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Evaluation of Artificial Insemination Efficiency and Reproductive Performance Traits in Smallholder Dairy Farms of West Wallaga Zone, Ethiopia

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Abstract

Ethiopia's livestock sector, the largest in Africa, plays a crucial role in the national economy, significantly contributing to agricultural GDP and foreign currency earnings. Despite its size, the productivity of Ethiopian livestock is notably low due to inadequate management practices, limited genetic diversity, and insufficient animal health services. The predominance of local breeds and the limited use of crossbreeding and artificial insemination (AI) pose challenges for improving livestock productivity. Smallholder farmers, who manage most of the cattle population, often lack systematic breeding practices and face obstacles in adopting AI. This study investigates the efficiency of AI in smallholder dairy farms within the West Wallaga zone, focusing on the reproductive performance differences between local and crossbred cows. The primary objective is to analyze the reproductive performance of local and crossbred cows and examine the impact of management practices on conception rates and delivery outcomes across different districts. Using Multiple Correspondence Analysis (MCA), this study evaluates conception status and delivery outcomes across various districts and years. The analysis highlights variations in reproductive traits, such as conception rates, calving intervals, and healthy calf deliveries. Findings indicate that crossbred cows achieve earlier reproductive milestones and higher milk yields than local breeds. Conception rates vary significantly across districts, with notable increases in Lalo Asabi, while Gimbi remains stable. The analysis also reveals differences in delivery outcomes, with Gimbi showing consistent results and Lalo Asabi experiencing fluctuations, including rising abortion rates. This study underscores the complexities influencing fertility outcomes in Ethiopian livestock, emphasizing the need for improved reproductive management strategies tailored to regional conditions. Addressing the identified challenges will be crucial for enhancing livestock productivity and supporting the livelihoods of smallholder farmers in the region.

Keywords: Artificial Insemination; Crossbreeding; Smallholder Dairy; Reproductive Performance

Abbreviations: AI: Artificial Insemination; MCA: Multiple Correspondence Analysis

Introduction

Ethiopia is home to the largest livestock population in Africa, with approximately 70 million cattle, 42.9 million sheep, 52 million goats, 8.1 million camels, and 59.5 million chickens [1]. Livestock production plays a crucial role in the country's economy, contributing between 35% and 49% of the agricultural GDP and accounting for 16% to 17% of national foreign currency earnings [2].

Despite this rich diversity in animal genetic resources, the productivity of Ethiopian livestock remains low. Local cattle breeds make up 97.4% of the population, with crossbreeds and exotic breeds comprising only 2.32% and 0.31%, respectively. This underperformance is attributed to several factors, including poor management practices, limited genetic potential, inadequate animal health services, and regional disparities [3,4]. To address these challenges, experts have advocated for selective breeding and crossbreeding local cattle with highly productive exotic breeds as strategies to improve local livestock productivity [5].

In Ethiopia, cattle production is primarily practised by smallholder farmers, who rely on animals for multiple purposes, including milk, meat, and labour. However, there is limited specialization or systematic breeding in the sector [6]. Artificial insemination (AI) has long been considered a promising method to enhance the genetic potential of dairy cattle. Yet, its adoption has been limited, with significant regional differences in farmers' awareness and acceptance of AI technology [7]. The efficiency of AI services remains low due to challenges such as inadequate heat detection, poor insemination timing, infrastructure issues, and financial constraints [8]. Furthermore, the absence of a robust record-keeping system, problems in oestrous detection, suboptimal selection methods, and insufficient management of AI bulls and inseminated cows further compound the problem [9].

In West Wallaga zone, AI adoption faces numerous obstacles. Despite the significance of these challenges, little research has been conducted on the factors affecting AI efficiency in dairy farms in this region. This study aims to fill this research gap by evaluating the reproductive performance traits and AI efficiency in smallholder dairy farms of West Wallaga Zone.

Materials and Methods

Description of the Study Area

The study was conducted in three districts (i.e. Gimbi, Najo, and Lalo Asabi) of West Wallaga zone, Oromia regional state of Ethiopia. West Wallaga lies at 9.4378°N, and 35.3905°E. West Wallaga has a wet tropical and receives an annual rainfall between 1000 - 2200 and is characterized by a light rain that starts in April and heavy rain continues from May up to September. Mixed crop-livestock is the major agricultural system of the district and Vegetable crops, and Coffee are major cash crops produced. (Figure 1)

