%)	8 (16%)	53(15%)	0.59	0.44
Record Keeping	Yes	43 (14.63%)	46 (15.7%)	11 (22%)	11 (21.2%)	54(15.74%)	0.00	1.00
	No	251 (85.37%)	247 (84.3%)	38 (78%)	41 (78.85%)	289(84.26%)	0.00	1.00
Breed Preference	HF	69 (23%)	63 (21%)	5 (10%)	11 (22%)	74(22%)	3.84	0.05*
	Jersey & HF	202 (69%)	207 (70%)	40 (82%)	35 (70%)	242(71%)	0.84	0.36
	Jersey	23 (7.8%)	23 (7.8%)	4 (8%)	4 (8.33%)	72(7.87%)	0.40	0.53

The significant differences observed in sex distribution between midland and highland populations may be attributed to socio-cultural or demographic factors that influence participation of population structure in these regions. Like ways, higher proportion of males in midland compared to highland could reflect gender-specific roles or economic activities related to livestock management, where males may be more involved in certain areas. Conversely, the higher percentage of females in highland might be indicated in migration due to resource scarcity patterns and household labor division adaptation difference. Predominance of married participants suggested that dairy production in these communities was mainly carried out by adults who are likely settled, had families to support and possibly had accumulated knowledge and capital for livestock management and younger individuals are less to involve in this sector.

Table 2 [Insert Here](#)

Socioeconomic Characteristics and Management Factors of Dairy Owners

Socio-economic characteristics of the respondents associated to genetic improvement activities in dairy production across different agro ecological zones and milk sheds in the Amhara region were evaluated. Genetic improvement experiences, age of respondents, cultivated and pasture land holding as sources of feed, bull expense for mating, distance of AI center, price of AI service and family size as labor availability were assessed and summarized in Table 3. So, average dairy owners engaged in dairy farming were approximately 12.25 ± 6.18 years with no significant variation between agro ecologies and milk sheds. Whereas, the mean ages of respondents were about 48.19 ± 9.97 years old with the range of 46.00 ± 8.90 years in Bahir Dar to 52.05 ± 10.9 years in Gondar which suggesting that dairy farming was largely practiced by middle aged households with potentially experienced in dairy production. The current finding was almost similar to the report of Getachew and Tadele (2015) who found that the overall mean age of cattle producer households were middle aged (46.33 ± 12.87 years) in Cencha Woreda, Gamo Gofa Zone of Southern Ethiopia. Whereas, family size was notably larger in the midland areas (6.26 ± 9.92 persons) and in Bahir Dar milk shed (6.41 ± 0.63 persons) compared to their counterparts in the highlands (4 ± 1.56 persons) with average of 5.52 ± 3.03 which might be implied greater labor availability. However, this was often constrained by migration pressures and limited youth engagement in agriculture due to pulling and pushing factors to move. This finding was comparable with the result reported by Addis et al (2016) who reported that average family size was 5.7 persons per family in Gondar town area and Tollossa et al (2014) who reported that the average family size in Borana Oromia region was 7.76 persons per family.

Table 3
Least square mean $\pm$ standard deviation for Socio economy of genetic improvement activities in dairy production

