



**PERFORMANCE EVALUATION AND SCALING OPTIONS FOR DOYOGENA SHEEP
COMMUNITY-BASED BREEDING PROGRAM IN CENTRAL ETHIOPIA**

PHD DISSERTATION

ADDISU JIMMA FALITA

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

October, 2025



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ADDISU JIMMA FALITA

MAJOR SUPERVISOR: Prof. ABERRA MELESSE (PhD)

CO-SUPERVISORS: Dr. AYNALEM HAILE (PhD)

Dr. TESHAYE GETACHEW (PhD)

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY IN ANIMAL BREEDING AND GENETICS

October, 2025

STATEMENT OF THE AUTHOR

I, the undersigned, hereby declare that this PhD thesis is my original work, has not been presented for a degree in any other university and that all source of materials used for the study have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for PhD degree at Hawassa University and it is deposited at the University's library to be made available for users under the rule of the library. I declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this dissertation in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

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Signature: 

Place: School of Animal and Range Sciences, College of Agriculture, Hawassa University,
Hawassa

Date of Submission: October 12, 2025

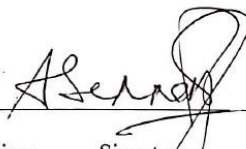


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Aberra Melesse (PhD, Professor)		12/1/2026
Name of Major Advisor	Signature	Date
Aynalem Haile (PhD)		12 January 2026
Name of Co-Advisor	Signature	Date
Tesfaye Getachew (PhD)		12 January 2026
Name of Co-Advisor	Signature	Date

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Aserra Melesse

Name of the Major Advisor

[Signature]

Signature

07.11.2025

Date

Simret Bettha

Name of the Internal Examiner I

[Signature]

Signature

07.11.2025

Date

Haile Woldearagan

Name of the Internal Examiner II

[Signature]

Signature

07.11.2025

Date

LADELE MIRKENA

Name of the External Examiner

[Signature]

Signature

2025-11-07

Date

S Approval

Asst. Prof. (PhD)
Hewan Development
PPPC/PPCS አዲስ አበባ
የጥናትና ቴክኖሎጂ
Research and Technology
Transfer Associate Dean

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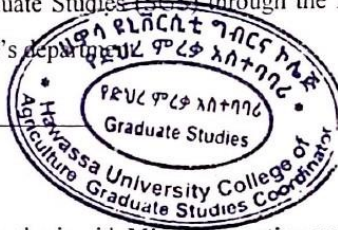
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Simret Betsha  07.11.2025
Name of the Internal Examiner one Signature Date

Haile Welaregay  07.11.2025
Name of the Internal Examiner two Signature Date

TADELE MURKENA  2025-11-07
Name of the External Examiner Signature Date

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 Temesgen Desalegn Darago(PhD)
Director, School of Animal and Range Sciences
 12/01/2026
DGC/SGC Signature Date

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Dedication

To

My late father, Jimma Falita Whom I lost during my PhD study.

LIST OF ABBREVIATIONS

AI	Artificial Insemination
ARR	Annual Reproductive Rate
BWT	Birth Weight
BOKU	the University of Natural Resources and Life Sciences
CBBP	Community-Based Breeding Program
CSA	Central Statistical Authority
CV	Coefficient of Variation
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
IBC	Institute of Biodiversity Conservation
ILRI	International Livestock Research Institute
ICARDA	International Center for Agricultural Research in the Dry Areas
LI	Lambing Interval
LSB	Litter Size at Birth
LSW	Litter Size at Weaning
LSSM	Lamb Survival birth to Six Month
LSW	Litter Size at Weaning
LWB	Litter Weight at Birth
LWW	Litter Weight at Weaning
MOA	Ministry of Agriculture
NARS	National Agriculture Research System
ROI	Return On Investment

WWT	Weaning Weight
SD	Standard Deviation
SMW	Six Month Weight
EPPW	Ewe Post-Partum Weight
PWLS	Pre Weaning Lamb Survival
REML	Restricted Maximum Likelihood
NARS	National Agricultural Research System
m.a.s.l	meters above sea level
SAS	Statistical Analysis System

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LIST OF ARTICLES AND MANUSCRIPT

This dissertation is based on the following papers mentioned below.

- I. Addisu Jimma, Aberra Melesse, Aynalem Haile, and Tesfaye Getachew. 2025. Exploring Genetic Parameters and Correlations among Growth, Reproductive, and Survival Traits in Doyogena Sheep. *Advances in agriculture* <http://dx.doi.org/10.1155/aia/6658918>
- II. Addisu Jimma, Aberra Melesse, Aynalem Haile, and Tesfaye Getachew. 2024. Evaluating Flock Dynamics, Offtake-rate, and Farmers' Perception on Benefits of Community Based Breeding Program in Doyogena District, Central Ethiopia. *J. Anima. Health Prod.*12 (1):108-120. <http://dx.doi.org/10.17582/journal.jahp/2024/12.1.108.120>
- III. Addisu Jimma, Aberra Melesse, Aynalem Haile, and Tesfaye Getachew.2025. Devising up and out-scaling options for Doyogena sheep community-based breeding programs in Central Ethiopia. (Under review).

PERFORMANCE EVALUATION AND SCALING OPTIONS FOR DOYOGENA SHEEP COMMUNITY-BASED BREEDING PROGRAM IN CENTRAL ETHIOPIA

School of Animal and Range Sciences, College of Agriculture, Hawassa University, Ethiopia

Addisu Jimma (MSc.)

