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

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Abstract

Ethiopia has one of the largest livestock populations in Africa, with cattle playing a crucial role in both agriculture and the economy. However, livestock productivity, particularly in milk production, remains low due to factors such as poor genetic potential, shortage of in quality and quantity and inadequate veterinary services. Artificial insemination (AI) has been introduced to improve cattle genetics, but its effectiveness varies across regions. Despite the introduction of AI, challenges in reproductive performance and efficiency in smallholder dairy farms persist, limiting the potential for productivity improvements. This study addresses gaps in understanding these reproductive outcomes and evaluates AI efficiency in smallholder farms. The primary objective is to assess reproductive performance and AI efficiency in smallholder dairy farms in West Wollaga, Ethiopia. Statistical analyses, including analysis of variance (ANOVA) and multiple correspondence analysis (MCA), were conducted to explore breed- and district-level differences in reproductive performance. Crossbred cows demonstrated superior reproductive performance compared to local breeds, with earlier reproductive maturity and shorter calving intervals. District-level differences were observed, with cows in Boji exhibiting longer days open and calving intervals compared to those in Guliso. Temporal trends showed improvements in conception rates, particularly in 2021 and 2022, likely due to enhanced management and veterinary interventions. The study highlights significant breed- and district-level differences in reproductive performance, with crossbred cows showing better outcomes than local breeds. Environmental and management factors at the district level also influenced reproductive success. The findings underscore the need for region-specific strategies to improve reproductive performance and AI efficiency in Ethiopian smallholder dairy farms.

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

Introduction

Ethiopia has one of the largest livestock populations among developing African nations. As of recent estimates, the country's livestock comprises approximately 66 million cattle, 84 million sheep and goats, 19.5 million equines, and 41.35 million chickens. Among cattle, local breeds dominate, accounting for 96.76% of the population, while crossbreeds and exotic breeds make up only 2.71% and 0.41%, respectively. There are about 12.8 million milking cows in the country, with an average lactation period of six months and a daily milk yield of 1.45 litres per cow. In the 2021/2022 fiscal year, total milk production reached around 3.87 billion litres [1].

Livestock plays a crucial role in the livelihoods of rural communities in developing nations, providing both direct and indirect benefits. In these economies, livestock significantly contributes to the welfare of millions of vulnerable producers and consumers [2]. In 2017, Ethiopia's livestock sector accounted for approximately 40% of agricultural GDP, 20% of the overall GDP, and 20% of national foreign exchange income [3].

Despite Ethiopia's vast and diverse animal genetic resources, livestock productivity remains low due to factors such as inadequate veterinary services, poor genetic potential, and suboptimal management practices [4-6]. The rapidly growing human population and the low productivity of indigenous cattle further exacerbate the challenge of meeting the country's protein needs [7]. Ethiopia has struggled to achieve self-sufficiency in milk production, relying on imported powdered milk to bridge the gap between domestic demand and supply [1]. The country's cattle production is largely based on smallholder subsistence farming, with animals raised for multiple purposes without specialized breeding programs [8]. To enhance the productivity of indigenous cattle, the introduction of crossbreeding programs with highly productive exotic breeds has been proposed as a viable solution [9].

Artificial insemination (AI) is considered the most effective biotechnological tool for improving livestock reproductive performance. It is widely used in developing countries due to its affordability and simplicity [10]. In Ethiopia, AI has been employed for genetic improvement for several years [11,12], making high-quality genetic material accessible to cattle farmers. However, the provision of AI services across the country remains uneven. Thus, considerable effort is required to enhance cattle productivity and reproductive performance through systematic breeding programs. Furthermore, extensive research is needed to evaluate the efficiency and challenges of AI at both national and regional levels.

Although some studies have assessed AI effectiveness in Ethiopia, these are limited in scope and not fully representative of the country's farming conditions. Many analyses have used a univariate approach, leaving gaps in understanding that could be addressed through multivariate methods like multiple correspondence analysis. Comprehensive evaluation of reproductive performance traits and AI efficiency is difficult without such advanced methodologies. In the study area, little research has been conducted on the reproductive performance of dairy cows and AI service efficiency, necessitating further investigation. This study aims to fill that gap by evaluating these factors in smallholder dairy farms.

Materials and Methods

Description of the Study Area

The study was conducted in the West Wollega Zone Oromia Regional States in Ayira, Guliso, and Boji Dirmeji districts among the 21 districts of this zone. West Wollega lies between 9.1769°N and 35.0388°E. This zone receives an annual rainfall between 1000 to 2200mm and is characterized by a light rain that starts in April and heavy rain that continues from May up to September. The mixed crop-livestock production system is practiced but coffee is a major cash crop in this area.

Study Population and Design

The study was carried out using both cross-sectional and retrospective study designs between December 2022 and January 2023 in West Wollega. For the retrospective study, data from AI service records (AI certificates and AI case books) were collected from animal health clinics in the respective districts. These records were used to assess the reproductive performance of dairy cows. Key reproductive metrics evaluated included age at first service (AFS: the age of a heifer when she is first inseminated or bred), age at first calving (AFC: the age of a heifer when she gives birth to her first calf), days open (DO: the period between calving and successful conception), calving interval (CI: the duration between two successive calvings for a cow), and number of services per conception (NSPC: the average number of inseminations required to achieve a successful pregnancy).

The study also utilized secondary data from the AI service recording books of inseminators in the districts' animal health clinics. This data helped to analyze the reproductive performance of dairy cows by examining the relationship between the total number of inseminated cows, conception rates, and calf birth rates between 2019 and 2022.

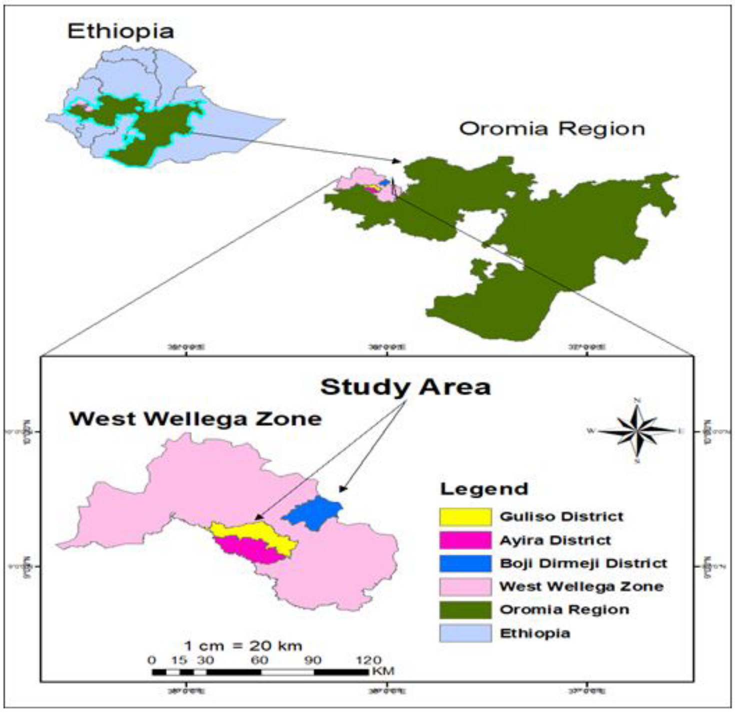

Figure 1: Study area map

Data Analysis

For all statistical data analyses (analysis of variance and multiple correspondence analysis), SAS JMP Pro version 18 [13] was used.

