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Genetic improvement of indigenous cattle breeds in Ethiopia: A systematic review of the Fogera cattle open nucleus breeding scheme

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Abstract: Fogera cattle are one of the valuable indigenous milk-type local breeds of Ethiopia, widely adapted to the area around Lake Tana in the Amhara region. The objective of this systematic review was to evaluate the performance of the Fogera cattle breed under an open nucleus breeding scheme. The review was done systematically by collecting published and unpublished data sources on the breed. The overall milk yield of the nucleus Fogera cattle herd was 2.26±0.794L/day. From the total herd, the top 10% and 25% of them produced daily milk yields of 3.31 and 2.87L, respectively, and some elite cows gave an average of 5.45±0.73L/day with a maximum yield of 8L/day. The predicted 305-day milk yield for the top 10% and 25% of the total herd was 883.64 and 772.83L, respectively. The average lactation milk yield and lactation length were reported to be 489±184L and 243±72.79 days, respectively. The respective heritability estimates for the aforementioned traits were 0.20±0.23 and 0.27±0.001. The birth and weaning weights (at 8 months of age) of village Fogera cattle born from community-based breeding programmes (CBBP) were 23.77±.21 and 85.89±1.07kg, respectively. The average weaning age for the CBBP herds was reduced to 8 months. The overall calf mortality in the nucleus herd was 3%. The CBBP demonstrated that it could act as a significant entry point for ensuring the conservation and restocking efforts of this breed as a country asset.

Keywords: Community-based breeding programme, Ethiopia, Growth traits, Milk yield, ONBS, Reproductive traits

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Introduction

Indigenous animal genetic resources are believed to preserve much of the current global genetic diversity, with millions of people directly depending on them (FAO, 2023). Indigenous cattle breeds constitute an important reservoir of genetic material, for which developing nations have failed to provide adequate recognition through their sustainable use and conservation, which puts them at risk of extinction. For example, Sheko cattle in Ethiopia are highly threatened because of cross-breeding with other local cattle, and others like Fogera, Begayit, Ogaden and Borena cattle breeds in Ethiopia are also facing various degrees of threat that challenge their existence as a breed (IBC, 2004). These breeds are decreasing and deteriorating in terms of both population size and genetic diversity due to paradigm shifts in the existing farming system and production system and farm size dynamics of the native habitat, leading to a subsequent genetic dilution (Kebede *et al*, 2013; Tesfa *et al*, 2017; Adisu *et al*, 2021).

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The increasing demand for dairy products because of high population growth, urbanization and improved standards of living is pushing Ethiopia's livestock keepers to increase the productivity of their animals (Shapiro *et al*, 2015). Shapiro *et al* (2017) indicated that, to realize genetic improvement programmes in Ethiopia, the best contributors are a range of agro-climates and production systems, feed and water availability, and small to large-scale farms. Since the 1960s, selective breeding and crossbreeding have been implemented for the genetic improvement of Ethiopian cattle (Chebo and Alemayehu, 2012). However, the anticipated improvement in milk production and productivity has not yet been achieved, even with crossbreeding. The reasons for this, as indicated by Shapiro *et al* (2015), include separate implementation interests between research and development officials, the absence of a clear and implementable strategy that targets the improvement scenario of indigenous breeds, and the absence of sustained support from different stakeholders.

Fogera cattle are one of the promising breeds of Ethiopia that are widely adapted to the plain of Lake Tana in the Amhara region. The Fogera cattle breed is known for its relatively higher milk yield, larger body frame and traction power, better resistance to internal parasite infestation, and sound adaptability to waterlogged Fogera plains, which is attributed to its long legs (Tesfa, 2015). The milk production potential and draught power of the breed are farmers' preferred traits (Zewdu, 2004; Bitew *et al*, 2007). In its production environment, the breed is used as a dam line for milk yield improvement (with Holstein Frisian semen) while the bulls are used in crossbreeding with local highland zebu cattle, which perform poorly under smallholder production system, to improve milk yield, growth rate and draught power (Tesfa *et al*, 2017, 2022). The population size of Fogera cattle is declining at an alarming rate, therefore urgently requiring conservation efforts for future potential use of the breed.

The Andassa Livestock Research Center (ALRC) has been implementing selective breeding and conservation efforts both on station and on farm to safeguard the Fogera breed from extinction and increase its productivity. The center was established in 1964 as the Imperial Fogera Cattle Conservation Centre, with 57 Fogera cows and three bulls purchased from the local area. It was then re-organized as a farm in 1980-1981 and started its operation with the main objective of conserving Fogera cattle and producing F1 Holstein × Fogera crossbreds for distribution to farmers to increase milk production. It was upgraded into a livestock research centre in 2000 (ALRC, 2017). However, in its 40-year journey, it did not provide any visible, significant and sustainable positive change to farmers' lives. Among the reasons is the inability to design and formulate an effective breeding programme. This is a key problem not only for ALRC case but also for all farms, ranches and multiplication centres found in the country.

In 2007, an open nucleus breeding scheme linking the ALRC nucleus and the village herds was designed for Fogera cattle improvement, and the programme was also used as a model for other breeds under different research centres, farms and multiplication centres. The ultimate objective of the breeding scheme was to restock the declining village Fogera cattle populations and improve the livelihood of the farmers. This manuscript summarizes the productive performances, past achievements, shortcomings and lessons learned under the open nucleus breeding scheme and community-based breed programme (CBBP) and indicates gaps and future directions for the sustainability of breeding initiatives.

Material and methods

Data sources

Various researchers, professionals and students (PhD and MSc) involved in the Fogera cattle breeding programme published articles, proceedings and case studies at the level of the two nucleus herds (ALRC and CCBIR) as well as on the community herds. From the summary, above 10 MScs, 2 PhD dissertations, 42 published journal articles and above eigh national, regional, and societal proceedings had information regarding Fogera cattle production and productivity. Besides, more than ten articles have used the genetic potential of Fogera cattle in comparison with other national and internationally recognized breeds for genetic diversity, selection signatures and molecular conservation studies. For this case study, data from more than 17 papers and thesis works with full information on the breed done under the open nucleus breeding scheme were analyzed and compared, while research articles with little information on the Fogera cattle were used to discuss and supplement the main findings. The collected data were analyzed by SAS (2002) and MS Excel was used to develop graphs and trend lines. Besides, articles published online on different Ethiopian breeds were used to discuss the main findings of the case study (Table 1).