Major supervisor: Aberra Melesse (Professor, PhD)

Co-supervisors: Aynalem Haile (PhD) and Tesfaye Getachew (PhD)

ABSTRACT

The studies were carried out to: (1) explore genetic parameters for growth, reproductive, and survival traits; (2) assess morphological changes in the animals and socioeconomic benefits to the community, and describe the flock dynamics of Doyogena sheep; and (3) develop and compare effective scaling options for Doyogena Community Based Breeding Program (CBBP). Data were collected over ten years (2013–2022) on the following traits: birth weight (BWT), weaning weight (WWT), six months weight (SMW), annual reproductive rate (ARR), lambing interval (LI), litter weights and sizes at birth (LWB, LSB) and weaning (LWW, LSW), ewe post-partum weight (EPPW), pre-weaning lamb survival (PWLS), and lamb survival up to six months (LSSM). Variance components and genetic parameters were investigated using the average information-restricted maximum likelihood algorithm were applied in a multivariate mixed model. The WOMBAT and DMU software was used for analyses. A survey of 260 farmers (130 CBBP members, 130 non-members) captured perceptions and flock data. Five scaling strategies were modeled using gene flow method, assuming a nucleus and production unit structure. Results indicated that the Additive heritability estimates were 0.37 (BWT), 0.26 (WWT), 0.21 (SMW), 0.10 (LSB), 0.24 (LWB), 0.03 (LSW), and 0.22 (LWW). For LI, ARR, EPPW, PWLS, and LSSM, estimates were 0.15, 0.12, 0.14, 0.10, and 0.08, respectively. Most performance traits showed positive and significant ($P < 0.001$) annual genetic trends. Positive and low to moderate genetic correlations were observed between growth traits (WWT, SMW) and most reproduction and lamb survival traits. CBBP members had significantly ($p < 0.05$) larger flock size, with more lambs under 3 months, male lambs (3-6 months), intact males (6-12 months), breeding rams, and mature ewes. The primary routes of sheep entry into flocks were birth (81%), and purchase (17%). The total number of entries (284 vs. 240) and births (148 vs. 112) was higher ($p < 0.05$) for CBBP members than non-members. The offtake-rate, representing the proportion of sheep exiting the flock was also significantly higher ($p < 0.05$) for CBBP members (36.45%) than non-members (17.35%). The CBBP was attributed to performance improvements in traits such as growth, coat color, litter size, survival, and lambing interval. Among scaling options, strategy 3 showed the highest return on investment (ROI) at the

production unit level (\$122), while Strategy 5 showed the highest nucleus ROI (\$8.5) and the greatest accumulated discounted benefits (nucleus: \$62,847; production: \$353,757). The highest genetic progress at the nucleus level was achieved with strategy 4 (27.88 kg), where a proportion of sires were produced through AI (Artificial Insemination). Strategy 2 and 5 also outperformed the baseline strategy 1 at SMW trait levels, indicating that increasing the number of breeding females and retaining all candidates has a positive effect. Although strategy 3 did not achieve the highest genetic gains, it delivered a competitive nucleus trait level (SMW=26.00 kg) while maximizing dissemination, leading to exceptional economic outcomes. The AI-based strategies (strategies 4 and 5) produced higher SMW, but their economic returns varied. The medium heritability and moderate correlations between growth and litter weight traits (LWB and LWW) suggest the importance of considering litter weight in addition to growth traits in selection processes. The CBBP was effective and well-accepted by participants. Scaling up is recommended to benefit more farmers. The AI integration scaling strategy can accelerate genetic progress, optimal economic outcomes depend on effective candidate retention, dissemination strategies, and aligning breeding strategies with operational capacity. Policymakers and practitioners should tailor adoption strategies to their specific genetic improvement targets, financial constraints, and infrastructural readiness to ensure that both genetic and economic goals are met sustainably.

Keywords: CBBP, Doyogena-sheep, Flock dynamics, Genetic parameters, Offtake-rate, scaling

1. GENERAL INTRODUCTION

1.1. Background

Sheep are an important livestock species reared in the pastoral, agro-pastoral, and crop-livestock farming systems of Ethiopia, with an estimated population of 38 million (CSA, 2022) distributed across various agro-ecological zones. The variation in agro-ecology and cultural diversity has guided the evolution of diverse sheep genetic resources. Smallholder farmers and pastoral communities derive substantial livelihood benefits from sheep production (Kosgey and Okeyo, 2007). Sheep are considered a living bank and a safety net during periods of crop failure and environmental hazards, and they also serve important socio-economic and cultural functions (Tibbo, 2006; Adane and Girma, 2008; Edea et al., 2010). However, productivity remains low due to several limiting factors (Gizaw et al., 2013).

The main reason for inefficient productivity per animal is the lack of appropriate breed improvement programs in developing countries (Scholtz et al., 2013; Gizaw et al., 2013). Thus, improving local genotypes using proper genetic improvement strategies could be a primary solution for bridging the productivity gap and addressing the challenges the sector faces (Haile et al., 2019). Smallholder and pastoral production systems in the tropics, particularly in Ethiopia, have received little attention in developing appropriate breeding objectives and strategies for livestock in general and for sheep in particular (Kosgey, 2004).

Past efforts to genetically improve small ruminants aimed to enhance the performance of local breeds through crossbreeding with imported exotic breeds (Tibbo, 2006; Rummel et al., 2005; Duguma et al., 2009). However, these earlier breed improvement programs failed to transform animal productivity in a way that contributed significantly to the local and national economy.