Analysis of Variance: Reproductive performance traits (AFS, AFC, CI, DO, NSPC) 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 Tukey test at a 95% confidence interval. The linear model employed was:

$$Y = \mu + B_i + P_j + \varepsilon_{ij} where :$$

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

μ = Overall mean

B_i = Fixed effect of the ith breed of cow (i = 2: local, crossbred)

D_j = Fixed effect of the jth district (j = 3: Ayira, Boji, and Guliso)

ε_{ij} = Random residual error term

Multiple Correspondence Analysis (MCA) was applied to retrospective data collected between 2019 and 2022. This data included variables such as the conception status of cows (conceived or not conceived), delivery status of pregnant cows (delivered or aborted), and the sex of calves (male or female) in each district studied. MCA was used to explore associations among these categorical variables, along with the year of data collection (2019–2022) and the district (Ayira, Boji, or Guliso), to identify patterns and relationships within the dataset.

Results and Discussions

Effect of Breed and District on Reproductive Performance Traits

The stacked bar chart below provides a visual comparison of various reproductive performance traits, by breed types (crossbred and local) across the three districts (Ayira, Boji Dirmeji, and Guliso). The chart shows five reproductive parameters, represented by different colours in the stacked bars: Age at First Service (AFS), Number of Services per Conception (NSPC), Age at First Calving (AFC), Days Open (DO), and Calving Interval (CI).

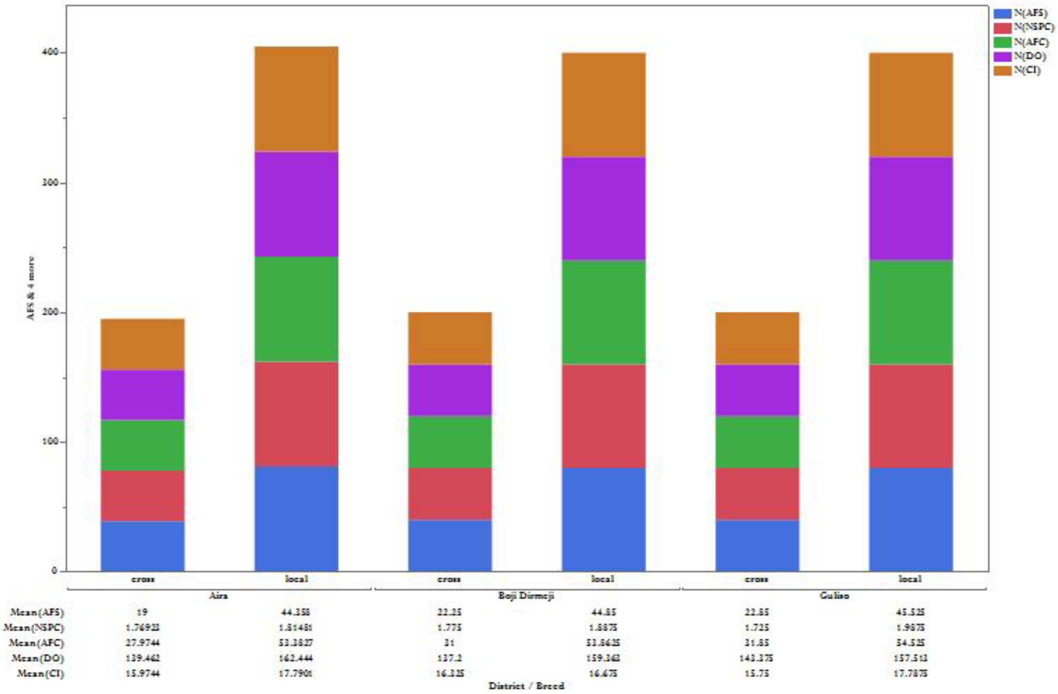

Figure 2: Stacked bar chart of the reproductive performance traits by breed and district

Breed and District Comparison

Crossbred Cows: Across all districts, crossbred cows generally show lower values in AFS, AFC, DO, and CI compared to local cows, indicating better reproductive efficiency. For instance, crossbred cows in each district have lower overall stacked bar heights compared to their local counterparts, demonstrating earlier maturity and faster postpartum recovery.

Local Cows: Local cows in each district have notably higher values across all reproductive traits, resulting in taller bars. This suggests delayed reproductive maturity and longer recovery intervals, which are less optimal for reproductive efficiency.

District-Specific Observations

Ayira District: In Ayira, local cows show the highest combined reproductive trait values, suggesting they reach reproductive milestones later and have longer recovery periods post-calving compared to crossbred cows in Ayira. This indicates that crossbreds are more efficient in Ayira, reaching reproductive maturity and recovering postpartum faster than local cows.

Boji Dirmeji District: The differences between crossbred and local cows in Boji Dirmeji are similar, with local cows exhibiting higher AFS, AFC, DO, and CI values. Crossbreds in Boji Dirmeji also show a significant reduction in reproductive traits compared to local cows.

Guliso District: Crossbred cows in Guliso continue to outperform local cows, although the gap in reproductive traits between breeds appears slightly narrower here than in Ayira and Boji Dirmeji. However, local cows in Guliso still exhibit greater reproductive trait values than crossbreds, signifying that crossbreeding continues to be beneficial.

ANOVA Results of the Reproductive Performance Traits

Two-way ANOVA was conducted to assess the effects of cow breed (local vs. crossbred) and district (Ayira, Boji, and Guliso) on reproductive performance traits, including Age at First Service (AFS), Age at First Calving (AFC), Days Open (DO), Calving Interval (CI), and Number of Services per Conception (NSPC). The results reveal significant differences of breed and district for most reproductive traits, providing insights into how these factors influence reproductive efficiency in cattle.