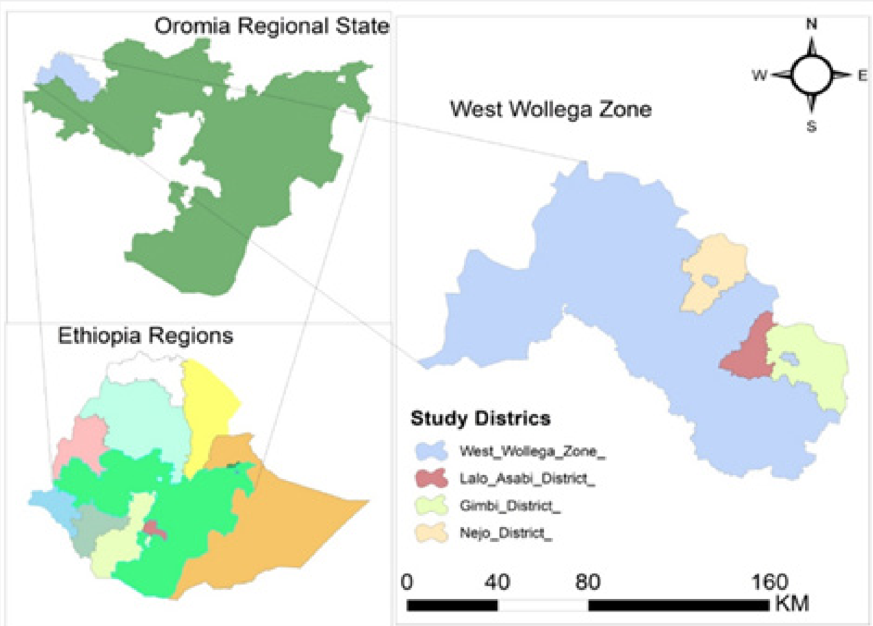

Figure 1: study area map.

Study Population

The districts (i.e. Gimbi, Najo, and Lalo Asabi) were selected among the 21 districts of the West Wallaga zone based on purposive sampling on their huge livestock population and utilization of AI. This study utilized data collected from the record books of Artificial Insemination (AI) centres within Animal Health Clinics across selected districts. Data were gathered from AI certificates and insemination casebooks for the period between 2019 and 2022. The study included only cows with complete and comprehensive records, focusing on key reproductive parameters (such as age at first calving, parity, number of services per conception, and overall conception rates). Analyzing this data was aimed at assessing AI service performance and reproductive performance.

Data Analysis

For all statistical data analyses (analysis of variance and multiple correspondence analysis), SAS JMP Pro version 18 [10] was used.

Analysis of Variance: Reproductive performance traits (AFS, AFC, CI, DO, MY) were subjected to a two-way analysis of variance using the general linear model procedure of SAS JMP Pro software to determine the effect of breed and parity. Treatment means were separated using the Tukey test at a 95% confidence interval. The linear model employed was:

$$Y_{ij} = \mu + B_i + P_j + \varepsilon_{ij}$$

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where:

Y_{ij} = Observed value of the reproductive performance traits (AFS, AFC, CI, DO, MY)

μ = Overall mean

B_i = Fixed effect of the i^{th} breed of cow (i = 2: local, crossbred)

D_j = Fixed effect of the j^{th} district (j = 3: Lalo Asabi, Ginbi, Najo)

ε_{ij} = Random residual error term

Multiple Correspondence Analysis (MCA): Retrospective data collected from 2019 to 2022 on the conception status of cows, delivery status of pregnant cows, and sex of calves born in each study district was subjected to multiple correspondence analysis. To examine the association among the categorical variables (i.e., conception status [conceived/not conceived], delivery status [delivered/aborted], sex of calf [male/female], year [2019 – 2022], and district [Gimbi, Lalo Asabi, Najo]) together.

Results and Discussions

Effect of Breed and District on Reproductive Performance Traits

The two-way ANOVA results provide insights into the reproductive performance traits of local and crossbred cows. The key factors analyzed-breed and district-significantly influenced various traits, with breed having a stronger effect on most variables. (Table 1)

Table 1: Least square means results of reproductive performance traits.

	Effect & Level	AFS	AFC	DO	CI	MY	NSPC
		LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Breed	Local	46.5^a±0.1	55.5^a±0.2	186.8^a±0.2	17.4^a±0.1	485.0^a±32.5	1.9^a±0.1
	Crossbred	35.9^b±0.2	45.2^b±0.2	183.0b±0.2	16.1^b±0.2	1028.5^b±40.7	1.7^b±0.0
	P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0499*
District	Lalo Asabi	40.9^a±0.2	50.1^a±0.2	184.9^a±0.3	16.7^a±0.2	744.7^a±38.2	1.9^a±0.1
	Ginbi	40.8^a±0.2	50.9^a±0.2	184.5^{ab}±0.3	16.5^a±0.2	806.8^a±39.8	1.9^a±0.1
	Najo	41.3^a±0.2	50.4^a±0.2	185.5^b±0.3	16.4^a±0.2	718.5^a±38.9	1.6^b±0.1
	P-value	*0.1013*	*0.0882*	*0.0047*	*0.8196*	*0.2532*	*0.0009*

^{a,b} means on the same column with different superscripts for a given trait are significantly different (P<0.05); ns = not significant; AFS = age at first service; AFC = age at first calving; DO = days open; CI = calving interval; MY = milk yield; NSPC = Number of services per conception.

Breed Effects

The analysis shows statistically significant differences between local and crossbred cows for all reproductive performance traits (P < 0.05). Crossbred cows exhibited a lower age at first service (35.9 months) compared to local cows (46.5 months), indicating that crossbred cows mature reproductively at a younger age. Similarly, crossbred cows calved earlier, with a lower age at first calving (45.2 months) than local cows (55.5 months). This earlier achievement of reproductive milestones in crossbred cows suggests greater genetic potential for reproductive efficiency [11].

