

Field Performance, Semen Quality, and Economic Evaluation of Female Sexed Semen Artificial Insemination in Dairy Cattle across Selected Agro-Ecologies of Ethiopia

Ashenafi Kebede Hailemariam¹

Addis Ababa Science and Technology University

Getnet Assefa²

Program Director, NPA-FORAGE, Land O'Lakes Venture37

Mengistie Taye³

Bahir Dar University

Ayele Mandefro Ademe

aye.le.mandefro@aastu.edu.et

Addis Ababa Science and Technology University

Research Article

Keywords: Artificial insemination, dairy cattle, reproductive performance, semen quality, sexed semen, Ethiopia, female calf production, economic analysis

Posted Date: August 4th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10160439/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

Ethiopia possesses the largest cattle population in Africa, yet dairy productivity remains low due to limited genetic potential, poor reproductive performance, and inefficiencies in artificial insemination (AI) services. Female sexed semen technology has emerged as an important reproductive biotechnology for increasing the proportion of replacement heifers and accelerating genetic improvement in dairy herds. However, information regarding its effectiveness, semen quality, reproductive performance, and economic benefits under Ethiopian production conditions remains limited. This study evaluated the effectiveness and efficiency of female sexed semen artificial insemination in selected agro-ecologies of Ethiopia.

Methods

The study was conducted in Hawassa, Shashemene, Bahir Dar, and Debre Birhan during pilot (2020/2021) and scaling-up (2024/2025) implementation phases of sexed semen technology. A mixed-methods approach was employed using farmer surveys ($n = 60$), AI technician assessments ($n = 9$), livestock expert interviews ($n = 4$), reproductive performance records, and laboratory semen quality evaluation. Data were analyzed using descriptive statistics, analysis of variance, and General Linear Models in SPSS version 26 and R version 4.2.1.

Results

Economic analysis revealed that sexed semen generated the highest net profit (100,386 ETB per calf), followed by bull mating (66,316 ETB) and conventional semen (58,425 ETB). Semen laboratory results further indicated that conventional semen had better quality in terms of motility (59.23%), morphology (59.45%), and viability (92.56%) compared to sexed semen, which showed values of 38.46%, 45.20%, and 72.72%, respectively. These differences were statistically significant ($P < 0.001$). Strong positive correlations were observed between semen quality parameters and fertility outcomes. Conventional semen showed higher motility, viability, and morphology ($P < 0.001$).

Conclusion

Female sexed semen improves female calf output and farm profitability but is constrained by reduced semen quality and variable field-level AI efficiency. Strengthening AI service delivery, technician training, and farm-level management is essential to maximize its effectiveness in Ethiopia.

Background

Livestock production plays a fundamental role in the Ethiopian economy and contributes substantially to agricultural development, food security, and rural livelihoods. The livestock sector contributes approximately 16% of the national gross domestic product and between 27% and 30% of agricultural gross domestic product, while generating nearly 13% of national export earnings. Dairy production is particularly important because milk and milk products provide income, nutrition, employment opportunities, and household food security (1).

Ethiopia possesses approximately 70 million cattle, representing the largest cattle population in Africa. However, more than 97% of these animals are indigenous breeds characterized by relatively low milk production potential. Consequently, national milk productivity remains below regional and global averages despite the large cattle population. Indigenous cows generally produce between 0.5 and 2 liters of milk per day under traditional production systems. This low productivity has been attributed to genetic limitations, poor nutrition, inadequate animal health services, and weak reproductive management (2).

Artificial insemination has long been promoted as a strategy for accelerating genetic improvement and increasing dairy productivity. Through the dissemination of superior genetics, AI enables the rapid improvement of milk production and reproductive performance. Nevertheless, the effectiveness of AI programs in Ethiopia has often been constrained by insufficient resources and equipment; unreliable supply of liquid nitrogen; low-quality semen; absence of basic equipment; inadequate infrastructure; poor management and coordination system; high turnover rate among AI technicians; insufficient incentives; lack of acknowledgment for AI technicians; and sporadic service delivery system that is unavailable on weekdays, weekends, and holidays. Furthermore, one major obstacle impeding the nation's efforts to develop the dairy breed is improper record-keeping at the farm level (3).

Recent advances in reproductive biotechnology have introduced sex-sorted semen as an innovative tool for dairy cattle breeding. Sexed semen technology allows the separation of X- and Y-chromosome-bearing sperm cells, thereby increasing the probability of producing offspring of the desired sex. In dairy production systems, female calves are preferred because they contribute directly to herd replacement and genetic improvement (4)(5)(6).

The use of sexed semen offers several potential advantages, including increased female calf production, accelerated herd expansion, reduced dystocia, improved animal welfare, and enhanced economic returns (7)(8). However, sperm sorting procedures can negatively affect sperm quality, resulting in lower fertility and conception rates than conventional semen. Consequently, evaluating the field performance of sexed semen under local production conditions is essential before large-scale implementation (9)(10).

Although sexed semen technology has recently been introduced into Ethiopia through pilot and scaling-up programs, limited information is available regarding its reproductive performance, economic benefits, technician efficiency, and semen quality under different agro-ecological conditions. Therefore, this study was conducted to evaluate the effectiveness and efficiency of female sexed semen artificial insemination in selected agro-ecologies of Ethiopia.