Data analysis

Daily milk yield (L), lactation milk yield (L), birth weight (kg) and weaning weight (kg) performance were the dependent variables, while breeding period (year), sex, season and district were used as independent variables for the analysis of quantitative traits. The fixed factors were analyzed by the GLM procedure of SAS (2002) software. Genetic parameter estimation for pre-weaning growth performance and milk-related traits was done by the statistical procedure of Wombat software (Meyer, 2007) in the case of Kassahun *et al* (2020) and ASReml (Gilmour *et al*, 2015) in the case of Tesfa (2015). Heritability, repeatability, and genetic and phenotypic correlations were estimated. Survival of calves at the nucleus herd was done with the Cox proportional hazards model (Cox, 1972) of Stata software (SE 14) (1996–2021) in the case of Gessesse

Table 1. Data sources used for the systematic review. ALRC, Andassa Livestock Research Center; CCBIR, Chagni Cattle Breeding and Improvement Ranch.

Publication types	Publication/ releasing years	Articles' focus	Working sites	Study topics	No. of publications
MSc thesis	1992 to 2019	Fogera cattle breed	ALRC, CCBIR and on farm	Growth, milk, reproduction, survival	6
Scientific articles	2005 to 2023	Fogera cattle breed	ALRC, CCBIR and on farm	Growth, milk, reproduction, survival, population number	15
	1982 to 2023	Ethiopian indigenous cattle breeds	Different sites in Ethiopia	Production system, growth, milk, reproduction	10
Proceedings	2007 to 2019	Fogera cattle breed	ALRC, CCBIR and on farm	Production system, growth, milk, reproduction, survival	5
Reports and working documents	2004 to 2023	Fogera and other Ethiopian indigenous cattle breeds	Different sites in Ethiopia	Production system, breeding design, strategic plan	8

et al (2021a), and the chi-square test of SPSS (version 22) was used in the case of Mola *et al* (2019).

Results

Description, distribution and adaptive potential of Fogera cattle

The Fogera breed is characterized and well known by its pied coat of black-and-white or black-and-grey; short, stumpy, pointed horns; hump ranging from thoracic to cervico-thoracic; folded dewlap, of moderate to large size; docile temperament; and is used for draught, milk and meat (Rege and Tawah, 1999; DAGRIS, 2007). It is highly tolerant or resistant to heat stress and solar radiation, which could be due to its dominantly white coat colour with short hair. Additionally, the breed is known for its adaptation to high altitudes, tolerance to parasite and disease infestation, fly burden, wet soils or swampy areas, low-quality feed and other unfavourable environmental conditions (Alberro and Haile-Mariam, 1982).

Farmers keeping Fogera cattle reported the breed is known for its drought tolerance, better milk yield and growth rate (Tesfa *et al*, 2022), and its environmental adaptation and meat production potential (Kassahun, 2019). The breed is reared in districts surrounding Lake Tana and is one of the most populous and productive breeds in the Amhara region (Tesfa, 2015) and the country (IBC, 2004). Additionally, the breed is found and conserved at ALRC, Chagni Cattle Breeding and Improvement Ranch (CCBIR), and their surrounding kebeles (a small administrative unit in Ethiopia). Figure 1 shows the Fogera cattle distribution districts and working sites.

Description of the breeding strategy

The open nucleus breeding scheme (Figure 2) was the strategy employed since 2007 to conserve, improve and restock the declining population of Fogera cattle. The nucleus was established in early 1964 by the Emperor's regime (ALRC, 2017). The scheme was implemented in selected districts where the pure line breed was intended to be produced, namely Wagetera kebele of Fogera District and Metrha Abawarka kebele of Gondar Zuria District. However, due to high levels of admixture observed in the village herd, the breeding scheme has been closed since 2015. This has prevented the introduction of heifers from the village herd to the nucleus herd to safeguard the latter from genetic dilution (Figure 3; Tesfa *et al* (2017)).

The districts involved in the open nucleus breeding scheme study were selected through the participation of researchers and experts, with criteria such as the presence of true-to-type Fogera cattle (50%), accessibility and presence of knowledgeable farmers (25%), and others like the willingness of farmers, availability of communal grazing land, and enough land for feed development (25%). After the selection, a discussion was done with the community on points like the importance and productivity of the breed, its value for them, and the need for conservation and improvement strategies. After a consensus was built with the community, farmers were selected to hold the breeding bulls and serve the community. Those farmers were selected based on wealth status, cattle management practices and the presence of a better educational background for record keeping. The bulls were provided under a written contractual agreement for four years of service to avoid inbreeding, after which the bulls became the property of the recipients. The participating farmers were then arranged as a community-based breeding programme, having their own committee to manage and decide on the activity with the researchers leading the programme (Tesfa *et al*, 2019).

The meta-analysis was done for production traits like daily milk yield, lactation milk yield, lactation length;