In terms of postpartum reproductive health, crossbred cows had fewer days open (183 days) compared to local cows (186.8 days). A shorter number of days open reflects quicker postpartum recovery and earlier conception, further indicating better reproductive health in crossbred cows [12]. Crossbred cows also demonstrated a shorter calving interval (16.1 months) compared to local cows (17.4 months), which is consistent with their faster recovery and fewer days open.

Milk yield was substantially higher in crossbred cows (1028.5 liters) compared to local cows (485 liters). This finding aligns with the established benefits of crossbreeding, particularly in improving productivity through increased milk yields [13]. Although the difference in the number of services per conception (NSPC) between breeds was small, it was statistically significant (P = 0.0499). Crossbred cows required fewer services (1.7) than local cows (1.9), which reflects a higher reproductive efficiency.

District Effects: In contrast to breed, districts had less impact on reproductive traits. No significant differences were found in age at first service (P = 0.1013) or age at first calving (P = 0.0882) across districts, indicating that local environmental factors may not play a critical role in determining when cows reach reproductive milestones.

However, days open (P = 0.0047) and NSPC (P = 0.0009) did vary significantly across districts. Cows in Najo had slightly longer days open (185.5 days) than those in Lalo Asabi (184.9 days) and Ginbi (184.5 days), though this difference is minor, and its biological significance is unclear. For NSPC, cows in Najo required fewer services per conception (1.6) compared to those in Lalo Asabi and Ginbi (1.9), suggesting better fertility or management practices in Najo [14].

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Milk yield did not significantly differ across districts (P = 0.2532), although cows in Ginbi produced slightly more milk (806.8 litres) than those in Lalo Asabi (744.7 liters) and Najo (718.5 liters). These findings suggest that breed, rather than district, has a more substantial influence on milk production [15].

The study's results highlight the advantages of crossbreeding local cows with exotic breeds in terms of reproductive efficiency and milk yield. Crossbred cows reach reproductive maturity earlier, have shorter calving intervals, and produce more milk, findings that align with previous research on the benefits of crossbreeding [16]. While district-specific factors such as NSPC and days open warrant further investigation, breed remains the dominant factor in influencing reproductive performance. Thus, improving breeding practices and expanding crossbreeding programs may significantly enhance productivity.

Multiple correspondence Analysis (MCA)

Pearson chi-square test of independence was conducted to assess the relationship between district (Lalo Asabi, Gimbi, and Najo) and year (2019–2022) on the conception status (conceived/not conceived), delivery status (healthy calf birth/aborted), and sex of calf born (female/male) of inseminated cows. These analyses aimed to determine if conception status, delivery status, and sex of calf born were significantly different across districts over the study period.

Conception status (conceived/not conceived) of cows in the study districts: Table 2 below shows the results of the conception status of inseminated cows. The results from each district show distinct patterns in conception and non-conception rates.

Table 2: Conception status of inseminated cows across study districts.

Effect & Attributes 2019		Year				X^2	P value
		2020	2021	2022			
Lalo Asabi	Conceived	410 (17.8%)	501 (21.8%)	499 (21.7%	548 (23.9)	23.96	0.0001
	Not conceive	102 (4.4%)	60 (2.6%)	99 (4.3%)	74 (3.2%)		
Gimbi	Conceived	450 (19.8%)	470 (20.6%)	542 (23.8%	502 (22%	3.87	0.2754
	Not conceived	58 (2.6%)	80 (3.5%)	82 (3.6%)	90 (4%)		
Najo	Conceived	502 (17.2%)	520 (17.8%)	522 (17.9%	562 (19.3%)	15.39	0.0015
	Not conceived	150 (5.1%)	230 (7.9%)	180 (6.2%)	248 (8.5%)		

Lalo Asabi experienced a notable increase in conception rates over the study period. The percentage of cows that conceived increased from 17.8% in 2019 to 23.9% in 2022, while non-conception rates decreased from 4.4% to 3.2%. The chi-square test revealed a significant association between year and conception status (P = 0.0001). This improvement may reflect enhancements in reproductive management and environmental factors, consistent with findings in other studies on herd management and insemination techniques [17].

In Gimbi, conception rates remained relatively stable, fluctuating from 19.8% in 2019 to 22% in 2022. The non-conception rate saw a slight increase, from 2.6% in 2019 to 4% in 2022. However, the chi-square test showed no significant association between year and conception status (P = 0.2754). This stability might indicate consistent environmental conditions and insemination practices, as suggested by [18], who found that districts with stable herd management practices often maintain steady reproductive outcomes.

Najo showed a mixed trend, with conception rates rising from 17.2% in 2019 to 19.3% in 2022. Simultaneously, non-conception rates also increased, from 5.1% to 8.5%. The chi-square test demonstrated a significant relationship between year and conception status (P = 0.0015). The simultaneous rise in both conceived and non-conceived outcomes suggests that multiple factors, such as insemination practices, nutritional challenges, or health issues, could be affecting fertility. Similar findings on the complexity of reproductive success have been discussed by [19].