Materials and Methods

The study was conducted in four major urban and peri-urban dairy production areas of Ethiopia: Hawassa, Shashemene, Bahir Dar, and Debre Birhan (Fig. 1). These locations were purposively selected because of their relatively advanced dairy production systems and their involvement in the implementation of female sexed semen artificial insemination (AI) programs. The study evaluated two implementation phases of sexed semen technology: the pilot phase (2020/2021) and the scaling-up phase (2024/2025). Data collection was undertaken during 2024 and 2025 using both retrospective reproductive records and field surveys.

Hawassa is located approximately 275 km south of Addis Ababa at an altitude of about 1750 m above sea level and receives an average annual rainfall of 955 mm. Shashemene is situated within the Rift Valley at elevations ranging from 1700 to 2600 m above sea level with annual rainfall between 700 and 950 mm(11). Bahir Dar is located in northwestern Ethiopia at elevations ranging from 1750 to 2300 m above sea level and receives annual rainfall of approximately 800–1250 mm (12). Debre Birhan is located 130 km northeast of Addis Ababa in the central highlands of Ethiopia and receives annual rainfall ranging from 781 to 1279 mm (13).

Conventional and sexed semen samples were obtained from the Livestock Development Institute (LDI), formerly known as the National Artificial Insemination Center, located at Kality, Addis Ababa. The institute is the sole national semen production center in Ethiopia and supplies semen to AI service providers throughout the country and regional Artificial insemination centers (RAIC) and nine selected AI technicians (14).

Results

Study design

A mixed-methods research design integrating quantitative and qualitative approaches was employed. Primary data were collected through structured questionnaires administered to dairy farmers, AI technicians, and livestock experts. Secondary reproductive records were obtained from livestock and fishery development offices and AI service centers. The study evaluated reproductive performance, technician efficiency, semen quality, and economic outcomes associated with female sexed semen technology and compared them with conventional artificial insemination practices.

Sampling procedures and study population

A total of 60 dairy farm owners were purposively selected based on their participation in the sexed semen program and willingness to participate in the study. The respondents were distributed across the study locations as follows: Hawassa (20), Shashemene (20), Bahir Dar (12), and Debre Birhan (8).

Nine AI technicians involved in the implementation of sexed semen programs during both study periods were selected purposively. Three technicians were selected from each participating region. In addition, four livestock experts, one from each study location, were interviewed to provide technical insights and validate field observations.

Data collection tools Questionnaire survey

Farmer survey

The questionnaire content was reviewed and commented on by livestock experts and advisors from Debre Birhan Agricultural research center and Addis Ababa Science and Technology University. Based on their feedback, minor revisions were made to improve clarity and relevance. The questionnaire was also pre-tested with a sample of the target population to ensure usability. Structured questionnaires were administered through face-to-face interviews using a single-visit survey approach. Information collected included household characteristics, herd size, feeding systems, reproductive management practices, breeding methods, perception of sexed semen technology, and constraints affecting dairy production (15).

AI technician survey

Information was collected from AI technicians regarding the number of inseminations performed, conception rates, calf sex ratios, technician efficiency, and operational challenges associated with sexed semen and conventional semen use.

Expert survey and reproductive records

Secondary reproductive performance records were obtained from livestock and fishery development offices in the study areas. The records included the number of inseminations, conception outcomes, calving rates, calf sex ratios, and breeding method information during both implementation phases.

Semen samples and laboratory analysis

Laboratory evaluation of semen quality was conducted at the Bahir Dar Artificial Insemination Center and the Livestock Development Institute laboratory.

A total of 82 frozen semen straws were collected from different levels of the AI delivery chain, including the Livestock Development Institute, regional AI centers, city AI centers, AI technicians, and commercial dairy farms. Four sexed semen straws contained no semen and were excluded from analysis. Consequently, 78 semen samples (52 conventional and 26 sexed semen samples) were included in the final laboratory evaluation. Samples were then transported to laboratory within a 5 L – 196°C liquid nitrogen container for semen quality evaluation. Maximum care for semen tank management was taken during collection and transportation to avoid any damage to semen at the time of collection, handling, storage, and transportation. The container was filled daily with liquid nitrogen. Laboratory examination was then conducted at LDI and Bahir Dar AI center to assess sperm motility, viability, and morphological defects, following the guidelines provided by (2).

Each frozen bull semen was examined by extracting a single semen straw from a –196 °C container using tweezers, wiping it immediately with a towel, and placing it in a 37 °C water bath for 30 s (2).

Then the tip was cut and the thawed semen was dropped on to slide and a small beaker for motility and viability tests. The slide was covered with a cover slip and put under a heat-staged phase contrast microscope, and semen was examined under 400X magnification and the motility percentage was calculated by dividing the number of motile sperm by the total number of sperm observed and multiplying by 100 (2).