This was due to various reasons, including the implementation of programs with little consideration for farmers' needs, insufficient farmer participation, inadequate attention to local infrastructure, and the poor adaptability of exotic breeds (Duguma et al., 2009; Tibbo et al., 2010). Therefore, an alternative sheep breeding strategy is needed one that is applicable, cost-efficient, and focused on developing objective traits while considering the culture of sheep producers. This strategy should employ a participatory (bottom-up) approach suited to low-input systems to improve local genotypes (Mueller et al., 2015).

Recently, a new approach known as community-based breeding has emerged as a viable option to achieve genetic gains that improve sheep productivity. This approach has attracted global interest. It has been tested in different countries with encouraging results observed in performance traits; for instance, in sheep and goats in Ethiopia, dairy goats in Mexico, and llamas, alpacas, and sheep in South America (Haile et al., 2018a). These programs have enhanced the overall productivity of indigenous breeds while maintaining their genetic diversity.

In 2009, the International Center for Agricultural Research in the Dry Areas (ICARDA), the International Livestock Research Institute (ILRI), and the Austrian University of Natural Resources and Life Sciences (BOKU), in collaboration with the National and Regional Agricultural Research Systems (NARS) in Ethiopia, initiated community-based breeding programs (CBBPs) (Mirkena et al., 2012). Over the past decades (2009 to 2018), these breeding programs in Ethiopia have led to benefits such as increased productivity, higher rates of multiple births, better growth rates, and reduced lamb mortality (Haile et al., 2020). Additionally, the average income of sheep producers in Bonga, Horro, and Menz has increased by 20% and meat for home consumption from slaughter of one sheep per year to three due to CBBPs. A total of 3,200 household farmers in 40 villages from 35 functional producer cooperatives are directly

benefiting from the breed improvement program (Gutu et al., 2015; Haile et al., 2018b). The Doyogena sheep CBBP is one of the most well-organized and successful programs, with 8 strong cooperatives and more than 1,200 members.

1.2. The research gap

Evaluating the progress of CBBPs is important for understanding their implementation procedures, performance levels, and benefits to the livelihoods of sheep producers (FAO, 2010; Mueller et al., 2015). Among performance evaluations, quantifying the phenotypic and genetic trends of traits (growth, reproduction, and survival) is a crucial aspect of animal breed improvement programs. Previous evaluations of the Doyogena sheep breed focused on individual traits in isolation using univariate analysis (Habtegiorgis et al., 2020 and 2022a). However, this approach failed to capture potential interrelationships and genetic correlations between growth, reproductive and survival traits. This limitation hindered a full understanding of the breed's complex genetic architecture and the optimization of the selection process. In a breed improvement program, the economic value of the final product generally depends on multiple traits, as highlighted by Bernardo (2002). To address this limitation, the current study proposes a multivariate analysis to uncover relationships between growth, reproduction, and survival traits. By exploring these genetic associations, the breeding scheme can identify animals with desirable characteristics across multiple traits.

This integrated approach ensures that the selection process considers the interplay among growth, reproduction, and survival, leading to a more balanced and optimal breeding strategy. Selecting animals with improved genetic potential for all these traits can enhance the overall productivity, adaptability, and profitability of the Doyogena sheep breed. The knowledge gained

from the multivariate analysis will guide the development of more efficient breeding schemes, enabling the selection of animals with superior genetic merit across a range of economically important traits.

Besides quantitative (phenotypic and genetic) evaluation, the effectiveness of any livestock genetic improvement program is determined by farmers' perceptions. Hence, an assessment of farmers' perceptions should be considered to evaluate the programs' successes and failures (Kosgey et al., 2006). In Ethiopia, few studies have attempted to evaluate pilot CBBP sites (e.g., for Bonga, Menz, and Horro sheep). These studies considered farmers' views on implementation procedures of the CBBPs, biological and socio-economic benefits, and the genetic performance of breed improvement cooperatives with the participation of sheep producers (Gutu et al., 2015; Haile et al., 2020). However, no studies have specifically targeted the Doyogena Sheep CBBPs.

Doyogena sheep breed improvement program is one of the well-progressing CBBPs at the country level. A preliminary evaluation of the programs shows that farmers have increased their breeding awareness by keeping fast-growing animals for breeding while culling unproductive or inferior ones for slaughter, which has minimized unwanted mating. In addition, farmers have started keeping sheep as a main source of income and are selling selected rams at better prices. Improvements have also been observed in growth performance traits such as birth, weaning, and six-month weight (Habtegiorgis et al., 2020; Jimma et al., 2021). The encouraging performance of the Doyogena sheep CBBPs has begun to attract attention from various institutions (Abebe, 2018).

In end of 2024, the Ministry of Agriculture (MOA) and the International Center for Agricultural Research in the Dry Areas (ICARDA) launched the National Red Meat Strategy, which includes

a focus on scaling up sheep and goat CBBPs. The breeding program is expected to benefit smallholder sheep and goat breeders (MOA, 2024). Over the last ten years, CBBPs have undergone different evaluation stages, and a report by Mueller et al. (2018) indicated that these pilot CBBPs are technically feasible and financially rewarding. This proven technology is needed as a strategy to reach a wider range of smallholder sheep keepers through scaling. This would create an opportunity to increase productivity, maximize benefits, ensure sustainable breed improvement techniques, and enhance livestock genetic quality. However, most sheep breed improvement programs in Ethiopia lack a strategy for scaling.

1.3. General objective

- To investigate genetic parameters for performance traits of Doyogena sheep while assessing farmers' perceptions, morphological changes in animal and describe flock dynamics and develop and compare scaling options for Doyogena CBBP.