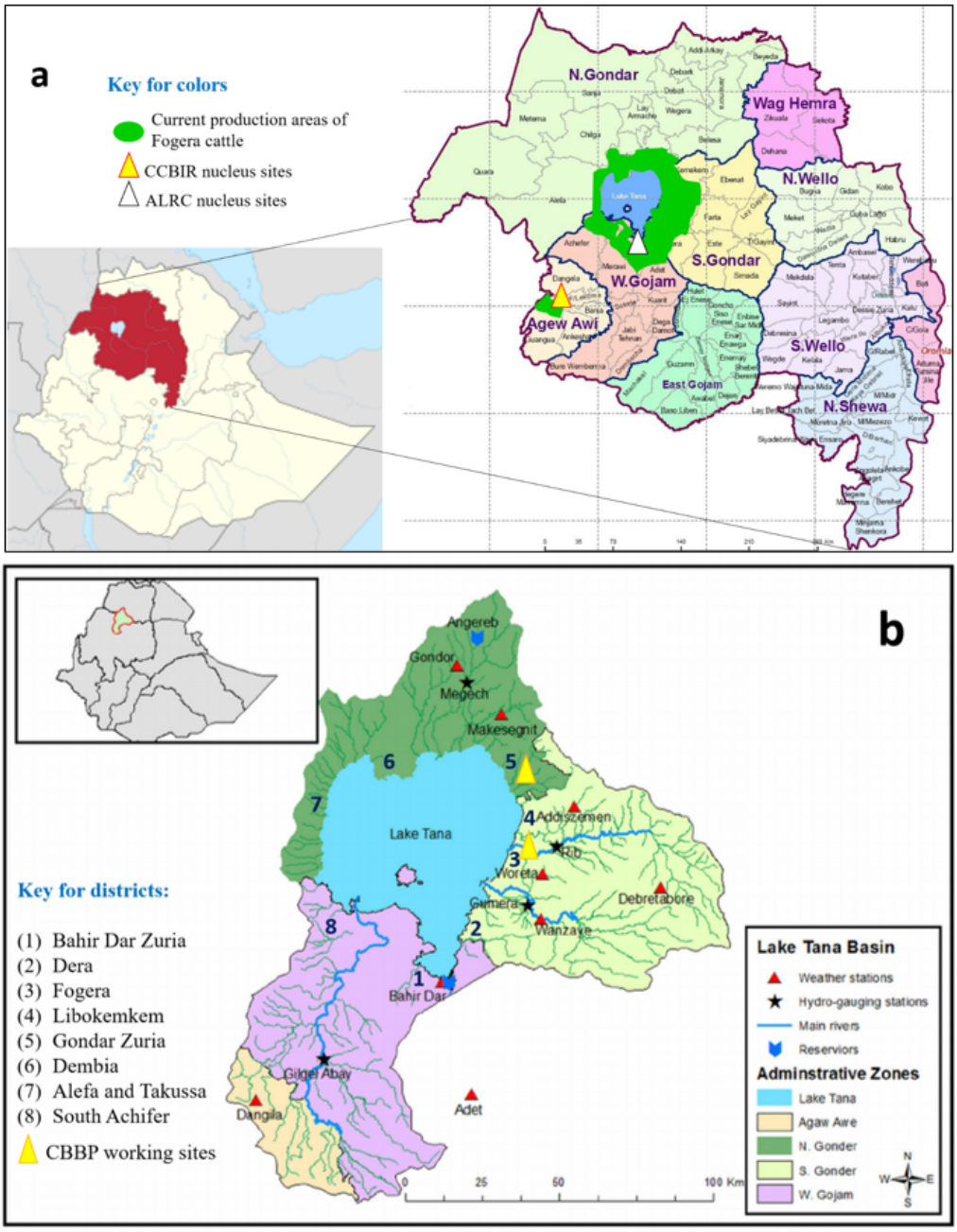

Figure 1. a) Distribution of Fogera cattle in the Amhara region, and Andassa Livestock Research Center (ALRC) and Chagni Cattle Breeding and Improvement Ranch (CCBIR) nucleus sites (Tesfa *et al*, 2022); b) Districts suitable for the production of Fogera cattle breed and community-based breeding programmes (CBBP) working sites (Tesfa *et al*, 2017)

growth-related traits for birth weight and weaning weight; reproductive performance traits for age at first calving, calving interval, and days open; and calf survival in Fogera cattle kept under an open nucleus breeding scheme.

Productive and reproductive performances

Milk yield performance of Fogera cattle

According to the report of Tesfa *et al* (2019), the milk yield of Fogera cattle at ALRC showed an increasing trend from 2002 to 2017, with a lower yield between 2005 and 2007. The inbreeding rate during this time, according to the author, contributed to this outcome. Removing the inbred individuals increased the output from 1.92 to 2.43L per day. From the total herd, the top 10% and 25% had an average milk yield of 3.31L and 2.87L per day, respectively. At ALRC, there were four groups of pure nucleus herds with an average of 45 cows and one mating bull. These were selected and grouped based on their estimated breeding value (EBV) for milk yield and family relationships to minimize inbreeding; the top 45 individuals with higher EBV were grouped as group I, and next 45 individuals with group II and the like for group III and IV (Table 2).