Parameter	Midland	Highland	Bihardar	Gondar	Overall Agro	Overall MS	Overall
Starting years	12.00 $\pm$ 6.50 ^a	12.40 $\pm$ 7.10 ^a	11.97 $\pm$ 6.80 ^a	12.62 $\pm$ 6.00 ^a	12.20 $\pm$ 6.80 ^a	12.30 $\pm$ 6.40 ^a	12.25 $\pm$ 6.20 ^a
Respondents Age (year)	48.27 $\pm$ 6.48 ^b	47.30 $\pm$ 11.00 ^b	46.00 $\pm$ 8.90 ^c	52.05 $\pm$ 11.00 ^a	47.79 $\pm$ 9.00 ^a	49.03 $\pm$ 10.00 ^{ab}	48.41 $\pm$ 9.00 ^a
Family size	6.26 $\pm$ 9.92 ^a	4.00 $\pm$ 1.56 ^c	6.41 $\pm$ 0.63 ^a	5.38 $\pm$ 2.01 ^b	5.90 $\pm$ 1.32 ^b	5.13 $\pm$ 4.74 ^b	5.52 $\pm$ 3.03 ^b
Bull mating expense (ETB)	400.53 $\pm$ 51 ^a	230.00 $\pm$ 45 ^a	330.75 $\pm$ 511 ^a	416.67 $\pm$ 389 ^a	315.27 $\pm$ 277 ^a	353.16 $\pm$ 482 ^a	373.71 $\pm$ 450 ^a
Distance to AI center (km)	2.81 $\pm$ 4.44 ^a	1.40 $\pm$ 1.88 ^a	2.43 $\pm$ 4.48 ^a	3.09 $\pm$ 3.76 ^a	2.67 $\pm$ 4.27 ^a	2.64 $\pm$ 4.26 ^a	2.64 $\pm$ 4.26 ^a
Price of AI service (ETB)	150.86 $\pm$ 319 ^b	18.00 $\pm$ 6 ^d	53.01 $\pm$ 171 ^c	309.24 $\pm$ 428 ^a	137.57 $\pm$ 305 ^b	137.57 $\pm$ 305 ^b	137.57 $\pm$ 305 ^b
Grazing hours/day	4.62 $\pm$ 3.27 ^a	0.67 $\pm$ 1.15 ^b	4.83 $\pm$ 2.62 ^a	5.35 $\pm$ 9.41 ^a	4.49 $\pm$ 3.30 ^a	4.49 $\pm$ 3.30 ^a	3.87 $\pm$ 4.12 ^a
Cultivated land (ha)	1.30 $\pm$ 1.12 ^a	NA	1.25 $\pm$ 1.22 ^a	1.40 $\pm$ 0.86 ^a	1.30 $\pm$ 1.12 ^a	1.30 $\pm$ 1.12 ^a	1.32 $\pm$ 1.08 ^a
Pasture land (ha)	0.31 $\pm$ 0.34 ^a	NA	0.36 $\pm$ 0.38 ^a	0.52 $\pm$ 0.18 ^a	0.31 $\pm$ 0.34 ^a	0.44 $\pm$ 0.34 ^a	0.32 $\pm$ 0.31 ^a
Forest land (ha)	0.32 $\pm$ 0.70 ^a	NA	0.34 $\pm$ 0.73 ^a	0.06 $\pm$ 0.09 ^a	0.32 $\pm$ 0.70 ^a	0.32 $\pm$ 0.70 ^a	0.26 $\pm$ 0.56 ^a

Breeding service access were showed marked differences between zones and natural mating **costs** were higher in the midlands (400.53 $\pm$ 509.68 ETB) and Gondar (416.67 $\pm$ 389.44 ETB) than in the highlands (230 $\pm$ 44.72 ETB). In contrast, artificial insemination (AI) service was significantly more expensive and less accessible in Gondar (309.24 $\pm$ 427.95 ETB; 3.09 $\pm$ 3.76 km) than in Bahir Dar (53.01 $\pm$ 170.78 ETB; 2.43 $\pm$ 4.48 km). Highland farmers paid the least for AI services (18 $\pm$ 6.32 ETB) and were located closest to AI centers (1.40 $\pm$ 1.88 km), suggesting better access to reproductive technologies in these areas. Feeding practices also differed substantially with a grazing hours per day were significantly longer in midland areas (4.62 $\pm$ 3.27hours) and Gondar milk shed (5.35 $\pm$ 9.41hours) compared to the highlands (0.67 $\pm$ 1.15 hours) which reflected inequalities in land availability. Regarding land holdings, averaged cultivated land per household was 1.30 $\pm$ 1.12 hectares with slightly higher figures reported in Gondar (1.4 $\pm$ 0.86 ha) milk shed areas. Pasture land was available primarily in the midland (0.31 $\pm$ 0.34 ha) and Bahir Dar (0.36 $\pm$ 0.38 ha) and Gondar (0.52 $\pm$ 0.18ha) milk shed, while highland areas lacked measurable pasture and forest land which highlighted the major constraints of feed availability. Due to rapid urbanization and provision of communal land to unemployed youth in the area, farmers do not have extra land to develop improved animal feeds and have no access to communal grazing land. Earlier research foundation on the average land holdings per HH from the southern nation, nationalities of peoples republic state (SNNPRS) was 1.16 $\pm$ 0.65ha which is not low compared to the fact that 46.5% of the farmers in SNNPRS households own only 0.1 $\pm$ 0.5ha of farm land (CACC, 2002). The socio-economic characteristics of dairy farmers in Amhara region, including age, landholding, labor availability, and access to breeding services, significantly influenced genetic improvement activities. Middle-aged farmers faced with constraints like limited AI access, high service costs and feed shortages, affecting dairy productivity across diverse agro-ecological zones.