1.4. Specific objectives

- ✓ To investigate the genetic parameters for growth, reproduction, and survival, as well as the associations among growth and other economically important traits in Doyogena CBBPs.
- ✓ To assess the morphological changes in animal performance and socioeconomic benefits to the community, and describe the flock dynamics in Doyogena CBBP.
- ✓ To develop and compare scaling options for Doyogena sheep CBBPs.

2. LITERATURE REVIEW

2.1. Sheep genetic diversity in Ethiopia

The Farta, Menz, Sekota, Simien, Tikur, Wollo, Afar, BHS(Black head Somali sheep), Adilo (Doyogena), Arsi-Bale, Horro, Bonga, Gumz, and Washera sheep are the 14 distinct breeds of Ethiopian sheep, classified according to their phenotypic traits (IBC, 2004; Workneh et al., 2004). Later research, which genetically described the native Ethiopian sheep population using microsatellite DNA markers, divided the 14 phenotypically identified breeds into nine breed groupings (Gizaw et al, 2007). The sheep types could be categorized based on their geographic location and/or the ethnic groups that care for them, these sheep are given names. According to tail type, the sheep have also been divided into four main groups: fat-rumped, short-tailed, long-tailed, and thin-tailed sheep (Gizaw et al, 2007). These sheep breeds are found in Ethiopia's sub-alpine, arid, sub-humid lowland and wet highland agro-ecological zones. It is believed that approximately 99% of Ethiopia's sheep are local breeds (Mengesha and Tsega, 2012). These local sheep reproduce year-round under uncontrollable mating (Getachew, 2008). The majority of sheep populations are maintained through a conventional, low-input, subsistence-focused production system.

2.2. Significance of CBBPs and scaling options

Human populations are growing rapidly in developing nations, especially in Ethiopia, while farmland and grazing land are steadily declining, and livestock production is adversely affected by severe weather (IBC, 2012; Lemma, 2016; Hidosa and Guyo, 2017). Accordingly, raising sheep and goats is a crucial strategy for mitigating these challenges and feeding the growing human population. This is due to their rapid return on investment through multiple births, short

gestation periods, fast growth, efficient use of limited resources and inherent resilience to climate stress (Feleke et al., 2016; Jemberu et al., 2022; Habte et al., 2022). However, several issues contribute to their low productivity.

Breed improvement program was tested in pilot CBBPs across different production systems and diverse sheep breeds to enhance the livelihoods of smallholders. The evaluation report of the pilot CBBPs (Bonga, Horro, and Menz), as indicated by Mueller et al. (2018), Haile et al. (2020), and Gutu et al. (2015), showed that the breed improvement program, assessed through various evaluation procedures (quantitative, qualitative, and farmers' perspectives), was technically viable and financially rewarding. These three CBBP sites (Bonga, Horro, and Menz) demonstrated significant improvements in productivity (physical changes) in body size, twinning, growth rate, lower lamb mortality, and better market prices compared to non-CBBP farmers. In addition, farmers' yearly income and market participation increased, and their consumption habits improved due to the proper implementation of the CBBPs. Most of the households participating in the Menz site (one of the CBBPs) graduated from the government-run safety-net program, which addresses short-term food needs through emergency relief. Therefore, in addition to the quantitative evaluation of CBBPs, farmers' perceptions play a significant role in determining the significance of genetic improvement programs, particularly in terms of socio-economic status and morphological changes in animal. This includes focusing on objective traits, consumption patterns, income, and knowledge (Kosgey et al., 2006; Lamuno et al., 2018).

The success of pilot CBBPs in Ethiopia justifies their expansion. To secure government and private investment, a clear evaluation framework projecting tangible benefits is essential. While

breeding plans require appropriate level of evaluation, the core criteria of evaluation for CBBPs are genetic progress and economic return. Modeling expansion strategies must use existing CBBPs as a benchmark (Mueller et al., 2019). Key parameters include flock averages (production, reproduction), population structure (number of ewes/rams), survival rates, and selection procedures. As demonstrated in Menz sheep programs (Mueller et al., 2019), a practical selection index (e.g., six-month weight) can be used to drive genetic gain.

Economically, evaluation should focus on maximizing return on investment, using a long-term horizon and a low discount rate (FAO, 2010; Mueller et al., 2019). A cost-benefit analysis for each scaling strategy requires detailed monetary inputs: operational costs, and average annual costs and incomes.

2.3. Flock structure, composition and dynamics

The proportion of a flock of sheep, which is made up of diverse age and sex classes of animals, is called the flock structure. The flock composition, in terms of age and sex classes, is used as an indicator of the management objectives for the owner and the production system, which includes reproduction, mortality, and offtake-rates of the flock. There are large variations in performance among breeds, within breeds, and between regions and farming systems, as well as differences in management practices, ownership patterns, and production objectives (Ayalew et al., 2002; Melesse et al., 2013). For instance, at the CBBP level, keeping fast-growing lambs, reducing lamb mortality, and increasing multiple births resulted in significant improvements in flock structure, composition, and size (Haile et al., 2014; Haile et al., 2020). Flock size and composition per household are influenced by various factors: wealth status, household family size, education, farmland size, the age of the household head, and overall farm production objectives (Deribe, 2009). A study in the northwestern lowlands of the Amhara region indicated