Table 1: Least square means results of reproductive performance traits

Effect and Level	**AFS LSM±SE** (Months)	**AFC LSM±SE** (Months)	**DO LSM±SE** (Months)	**CI LSM±SE** (Months)	**NSPC LSM±SE**
District					
Ayira	38.65^{ab} ±0.26	48.13^{ab} ±0.27	168.09^{b} ±3.08	15.09^{ab} ±0.1	2.1±0.07
Boji Dirmeji	39.27^{a} ±0.26	48.76^{a} ±0.27	178.56^{a} ±3.08	15.38^{a} ±0.10	2.0±0.07
Guliso	38.29^{b} ±0.26	47.77^{b} ±0.27	164.47^{b} ±3.08	14.95^{b} ±0.10	2.0±0.07
P value	0.0254	0.0279	0.0031	0.0096	0.5671
Cow Breed					
Local	45.38^{a} ±0.16	54.87^{a} ±0.18	197.11^{a} ±2.13	16.03^{a} ±0.07	2.1±0.05
Crossbred	32.09^{b} ±0.26	41.56^{b} ±0.26	143.64^{b} ±3.03	14.25^{b} ±0.10	1.9±0.07
P value	0.0001	0.0001	0.0001	0.0001	0.0577

^{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; NSPC = Number of services per conception.

Breed Effects: Breed had a significant impact on most reproductive traits, except for the number of services per conception (NSPC). Crossbred cows reached reproductive maturity earlier than local breeds, with a significantly lower age at first service (AFS) of 32.1 months compared to 45.4 months for local breeds ($p < 0.0001$). A similar trend was observed for age at first calving (AFC), with crossbreds calving earlier (41.6 months) than local cows (54.9 months, $p < 0.0001$). These findings support previous research, which suggests that crossbreeding improves reproductive efficiency by enhancing growth and reproductive traits through genetic advancements [14].

Additionally, the days open (DO) period was shorter for crossbred cows (143.6 days) than for local breeds (197.1 days, $p < 0.0001$), indicating faster resumption of reproductive cycles post-calving. This shorter DO contributed to a reduced calving interval (CI) for crossbreds (14.3 months) compared to local breeds (16.0 months, $p < 0.0001$). The shorter CI suggests that crossbreds exhibit better reproductive performance, potentially due to improved hormonal balance and fertility [15]. While NSPC was slightly lower for crossbreds (1.9) compared to local cows (2.1), this difference was not statistically significant ($p = 0.0577$), indicating similar insemination success rates across breeds.

The results highlight that crossbred cows generally outperform local breeds in key reproductive traits, including earlier maturity and shorter recovery intervals between calvings. These findings align with studies showing that crossbreeding can enhance reproductive efficiency through hybrid vigour and improved genetic potential [16]. The lack of significant differences in NSPC suggests that breed differences in reproductive performance are primarily related to maturation and recovery, rather than insemination success.

District Effects: The reproductive traits also varied significantly across the districts studied. For AFS, Boji district had the highest mean (39.3 months), while Guliso had the lowest (38.3 months, $p = 0.0254$). A similar pattern was observed for AFC, where Boji had a significantly higher mean (48.8 months) compared to Guliso (47.8 months, $p = 0.0279$). These differences suggest that local environmental conditions, management practices, or resource availability may delay reproductive maturity in some districts [17].

Boji also had the longest DO (178.6 days), significantly higher than Ayira (168.1 days) and Guliso (164.5 days, $p = 0.0031$). This extended period may reflect challenges related to fertility or postpartum recovery, possibly linked to feed quality or reproductive health management in Boji [18]. Similarly, the CI in Boji (15.4 months) was longer than in Guliso (15.0 months, $p = 0.0096$), indicating potential issues with reproductive recovery or delayed rebreeding in that district [19]. Despite these differences in other reproductive traits, NSPC did not vary significantly across districts ($p = 0.5671$), suggesting that insemination success was relatively consistent regardless of location.

Both breed and district had a significant influence on reproductive traits. Crossbred cows consistently demonstrated superior reproductive performance, while cows in the Guliso district showed better reproductive efficiency compared to those in Boji. These findings underscore the importance of selecting appropriate breeds and adapting management practices to local conditions to improve reproductive outcomes. This has critical implications for increasing productivity and sustainability in cattle production systems [20]. Future research should focus on district-specific factors, such as feed quality and veterinary services, to further improve reproductive performance, particularly in regions with longer reproductive intervals.

District-Specific Effects on Reproductive Traits: The reproductive performance traits, i.e., AFS, AFC, DO, and CI, varied across districts (Ayira, Boji, and Guliso), pointing to the influence of local environmental and management factors. For instance, Boji exhibited the highest mean AFS and AFC, suggesting that cows in this district took longer to reach reproductive maturity than those in Guliso. This delay could be associated with factors such as climate, resource availability, and district-specific management practices, which may affect feed quality, health care, and other environmental supports necessary for optimal reproductive development.

In Boji, cows also experienced the longest DO and CI, indicating challenges related to postpartum recovery and rebreeding efficiency. These prolonged intervals suggest possible issues with fertility or postpartum health management, which may be affected by local conditions such as nutritional resources, veterinary care availability, and general management practices. This district-specific variation underlines the importance of adapting reproductive management to address unique environmental challenges that may hinder reproductive efficiency in each district.

Environmental and Management Practices as Influential Factors: The results imply that environmental factors, including feed quality, healthcare access, and possibly climatic conditions, contribute to observed differences in reproductive performance across districts. The lower AFS and AFC in Guliso suggest that cows there benefit from more favourable conditions for reaching reproductive maturity earlier. Similarly, the shorter DO and CI in Guliso indicate a faster return to fertility postpartum, possibly due to better feed or health management, which supports quicker recovery and rebreeding.

Implications for Reproductive Management: The study underscores the importance of considering district-specific factors when planning breeding and reproductive management strategies. By understanding the environmental and management constraints in each district, farmers can tailor interventions—such as improved feeding programs or enhanced veterinary services—to mitigate delays in reproductive traits and enhance overall productivity. This insight highlights that district-specific adaptations can be crucial in optimizing reproductive performance, making it essential for breeders and dairy farmers to consider local environmental conditions and adapt practices accordingly to improve reproductive outcomes sustainably.

Pearson Chi-Square Test of Independence and Multiple Correspondence Analysis (MCA)

A Pearson chi-square test of independence as well as MCA were conducted to determine the relationship between district (Aira, Boji, Guliso) and year effect (2019, 2020, 2021, 2022) on conception status (conceived or not conceived), delivery status (healthy calf born (HCB) or aborted), and sex of calf born (female/male).