Sperm viability and morphological abnormalities were assessed using the Eosin-Nigrosin stain. First, a drop of semen was mixed with two drops of eosin for 30 s, and then two drops of nigrosin were added to the first mix and mixed again for 30 s. Then a drop of the mixture was put on the edge of a slide and pulled across by using another slide, leaving a smear; thereafter, it was heat dried and oil immersed. More than 300 spermatozoa were counted under a phase contrast microscope at a magnification of 1000X.

Viability percentage was done by dividing the number of live or dead sperm by the total number of sperm cells counted and multiplying by 100. Numbers of morphological defects were counted one by one, and the total sum was divided by the total sperm and multiplied by 100 (2).

Data management and statistical analysis

Primary data collected from AI technicians, AI experts, and dairy farmers through the survey tools, and the data obtained from the cities' livestock and fishery development offices were entered into a Microsoft Excel spreadsheet, cleaned, edited, and coded presented using descriptive statistics such as means, frequency distribution, and percentage in the Statistical Package for the Social Sciences (SPSS) version 26. Laboratory results were entered into Microsoft Excel and summarized using descriptive statistics to describe mass motility, morphology, and live spermatozoa. For inferential analysis, the data were analyzed using the General Linear Model (GLM) procedure in R software (version 4.2.1; Harris, 2022).

Mean separation was conducted using the Least Significant Difference (LSD) test at $P \leq 0.05$. In addition, descriptive statistical analyses were performed to assess variations in the measured parameters across locations, parities, breeds, and semen types (female sexed and conventional frozen semen).

The effects of semen type, parity, location, and breeding method on reproductive and semen quality parameters were evaluated. Differences among treatment means were compared using the Least Significant Difference (LSD) test. Statistical significance was declared at $P < 0.05$.

Economic analysis

The economic impact of different breeding methods was evaluated using partial budget analysis. Net profit per calf born was estimated for sexed semen, conventional artificial insemination, and bull mating systems. Costs considered included milk feeding, concentrate supplementation, roughage feeding, veterinary expenses, labor costs, and miscellaneous management costs incurred from birth to one year of age. The total production cost per calf was estimated at 50,950 Ethiopian Birr (ETB). Net profit was calculated by subtracting total production costs from the market value of calves produced under each breeding method.

Statistical models

Model: Linear Mixed Model (LMM)

$$Y_{ij} = \mu + L_i + B_j + e_{ij}$$

Where:

- Y_{ij} = semen quality trait (motility, viability, morphology)
- μ = overall mean
- L_i = effect of location/stage (LDI, Regional AI Center, AI Technician)
- B_j = random effect of batch/bull
- e_{ij} = residual error

Results

Household characteristics of dairy farmers

A total of 60 dairy farm owners participated in the study. Most respondents were male (85.0%), while females accounted for 15.0% of participants. The educational status of respondents was relatively high, with 40.0% having education above secondary school and 35.0% completing secondary education. The majority of respondents (71.7%) were between 31 and 50 years of age. Dairy farming was the principal occupation for 86.7% of respondents, while 10.0% were engaged in multiple income-generating activities. Most respondents (90.0%) were married (**Table 1**).

Table 1. Socio-demographic characteristics of dairy farm owners (n = 60)

Variable	Category	Frequency	Percentage (%)
Sex	Male	51	85.0
	Female	9	15.0
Education	Illiterate	2	3.3
	Read and write	5	8.3
	Primary school	8	13.4
	Secondary school	21	35.0
	Above secondary	24	40.0
Occupation	Dairy production	52	86.7
	Other occupations	8	13.3

The majority of respondents were involved in small to medium scale urban dairy production systems characterized by limited land availability and market-oriented milk production (**Table 2**).

Table 2. Distribution of Households by Grazing Land Holding Size (n = 60)

Grazing Land Holding Size (ha)	Frequency (n)	Percent (%)
0.00 – 0.10	55	91.7
0.10 – 1.00	3	5.0
1.00 – 5.00	1	1.7
> 5.00	1	1.7
Total	60	100.0

The majority of respondents (75%) relied exclusively on artificial insemination (AI) services for breeding, while 25% used a combination of AI and natural mating (bull service). Most respondents reported communicating with AI technicians primarily via telephone (**Table 3**).

Table 3. Breeding Services Utilized and Communication Channels with AI Technicians among Respondents (n = 60)

Variable	Category	Frequency (n)	Percent (%)
Types of service	Using AI service	45	75.0
	Both (AI & Bull)	15	25.0
Communication with AI technicians	Phone call	60	100.0
Total respondents	—	60	100.0

Post-thaw semen quality differed significantly between semen types (**Table 4**). Conventional semen exhibited higher progressive motility ($59.23 \pm 14.22\%$ vs. $38.46 \pm 10.37\%$), normal morphology ($59.45 \pm 9.86\%$ vs. $45.20 \pm 12.45\%$), and viability ($92.56 \pm 4.74\%$ vs. $72.72 \pm 14.09\%$) than sexed semen ($P < 0.001$ for all parameters).