that, of the total sampled Gumuz sheep under farmer management conditions, about 43% were adult females, while the percentage of rams in the flock was only 5.8% (Abegaz, 2007). In the Menz sheep flock, breeding ewes constituted the majority (47%), followed by lambs (19%) and ewe lambs (14.3%), with a smaller proportion of breeding rams (6.5%) and castrates (4%). Similarly, in the Afar pastoral system, breeding ewes were dominant (49%), followed by lambs (24%) and ewe lambs (18%), with breeding rams at 2.8% and castrates at 0.8% (Getachew, 2008). In the Southern Region of Ethiopia, out of a total of 4,735,604 sheep, about 69% of the sheep population was female, while 31% was male (CSA, 2020). Sheep flock size per household in different production system was different. For instance, average flock sizes per household were 6.42 in Eastern Ethiopia of mixed crop livestock production system (Nigussie et al., 2015), 22.6 for Wollo highland sheep (Amare et al., 2018) and 20.1 for Sub-alpine sheep (Gizaw, 2008). Average flock sizes of 5.0 and 6.1 sheep have been reported by Tsedeke (2007) and Deribe (2009), respectively, in the Alaba area in South Ethiopia. In the Doyogena district, Kembata zone, 4 sheep per household have been reported by Taye (2016). According to CSA (2020), among the total sheep keepers in Ethiopia, 20% of those with sheep holdings per household have 1-4 sheep, 8.82% have 5-9 sheep, and 5% have 10-49 sheep per household.

2.4. Productive traits of sheep

The overall productivity and economic benefits of small ruminants are determined by the growth traits at the different development stages. As a key production indicator with implications for the reproductive efficiency, body weight at different ages are an especially important traits for mutton type breeds (Momoh et al., 2013). Therefore, a strategy to enhance the meat production of sheep can be by improving of the growth potential of lambs by selecting animals with the highest genetic merit for growth traits (Baneh, 2009). Growth of lambs particularly during the

pre-weaning stages is significantly affected by breed, mothering ability of the dam and the environment under which the animals are kept including feed supply (Mengistie, 2008). Age of the dam, the pre-mating weight of the dam, birth type, sex and season are among the factors affecting the performance of sheep.

2.4.1. Birth weight (BWT)

Birth weight, recorded within 24 hours of birth, is a critical component of sheep productivity due to its strong correlation with lamb survival and subsequent weights at different growth stages (Gbangboche et al., 2006; Mengistie et al., 2010; Notter, 2012; Momoh et al., 2013). Heavier birth weights are typically associated with single lambs, larger dams, and better management conditions (Mengistie et al., 2010). These lambs generally exhibit larger adult weight, faster growth rates, and higher weaning weights, leading to improved survival, feed conversion, and overall returns (Momoh et al., 2013; Deribe et al., 2014). Birth weight is affected by various non-genetic factors such as parity, year and season of birth, dam's age, type of birth, and the lamb's sex, as well as the prenatal maternal environment (Mousa, 2013; Deribe et al., 2014).

Reported birth weights (BWT) vary by breed. In the early setup of CBBPs, preliminary BWT for Menz, Horro, and Bonga sheep were 2.27, 3.12, and 3.42 kg, respectively (Haile et al., 2014). Among the sheep breeds, the lowest BWT of 1.98 kg was recorded for Menz sheep in Debre Birhan Agriculture Research Centre (DBARC) (Getachew, 2008), and the highest BWT of 3.6 kg was reported for Bonga sheep in Bonga Agricultural Research Center (Metsafe, 2015).

2.4.2. Weaning weight (WWT)

Weaning weight is measured at 90 days of age after birth. It is a trait of great economic importance in sheep production, and it has an influence on growth rate and survival (Mengistie et

al., 2010). Thus, WWT and post-weaning growth rates of lambs are as important as the pre-weaning growth performances of lambs, which are largely linked with survivability, prematurity, and age at first mating.

The trait is influenced by several factors. Report indicated by Kassahun (2000) in the tropics, seasonal variation in growth rate is observed due to feed supply differences in the region. Because of weaning shock (a period of stress for lambs following separation from their mother, leading to slow growth, and weight loss), a lower growth rate was observed at post-weaning time (Mengistie et al., 2010). Effects of non-genetic factors on weaning weight (year and season of birth, birth type, and sex of lamb) were reported by different scholars (Akhtar et al., 2012; Deribe et al., 2014).

2.4.3. Post-weaning weights at different ages

Post-weaning growth is more heritable than pre-weaning growth stage, most likely at the pre-weaning growth stage lamb fully depends on its dam milk. During a period of post-weaning growth nutrition is a limiting factor interms of quality and quantity due to the physiological transition from highly digestable diet to solid feed (Campbell et al., 2017). The primary interest in estimating the heritability of different body weight traits is to identify the most effective selection criterion to improve body weight at different growth stage. Selecting lambs at post-weaning weight can be achieved better progress in weaning weight. This is due to the higher h^2 of the post-weaning weight and its moderate to high genetic correlation with direct components of weaning weight (Balasundaram et al., 2023a and 2023b). Habtegiorgis et al. (2020) reported positive genetic correlations between post-weaning weight traits (especially 3 and 6 months weight). This means that for increasing WWT (weaning weight) resulting in increasing of SMW

(six-month weight) and which could be used as selection criteria for improvement in bodyweights traits.

2.5. Reproductive traits

Reproduction rate is an important trait in any sheep enterprise, as it is closely linked to the income and profitability of sheep production through the increase in the number of additional animals (Montossi et al., 2013; Rather et al., 2020; Abera, 2021). A study by Olivier (2014) indicated that improving reproduction would also enhance selection intensity by providing a surplus of candidate animals for selection. Fertility and reproduction rates are influenced by genetics, nutrition, and management has a significant role (Petrovic et al., 2012). The monetary value of these traits is largely tied to ovulation rate and litter size (Notter, 2008). Therefore, all economically important reproductive traits should be included in the breeding objectives of livestock improvement programs, as the genetic progress of traits contributing to lamb production is permanent, cumulative, cost-effective, and sustainable (Hysen et al., 2015).