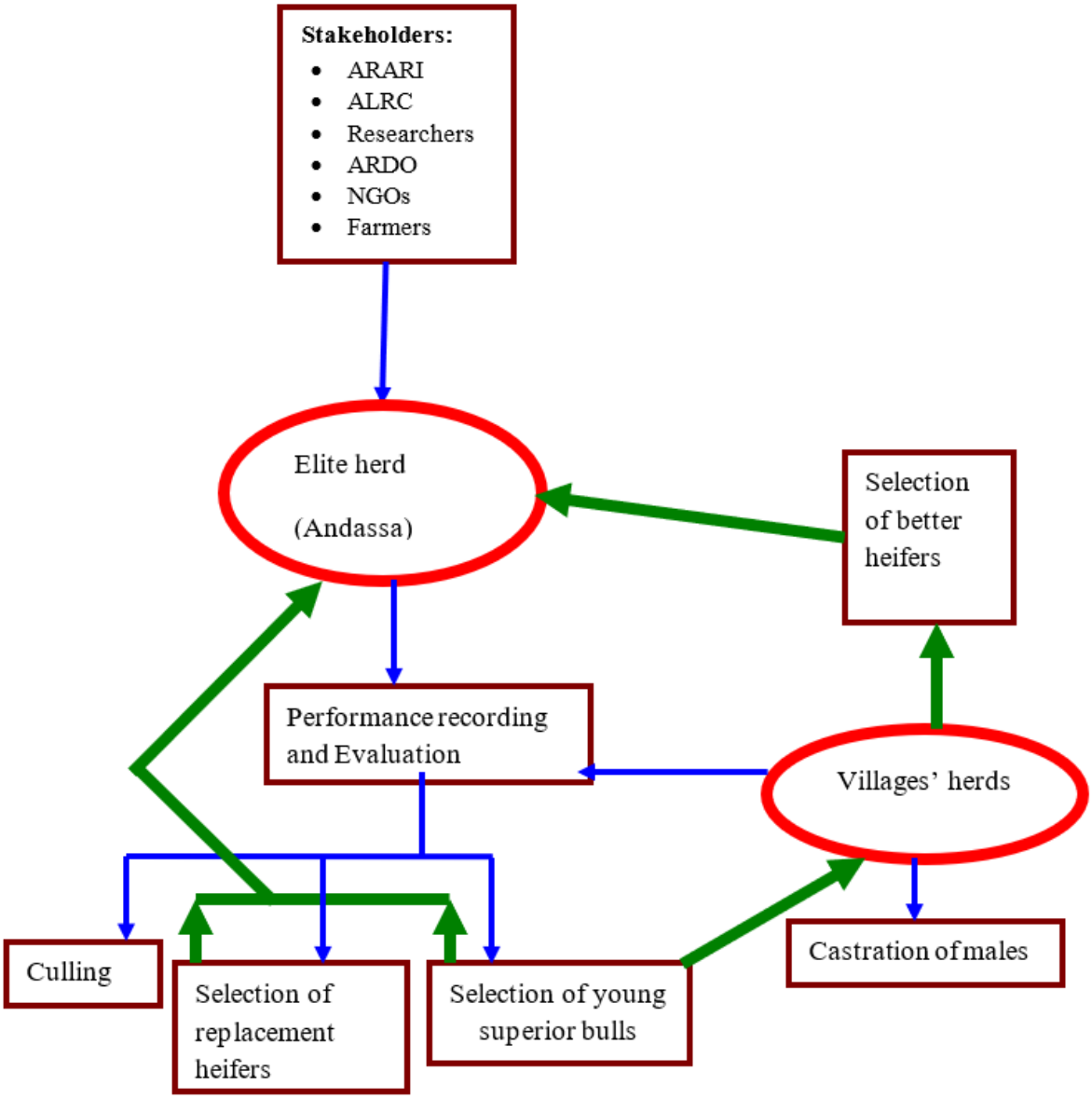

Figure 2. Open nucleus breeding scheme (ONBS) (Tesfa *et al*, 2019)

As indicated in Table 2, the daily milk yield per cow had a big variation from 0.4 to 7.2L per day, which still allows for improvement within breed selection. The predicted 305-day milk yield also indicated a big variation among breeds and ranged from 274 to 1,194L of milk with an overall average of 578.26L. The top 10% and 25% of the total herd had a 305-day milk yield of 883.64 and 772.83L, respectively (Tesfa *et al*, 2019). According to the experiment by Bitew *et al* (2021) on the potential exploitation of the breed for milk yield, cows were divided into two groups: group one received concentrate feed adjusted based on their daily milk yield in addition to grazing, while group two relied on grazing alone (control). The cows in group one gave 4.69L of milk per day compared to 2.21L in the control group. This indicated that the breed's genetic potential may have been masked by poor environmental conditions, which need to be improved through delivering additional feeds and husbandry practices.

According to Kassahun *et al* (2020), the average daily milk yield (DMY) and lactation length (LL) of the breed were 1.98±0.60L and 243±72.79 days, respectively, and the lactation milk yield (LMY), which is calculated by multiplying DMY by LL, was 489±184L. As shown in the trend (Figure 4), the results for these parameters exhibited significant variability and inconsistency over the reported years, which was due to the lower selection intensity and number of animals considered in the selection procedure (Kassahun *et al*, 2020). According to the genetic parameters estimate, heritability for DMY, LL and LMY was 0.33±0.27, 0.20±0.23, and 0.27±0.001, respectively. Besides, the repeatability of the respective traits of interest was 0.33, 0.48, and 0.55 (Kassahun *et al*, 2020).

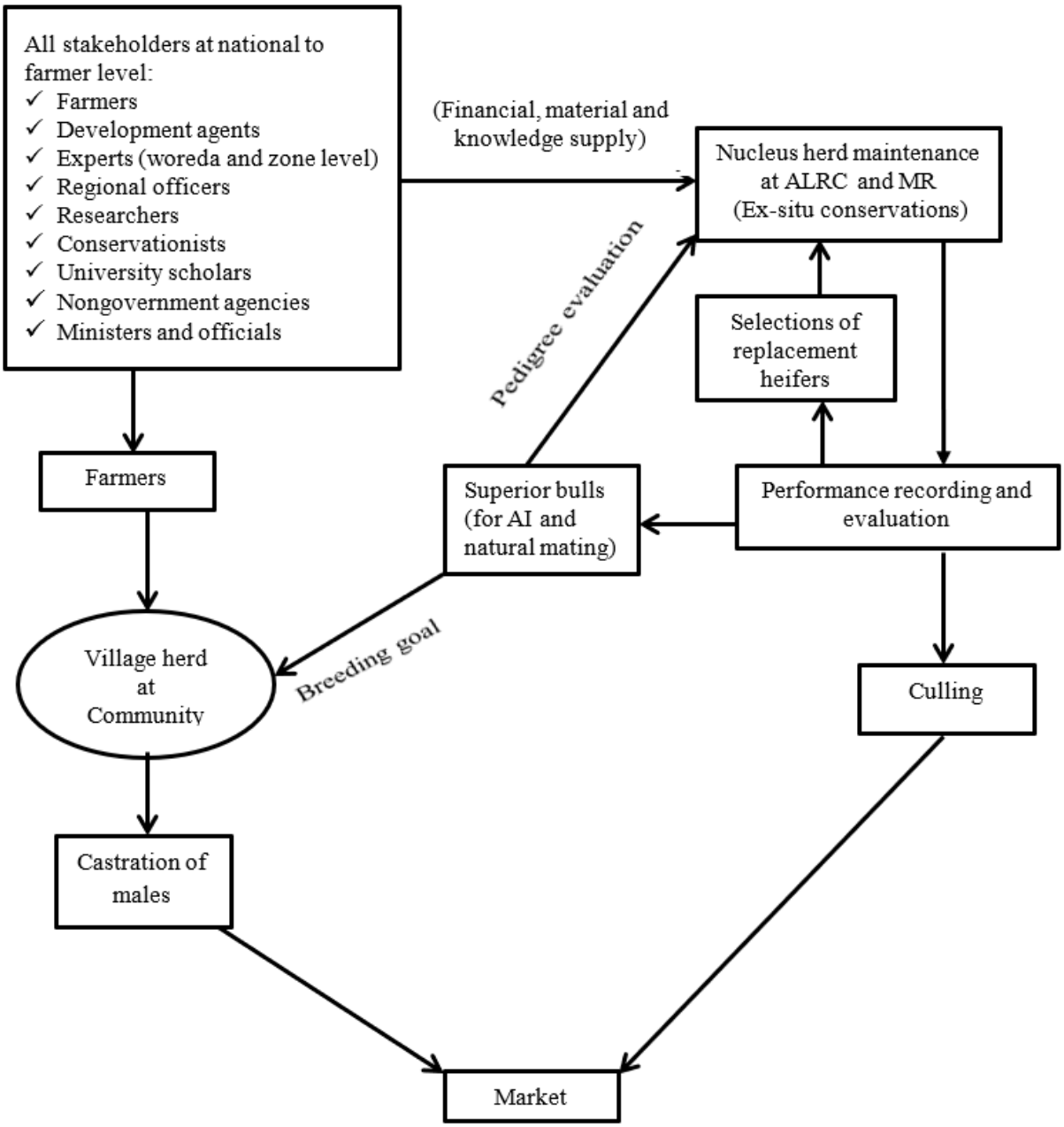

Figure 3. Closed breeding scheme (Tesfa *et al*, 2017)