Table 3 [Insert Here](#)

Purpose of Keeping Dairy Cattle Hybrids

The study was investigated the main objectives of keeping hybrid dairy cows across midland and highland agro ecological zones to optimize the feeds, customers, breed type, trait to be improved and management strategies. Similarly, Ethiopian livestock production system is predominantly extensive with indigenous breeds and low-input/low output husbandry practices (Mekuriaw and Lacey, 2021). So, farmers stated that keeping hybrid cows were primarily for immediate cash income through milk sales, followed by breeding stock replacement, fattening for meat and lesser extent for power (Table 4). These priorities were quantitatively analyzed using the Wilcoxon signed-rank test, a nonparametric method suitable for ranked data. The study revealed a strong alignment in the primary purpose of hybrid dairy cow keeping across both midland and highland agro ecological zones were the highest priority with the weighted index values for milk production was 0.39 in the midlands and 0.44 in the highlands with the overall index of 0.41 that clearly illustrated the dominant role of milk as a source of immediate cash income for farmers. This consistency suggested a shift away from traditional roles of cattle toward more specialized and market oriented dairy production systems, driven by income generation rather than cultural or symbolic purposes. In the midlands, breeding stock was ranked second with a weighted index of 0.31, highlighting a strong interest in herd replacement and genetic improvement. Conversely, in the highlands, breeding stock was a lower priority (index = 0.12), while meat production was given greater importance, ranking second with a weighted index of 0.35 compared to 0.18 in the midlands. These variations per agro ecology was due to market opportunities, land use constraints, or household production strategies, where highland farmers possibly choose for meat as a quicker income source due to limited access to breeding infrastructure feed resources. This contrast demonstrates how localized economic and ecological contexts shape farmers' decisions beyond their shared priority for milk production.

Table 4
Purpose of Keeping Hybrid Dairy Cattle across Agro ecologies

Aims	Agro Ecology										In the study Area				Weighted Index Value	Rank	P value
	Midland (294)					highland (49)					Overall index (343)						
	R _{1 F}	R _{2 F}	R _{3 F}	R _{4 F}	weighted index	R _{1 F}	R _{2 F}	R _{3 F}	R _{4 F}	weighted index	R _{1 F}	R _{2 F}	R _{3 F}	R _{4 F}			
Milk	78	19	0	0	0.39	13	7	0	0	0.44	91	26	0	0	0.40	1	
Growth for Meat	17	25	12	3	0.18	12	3	0	2	0.36	29	28	12	5	0.21	3	
Breeding Stock	31	36	19	8	0.30	1	5	2	0	0.14	32	41	21	8	0.27	2	
Power Animal	11	14	14	7	0.13	1	1	1	1	0.06	12	15	15	9	0.12	4	
Sum	137	94	45	18	1	27	16	3	3	1	164	110	48	21	1		
X ² test	5.1					8.57					3.3						
P value	0.002					0.009					0.004						
F = Frequency; R = Rank																	

Table 4 [Insert Here](#)