2.5.1. Litter size (LS)

Litter size (LS) is the most economically important trait in lamb production, defined as the total number of lambs born per lambing (Bromley et al., 2001). It is a key component of reproductive efficiency (Olesen et al., 1995), with high economic merit and a significant impact on profitability in small ruminant enterprises. A larger litter size allows for greater selection pressure to be applied to breeding goal traits (Shaath et al., 2004). Thus, litter size indirectly contributes to the improvement of quantitative traits. It can be enhanced through within-breed selection (Ibrahim, 1998) and crossbreeding schemes (Abera, 2021; Kao et al., 2022), which involve crossing prolific breeds with non-prolific ones. However, improving reproductive

efficiency solely through the selection of litter size may lead to slow genetic progress because the heritability of LS is typically low (Latifi et al., 2017). Conventionally, LS is considered and evaluated as a trait of females. It depends on ovulation rate and is influenced by the number of fertilized oocytes (Hiwot et al., 2020; Ngcobo et al., 2022). A higher ovulation rate results in more oocytes being available for fertilization (Drouilhet et al., 2013). Various studies have reported differences in LS among sheep breeds, influenced by several factors. For instance, Berhanu and Aynalem (2009) noted that LS increases with parity, and ewes born as twins tend to have higher LS compared to those born as singles. For Iranian Afshari flocks, Mohammadi et al. (2011) reported the highest LS at the sixth parity (1.25 lambs) and the lowest at the first parity (1.09). In Finnish Landrace sheep, LS was estimated to range from 2.32 to 2.76 lambs per ewe, depending on lambing season, year, ewe nutrition levels, and management type (Sormunen and Suvela, 1999; Bermejo et al., 2010). In tropical sheep breeds, LS varies between 1.08 and 1.75, with an average value of 1.38 (Girma, 2008). In Ethiopia, LS ranges from 1.01 in Black Head Somali sheep to 1.7 in the Arsi-Bale breed. Sheep breeds such as Afar, Menz, and Black Head Somali (BHS) generally exhibit low LS, close to one lamb per parturition (Getachew, 2008; Mirkena et al, 2010). In contrast, higher LS have been reported in breeds such as Arsi-Bale, Bonga, Doyogena, Adilo, and Horro. For example, LS in Bonga and Horro sheep was 1.40 and 1.36, respectively (Edea, 2008). LS of 1.17 and 1.11 were reported for Gumuz and Washera sheep under village conditions. Taye et al. (2016) and Habtegiorgis et al. (2020) reported LS values of 1.45 and 1.54 for Doyogena sheep, respectively

2.5.2. Lambing interval (LI)

Lambing interval (parturition interval) refers to the number of days between successive parturitions. The parturition interval in sheep is influenced by various factors such as breed type,

management practices, ewe parity, year of lambing, season, and postpartum body weight (Gbangboche et al., 2006; Mengiste, 2008; Mourad et al., 2015; Abebe et al., 2016; Tesema et al., 2018; Zeleke et al., 2020). Reproductive efficiency is closely linked to the length of the parturition interval; ewes with an extended lambing interval exhibit lower reproductive competence (Deribe, 2009). Which is associated with prolonged lactation anaestrus, poor body condition and disease. Under normal circumstances, indigenous small ruminants are expected to lamb (or kid) at least three times within two years (Girma, 2008; Getahun, 2008). In Ethiopia, a short lambing interval was reported 199.2 days for the Gumuz sheep (Abegaz, 2007) and 203 days for Begait sheep (Amare et al., 2019). For Menz sheep reared in the Ethiopian highlands, the lambing interval (LI) was reported to be 252 days (Mukasa-Mugerwa and Lahlou-Kassa, 1995). Different values of LI for various sheep breeds and populations are reported in the literature. For example, Mohammadi et al. (2011) reported a LI of 306 days for Iranian Afshari flocks, whereas Musa et al. (2005) observed a shorter LI of 207 days in West African sheep. Similarly, Gbangboche et al. (2006) estimated a LI of 242 days for Djallonke sheep. The variations in LI across breeds may result from genetic differences among breeds. However, factors such as the year and month of lambing, the number of lambing, birth type, management practices, and nutritional conditions also influence LI. Feed availability, which is influenced by variations in rainfall patterns and distribution across years and seasons, plays a critical role in herbage production and affects the ability of ewes to return to estrus early after lambing (Berhanu and Aynalem, 2009).

2.6. Lamb survival rate

Higher lamb survival rates are essential for stock replacement and the potential for selective breeding. The extent to which lambs survive to a marketable age is a key indicator of the

effectiveness of sheep production systems. Low survival rates often indicate low productivity. Lamb survivability under village conditions is one of the main factors adversely affecting lamb production and remains a significant source of productive loss, resulting in substantial economic impacts for sheep farming (Abassa, 1995). Lamb mortality is the primary cause of low survival rates. Factors influencing lamb mortality are closely associated with genetics and management systems. These include genetic group, birth weight, type of birth, season, and year of birth. Mortality rates are further exacerbated by poor management practices, such as lamb exposure to wild animals, diseases, dehydration (as lambs are often required to travel long distances without water), heat stress, and a lack of veterinary services (Getachew et al., 2015; Bangar et al., 2016). Consequently, lamb mortality leads to direct and significant economic losses for sheep producers and is a major contributor to the low productivity of sheep farming in the tropics. Pre-weaning mortality alone accounts for approximately 15–20% over extended periods across various countries (Dwyer et al., 2016). Lamb mortality at Doyogena CBBP, mixed crop livestock production system in Keffa zone, and village management in Jimma area were 4.72% (Habtegiyorigis et al., 2022b), 6.86% (Fesseha et al., 2023), 18.5% (Brehanu and Aynalem, 2011), respectively.