Table 2. Milk yield performance of the four pure nucleus herds at the Andassa Livestock Research Center (ALRC). Source: Tesfa *et al* (2019)

Herd type	Milk yield (L/day)			
	Mean	SD	Minimum	Maximum
Overall	**2.26**	**0.794**	**0.4**	**7.2**
Fogera Group I	2.24	0.731	0.7	5.5
Fogera Group II	2.52	0.863	0.6	6.1
Fogera Group III	2.05	0.814	0.4	7.2
Fogera Group IV	2.18	0.707	0.6	4.5

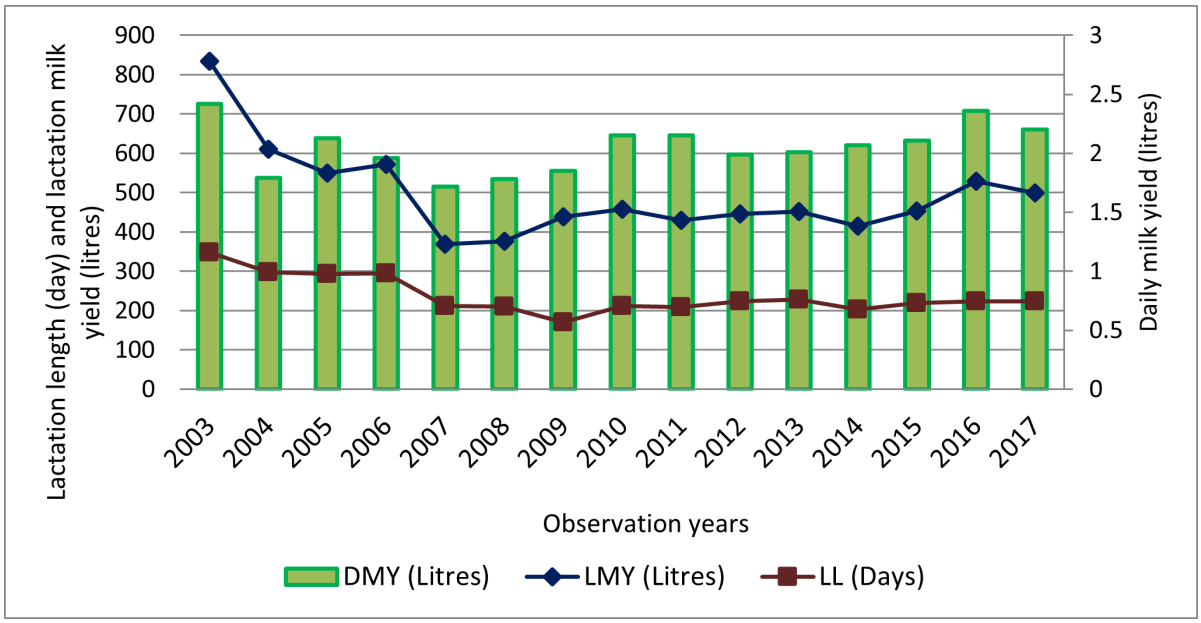

Figure 4. Lactation length (LL), lactation milk yield (LMY) and daily milk yield (DMY) of Fogera cattle across selection years (Kassahun *et al*, 2020)

Growth performances

Performance under Nucleus herd. The birth and weaning weight of Fogera calves in the two nucleus herd populations is presented in Figure 5. According to the trend across selection years, both weaning and birth weight showed variability in both sites. The main reasons for this inconsistency were variations in the management of pregnant cows and calves, climate variability exerting an effect on feed availability, poor recording systems, and differences among individual animals included in the selection process during different years (Bekele, 2012; Tesfa *et al*, 2016; Kassahun *et al*, 2022). Besides, the observed inbreeding in the nucleus herd during 2006-07 (Mekuriaw and Bitew, 2006) and varying management aspects (Kassahun *et al*, 2022) at ALRC contributed to the declining trend of birth and weaning weight of Fogera calves.

The heritability estimate for the pre-weaning growth rate of Fogera cattle at the two nucleus herds is summarized in Table 3. It was observed that the heritability for birth weight had declined with the advancement of years at ALRC. Differences across years might be due to management differences that influence the environmental part of the estimated genetic parameter, the number of data points, and differences in methods of estimation among the authors. The heritability estimate at CCBIR was lower compared to ALRC; even the estimate for the F1 crossbreed between the Fogera and Holstein Friesian was lower for birth weight and pre-weaning average daily gain (PWADG) and comparable for weaning weight (Table 3). The lower estimate at CCBIR for pre-weaning growth parameters was attributed to the presence of management variations, poor nutritional status of the animals, high environmental stress and data record quality (Bekele, 2012; Zeleke, 2014).

Performances under community-based breeding programme (CBBP) . As an open nucleus breeding scheme, ALRC distributed about 17 pure improved Fogera bulls selected based on their estimated breeding value and physical soundness in two kebeles to conduct a community-based breeding programme since 2012. Trained enumerators collected data for 8 conscutive years on birth and weaning weight from 2,180 calves born by distributed improved bulls and village local bulls for performance comparison. The birth and weaning weights (at 8 months of age) of the village herds born from improved bulls were 23.77±0.21 and 85.89±1.07kg, respectively (Tesfa *et al*, 2019). The average weaning age was lowered from one year to 8 months. Based on the monitoring data at CBBP villages, the average birth and weaning weight of calves born from village local bulls were 20.21 and 85.14kg (at 1 year of age), respectively. This indicated that attempts made through the open nucleus breeding programme, beyond the conservation and restocking efforts, can achieve the genetic improvement of the indigenous Fogera cattle breed (Tesfa *et al*, 2019).