Conception Status (conceived/not conceived) of Inseminated Cows

Pearson Chi-Square Test of Independence: Table 2 below shows the results of the conception status of inseminated cows. The results show statistically significant associations between district, year, and conception status, suggesting that both geographical location and temporal factors played a role in influencing the conception rates.

Table 2: Conception status of inseminated cows

Variable		Year				χ^2	P-Value
		2019	2020	2021	2022		
Ayira	Not conceived	77 (11.72)	78 (11.87)	67 (10.20)	60 (9.13)	53.555	0.0001
	Conceived	33 (5.02)	115 (17.5)	74 (11.26)	153 (23.29)		
Boji	Not conceived	103 (8.76)	104 (8.84)	108 (9.18)	100 (8.5)	59.212	0.0001
	Conceived	108 (9.18)	101 (8.59)	290 (24.66)	262 (22.28)		
Guliso	Not conceived	123 (7.42)	151 (9.11)	168 (10.14)	156 (9.41)	56.996	0.0001
	Conceived	102 (6.16)	351 (21.18)	234 (14.12)	372 (22.45)		

For Aira district, the chi-square test indicated a significant relationship between year and conception status, $\chi^2 = 53.555$, $p = 0.0001$. Notably, the number of cows that conceived increased over time, peaking in 2022 with 153 conceived cows, while the number of non-conceived cows decreased consistently from 2019 (77) to 2022 (60). This pattern suggests an improvement in conception outcomes in Aira, potentially due to improved herd management practices, environmental conditions, or veterinary interventions [20].

Similarly, in Boji, the chi-square value was $\chi^2 = 59.212$, $p = 0.0001$, indicating a significant association between year and conception status. The number of conceived cows dramatically increased from 108 in 2019 to 290 in 2021, although there was a slight decline in 2022 (262 conceived cows). This trend suggests a strong year effect, particularly in 2021, which may reflect optimal conditions or interventions that significantly boosted conception rates [15]. Despite the slight drop in 2022, conception rates remained higher than in 2019, showing consistent improvements over time.

In Guliso, the chi-square test revealed a significant association as well, $\chi^2 = 56.996$, $p = 0.0001$. Guliso showed a substantial increase in conceived cows from 102 in 2019 to 372 in 2022, alongside a decrease in non-conceived cows, which peaked in 2021 (168) and reduced to 156 by 2022. These results suggest that Guliso, like the other districts, experienced an upward trend in conception rates, with 2022 being the most successful year. The factors contributing to these improvements may include enhanced fertility protocols, improved nutrition, and targeted insemination timing [21].

Overall, the results indicate that both district and year significantly influenced conception outcomes for inseminated cows. Each district demonstrated a positive trend in conception rates, particularly in later years, which could be attributed to several factors such as advancements in reproductive technologies, environmental conditions, or enhanced veterinary support [22]. The consistently significant p-values across all districts suggest that these improvements were not due to random variation but likely reflect systematic changes in management and environmental conditions over time. Further studies are recommended to explore specific factors contributing to the observed trends and to determine if these improvements are sustainable in the long term.

Multiple Correspondence Analysis (MCA)

MCA was conducted to explore the associations among conception status (conceived vs. not conceived), district (Ayira, Boji, Guliso), and year (2019, 2020, 2021, 2022). The results found offer insights into these relationships by analyzing inertia, chi-square statistics, and the distribution of contributions across dimensions.

Inertia and Singular Values: The MCA generated six dimensions, accounting for the total inertia of the dataset. The first dimension explained 19.33% of the variance, with a singular value of 0.62184 and a chi-square value of 4098.2. This was followed by dimensions that explained 18.25%, 17.27%, 16.26%, 14.88%, and 14.01%, respectively, culminating in a cumulative explanation of 100% of the inertia. The relatively high inertia of the first two dimensions indicates that they capture the most significant associations among the variables [23].

Table 3: Principal inertias, percentages, column coordinates and partial contributions of conception status

Singular values and inertia				Column coordinates			Partial Contribution	
SV	Inertia	X^2	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.62184	0.38669	4098.2	19.33	Aira	-0.582	-0.174	0.05504	0.00519
0.60415	0.36500	3868.4	18.25	Boji	1.033	-0.264	0.31002	0.02144
0.58763	0.34531	3659.7	17.27	Guliso	-0.502	0.256	0.10326	0.02846
0.57033	0.32528	3447.4	16.26	2019	0.696	1.072	0.06532	0.16404
0.54552	0.29760	3154.0	14.88	2020	-1.045	0.573	0.24287	0.07724
0.52926	0.28012	2968.8	14.01	2021	0.867	-0.154	0.17483	0.00585
				2022	-0.232	-0.866	0.01460	0.21656
				Conceived	-0.094	-0.342	0.00620	0.08756
				Not conceived	0.421	1.539	0.02786	0.39367

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

Contribution of Districts to Inertia: Districts showed distinct patterns across dimensions. Boji had the highest contribution to the first dimension (0.31002), indicating a strong relationship with the variables in that dimension. Aira and Guliso contributed less to this dimension, with contributions of 0.05504 and 0.10326, respectively. This suggests that the geographical variation, particularly in Boji, played a significant role in shaping the outcomes of interest [24]. District Boji's coordinates (1.033, -0.264) suggest a strong association with Dimension 1, reinforcing the district's distinctive profile compared to Aira and Guliso.

Yearly Effects and Their Associations: The year effect also displayed notable variability. The year 2020 contributed the most to the first dimension (0.24287), followed by 2021 (0.17483) and 2019 (0.06532), while the year 2022 contributed minimally (0.01460). The positioning of 2020 (coordinate -1.045 in Dimension 1) contrasts sharply with 2019 (0.696), indicating significant variation in conception patterns across these years. The proximity of 2020 to negative values in Dimension 1 suggests a year of lower conception rates, perhaps reflective of external influences such as health or environmental factors [25].

Conception Status: Conception status revealed a marked association with both dimensions, especially Dimension 2. The status of "Not conceived" had a high contribution to Dimension 2 (0.39367), which was significantly greater than the contribution of the "Conceived" category (0.08756). This implies a stronger variation in the pattern of non-conception across the variables than in conception. In particular, the position of "Not conceived" (0.421, 1.539) suggests its closer association with certain years or districts, possibly reflecting local environmental or socioeconomic conditions affecting fertility rates [26].