2.7. Estimation of genetic parameters

The estimation of genetic parameters and correlations for growth traits at different ages is important for sheep production. This information allows for assessment of genetic variability and its fundamental for determining optimal breeding strategies to improve efficiency (Behzadi et al., 2007; Areb et al., 2021a; Habtegiorgis et al., 2020). Therefore, knowledge of genetic parameters is crucial for understanding the environmental factors and genetic effects that influence lamb growth at various ages and reproductive traits. Among the environmental factors

affecting lamb growth, the most significant are season, year, sex, litter size, parity, and the age of the dam (Akhtar et al., 2012; Deribe et al., 2014). Meanwhile, the key random factors include direct genetic effects, maternal genetic effects, and environmental influences on both the lamb and its dam. According to Yacob (2008), estimated genetic parameters include heritability, repeatability, and correlations between traits.

2.7.1. Heritability of growth and reproductive traits

Heritability is the proportion of phenotypic variance attributable to genotypic variance, representing the fraction of variation among individuals in a population that is due to differences in additive genetic influences (Falconer and Mackay, 1996). It is a key factor in determining the extent of genetic improvement achievable for any trait (Haile, 2006; Getabalew et al., 2019). When individuals are selected based on their phenotypic characteristics, the success of improvement programs can be predicted by understanding the relationship between phenotypic and breeding values. Heritability measures the degree of correspondence between phenotypic traits and genetic potential (John et al., 2018). Accurate heritability estimation is essential for determining an individual's breeding value, as genotypic values result from the cumulative effects of genes (Kanakaraj, 2001). Additionally, estimating genetic, phenotypic, and environmental trends is necessary to make informed comparisons of various selection and management approaches (Mohammadi and Abdollahi, 2015). For traits with moderate heritability, improvement programs should include both genetic enhancements and environmental modifications to achieve optimal outcomes (El-Arian et al., 2008). However, female reproductive traits tend to have lower heritability estimates compared to production traits. This is because reproductive traits are more significantly influenced by environmental factors

and can often be improved more effectively through environmental management than through genetic selection (Chrulukovian, 2006).

2.7.1.1. Heritability of growth traits

The interest in the heritability of various weights (weight at birth, weaning, and six months) lies primarily in selecting the most appropriate weight to use as a selection criterion for improving the desired traits (Balasundaram et al., 2023a and 2023b). Body weight and rate of gain are among the most economically important and easily measured traits in sheep (Mekuriaw and Haile, 2014). Estimates of direct heritability were low to moderate for BWT (0.18-0.32), WWT (0.10-0.26) and SMW (0.16-0.26) in Horro sheep (Abegaz et al., 2002).

Table 1: Heritability estimates for growth traits of some Ethiopian sheep breeds

Breed	h ² a for Growth traits			Analysis	Source
	BWT	WWT	SMW		
Horro	0.18 – 0.32	0.10 - 0.26	0.16 - 0.26	multivariate	Abegaz et al., 2002
Menz	0.019 ± 0.036	0.19 ± 0.057	0.46 ± 0.081	multivariate	Gizaw et al., 2014
Afar	0.13 - 0.38	0.11 – 0.37	0.14 - 0.32	univariate	Yacob, 2008
BHS	0.20 – 0.58	0.00 - 0.29	0.00 - 0.43	univariate	Yacob, 2008
Bonga	0.56 ± 0.030	0.36 ± 0.030	0.22 ± 0.040	univariate	Areb et al., 2021
Abera	NA	0.13 - 0.38	0.20-0.49	univariate	Alemayehu et al., 2022
Doyogena	0.33 ± 0.06	0.14 ± 0.06	0.13 ± 0.04	univariate	Habitegiyorgis et al., 2022a

Note: h²a =direct heritability, NA = Not Available

While low heritability estimates were found for BWT (0.019 ± 0.036) and WWT (0.19 ± 0.057) but high for SMWT (0.46 ± 0.081) in Menz sheep using multivariate analysis (Gizaw et al., 2014). Heritability estimates for Menz and Horro sheep were generally moderate, with values of 0.22 and 0.26 for birth weight, respectively (Tibbo, 2006). The most productive traits were

moderate to high direct heritability for indigenous sheep breed. Heritability estimates of growth traits for some local sheep breeds are indicated Table 1.

The high heritability estimates for productive traits are due to the high genetic variances attributed to these traits, implying the possibility of improvement through selection. Maternal heritability is a function of maternal variance, which arises from the environment (dam effect). However, at weaning, when the lamb is separated from the dam, the maternal environment is withdrawn, and thus the effects of this environment on variance decline as the lamb grows and becomes independent (Meyer, 1992).

2.7.1.2. Heritability of reproductive traits

The overall ewe reproduction features include fertility, litter size, and lamb survival. The heritability estimates for these qualities appear to be modest, reflecting the little genetic variance in most reproductive traits. According to Abegaz et al. (2002), the direct heritability of fertility for Horro sheep was 0.02, while random and fixed effects accounted for 0.06. Both estimates are low, indicating the low heritability of this trait. Similarly low heritability estimates for reproductive traits (0.085 for LS and 0.009 for LI) were reported by Tera et al (2021) for Bonga sheep using univariate analysis. Heritability estimate using multivariate analysis were low to moderate for menz and low for Bonga, Horro, and Semein sheep breed (Besufkad et al., 2025). The importance of litter size is that an increase in the number of lambs weaned per ewe per year offers the greatest single opportunity for increasing the efficiency of any kind of sheep production. Heritability of litter size for Horro sheep was estimated to be 0.15 and 0.07 for the direct additive and repeatability models (Abegaz, 2002) which is slightly higher than the 0.06 to

0.11 estimated by Abegaz et al. (2002). Heritability estimates of reproductive traits for some local sheep are indicated Table 2.