Table 4. Comparison of post-thaw semen quality characteristics between conventional and sexed semen

Semen type	Mass motility (%)	Normal morphology (%)	Viability (%)
Conventional semen	59.23 ± 14.22	59.45 ± 9.86	92.56 ± 4.74
Sexed semen	38.46 ± 10.37	45.20 ± 12.45	72.72 ± 14.09

Reproductive performance across locations

Location significantly affected reproductive performance indicators ($P < 0.05$). Debre Birhan consistently recorded the highest numbers of inseminated animals and calves born, whereas Bahir Dar recorded comparatively lower values.

Female calf production increased substantially during the scaling-up phase across all study locations. Overall reproductive output improved between the two implementation periods, suggesting increased adoption and utilization of sexed semen technology (Table 5).

Table 5. Mean reproductive performance across study locations

Location	NSPC (mean)	Female calves born (mean)	Total calves born (mean)
Bahir Dar	1.20	1.44	1.73
Debre Birhan	1.41	2.00	3.19
Shashemene	1.41	1.17	1.84
Hawassa	1.54	1.12	1.75

AI technician performance and parity effects

Parity significantly influenced reproductive performance ($P < 0.001$). Older cows recorded the highest numbers of inseminations and calves born, whereas heifers exhibited the highest technician efficiency. Technician efficiency averaged 65.6% in heifers, 57.8% in first-parity cows, and 44.3% in older cows during the pilot phase. Similar trends were observed during the scaling-up phase (Table 6).

Table 6. Technician efficiency according to parity

Parity group	Technician efficiency (%)
Heifers	65.6
First parity cows	57.8
Older cows	44.3

Comparison of sexed and conventional semen across parity groups

Conventional semen produced significantly higher total calf output than sexed semen across all parity groups ($P < 0.05$). However, sexed semen consistently generated a higher proportion of female calves.

The greatest reproductive efficiency for sexed semen was observed in heifers and first-parity cows, whereas older cows showed lower fertility performance (Fig. 2).

Correlation between semen laboratory quality and reproductive performance

Pearson correlation analysis showed strong positive relationships among semen quality parameters, including motility, morphology, and viability. Motility was highly correlated with viability ($r = 0.91$, $P < 0.01$) and morphology ($r = 0.88$, $P < 0.01$). Semen quality parameters were positively associated with calving rate and negatively associated with service per conception. Viability exhibited the strongest relationship with fertility outcomes ($r = 0.74$ with calving rate and $r = -0.69$ with service per conception) (Table 7).

Table 7. Pearson Correlation Matrix between Semen Quality and Fertility

Variables	Motility	Morphology	Viability	Service/conception	Calving rate
Motility	1	0.88**	0.91**	-0.63*	0.71**
Morphology	0.88**	1	0.86**	-0.55*	0.66*
Viability	0.91**	0.86**	1	-0.69**	0.74**
Service per conception	-0.63*	-0.55*	-0.69**	1	-0.72**
Calving rate	0.71**	0.66*	0.74**	-0.72**	1

Economic performance of breeding methods

Economic analysis demonstrated substantial differences among breeding methods. Sexed semen generated the highest net return per calf born (100,386 ETB), followed by bull mating (66,317 ETB) and conventional AI (58,425 ETB).

Across all parity groups, heifers inseminated with sexed semen generated the greatest economic return (**Table 8**).

Table 8. Net profit (ETB) per calf born under different breeding methods

Parity group	Bull mating	Conventional semen	Sexed semen
Heifers	70,312	58,837.57	102,444.84
First parity cows	64,913.01	58,458.41	101,887.70
Older cows	63,725.23	57,980.15	96,825.82
Overall mean	66,316.74	58,425.38	100,386.12

Across all parity groups, the proportion of female calves born varied significantly between conventional and sexed semen (**Fig. 3**). Sexed semen consistently produced a significantly larger percentage of female calves than conventional semen. In heifers, the average female calf ratio from sexed semen was 94.4%, while conventional semen produced 46.7% female calves.

Discussion

This study evaluated the effectiveness and efficiency of female sexed semen artificial insemination technology under different dairy production systems in Ethiopia by integrating farm-level surveys, reproductive performance records, semen quality assessments, and economic analyses. The findings provide important insights into the practical application of sexed semen technology and its potential contribution to dairy herd improvement under Ethiopian conditions.

The household survey indicated that most dairy producers were male, educated, and engaged primarily in dairy farming as their main occupation. The predominance of urban and peri-urban dairy systems with limited land holdings reflects the increasing intensification of dairy production in Ethiopia. Similar findings have been reported by (16) who described the expansion of market-oriented dairy farming in urban and peri-urban areas where land scarcity limits forage production and increases dependence on purchased feeds. The reliance on artificial insemination by most respondents further demonstrates the growing acceptance of reproductive technologies among dairy producers.

The reproductive performance results demonstrated clear differences between conventional and sexed semen. Although conventional semen resulted in a greater number of calves born, sexed semen produced substantially higher numbers of female calves. This outcome is consistent with the primary objective of sexed semen technology, which is to increase the probability of producing female offspring. Previous studies by (16) reported that sexed semen can produce more than 85–90% female calves when used under appropriate management conditions. The increased production of replacement heifers observed in the present study represents a significant advantage for dairy herd expansion and genetic improvement.