Multiple correspondence analysis (MCA) identified key patterns in the data, revealing six dimensions, with the first two explaining a substantial portion of the variance. Figure 2 presents a bi-dimensional plot illustrating the relationships among variables.

Dim 1 accounted for 19.58% of the total inertia, while Dim 2 explained an additional 16.83%, contributing to a cumulative variance of 36.40%. These results indicate that the variation in conception status across districts and years is meaningful and not due to random chance. According to [20], a cumulative variance above 30% in MCA typically reflects a robust pattern of association in categorical datasets. (Table 3)

The interpretation of the first two dimensions provides insight into how each category relates to conception status. In Dim 1, the conception status of "not conceived" is strongly associated with positive values (coordinate = 1.524), while "conceived" aligns with negative values (coordinate = -0.367). This suggests that the first dimension differentiates between successful and unsuccessful

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conception outcomes. Specifically, districts and years with higher contributions to Dim 1 are more closely associated with failed conception (i.e., not conceived), while those with lower scores tend to correspond with conception success.

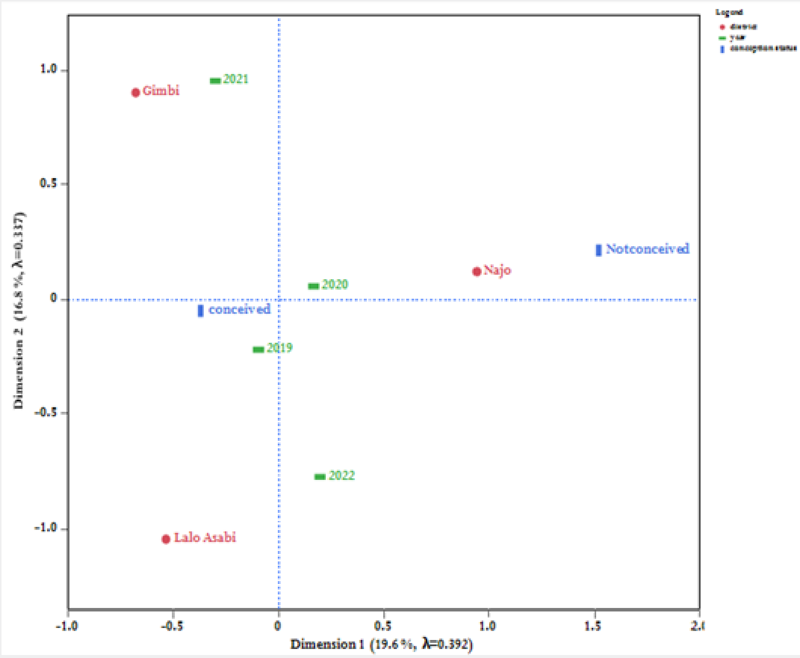

Figure 2: A bi-plot display of the conception status of inseminated cows.

Table 3: Inertia and column coordinates of conception status

Inertia				Column Coordinates			Partial Contribution	
SV	Inertia	X^2	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.62571	0.39151	8873.8	19.58	Gimbi	-0.675	0.902	0.11794	0.24521
0.58011	0.33653	7627.6	16.83	Lalo Asabi	-0.531	-1.048	0.07349	0.33354
0.57761	0.33363	7561.9	16.68	Najo	0.944	0.121	0.29578	0.0056
0.57709	0.33303	7548.3	16.65	2019	-0.092	-0.22	0.0016	0.01073
0.57312	0.32846	7444.8	16.42	2020	0.171	0.056	0.00617	0.00078
0.52616	0.27684	6274.8	13.84	2021	-0.297	0.954	0.01927	0.23173
				2022	0.201	-0.776	0.00929	0.16153
				Conceived	-0.367	-0.051	0.09254	0.00211
				Not conceived	1.524	0.214	0.38391	0.00877

SV = singular value; X^2 = chi-square; Dim = dimension

For Dim 2, the district of Lalo Asabi shows a strong negative association with this axis (coordinate = -1.048), while Gimbi is positively associated (coordinate = 0.902). This differentiation indicates that the outcomes in these two districts are significantly different. Lalo Asabi tends to be associated with lower conception success in comparison to Gimbi. Previous studies have shown that regional disparities in cattle reproduction can be linked to differences in environmental conditions and herd management practices [19], which might explain the divergence between these districts.

District-Level Associations

The column coordinates reveal distinct patterns in how the districts relate to conception outcomes. Najo, with a positive coordinate on Dim 1 (0.944), appears to be more closely associated with "not conceived" outcomes compared to Lalo Asabi and Gimbi. This suggests that Najo experienced higher levels of failed conception relative to the other districts, particularly when examining the cumulative effects over the four years. In contrast, Gimbi is positioned negatively on Dim 1 (-0.675), indicating that it is more associated with successful conception. The partial

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contributions to inertia confirm that Najo contributed the most to Dim 1 (29.58%), further reinforcing its association with failed conception outcomes.