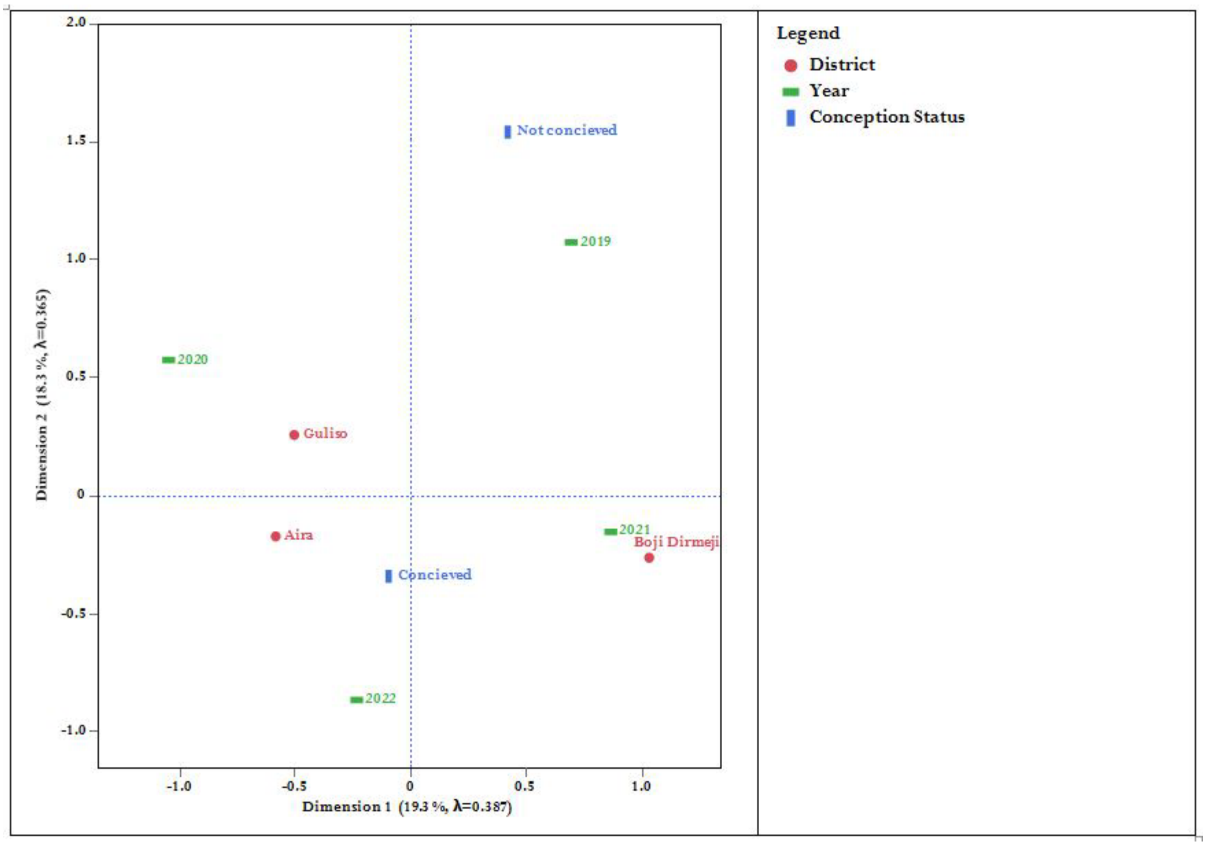

Figure 3: A bi-plot display of the conception status of inseminated cows

The analysis indicates that district and year effects have a profound influence on conception outcomes. Boji stands out as a district where conception status, particularly non-conception, was most strongly associated. The contribution of different years, particularly 2020, also points to an interplay of temporal factors, which might include shifts in healthcare, environmental conditions, or other factors influencing fertility 27]. Furthermore, the clustering of non-conception in certain years may hint at broader socioeconomic trends affecting reproductive health. The stronger association of "Not conceived" with both temporal and geographic variables suggests targeted interventions could be beneficial in specific years and districts.

In conclusion, the MCA reveals significant associations among conception status, district, and year. The high contributions of specific districts and years to the inertia suggest that these factors play an important role in understanding reproductive trends. The strong relationship between non-conception and both district and year underscores the need for a more nuanced understanding of the factors influencing fertility. Further research could explore the underlying causes of these patterns, particularly in districts like Boji and during years like 2020, to better inform public health interventions and policy [23,24].

Delivery Status (healthy calf birth/aborted) of Pregnant Cows

Pearson Chi-Square Test of Independence: Table 4 below shows the results of the delivery status of pregnant cows. The results show statistically significant associations between district, year, and delivery status, suggesting that both geographical location and temporal factors played a role in influencing the delivery status.

Table 4: Delivery status (healthy calf born / aborted) of pregnant cows across study districts

Variable		Year				χ^2	P-Value
		2019	2020	2021	2022		
Ayira	HCB	23 (6.13)	82 (21.87)	45 (12.0)	103 (27.47)	2.341	0.5046
	Aborted	10 (2.67)	33 (8.8)	29 (7.73)	50 (13.33)		
Boji	HCB	80 (10.51)	81 (10.64)	223 (29.3)	230 (30.22)	14.192	0.0027
	Aborted	28 (3.68)	20 (2.63)	67 (8.8)	32 (4.2)		
Guliso	HCB	68 (6.42)	276 (26.06)	177 (16.71)	305 (28.8)	11.925	0.0076
	Aborted	34 (3.21)	75 (7.08)	57 (5.38)	67 (6.33)		

HCB = healthy calf born

In Aira, the results revealed that there was no statistically significant association between year and delivery status, χ^2 = 2.341, p = .5046. The proportion of healthy calves born (HCB) and aborted deliveries remained relatively consistent over the four years, with 23 HCB and 10 aborted in 2019, increasing to 103 HCB and 50 aborted in 2022. Despite these fluctuations, the lack of significance suggests that temporal variations in delivery status in Aira were not meaningful. These findings align with previous research indicating that environmental and management factors may not always show consistent year-to-year variation within specific regions [28].

In Boji, the test showed a significant relationship between year and delivery status, χ^2 = 14.192, p = .0027. The number of healthy calves born increased steadily from 80 in 2019 to 230 in 2022, while the number of abortions fluctuated, with 28 recorded in 2019 and 32 in 2022. This significant association suggests that factors influencing pregnancy outcomes, such as veterinary interventions or environmental conditions, likely improved over time in Boji. The increasing HCB rate and relatively stable abortion numbers reflect better herd health management practices, which are known to reduce pregnancy losses in cattle [29].

Similarly, in Guliso, a significant association was found between year and delivery status, χ^2 = 11.925, p = .0076. Healthy calves born increased dramatically from 68 in 2019 to 305 in 2022, while abortion numbers showed less variation, rising from 34 in 2019 to 67 in 2022. The significant year effect highlights the impact of time-dependent factors, such as changes in farming practices, animal health interventions, and climatic conditions, on delivery outcomes [30]. This is consistent with studies that found increased veterinary interventions and improved herd management contributed to higher rates of healthy deliveries in rural districts [31].