Interestingly, the number of services per conception was lower for sexed semen than for conventional semen. This result differs from several studies conducted in Europe and North America, where conception rates following sexed semen insemination were often lower than those achieved with conventional semen (17). One possible explanation is that sexed semen in Ethiopia is primarily targeted toward heifers and first-parity cows, which generally possess higher fertility than older cows. Careful selection of animals for sexed semen insemination may therefore have contributed to the favorable reproductive performance observed in the present study (17).

Parity had a significant effect on reproductive performance. Heifers consistently exhibited superior reproductive efficiency compared with first-parity and older cows. The decline in fertility observed with advancing parity agrees with previous reports indicating that reproductive performance decreases as cows age due to cumulative physiological stress, metabolic demands associated with repeated lactations, and increased susceptibility to reproductive disorders. Similar trends have been reported by numerous dairy reproduction studies worldwide (18). These findings suggest that heifers represent the most suitable target group for sexed semen application.

Significant differences in reproductive performance were also observed among locations. Debre Birhan generally recorded higher reproductive outputs than the other study areas. Variations among locations may be attributed to differences in climate, feed availability, herd management practices, animal health services, and technical competence of inseminators. Previous Ethiopian studies have similarly demonstrated considerable regional variation in reproductive performance indicators. Such variability highlights the importance of adapting reproductive interventions to local production conditions (19).

The assessment of AI technicians revealed substantial variation in performance across parity groups. Technician efficiency was highest in heifers and lowest in older cows. These differences likely reflect the inherent fertility differences among animal categories rather than technician competence alone. Nevertheless, technician performance remains an important determinant of AI success. Proper semen handling, accurate heat detection, correct insemination timing, and adherence to standard operating procedures are essential for maximizing conception rates. Earlier studies have shown that inadequate technician training and poor field-level practices are major contributors to reduced AI efficiency in developing countries (20).

The laboratory evaluation demonstrated significantly higher post-thaw motility, morphology, and viability in conventional semen compared with sexed semen. These findings are consistent with previous reports indicating that sperm sorting procedures expose spermatozoa to physical and biochemical stress, which may reduce sperm quality and fertility potential. The flow cytometric sorting process used in sexed semen production is known to decrease the number of viable sperm cells per dose and may increase susceptibility to cryodamage during freezing and thawing. Similar reductions in motility and viability have been reported by several researchers evaluating commercially produced sexed semen (21).

Despite lower semen quality parameters, sexed semen generated greater economic returns than both conventional semen and bull mating. The higher profitability was primarily attributable to the increased production of female calves, which possess greater economic value in dairy production systems due to their role as future replacement animals and income-generating assets. The economic advantage observed in this study supports previous findings that sexed semen can improve long-term profitability when strategically used in genetically superior animals with high reproductive potential (22) .

The correlation analysis further demonstrated strong positive relationships among semen motility, morphology, viability, and fertility outcomes. Viability showed the strongest association with calving rate and service per conception, suggesting that sperm survival is a critical determinant of reproductive success under field conditions. These findings emphasize the importance of maintaining semen quality throughout storage, transportation, and handling processes. Earlier studies have similarly reported that deterioration in semen quality during storage and handling can significantly reduce conception rates in AI programs (23).

Although bull mating achieved higher conception rates than artificial insemination, reliance on natural service may limit genetic progress and increase the risk of inbreeding in dairy herds. Artificial insemination remains an indispensable tool for genetic improvement, disease control, and dissemination of superior germplasm. Therefore, efforts should focus on improving AI service delivery rather than replacing AI with natural mating. Strengthening technician training, improving liquid nitrogen supply systems, enhancing farmer awareness of heat detection, and promoting better herd management practices are likely to improve reproductive performance and maximize the benefits of both conventional and sexed semen technologies (24).

The economic analysis demonstrated clear advantages of sexed semen technology despite its relatively higher acquisition cost. Sexed semen generated the highest net profit across all parity groups, followed by bull mating and conventional semen. The economic superiority of sexed semen was primarily attributed to the increased production of female calves, which have greater market value and contribute directly to herd replacement and expansion (21).

The economic advantage was particularly evident in heifers, where sexed semen produced the highest net return per calf born. Female calves represent valuable future milk-producing animals and therefore contribute significantly to long-term farm profitability. Previous studies have similarly concluded that sexed semen becomes economically attractive when the value of replacement heifers exceeds the additional cost associated with semen sorting and specialized reproductive management (21).

Overall, the findings of this study demonstrate that female sexed semen technology has considerable potential to contribute to dairy development in Ethiopia. While challenges related to semen quality, reproductive efficiency, and service delivery remain, the technology offers substantial opportunities for accelerating genetic improvement, increasing replacement heifer availability, and improving the profitability of dairy enterprises. Strategic application of sexed semen in heifers and well-managed dairy herds is therefore recommended as part of broader national dairy development programs.

Conclusion

Breeding method, parity, and location significantly affected reproductive performance in dairy cattle. Bull mating achieved higher reproductive efficiency than artificial insemination under field conditions, indicating the need to improve AI service delivery. Reproductive performance was highest in heifers and declined with increasing parity.