Strategic deworming of internal parasites and scheduled vaccination against known diseases (anthrax, lumpy skin disease, foot and mouth disease and bovine pasteurellosis) were implemented as part of the flock health monitoring. Additionally, grazing land management, the introduction of waterlogged tolerant grass varieties and fattening technology for castrated village local bulls were introduced to CBBP villages to improve the production environment and create an income source for producers. According to (Tesfa *et al*, 2019), under the CBBP, the age at first calving (AFC) was reported to be 36 months, and compared with the

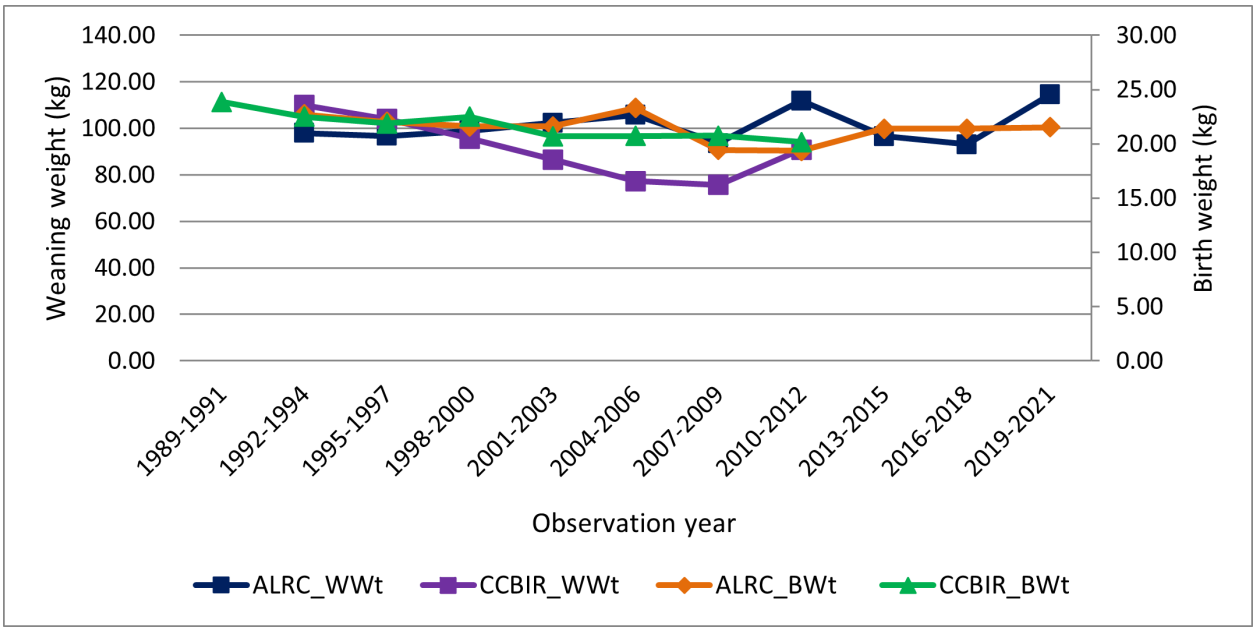

Figure 5. Birth weight and weaning weight at the two nucleus herds. ALRC_BWt, birth weight at the Andassa Livestock Research Center (ALRC); CCBIR_BWt, birth weight at the Chagni Cattle Breeding and Improvement Ranch (CCBIR); ALRC_WWt, weaning weight at ALRC; CCBIR_WWt, adjusted weaning weight at CCBIR (Bekele, 2012; Tesfa *et al*, 2016; Kassahun *et al*, 2022).

Table 3. Direct heritability estimate for pre-weaning growth traits at the two nucleus herds. BWt, birth weight; WWt, weaning weight; PWAGD, pre-weaning average daily gain; *, estimates were done for Fogera × Holstein Friesian (F1).

Parameters	BWt	WWt	PWADG	References
ALRC	0.38±0.32	0.22±0.25		Sewalem (1992)
	0.24±0.09	0.18±0.05		Tesfa *et al* (2019)
	0.21±0.07	0.26±0.01	0.55±0.19	Kassahun *et al* (2022)
CCBIR	0.03±0.02	0.06±0.03	0.05±0.03	Bekele (2012)
	0.13±0.04	0.24±0.08	0.16±0.07	Zeleke (2014)*

actual results before the programme, there was a one-year shortening of AFC. This shows how pure Fogera bulls contributed to upgrading the genetic makeup of the village herds. As traction power is a selective trait of the farmers, calves born through the breeding programme started ploughing at 31 months of age, while the farmers' local bulls did the same work at 41 months Tesfa *et al* (2019). The positive contribution of the open nucleus breeding programme at the on-farm level to the improvement of the genetics and environment was appreciated by participant farmers (Kassahun, 2019).

Reproductive performances of nucleus herd

The average reproductive performance of Fogera cattle at ALRC and CCBIR is presented in Figure 6. The overall average age at first calving (AFC) of 52.00±3.27 months and 52.17±3.17 months; calving interval (CI) of 19.86±2.15 months and 18.65±1.12 months; and days open (DO) of 341.62±90.89 and 280.27±53.86 days were reported at ALRC and CCBIR nucleus herds, respectively. The AFC (month) and DO (day) were lower at ALRC nucleus herds compared with CCBIR's while CI (month) was shorter in the CCBIR nucleus herd compared with the ALRC's (Figure 6). Variations between these two nucleus breeding herds might be attributed to the presence of agroecological differences among the sites. Due to the objectives of the breeding scheme, the improvement in reproductive performance was attained through indirect selection with daily and lactation milk yield. A comparable result for DO (9.5 months), higher CI (19.56 months), and lower AFC (50.8 months) was reported for the nucleus herd at CCBIR (Melaku *et al*, 2011) and a slightly lowered DO (10.17 months) (Gebeyehu *et al*, 2005), AFC (51.76 months), and CI (19.53 months) was reported for nucleus herd at ALRC (Tesfa *et al*, 2016). As reported by Sendeku *et al* (2016), the AFC and CI for on-farm Fogera cattle was 51.4±0.05 and 21.18±0.70 months, respectively.