Overall, the results underscore that while some districts, such as Aira, did not experience significant changes in delivery outcomes over time, others, like Boji and Guliso, demonstrated marked improvements. The significant year effects observed in Boji and Guliso suggest that specific interventions, possibly related to veterinary care, climate, or nutrition, have played a crucial role in improving pregnancy outcomes in these areas [32]. Further research could investigate the underlying causes of these temporal improvements to identify best practices that can be applied across similar contexts.

Multiple Correspondence Analysis (MCA)

MCA was conducted to explore the association among categorical variables: delivery status (healthy calf born [HCB] or aborted), district (Aira, Boji Dirmeji, and Guliso), and year (2019–2022). The results reveal important relationships among these variables, which are summarized below.

Singular values and inertia contributions: The singular and inertia values (Table 5) reflect the variability explained by each dimension in the analysis. The first dimension explains the highest variance, contributing 19.98% (χ^2 = 3693.1, Singular Value = 0.63218). Subsequent dimensions explain smaller proportions, with the second and third accounting for 17.73% (χ^2 = 3277.2, Singular Value = 0.59551) and 17.10% (χ^2 = 3160.9, Singular Value = 0.58485), respectively. Overall, the first four dimensions capture 71.01% of the variance in the dataset, while the remaining variance is distributed across the fifth and sixth dimensions (χ^2 = 2786.1 and 2571.4, respectively). This distribution suggests that the first two dimensions contain most of the meaningful variability, providing insights into the relationships among variables [23].

Table 5: Principal inertias, percentages, column coordinates and partial contributions

Singular values and inertia				Column coordinates			Partial contribution	
SV	Inertia	X^2	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.63218	0.39965	3693.1	19.98	Aira	-0.606	0.942	0.05588	0.15216
0.59551	0.35464	3277.2	17.73	Boji Dirmeji	1.035	-0.274	0.28255	0.02233
0.58485	0.34205	3160.9	17.10	Guliso	-0.432	-0.170	0.07814	0.01363
0.56913	0.32391	2993.2	16.20	2019	1.017	1.497	0.11584	0.28267
0.54909	0.30150	2786.1	15.07	2020	-0.881	0.692	0.15578	0.10843
0.52750	0.27826	2571.4	13.91	2021	0.640	-0.840	0.09669	0.18782
				2022	-0.309	-0.380	0.02727	0.04628
				Aborted	1.237	1.161	0.16373	0.16271
				HCB	-0.182	-0.171	0.02411	0.02396

SV = singular value; X^2 = chi-square; Dim = dimension; HCB = healthy calf born

Dimensional Contributions and Interpretation: The column coordinates further illuminate the relationships between districts, years, and delivery status. In the first dimension, Boji Dirmeji (1.035), 2019 (1.017), and Aborted delivery status (1.237) are positioned on the positive side, suggesting a strong association between these categories. Conversely, Aira (-0.606), Guliso (-0.432), and the HCB category (-0.182) are negatively associated with this dimension. The second dimension shows that Aira (0.942) and 2019 (1.497) are positively associated, while Boji Dirmeji (-0.274) and 2021 (-0.840) exhibit negative contributions. This distribution implies that the incidence of abortion was more strongly linked to Boji Dirmeji and the year 2019, whereas Aira and HCB deliveries are more closely aligned with subsequent years, particularly 2021 and 2022.

The Greenacre-adjusted inertia values confirm that the first dimension accounts for a significant portion of the variation (72.79%), while the second dimension only adds an additional 7.51%, suggesting diminishing returns from higher dimensions. This aligns with the principle that MCA is most interpretable through the first few dimensions [34].

Associations Among Variables: Analysis of partial contributions provides further insights into the key contributors to inertia. District Boji Dirmeji and the year 2020 contribute most to the first dimension (0.28255 and

0.15578, respectively), indicating that abortion cases are disproportionately concentrated in this district and during this year. Aira and Guliso contribute less to this dimension but exhibit higher contributions in the second and third dimensions. For example, Aira's contribution to Dimension 2 is substantial (0.15216), which corresponds to a relatively strong positive association with the healthy calf deliveries in later years, as indicated by the negative association between Aira and the Aborted delivery status (0.05588 contribution to Dimension 1).