Year-Level Associations

Regarding the influence of the year, the years 2021 and 2022 had notable associations with conception outcomes. Specifically, 2021 showed a positive association with Dim 2 (coordinate = 0.954), indicating a higher likelihood of conception failure in that year. The partial contribution to inertia for 2021 (23.17%) further underscores its impact on the overall variation in the data. Conversely, 2022 had a negative association with Dim 2 (coordinate = -0.776), suggesting that conception outcomes improved slightly in that year. The steady improvements in conception rates during 2022 could reflect advancements in reproductive management strategies, as well as environmental factors that may have influenced fertility, as has been observed in other studies [21].

Conception Status

The results also highlight the stark difference between conceived and not conceived outcomes. The category "not conceived" contributed the most to Dimension 1 (38.39%), reflecting the strong differentiation between successful and failed conceptions across the districts and years. This result underscores the importance of analyzing how environmental, management and regional factors impact reproductive outcomes, as has been emphasized by previous research [22].

Delivery status (healthy calf birth/aborted) of pregnant cows

The results of the delivery status (Table 3) of pregnant cows show distinct patterns in healthy calf born and aborted.

(Table 4)

Table 4: Delivery status of pregnant cows across study districts.

Effect & Attributes 2019		Years				X^2	p-value
		2020	2021	2022			
Lalo Asabi	Health calf born	368 (18.8%)	438 (22.4)	415 (21.2%)	469 (24%)	9.07	0.0284
	Aborted	42 (2.1%)	63 (3.2%)	84 (4.3%)	79 (4%)		
Gimbi	Health calf born	380 (19.3%)	412 (21%)	455 (23.2%	440 (22.4%	4.96	0.1747
	Aborted	70 (3.6%)	58 (3%)	87 (4.4%)	62 (3.2%)		
Najo	Health calf born	420 (19.9%	431 (20.4%)	430 (20.4%	445 (21%)	4.28	0.2325
	Aborted	82 (3.9%)	89 (4.2%)	92 (4.4%)	117 (5.6%)		

In Gimbi district, the proportion of cows that successfully delivered healthy calves increased slightly from 19.3% in 2019 to 22.4% in 2022. However, the percentage of abortions showed less variation, fluctuating between 3% and 4.4% over the same period. The chi-square test revealed no statistically significant association between year and delivery status in Gimbi (P=0.1747). This result suggests that delivery outcomes in Gimbi have remained relatively stable throughout the four-year period, potentially due to consistent management practices or environmental factors. Previous studies have found that stable environmental conditions and routine herd management are often linked to steady reproductive performance [22].

Lalo Asabi district exhibited more pronounced changes in delivery outcomes over time. The percentage of cows that delivered healthy calves increased from 18.8% in 2019 to 24% in 2022, representing a significant improvement. However, the abortion rate also increased slightly, from 2.1% in 2019 to 4% in 2022. The chi-square test indicated a significant association between year and delivery status in Lalo Asabi ($P<0.05$). The increase in both healthy deliveries and abortions could suggest improvements in fertility interventions, such as insemination techniques, alongside challenges like disease outbreaks or suboptimal nutrition affecting pregnancy outcomes. This aligns with findings from [23], who observed that improvements in reproductive interventions can lead to both higher pregnancy success rates and increased risk of pregnancy loss when other stressors are present.

In Najo, the proportion of cows delivering healthy calves remained relatively stable, ranging from 19.9% in 2019 to 21% in 2022. However, the abortion rate increased steadily over the same period, rising from 3.9% in 2019 to 5.6% in 2022. Despite these trends, the chi-square test did not reveal a significant association between year and delivery status in Najo (P=0.2325). This lack of significance suggests that while there has been an increase in abortions, the overall pattern of reproductive outcomes has not changed dramatically. It may be beneficial to investigate potential underlying causes, such as disease prevalence or nutritional deficits, that could be contributing to the increasing abortion rates in Najo. According to [21], rising abortion rates in cattle can be linked to environmental stressors or infectious diseases, which can vary between regions.

The MCA outputs are summarized in terms of inertia, singular values, and the contribution of each category to the first two dimensions. The cumulative percentage explained by these two dimensions reached 34.86%, indicating a moderate proportion of the variance captured by the first two dimensions of the analysis. Figure 3 below shows a bi-dimensional graph representing the associations among the categories of the analyzed variables.

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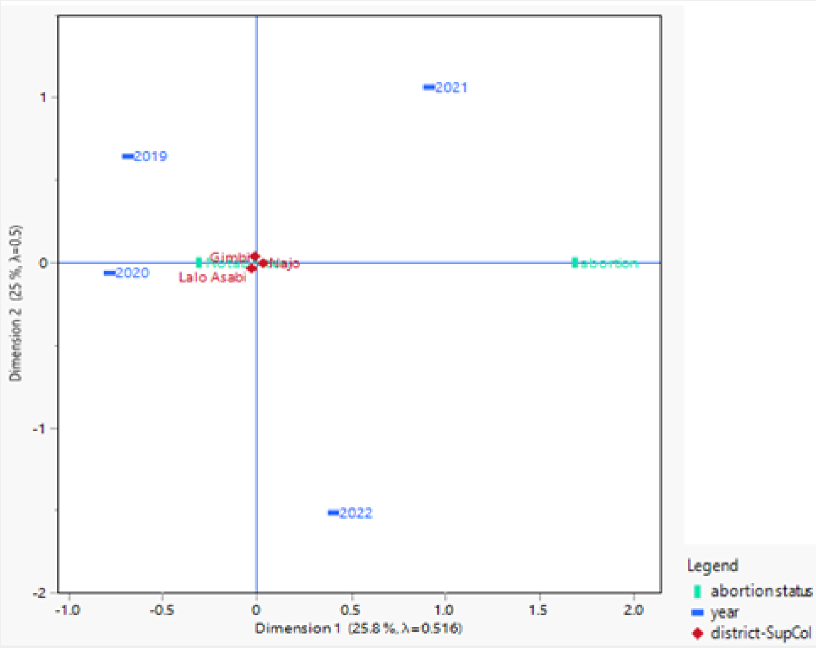