Sexed semen technology substantially increased female calf production and provided economic benefits despite its lower post-thaw semen quality compared with conventional semen. The findings suggest that sexed semen can be an effective tool for accelerating genetic improvement and dairy herd expansion when applied under appropriate management conditions.

Recommendations

Improving AI efficiency requires continuous training of technicians and farmers, better heat detection, and proper semen handling and storage. Strengthening liquid nitrogen supply and semen distribution systems is also essential. The use of sexed semen should be prioritized in heifers and high-fertility cows to maximize reproductive performance, female calf production, and genetic gain.

Abbreviations

Artificial Insemination (AI)

Ethiopian Birr (ETB)

Least Significant Difference (LSD)

Linear Mixed Model (LMM)

Livestock Development Institute (LDI)

Regional Artificial Insemination Centers (RAIC)

Statistical Package for the Social Sciences (SPSS)

Declarations

Ethics approval and Consent to participate

This study was conducted in accordance with the ethical principles of the Addis Ababa Science and Technology University (AASTU) and the National Research Ethics Review Guideline (2014) of the Federal Democratic Republic of Ethiopia. Ethical approval was obtained from the Institutional Research Ethics Review Committee of the Addis Ababa Science and Technology University before the commencement of the study.

Permission to conduct the study was obtained from the regional Livestock and Fishery Bureau and the respective city livestock offices. Verbal informed consent was obtained from all participants, including dairy farm owners, artificial insemination (AI) technicians, and livestock experts, before data collection. Participants were informed about the purpose of the study, the voluntary nature of their participation, their right to withdraw at any time without consequence, and the confidentiality of the information they provided. No personal identifiers were collected, and all data were analyzed and reported anonymously.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was financially supported by the Amhara Agricultural Research Institute (ARARI) and the Debre Birhan Agricultural Research Center through sponsorship of the corresponding author's MSc study. Additional financial, technical, and logistical support was provided by the Sustainable Commercialization of Sexed Dairy Genetics in East Africa (SCSDG) Project implemented by Land O'Lakes Venture 37. Addis Ababa Science and Technology University provided academic support and research training. The funding organizations had no role in the design of the study, data collection, analysis, interpretation of data, or preparation of the manuscript.

Authors' contributions

AKH conceived the study, conducted data collection and analysis, interpreted the findings, and prepared the original manuscript. AMA supervised the study, contributed to the study design and methodology, and critically reviewed and revised the manuscript. GA and MT provided technical and scientific guidance, contributed to data interpretation, and reviewed the manuscript for important intellectual content. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to express their sincere gratitude to the Livestock Development Institute (LDI), the Bahir Dar Artificial Insemination Center, Hawassa Artificial Insemination Center, and Shashemene Artificial Insemination Center for their technical support and cooperation during data collection and semen sample evaluation. We are also grateful to the regional livestock offices, artificial insemination technicians, and dairy farmers who participated in this study and provided valuable information and access to animals and farm records. Their contributions were essential to the successful completion of this research.

Authors and Affiliations

Ashenafi Kebede Hailemariam¹, Getnet Assefa², Mengistie Taye³, Ayele Mandefro Ademe*¹

¹Department of Biotechnology, College of Applied Sciences, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia

²NPA-FORAGE, Land O'Lakes Venture37; Program Director, Addis Ababa, Ethiopia

³Director, Institute of Biotechnology, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia