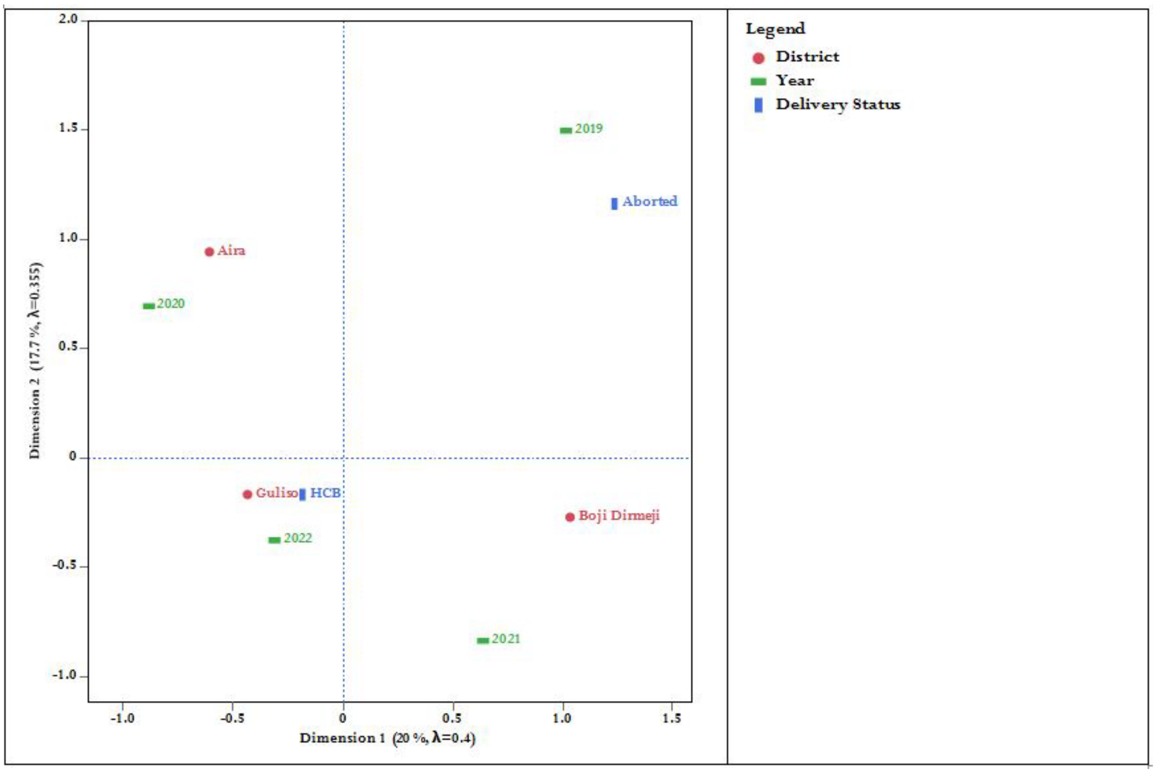

Figure 4: A bi-plot display for the delivery status of pregnant cow

The results suggest that geographical and temporal factors significantly influence delivery outcomes. Boji Dirmeji, in particular, exhibits a strong association with higher abortion rates, especially during the earlier years of the study period (2019 and 2020). This may reflect district-specific environmental or health-related factors influencing reproductive outcomes. These findings are consistent with prior research indicating that regional differences, possibly related to veterinary care and management practices, can significantly affect livestock reproductive performance [34].

Moreover, the shift in contributions to HCB deliveries in later years, especially in Aira and Guliso, suggests improvements in delivery outcomes over time. This may be attributed to improved herd management, veterinary interventions, or changes in environmental conditions that have positively impacted calving outcomes [35].

In conclusion, the MCA results underscore the importance of considering both spatial and temporal factors when examining reproductive outcomes in cattle. Boji Dirmeji emerges as a critical area for targeted interventions, particularly to reduce the high incidence of abortion observed. Furthermore, the observed improvements in delivery outcomes in Aira and Guliso provide promising evidence of the positive impact of interventions over time.

Sex of Calf Born (female / male) from Pregnant Cows

Pearson Chi-Square Test of Independence

Table 6 below shows the results of sex of calf born of the pregnant cows. The results show statistically significant associations between district, year, and sex of calf, suggesting that both geographical location and temporal factors played a role in influencing the sex of calf born.

Table 6: Sex of calf born across study districts

Variable		Year				X^2	P-Value
		2019	2020	2021	2022		
Ayira	Female	12 (4.74)	40 (15.81)	23 (9.09)	45 (17.79)	1.090	0.7795
	Male	11 (4.35)	42 (16.6)	22 (8.69)	58 (22.92)		
Boji	Female	31 (5.04)	43 (7.0)	104 (16.94)	123 (20.03)	6.249	0.1001
	Male	49 (7.98)	38 (6.19)	119 (19.38)	107 (17.43)		
Guliso	Female	32 (3.87)	128 (15.49)	85 (10.29)	151 (18.28)	0.592	0.8982
	Male	36 (4.36)	148 (17.92)	92 (11.14)	154 (18.64)		

In Ayira, the number of female calves born ranged from 12 in 2019 to 45 in 2022, while the number of male calves ranged from 11 in 2019 to 58 in 2022. The Pearson chi-square test yielded a chi-square value of 1.090 with a p--value of 0.7795. This result indicates no significant association between the sex of calves born and year in Ayira. The non-significant p-value ($p > .05$) suggests that the distribution of male and female calves across the years is relatively uniform, implying that external factors like year effects did not have a meaningful impact on calf sex distribution in this district [36].

In Boji, the distribution of female calves varied significantly across the years, with 31 female calves born in 2019 and 123 in 2022. Similarly, the number of male calves ranged from 38 in 2020 to 119 in 2021. The chi-square value for Boji was 6.249, with a p-value of 0.1001. Although this p-value is closer to the threshold for significance ($p < .05$), it remains non-significant. Therefore, there is insufficient evidence to conclude that the distribution of calf sex in Boji was influenced by year. Nevertheless, the higher number of female calves in recent years compared to earlier years may warrant further investigation into potential underlying causes, such as environmental or management factors specific to Boji [37].

In Guliso, a high number of both female and male calves were born in 2022, with 151 female calves and 154 male calves. The chi-square value for Guliso was 0.592, and the p-value was 0.8982, indicating no significant association between the year and the sex of calves born. Similar to Ayira, these results suggest that the distribution of calf sex did not vary substantially across the years. This consistency might reflect stable breeding practices or environmental conditions in Guliso that are less sensitive to temporal changes [38].

Multiple Correspondence Analysis (MCA)

MCA was conducted to explore the association among categorical variables: sex of calf born (female/male), district (Aira, Boji Dirmeji, and Guliso), and year (2019–2022). The results reveal important relationships among these variables, which are summarized below.

Overview of Inertia and Dimensions: The inertia and singular values indicate the proportion of variability explained by each dimension. The first dimension accounts for the highest percentage of variance, contributing 19.17% (χ^2 = 3075.0, Singular Value = 0.61927). The second and third dimensions explain 17.51% (χ^2 = 2807.7, Singular Value = 0.59173) and 17.29% (χ^2 = 2772.0, Singular Value = 0.58797) of the variability, respectively. Cumulatively, the first three dimensions explain 53.97% of the total variance, with diminishing contributions from additional dimensions. These results suggest that a significant portion of the variability in the data is captured by the first few dimensions, in line with common practices in MCA, which often emphasizes the first two or three dimensions [23].

Table 7: Principal inertias, percentages, column coordinates and partial contributions of sex of calf born

Singular values and inertia				Column coordinates			Partial contribution	
SV	Inertia	X^2	Per cent	Attribute	Dim 1	Dim 2	Dim 1	Dim 2
0.61927	0.38349	3075.0	19.17	Aira	-0.675	1.163	0.07455	0.24224
0.59173	0.35015	2807.7	17.51	Boji	1.130	0.00902	0.33618	2.35e-5
0.58797	0.34570	2772.0	17.29	Guliso	-0.423	-0.435	0.07927	0.09174
0.56770	0.32229	2584.2	16.11	2019	0.722	1.828	0.05599	0.39252
0.56247	0.31637	2536.8	15.82	2020	-1.207	0.106	0.30698	0.00258
0.53104	0.28200	2261.2	14.10	2021	0.756	-0.558	0.14046	0.08372
				2022	-0.029	-0.266	0.00026	0.02372
				Female	-0.089	-0.434	0.00330	0.08552
				Male	0.081	0.396	0.00301	0.07793

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

Associations Across Districts, Years, and Calf Sex: The column coordinates for districts show that Boji Dirmeji (1.130) is positively associated with the first dimension, while Aira (-0.675) and Guliso (-0.423) are negatively associated. This implies that Boji Dirmeji has a distinct relationship with the variables represented by the first dimension. The second dimension further distinguishes Aira (1.163) from Guliso (-0.435), suggesting notable regional differences in the patterns of calf births.