Figure 3: A bi-plot display for the delivery status of pregnant cow.

Singular Value and Inertia Contributions: The inertia values across the dimensions ranged from 0.30847 to 0.35321, reflecting the degree to which each dimension contributes to the overall variance in the dataset. Dim 1 explained 17.66% of the total variance, while Dim 2 explained an additional 17.2%, cumulatively accounting for 34.86% of the variance. Though these dimensions do not explain most of the variation, they provide meaningful insight into the relationships between variables [23].

Association Between Districts and Delivery Status: A closer examination of the column coordinates (Table 5) shows clear differences in the associations among districts, delivery status, and year. Gimbi is strongly associated with negative coordinates along both Dim 1 (-0.300) and Dim 2 (-1.008), which suggests that Gimbi differs from the other districts, particularly along Dim 2, which may relate to a specific trend within the district regarding delivery outcomes. In contrast, Najo has a positive association with Dim 1 (0.899) but only a modest positive association with Dim 2 (0.259). Lalo Asabi, however, presents a negative relationship with Dim 1 (-0.666) and a positive association with Dim 2 (0.732). These varied coordinate patterns suggest that the delivery status and temporal trends differ by district.

Table 5: Inertia and column coordinates of delivery status.

Inertia				Column Coordinates			Partial Contribution	
SV	Inertia	X^2	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.59432	0.35321	6399.8	17.66	Gimbi	-0.3	-1.008	0.02772	0.3206
0.58655	0.34404	6233.7	17.2	Lalo Asabi	-0.666	0.732	0.1358	0.16865
0.58281	0.33967	6154.5	16.98	Najo	0.899	0.259	0.26638	0.02274
0.57647	0.33232	6021.3	16.62	2019	0.163	-0.633	0.00564	0.08783
0.5677	0.32228	5839.4	16.11	2020	-0.503	0.465	0.05918	0.05181
0.5554	0.30847	5589.2	15.42	2021	0.221	-0.77	0.01197	0.14904
				2022	0.114	0.852	0.00327	0.18806
				Aborted	1.693	0.253	0.41484	0.00954
				Health calf born	-0.307	-0.046	0.0752	0.00173

SV = singular value; X^2 = chi-square; Dim = dimensiont5

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The association between delivery status and the dimensions is also notable. Abortion is strongly and positively associated with Dim 1 (1.693), while the health calf born is negatively related to Dim 1 (-0.307). This stark contrast indicates that Dim 1 likely captures the primary differentiation between successful births and abortions. It suggests a possible linkage between district-specific factors and higher abortion rates. This relationship could be reflective of regional disparities in veterinary services, environmental conditions, or agricultural practices [24].

Temporal Effects on Delivery Status

The year effects show substantial variability across the two dimensions. For example, 2020 and 2021 are positively associated with Dim 1 but negatively with Dim 2, suggesting that these years may be characterized by differing delivery outcomes compared to 2019 and 2022. Specifically, 2022 had a strong positive association with Dim 2 (0.852), while 2019 displayed a slight negative association (-0.633) along the same dimension. This finding suggests that external factors such as climatic conditions or local health interventions during specific years might have influenced delivery outcomes. Similar time-related trends have been reported in other livestock health studies, where environmental stressors were shown to affect calf mortality [25].

Contributions to Inertia: The partial contributions to inertia for each category reveal key insights. The district of Najo contributed significantly to Dim 1 (26.64%), suggesting that Najo plays a primary role in explaining variation in delivery outcomes. In contrast, Gimbi contributed more to Dim 2 (32.06%). Notably, abortion status contributed the most to Dim 1 (41.48%), further underscoring the strong association between this variable and the primary axis of variation. The strong contribution of abortion to Dim 1 suggests that abortion rates are a critical factor shaping the observed associations. Prior research supports this finding, highlighting that calf mortality, particularly abortions, is often linked to regional differences in veterinary care and disease prevalence [26].

The year 2022 contributed more to Dim 2 (18.81%) compared to other years, indicating a notable temporal effect in this dimension. The relationship between delivery outcomes and the year effect aligns with findings from livestock studies that suggest fluctuations in reproductive success across years may be driven by varying environmental conditions [27].

Sex of Calf born (female/male)

Table 4 below shows the results of the sex of calf born. The results from each district show distinct patterns in female and male-born calves.

(Table 6)

Table 6: Sex of calf born across study districts.