Major Constraints of Dairy Production

The Major Constraints of Dairy Production were feed price, market linkage, absence of AI technician, land shortage, labor shortage, lack of AI expert, N₂ and semen scarcity, security problem and water scarcity (Table 5). The persistent underperformance of dairy production and the limited realization of genetic improvement gains in northwest Ethiopia were not primarily biological failures, but rather the outcome of layered and interconnected socioeconomic and technical constraints. At the apex of these challenges were security-related disruptions, which emerged as the most critical system-wide constraint (weighted index = 0.30; $p = 0.002$). Insecurity accelerated rural–urban migration, particularly among younger household members, which created acute labor shortages (weighted index = 0.10) and transferred increasingly complex herd management responsibilities to aging farmers with limited physical capacity and institutional support. Beyond labor loss, security instability directly undermined the institutional backbone required for dairy genetic improvement. Farmers’ access to communal grazing lands, veterinary services and timely Artificial Insemination (AI) delivery was severely restricted, effectively breaking the service chain through which improved genetics could have been translated into productivity gains. Weak logistics, labor drain, and mounting economic pressure collectively resulted in low conception rates and compromised the productive performance of genetically improved crossbred cattle, thereby eroding farmers’ confidence in genetic upgrading programs.

Table 5
Major constraints of dairy production from the two major milk shed areas of the Amhara region

No	Major constraints	Milk Shed										Overall				Weighted value	Rank	P-Value
		Bihardar (245)					Gondar (98)											
		R ₁	R ₂	R ₃	R ₄	Index	R ₁	R ₂	R ₃	R ₄	Index	R ₁	R ₂	R ₃	R ₄			
1	Feed Price	17	15	4	1	0.16	6	2	1		0.09	23	17	5	1	0.117	3	0.07
2	Market Linkage	10	2	0	0	0.06	5	2	0	0	0.08	15	4	0	0	0.055	8	0.32
3	Absence of AI Technician	17	11	2	2	0.14	11	4	NA	2	0.17	28	15	2	4	0.126	2	0.04
4	Land Shortage	15	5	2	3	0.11	3	1	NA	NA	0.04	18	6	2	3	0.074	7	0.14
5	Labor Shortage	10	17	9	5	0.15	5	2	NA	NA	0.08	15	19	9	5	0.107	4	0.05
6	Lack of AI Expert	11	6	7	2	0.10	8	6	3	NA	0.16	19	12	10	2	0.102	5	0.02
7	N ₂ and semen	2	9	14	2	0.09	6	5	1	NA	0.12	8	14	15	2	0.081	6	0.18
8	Security	16	30	0	0	0.20	18	5	2	1	0.27**	34	75	15	1	0.299	1	0.002
9	Water Scarcity	NA	NA	NA	NA	NA	6	7	3	2	0.13	6	7	3	2	0.040	9	
	Sum	98	95	38	15	1	68	34	10	5	1	166	169	61	20	1		
	χ ²						8.43					18.68				11.27		
	P- Value						0.023					0.009				0.02		
NA = Not available or not rated during ranking, AI = Artificial Insemination																		

These systemic failures were compounded by critical technical bottlenecks. The shortage of functional AI technicians ranked as the second most important constraint (weighted index = 0.13; $p = 0.04$), reflecting a fragile service infrastructure that was incapable of supporting sustained genetic upgrading. Feed-related constraints further intensified these challenges. The high cost and limited availability of quality feed (weighted index = 0.12), with pronounced spatial variation being particularly severe in Bahirdar continued to suppress milk yield and reproductive efficiency. The poor performance of crossbred cattle observed in this study was further contextualized by the broader national productivity landscape, where indigenous cattle produced only an average of 1.35 liters of milk per cow per day (Mekuriaw and Lacey, 2021), and where the national prevalence of improved genetics remained extremely low, with only 2.2% of the cattle population comprising hybrid and exotic breeds (CSA, 2020a). These baseline limitations amplified the vulnerability of genetic improvement programs to systemic shocks and management failures. Finally, the statistically significant spatial variation in the severity of constraints ($\chi^2 = 11.27$; $p = 0.02$) underscored the inadequacy of uniform intervention approaches. Instead, the findings highlighted the necessity for regionally tailored, context-specific strategies to address the structural and institutional deficiencies that continued to undermine the effectiveness and sustainability of dairy genetic improvement initiatives in northwest Ethiopia.