Calf mortality rate

The overall calf mortality at ALRC and CCBIR was 3% (Gessesse *et al*, 2021b), which is comparable with the minimum standard (3–5%) set for the calf mortality rate (Heinrichs and Radostits, 2001). Gessesse *et al* (2021a) reported that season, breed and birth weight had a significant ($P < 0.05$) association with the incidence of calf mortality in both Fogera cattle nucleus herds, with a respective hazard ratio (HR) of

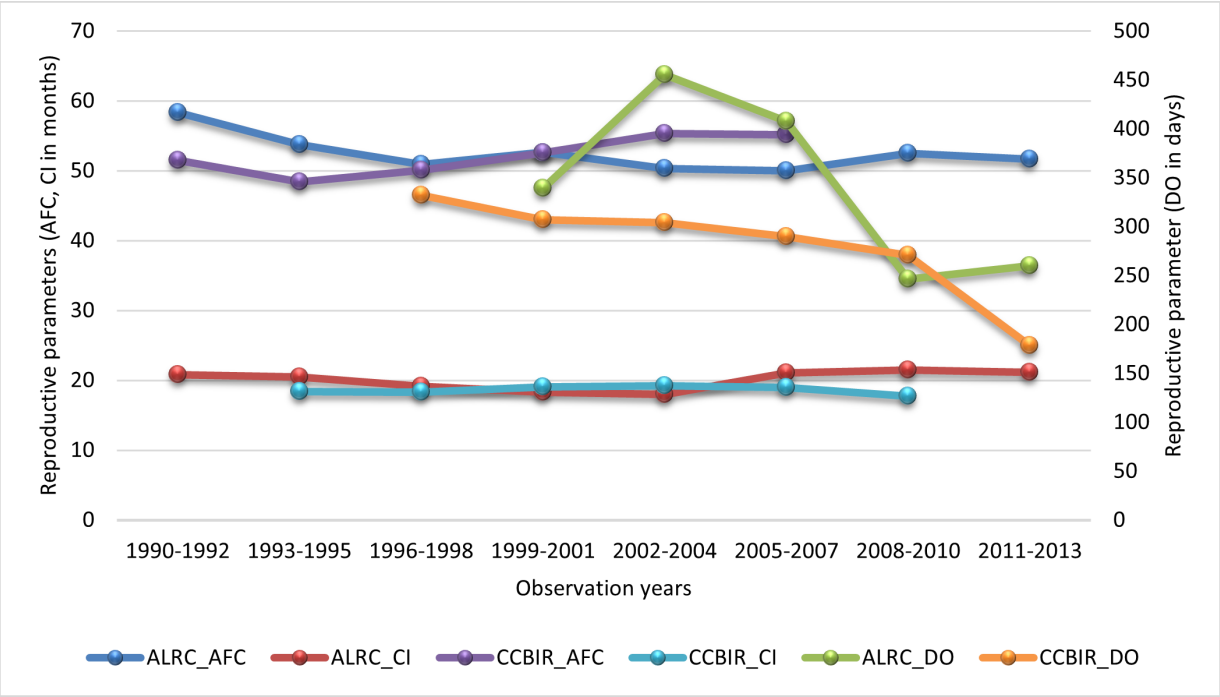

Figure 6. Reproductive performance of Fogera cattle at the two nucleus herds. ALRC_AFC, age at first calving at the Andassa Livestock Research Center (ALRC); CCBIR_AFC, age at first calving at the Chagni Cattle Breeding and Improvement Ranch (CCBIR); ALRC_CI, calving interval at ALRC; CCBIR_CI, calving interval at CCBIR; ALRC_DO, days open at ALRC; CCBIR_DO, days open at CCBIR (Bekele, 2012; Tesfa, 2015; Kassahun, 2019)

1.6, 0.55, and 0.88. Conversely, other potential risk factors such as calf sex, dam parity, year of birth and location did not show a significant effect on calf mortality rates at an early age of the calves at both ALRC and CCBIR (Gessesse *et al*, 2021b). The author indicated that among the significant risk factors, birth weight (HR = 0.88, P = 0.000) was found to be a very important determinant of calf mortality. Based on the health monitoring data, the overall morbidity and mortality rate reported for Fogera calves at ALRC were 12.96% and 7.5%, respectively (Figure 7) (Mola *et al*, 2019), and the diseases contributing to calf mortality were diarrhea, systemic infection, coccidiosis, and gastrointestinal parasites, in order of importance.

On the other hand, the work done at ALRC (Kassahun *et al*, 2023) indicated that the pre-weaning mortality rate of male calves (21.3%) was higher than that of female calves (13.4%). Based on the factors considered, the dry season and lightweight calves contributed more to calf mortality than the wet season and heavyweight calves, respectively. The main reasons for the contribution of these factors were the variability of feedstuffs across seasons and the ability to resist the new environment with a heavier weight at birth, respectively. The heritability estimates done for calf survival at 1, 4 and 8 months of age were 0.26, 0.22 and 0.38, respectively (Kassahun *et al*, 2023), which is categorized as a medium level of heritability.

Population status of Fogera cattle

The estimated population size of the Fogera cattle breed is declining progressively from about 800,000 in the 1980s (Alberro and Haile-Mariam, 1982) to 55,646 heads in 2017 (Tesfa *et al*, 2022), even though Girma *et al* (2016) argued for the presence of satisfactory genetic diversity in Fogera cattle. According to the breed keepers, the population of the Fogera cattle has decreased (40%), increased (13%), is stable (6%) or is not known (41%) (Tesfa *et al*, 2022), while respondents who replied to Kassahun (2019) indicated the population had increased (51.81%), decreased (31.81%), is constant (4.54%) or is not known (11.84%). The difference between the population trends of the two studies is that the respondents to Kassahun (2019) were participants in the open nucleus breeding scheme done by ALRC. Tesfa *et al* (2022) indicated the households in the production track of the breed had kept relatively pure Fogera (41%), Fogera-zebu mix (35%), and highland zebu (24%). The Fogera breed appeared to be threatened due to changes in the agricultural production system in the area and genetic dilution by interbreeding with other adjacent indigenous cattle breeds and by indiscriminate crossbreeding with exotic dairy cattle breeds. Population viability analysis indicated that the pure Fogera cattle are not viable, and population growth is decreasing due to feed shortages, interbreeding with other indigenous breeds, disease and parasites (Alemayehu *et al*, 2015).