Effect & Attributes 2019		Years				X^2	P value
		2020	2021	2022			
Lalo Asabi	Female	172 (10.2%)	227 (13.4%)	186 (11%)	243 (14.4%)	6.54	0.0881
	Male	196 (11.6%)	211 (12.5%)	229 (13.6%)	226 (13.4%)		
Gimbi	Female	220 (13%)	183 (10.8%)	222 (13.2%)	218 (12.9%)	14.91	0.0019
	Male	160 (9.5%)	229 (13.6%)	233 (13.8%)	222 (13.2%)		
Najo	Female	205 (11.9%)	210 (12.2%)	219 (12.7%)	223 (12.9%)	0.59	0.8995
	Male	215 (12.5%)	221 (12.8%)	211 (12.2%)	222 (12.9%)		

In Lalo Asabi district, the percentage of female calves born increased from 10.2% in 2019 to 14.4% in 2022. Similarly, the proportion of male calves remained relatively stable, ranging between 11.6% in 2019 and 13.4% in 2022. Despite these trends, the chi-square test did not reveal a statistically significant relationship between year and the sex of calves born in this district (P=0.0881). While the increase in female births over time may suggest a trend toward a more balanced sex ratio, the lack of statistical significance implies that this variation could be due to random fluctuations. Studies have shown that sex ratios in livestock are typically influenced by factors such as maternal condition or even insemination techniques [21], though in this case, these effects did not produce a significant outcome.

In Gimbi, notable fluctuations were observed in the sex distribution of calves born. The percentage of female calves declined slightly from 13% in 2019 to 12.9% in 2022, with a slight dip in 2020 (10.8%). Meanwhile, male births increased from 9.5% in 2019 to 13.2% in 2022, with the highest proportion observed in 2021 (13.8%). The chi-square test indicated a statistically significant association between year and calf sex in Gimbi ($P<0.05$). This suggests that factors specific to Gimbi may be influencing sex ratios, possibly through environmental or management-related changes. Research by [28] has demonstrated that environmental stressors or shifts in breeding practices can affect sex ratios, which might explain the significant variation seen in Gimbi during this period.

In Najo, the percentage of female calves born remained relatively consistent, ranging from 11.9% in 2019 to 12.9% in 2022. Similarly, the proportion of male calves stayed steady, varying from 12.5% in 2019 to 12.9% in 2022. The chi-square test

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revealed no significant association between year and calf sex in Najo (P=0.8995), suggesting that the sex ratio has remained stable across the study period. This stability might be due to consistent environmental and management conditions, which have been shown to produce balanced sex ratios in livestock [19]. In such cases, the biological mechanisms determining sex ratios may be operating under normal conditions without external stressors that could skew the results.

The MCA identifies how the categorical variables relate across the dataset by examining their positions along the primary dimensions derived from the analysis. The figure below shows a bi-dimensional graph representing the associations among the categories of the analyzed variables.

Singular Values and Inertia: The MCA extracted six dimensions, with the first two explaining a cumulative 34.33% of the total variance. Dim 1 explained 17.23% of the variance, while Dim 2 explained 17.1%. Though this cumulative explained variance is modest, these two dimensions reveal critical patterns in the relationships between the variables. This is in line with MCA studies in categorical data analysis, where the first two dimensions often capture the main associations but leave considerable unexplained variability for further exploration [23].

(Figure 4)

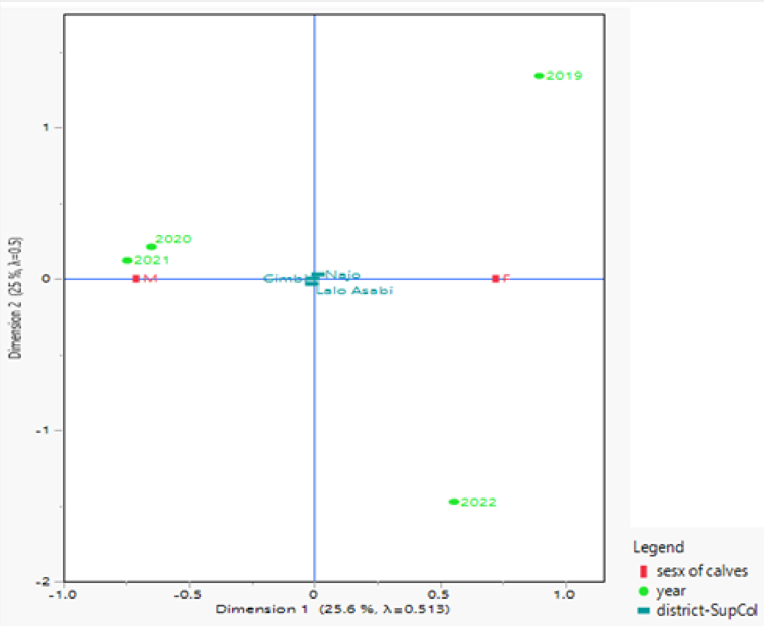

Figure 4: The status of sex calves born in the study district.