Table 5 [Insert Here](#)

Performance of Crossbred Dairy Cattle

Main effects on AAFSM, MY, CI, NSPC, CR, GI, WA, LL, milk price, feed price/kg, FCPD in kg and expense and incomes per lactation in different blood level for optimization was evaluated (Table 6). Main effects influenced each individual as a single factor affect performances without the complexity of other interactions. Meanwhile, HF hybrids showed the highest in the average milk yields (13.52 ± 4.19 liters/day) and Jersey were significantly superior in performances (10 ± 4.81 liter/day) than local dairy cows (1.99 ± 0.81 liter/day). Similarly, 50% HF*Fogera hybrids were produced 10.87 ± 3.76 liters/day from Debretabor city (Sena et al., 2014). Whereas, the average CI (1.41 ± 0.80 years) and AAFSM (1.66 ± 2.10 years) of HF hybrids than AAFSM of local (3.60 years) and 2.02 ± 3.15 years of Jersey hybrids. This earlier maturity increases the lifetime output and speeds herd replacement. Jersey hybrids are better in NSPC (1.40 ± 0.58) and CR (81.29 ± 24.01) than HF with NSPC and CR of 1.49 ± 0.57 and 76.03 ± 24.39 , respectively indicating that more inseminations for locals required more time, money and feed consumption expenses. However, HF hybrids consumed more feed per day (FCPD: 7.05 ± 1.88 kg versus 5.40 ± 1.10 kg for local cattle). NSPC was declined when HF blood level was increasing (50, 62.5, 75 and beyond 75%) aligned with the findings (Beneberu, 2023) and (Kefale, 2018) who documented that first-generation (F1) at 50% to 75% exotic blood exhibited optimal performance under Ethiopian conditions, while (F2 > 75%) showed a declined trends due to heterosis loss and adaptation challenges. Crossbreeding had a similar effect on CI (373 days) and an AAFSM of 2.75 years (Nibo, 2023). Specifically, Jersey crossbreds were reported to have produced around 10.00 ± 4.81 liters of milk per day, while HF hybrids were produced approximately 13.52 ± 4.69 liters per day (35; 36). The current study was aligned with on-station and on-farm average milk yield per lactation of HF hybrids (1293 to 2957 liters) with daily milk yields of 4.18 liters to 9.91 liters, respectively (Kefale, 2018). HF hybrids with 50% blood level produced an average lactation milk yield of 2203.23 ± 38.13 liters at Holetta research center (Kefale, 2018). This was lower than the current finding, 50% HF hybrids produced an average of 2856.62 ± 1253.42 liters per lactation. In addition almost similar report was presented from Holetta Agricultural Research Center (HARC) on lactation yields for HF crosses was 1,293 to 2,957 kg under research station and average daily yields was 4.18 to 8.7 liters and 9.91 liters on farms. Notably, 75% HF × Borena crossbreds at the HARC attained 2,900 kg/LL and 7 liters per day and 2,333 kg/LL at Jimma farms (Kefale, 2023). Similarly, 7.3 to 8.8 liters/day with LL of 10.4 months for crossbreds (50–75% exotic blood) was performed (38). Moreover local breeds also had a longer weaning age

at 12.19 ± 8.06 months, while HF and Jersey hybrid calves were weaned at age of 7.32 ± 2.50 and 7.54 ± 2.90 months, respectively. Surprisingly hybrids were milking after WA and local breeds weaned after lactation was stopped. Income per lactation progressively increased across breed types and exotic blood levels. Local breeds generated an average income of 35,500.93 ± 10,902.71 ETB per lactation. Whereas, Jersey hybrids, income rose significantly with higher exotic blood levels like 50%, 62.5%, 75%, and above 75% Jersey earned 163975.71 ± 72096.15, 162403.4 ± 140454.67, 134239.83 ± 55543.25 and 167811.86 ± 30,180.19, respectively with the average of 157107.70 ± 74568.57 ETB. Similarly, HF hybrids earned 178538.39 ± 87715.82 at 50% exotic blood level, increasing to 211447.89 ± 99183.22, 256094.13 ± 36458.06 and peaking at 275693.93 ± 133540.29 above 75% with bigger outliers. Therefore, unstable superiority and inferiorities performance paradox was observed from different hybrids so as to think to calculate composite index of score (CIV) (Debir, 2016).