*Corresponding author: ayele.mandefro@aastu.edu.et

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Figures

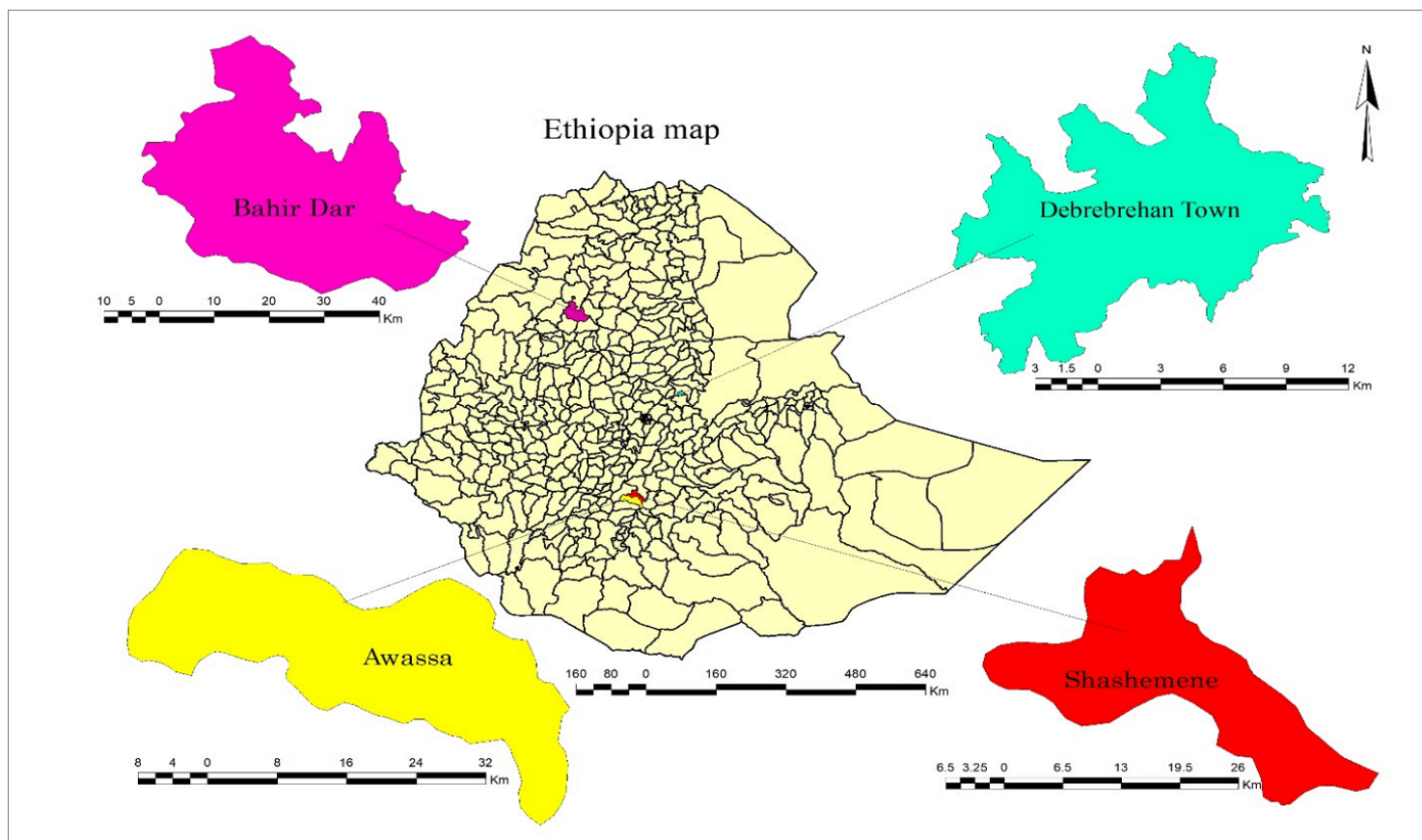


Figure 1

Map of the study area

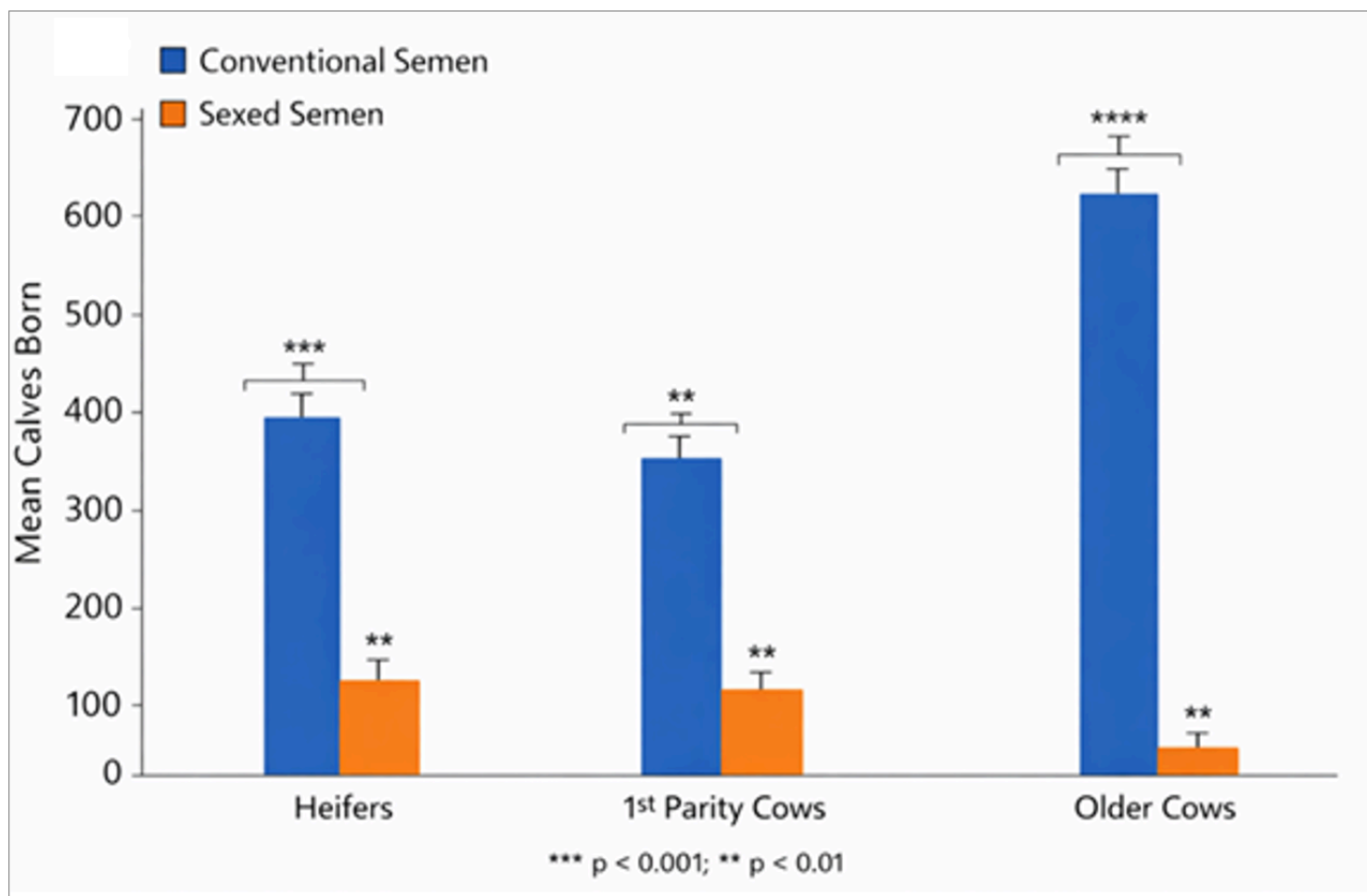


Figure 2

Mean calves born by semen types and parities