Table 7: Inertia and column coordinates foe sex of calf born

Inertia				Column Coordinates			Partial Contribution	
SV	Inertia	X²	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.58694	0.3445	5277.7	17.23	Gimbi	0.044	0.859	0.00062	0.23775
0.58489	0.3421	5240.8	17.1	Lalo Asabi	-0.742	-0.682	0.17629	0.14998
0.58176	0.33844	5184.8	16.92	Najo	0.683	-0.172	0.1528	0.00977
0.57359	0.32901	5040.3	16.45	2019	1.228	-0.188	0.3342	0.00788
0.56906	0.32383	4961	16.19	2020	-0.607	-0.347	0.08945	0.02939
0.56755	0.32212	4934.7	16.11	2021	-0.231	1.238	0.01316	0.38025
				2022	-0.264	-0.698	0.01785	0.12604
				F	0.476	-0.248	0.10881	0.02974
				M	-0.468	0.244	0.10683	0.0292

SV = singular value; X² = chi-square; Dim = dimension

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Districts and Temporal Patterns: The column coordinates for the districts show distinct patterns of association. Gimbi is positively associated with Dim 2 (0.859), indicating that Gimbi aligns with specific trends captured by Dim 2, though it shows little association with Dim 1 (0.044). In contrast, Lalo Asabi is negatively associated with both Dim 1 (-0.742) and Dim 2 (-0.682), suggesting that this district has unique characteristics relative to the other districts, particularly when linked to temporal effects and calf sex. Najo, on the other hand, shows a positive relationship with Dim 1 (0.683) and a weaker negative relationship with Dim 2 (-0.172), indicating its association with trends primarily captured by Dim 1.

The year variable also contributes significantly to the overall structure of the data. For instance, 2019 is strongly associated with Dim 1 (1.228), while 2021 is strongly associated with Dim 2 (1.238). This indicates that both years mark significant differences in calf sex or district-specific outcomes. The year 2020, with negative coordinates on both dimensions (-0.607, -0.347), may represent a period of less distinctive trends compared to other years, possibly reflecting external factors such as environmental or management changes that muted inter-district differences. These findings are consistent with research suggesting that the temporal dimension often plays a significant role in livestock production outcomes, particularly in relation to local ecological and economic conditions [29].

Associations Between Calf Sex and Other Variables: One of the main points of interest in this MCA is the relationship between the sex of calves and the other variables. Female calves are positively associated with Dim 1 (0.476) and negatively with Dim 2 (-0.248). Conversely, male calves are negatively associated with Dim 1 (-0.468) and positively with Dim 2 (0.244). This inverse relationship suggests that Dim 1 captures the most significant contrast between male and female calves. This pattern could indicate underlying biological, environmental, or management factors that differentially impact male and female calves across districts and years, possibly related to local breeding practices or differential survival rates between sexes [25].

Contributions to Inertia: The partial contributions to inertia provide further clarity regarding the role of each variable in shaping the dimensions. The year 2019 contributed the most to Dim 1 (33.42%), highlighting the distinctiveness of this year in terms of calf sex and district-level outcomes. Similarly, 2021 contributed the most to Dim 2 (38.02%), aligning with the patterns observed in the column coordinates. Among the districts, Lalo Asabi had the highest contribution to Dim 1 (17.63%) and Dim 2 (14.99%), which indicates that this district played a key role in shaping the variance across both dimensions.

Interestingly, the sex of calves contributed similarly to both dimensions, with female calves contributing 10.88% to Dim 1 and male calves contributing 10.68%. This balanced contribution reinforces the importance of sex in differentiating the data but suggests that both male and female calves have similar explanatory power in shaping the relationships within the dataset. The near-equal contribution of calf sex to the two dimensions may reflect complex interactions between calf sex and other factors like district and year, in line with previous studies that found similar patterns in livestock demographics [24].

Conclusion

This study highlights the significant differences in reproductive performance between local and crossbred cows in smallholder dairy farms. The study underscores the potential of crossbreeding as an effective strategy to enhance cattle productivity, particularly in terms of reproductive traits and milk yield. The evident genetic advantages of crossbred cows suggest that leveraging these traits in breeding and management practices could significantly improve overall livestock performance. Although local conditions influence specific reproductive characteristics, the findings indicate that crossbreeding offers a promising path forward for cattle productivity in various districts.

Localized approaches are essential for improving reproductive performance, as district-specific factors play a critical role in conception success. The analysis revealed significant year effects on conception rates in Lalo Asabi and Najo districts, while Gimbi did not exhibit notable temporal changes. This variability emphasizes the need for targeted interventions in districts experiencing lower conception rates. Further research should focus on understanding the underlying causes of these differences, such as genetic diversity and environmental conditions, to inform effective insemination programs.

The results of the multiple correspondence analysis indicate that delivery outcomes, particularly the incidence of healthy calf births and abortions, differ significantly across districts and years. Lalo Asabi showed improvements in healthy births alongside rising abortion rates, while Gimbi and Najo remained stable in their delivery outcomes. The findings highlight the necessity for district-specific management practices to address the varying factors influencing reproductive success. Additionally, understanding the implications of calf sex ratios and their correlations with environmental and management factors will be vital for optimizing breeding strategies and enhancing reproductive outcomes in cattle.

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