Table 6
Main Effect of Genetic Improvement on the Performances of Animal Breeding in the Study Area

No	Characters	Local	Jersey Hybrids (%)					HF Hybrids (%)				
			50	62.5	75	> 75	Overall	50	62.5	75	> 75	
			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
1	NSPC	2.01 ± 0.75	1.39 ± 0.55	1.40 ± 0.89	1.49 ± 0.53	1.30 ± 0.35	1.40 ± 0.58	1.71 ± 0.68	1.48 ± 0.57	1.39 ± 0.58	1.39 ± 0.58	
3	AAFSM (year)	3.35 ± 1.13	2.86 ± 3.89	1.8.02 ± 7.46	1.75 ± 0.59	1.65 ± 0.65	2.02 ± 3.15	1.84 ± 0.55	1.62 ± 0.47	1.56 ± 0.42	1.62 ± 0.42	
4	WA (month)	12.19 ± 8.06	7.38 ± 2.86	6.8 ± 2.95	8.00 ± 2.80	8.00 ± 3.01	7.54 ± 2.90	8.57 ± 3.11	7.18 ± 2.12	6.61 ± 2.06	6.90 ± 2.06	
5	LL/ Month	11.69 ± 4.97	8.07 ± 2.06	8.6 ± 1.52	7.61 ± 1.70	6.64 ± 0.50	7.73 ± 1.44	9.23 ± 2.32	8.80 ± 1.83	8.07 ± 1.86	7.50 ± 1.86	
6	GI (year)	5.12 ± 1.50	4.51 ± 1.29	5.06 ± 0.78	4.34 ± 1.07	3.9 ± 0.77	4.45 ± 0.98	5.4 ± 1.63	4.73 ± 1.04	4.44 ± 0.75	4.50 ± 0.75	
7	CI (year)	2.17 ± 0.82	2.96 ± 4.72	1.16 ± 0.18	1.32 ± 0.28	1.26 ± 0.27	1.68 ± 1.36	1.51 ± 0.52	1.30 ± 0.26	1.20 ± 0.31	1.60 ± 0.31	
8	Early my/day	3.21 ± 1.15	10.61 ± 4.25	13.4 ± 5.32	12.28 ± 5.10	14.52 ± 6.82	12.59 ± 2.64	13.56 ± 4.57	16.25 ± 4.92	17.75 ± 5.55	23.00 ± 5.80	
9	Mid my/day	1.79 ± 0.88	8.13 ± 3.67	11 ± 4.06	9.13 ± 4.73	11.43 ± 5.83	9.85 ± 2.28	10.94 ± 3.75	12.6 ± 4.18	13.66 ± 5.22	17.00 ± 6.40	
10	Late my/day	0.97 ± 0.53	6.33 ± 3.02	8.4 ± 3.97	6.39 ± 3.70	8.43 ± 5.80	7.17 ± 2.15	8.02 ± 3.58	9.17 ± 4.01	9.94 ± 4.70	13.00 ± 6.20	
11	Average my/day	1.99 ± 0.81	8.27 ± 3.52	10.93 ± 4.42	9.71 ± 5.16	11.10 ± 6.16	10.00 ± 4.81	10.87 ± 3.76	12.67 ± 4.10	13.78 ± 4.97	16.00 ± 5.90	
12	MY/LL	697.89 ± 201.78	2,004.65 ± 1036.19	2478 ± 1032.84	2213.18 ± 1058.04	2403 ± 1418.04	2274.09 ± 1131.41	2856.62 ± 1253.42	3245.92 ± 1178.72	334 ± 1329.65	364 ± 144	
13	Milk Price	63.08 ± 9.29	65.33 ± 11.70	88 ± 17.89	62.61 ± 8.90	64.29 ± 10.54	70.06 ± 12.26	65.32 ± 15.10	64.62 ± 17.86	75.28 ± 19.10	71.00 ± 18.00	
14	Feed Price/Kg	29.26 ± 11.39	40.72 ± 9.75	42.4 ± 9.45	41.91 ± 8.30	39.71 ± 5.57	41.18 ± 8.27	42.83 ± 10.04	41.10 ± 12.19	58.81 ± 36.16	41.00 ± 9.30	
15	FCPD In Kg	3.40 ± 1.10	5.48 ± 1.29	5.43 ± 0.46	5.31 ± 1.02	5.40 ± 1.66	5.40 ± 1.11	6.11 ± 1.56	7.37 ± 1.76	7.89 ± 2.25	6.80 ± 2.25	
16	Expense/LL	34,889.04 ± 9998.14	61173.50 ± 23028.49	61476.8 ± 13846.36	73288.57 ± 56964.52	42956.14 ± 18765.31	59723.75 ± 28151.17	72716.48 ± 28616.78	80787.43 ± 31033.77	116051.30 ± 93789.93	678 ± 36	
17	Income Per Lactation	44,022.9 ± 12728.28	167811.86 ± 30,180.19	162403.4 ± 140454.67	134239.83 ± 55543.25	163975.71 ± 72096.15	157107.70 ± 74568.57	178538.39 ± 87715.82	211447.89 ± 99183.22	256094.13 ± 136458.06	275 ± 133	