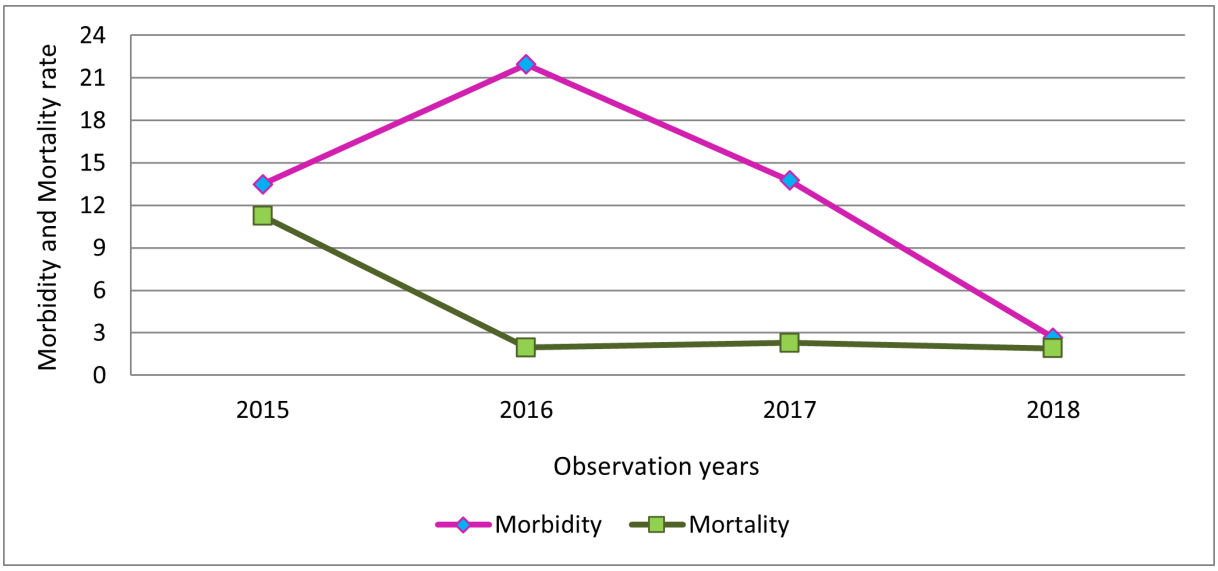

Figure 7. Morbidity and mortality percentage of Fogera cattle at the Andassa Livestock Research Center (ALRC) (adapted from Mola et al., 2019)

Discussion

The daily milk yield of the Fogera cattle at the on-station level indicated a wider variation across selection years, ranging from 0.4 to 7.2L per day, with an average of 2.26L. The reported average daily milk yield (DMY) and lactation milk yield (LMY) were higher than the 1.65±0.03L and 475.85L, respectively, reported for Horro cattle at on-farm conditions (Mekonnen *et al*, 2012) and LMY (425.34±24.06L) at Bako agricultural research centre, Ethiopia (Dabi, 2020). Relatively lower respective values of DMY, LMY and lactation length (LL) of 1.5±0.01L, 419.8±4.45L, and 284.1±0.15 days were reported for Horro cattle at the on-fam level (Mekonnen *et al*, 2021). Similarly, Mekonnen *et al* (2021) reported that the top 10% and 25% of the Horro cattle population produced 2.01 and 1.86L of milk/head/day, respectively, which is lower than that reported for Fogera cattle (Tesfa et al., 2019). Lower average DMY (1.7L) and higher LMY (507L) were also reported for Boran cattle (Haile *et al*, 2011). Mezgebe *et al* (2018) reported a higher average DMY (4.04kg) and average LMY (936kg) for Begait cattle in northern Ethiopia.

The reproductive performance of Fogera cattle observed under both open nucleus and community-based approaches at village herds was comparable with those of other Ethiopian indigenous cattle (Mohammed, 2020; Adisu *et al*, 2021). According to Tenagne *et al* (2023), the performance for calving interval (CI) and age at first calving (AFC) for indigenous cattle in northwest Ethiopia was 20.4±6.1 and 52.5±6.8 months, respectively. A slightly lower result for AFC and CI for Ethiopian Boran cattle at on-station set-up was 48.39±1.41 and 17.91±1.01 months, respectively (Hordofa and Melua, 2021), while a higher value for AFC and CI for the same breed at on-farm level was 53.0 and 18.0 months, respectively (Wario *et al*, 2016). Lower results for AFC (41.2±0.28 months), CI (13.9±0.3 months), and days open (100.5±4.5 days) were reported for Horro cattle in on-station conditions (Jalata *et al*, 2023). The observed variations in the reproductive performance traits between the Ethiopian indigenous cattle breeds might be due to differences in the adaptation of the various local breeds that make them useful for husbandry in different areas and their genetic diversity should therefore be conserved through appropriate programmes.

Conclusion and ways forward

This systematic review summarizes the efforts towards genetic improvement and conservation of Fogera cattle under the open nucleus breeding scheme at ALRC and CCBIR as a nucleus herd and at the on-farm level under CBBP. The results indicate that there was an improvement in milk and growth-related traits, although the trend was slow and decreasing. The presence of variation among individuals in traits of interest suggested there is room for improvement of the breed through selection. One can also assume that the breeding programme was successful, but there are still different problems masking the genetic potential, such as feed availability, management system of dams, data recording, and transfer of data from one researcher to the other. The closed breeding scheme, which the centre currently follows, has been strengthened with the full involvement of farmers, other stakeholders, researchers and experts at different levels. On top of this, the community-based breed productivity improvement programme acts as a big entry point to assure the conservation and restocking efforts of the breed as a country asset, and the programme is better supported with forage, health and extension works to assure sustainability. With these conclusions, the following recommendations are

suggested for sustainable breeding programmes in the future:

- Consistent data records are important for an accurate estimation of genetic and non-genetic parameters for better selection. Thus, a standard record-keeping practice should be adopted.
- The researchers working on the community-based breeding programme should estimate the breeding values of distributed bulls from the nucleus and their daughters for milk and growth-related traits in order to ensure the contribution of a real genetic gain from the distributed bulls.
- The breeding objective developed for milk-related traits should be revised to incorporate the potential of the breed for meat-related traits.
- As heritability for calf survival has been categorized as medium, it is advisable to include it in the selection index under the breeding programme.
- It is recommended to develop a reproductive biotechnology unit to speed up the genetic gain and multiply elite high-yielding animals, which should be established at one of the nucleus sites.

Author contributions

Assemu Tesfa and Kefyalew Alemayehu contributed to the study's conception and design. Data collection and meta-anlysis were done by Assemu Tesfa, Mengistie Taye and Demelash Kassahun. Data analysis and writing of the first manuscript draft were performed by Assemu Tesfa. All authors commented on the various versions of the manuscript, and read and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest.

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