Year effects also exhibit significant associations with the first two dimensions. For example, the year 2019 (0.722) is positively associated with Dimension 1, while 2020 (-1.207) is strongly negatively associated with the first dimension. This indicates that 2019 and 2020 represent contrasting patterns of calf births, with more favourable conditions or management practices likely present in one year versus the other. The partial contributions for 2020 further substantiate this observation, showing a large contribution (0.30698) to Dimension 1. The negative association between 2020 and calf sex may reflect environmental or management factors that disproportionately influenced male births during that year [34].

Similarly, the year 2021 (0.756) positively contributes to the first dimension, though less significantly than 2019. In contrast, the year 2022 (-0.029 for Dimension 1 and 0.9127 for Dimension 3) shows a shift in trends, with an emphasis on Dimension 3, suggesting a relationship between 2022 and the variability in calf sex. The data indicate that the proportion of female calves in 2022 is more pronounced, as seen in the strong positive association with female calf births in Dimension 3 (0.6265), compared to males (-0.5709).

Sex of Calves and Temporal Patterns: The sex of calves shows a less pronounced association with the first two dimensions, but it becomes significant in Dimension 3. Female calves are negatively associated with Dimension 1 (-0.089) and Dimension 2 (-0.434) but positively associated with Dimension 3 (0.6265), suggesting that the variability in female births aligns with more complex factors captured in this third dimension. Male calves exhibit an opposite trend, with positive contributions to Dimension 1 (0.081) and Dimension 2 (0.396) but negative association in Dimension 3 (-0.5709). This implies a distinct pattern of association between male births and specific years or districts.

Partial Contributions: The partial contributions to inertia further clarify the significance of specific variables. Boji Dirmeji contributes significantly to the first dimension (0.33618), suggesting that calf births in this district are uniquely affected by the factors underlying this dimension, potentially including management practices or environmental conditions. Aira's contributions to Dimension 2 (0.24224) and Dimension 1 (0.07455) also highlight the region's distinctive birth patterns.

Year effects are similarly significant, with 2020 contributing heavily to Dimension 1 (0.30698), aligning with its strong negative association with this dimension. The year 2019, on the other hand, makes substantial contributions to Dimension 2 (0.39252), reinforcing the year's unique characteristics in relation to calf births. Additionally, the high contribution of 2022 to Dimension 3 (0.28259) further supports the year's distinct pattern concerning the sex of calves.

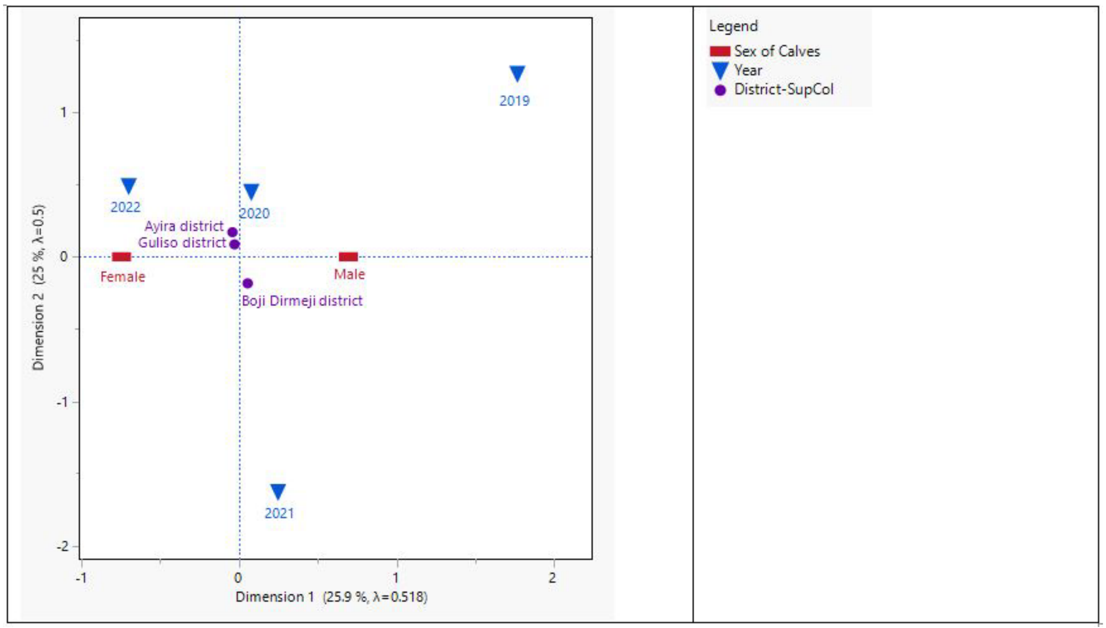

Figure 5: The status of sex calves born in the study district

The results indicate that district and year effects significantly influence the sex ratio of calves. The strong association between Boji Dirmeji and the first dimension, coupled with the distinct birth patterns in 2020, suggests regional and temporal factors, such as environmental conditions or livestock management practices, played a role in calf births during the study period. Previous research supports the influence of geographical and temporal factors on livestock reproductive outcomes [35].

The shift in associations over time, particularly the greater proportion of female calves in 2022, may indicate evolving reproductive outcomes influenced by improved veterinary care or management interventions. This finding aligns with studies showing that livestock management improvements can significantly alter birth outcomes [34].

The MCA reveals significant associations between districts, year, and the sex of calves born. Boji Dirmeji and the year 2020 emerge as key contributors to variability in calf births, while the year 2022 shows a distinct pattern with an emphasis on female births. These findings underscore the importance of considering both spatial and temporal factors in livestock reproductive management, and they suggest opportunities for targeted interventions to improve birth outcomes.

Conclusion

This study demonstrated that crossbred cows exhibit superior reproductive performance compared to local breeds, as indicated by earlier reproductive maturity, shorter calving intervals, and enhanced fertility. District-level analysis revealed significant variations, with certain regions, like Boji, showing delayed reproductive recovery, while others, such as Guliso, displayed better outcomes. Temporal trends highlighted improved conception rates across all districts, particularly in 2021 and 2022, driven by better herd management and veterinary interventions.

However, limitations such as the study's focus on a specific geographic region and reliance on retrospective data may restrict the generalizability of the findings. Future research should explore AI efficiency and reproductive outcomes in a broader range of regions and incorporate more advanced genetic and environmental analyses to develop tailored strategies for improving cattle productivity.

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