CR = Conception rate, NSPC = numbers of service per conception, GI = generation interval, FCPD = feed consumed per day, CI = calving interval, WA = weaning first sexual maturity, LL = lactation length, MY/LL = milk yield per lactation

Table 6 [Insert Here](#)

Conclusions

The study conclusively demonstrated that despite Ethiopia's strong potential for dairy genetic improvement change as hybrid vigor, the sustainable effectiveness of dairy cattle genetic improvement programs in Northwest Ethiopia. Keeping of hybrid dairy cows was to increase milk production, which serves as a key source of immediate cash income for owners followed by breeding replacement stock and growth massive animal for meat production. This reflected a shift from traditional multipurpose cattle use to specialized, market-oriented dairy systems, where milk yield, reproductive efficiency, and fast growth are highly prioritized traits for economic gains. Local market and ecological conditions are affecting farmers' management and breeding decisions.

However this was severely compromised by a combination of systemic socioeconomic and technical bottlenecks. The single greatest hindrance is security-related disruptions, which restrict smallholder farmers' access to essential inputs and services, compounding technical failures like shortages of AI technicians, escalating feed costs, and inconsistent semen quality. Genetic performance exhibited an unstable performance paradox where high-potential exotic crosses display conflicting trade-offs. Holstein Friesian (HF) hybrids are genetically and economically superior in productivity, showing the highest daily milk yields and subsequent Income per lactation. However, Jersey hybrids proved superior in reproductive efficiency, achieving a significantly lower number of services per conception (NSPC) and higher conception rate (CR) than HF. The optimal performance threshold for crossbreds was confirmed to lie between 50% to 75% exotic blood before performance declines.

Recommendations

- To advance sustainable dairy productivity, immediate policy action must focus on three critical areas:
- Addressing the foundational security barriers to ensure service and input access,
- Strengthening the reproductive service supply chain to improve AI efficiency, and
- Adopting a balanced, multi-trait selection strategy (potentially utilizing a Composite Index Score) to know the optimum average performances of hybrids while accounting for local environmental adaptability.

Declarations

Declaration of Interest Statement

As correspondent author, Addis Getu has submitted this comprehensive statement on behalf of all co-authors, in line with global standards for research transparency and publication ethics. We declare that there are no financial, commercial, or non-financial interests that could reasonably be regarded as influencing the objectivity, interpretation, or presentation of the results detailed in this manuscript.

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Availability of data and materials

The raw data supporting the analyses in this study are available from the corresponding author, Addis Getu, upon reasonable request.

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