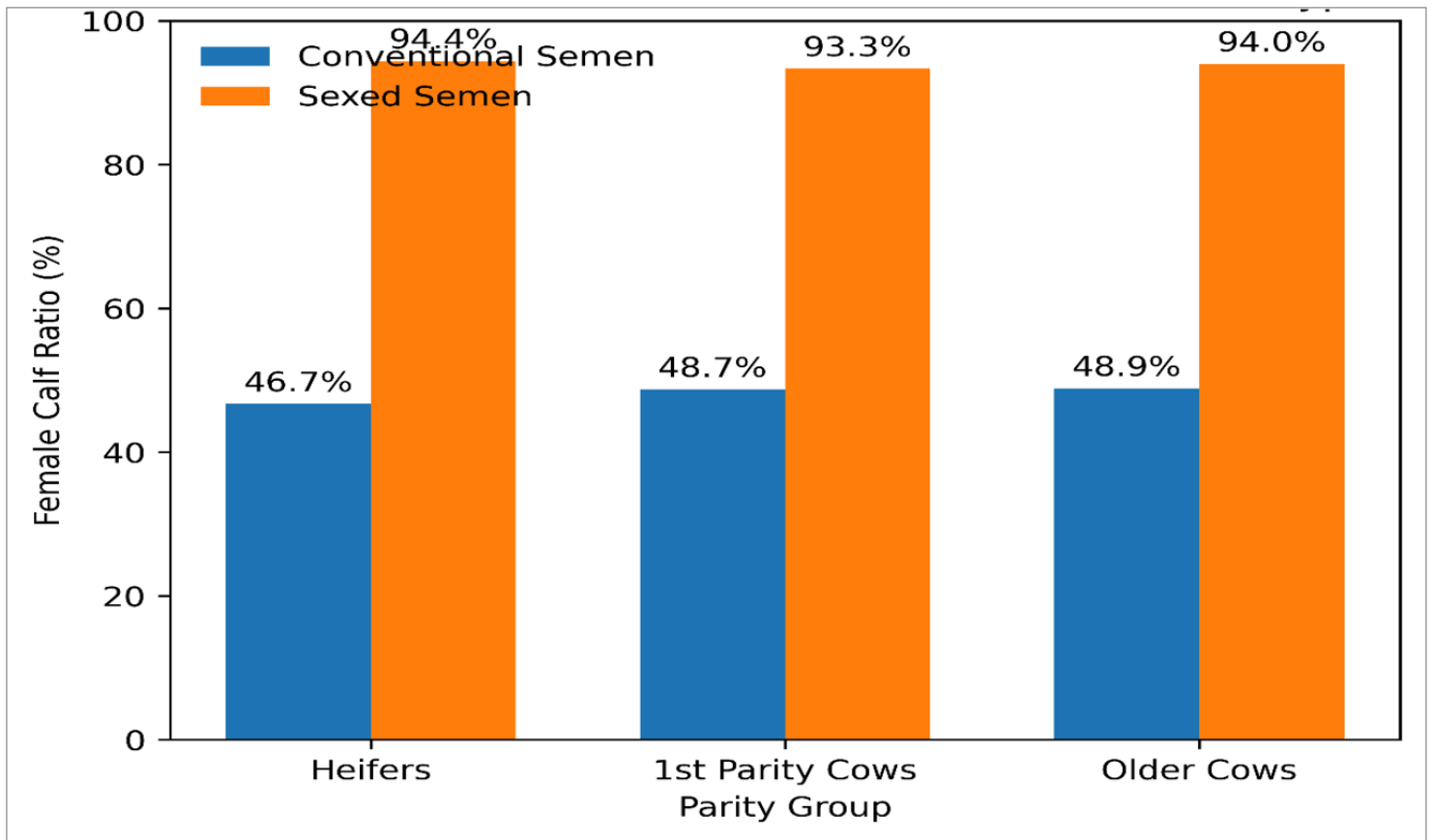


Figure 3

Female calf ratio (%) obtained from conventional and sexed semen across different parity groups

Supplementary Files

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- [Questionnaire.docx](#)