Table 2: Summary of heritability estimates for reproductive traits of some Ethiopian sheep breeds

Breed	h ² a for reproductive traits						Analysis	Source
	LI	LSB	ARR	LWB	LSW	LWW		
Doyogena	0.20	0.28	-	-	-	-	univariate	Habtegiyorgis et al., 2022a
Dawuro	0.001	0.10	0.09	-	-	-	univariate	Habtegiyorgis et al., 2023
Bonga	0.009	0.085	-	-	-	-	univariate	Tera et al., 2020
Menz	0.09	0.08	0.08	0.21	0.05	0.22	multivariate	Besufkad et al., 2025
Semein	0.19	0.14	0.17	0.14	0.16	0.12	multivariate	Besufkad et al., 2025
Horro	0.07	0.07	0.18	0.11	0.02	0.07	multivariate	Besufkad et al., 2025
Bonga	0.03	0.03	0.10	0.08	0.03	0.08	multivariate	Besufkad et al., 2025

Note: h²a =direct heritability

The amount of direct additive and maternal heritability for litter size were estimated 0.14 and 0.08, respectively for Iranian Kordi sheep (Shahdadi and Saghi, 2017). Moreover, ratio of permanent environmental variance to phenotypic variance for the breed was 0.01 to 0.03 (Shahdadi and Saghi, 2017). The direct heritability of litter size for Lori-Bakhtiari sheep in Iran was 0.10 (Vatankhah and Talebi, 2008). Litter size has medium heritability of 0.16 to 0.19 than the other component traits like fertility (0.10) and survival rate (0.09) for Awassi sheep breed (Juma and Alkass, 2006).

2.7.2. Repeatability estimates of reproductive traits

Repeatability is the intra-class correlation among repeated information of an individual (Pickering et al., 2012). It shows the gain in accuracy that can be predicted from the use of the multiple measurements mean instead of a single measurement (Kanakaraj, 2001). Basically, repeatability worth is more than heritability worth on the grounds that repeatability estimates encompass the permanent maternal environmental variance further to the additive genetic variance component (Abegaz and Duguma, 2000).

The accuracy of repeatability estimates for reproductive trends had been decreasing than heritability estimates for selection improvement due to the fact repeatability is a measure of correlation among performances of traits in different parities (Vatankhah et al., 2008). The estimated repeatability of the twinning rate for Horro sheep is 0.16 (Abegaz et al., 2002) while the repeatability of fertility was 0.02 and 0.08 when the service sire was considered random and fixed, respectively. The low repeatability values indicate that an animal evaluation for the traits based on repeated observations is more reliable than an evaluation on a single observation.

2.7.3. Genetic correlations

Genetic correlations represent the extent to which genetic factors are shared among performance traits. These correlations are vital for predicting indirect selection responses and determining optimal trait weighting and expected outcomes. Several studies have reported positive and moderate-to-high correlations between WWT and post-weaning weight traits (Baneh et al., 2013; Singh et al., 2016; Illa et al., 2020). However, the genetic relationship between BWT and body weight at later stages remains contentious. For instance, Haile et al. (2020) observed low correlations between BWT and SMW in Bonga and Horro sheep. Similarly, weak genetic

associations between BWT and other weight measures have been reported for Bharat Merino and Nellore sheep by Gowane et al. (2010a) and Illa et al. (2020), respectively. Accurate estimates of genetic and environmental parameters for breeding goal traits are essential to design an effective selection program (Mohamed et al., 2012).

Reproductive traits exhibit favorable genetic correlations with litter weight weaned, ranging from 0.41 to 0.99, as reported by Snowden (2008). The study also highlighted that selecting for this trait could promote a balanced biological composite, improving fertility, lambing rates, survival, lactation, and growth. Mohammadi et al. (2014) observed positive, albeit relatively low, genetic correlations between BWT and LSB and LSW, alongside strong genetic correlations between BWT and LWB and LWW. Additionally, Mohammadi et al. (2014) reported moderate positive genetic correlations between live weight after weaning and reproductive traits, including litter size and litter weights at birth and weaning. However, direct selection for reproductive traits is hindered by their low heritability (Safari, 2005) and the challenge of measuring them early in life. As Snyman et al. (1998) noted, this limitation makes early-stage selection based on animal performance impractical. Hence, it is vital to identify reproductive traits that correlate with readily measurable traits possessing moderate to high heritability.

2.7.4. Phenotypic correlations

Phenotypic correlation describes the relationship between the phenotypic values of different traits. It indicates whether animals with high values for one trait also tend to have high, low, or average values for another. This correlation can either positively or negatively influence breed improvement programs. Phenotypic correlations arise from the combined effects of additive genetic and environmental factors (Sebastia et al., 2018). For Horro sheep, the phenotypic

correlations of birth weight with weaning weight, multiple births (twinning), and the number of lambs at weaning were 0.37, 0.77, and 0.45, respectively (Abegaz, 2002). The same study reported that the phenotypic correlation of litter size at birth with weaning weight and litter size at weaning was 0.26 and 0.45, respectively. Similarly, for Iranian Kordi sheep, phenotypic correlations among reproductive traits were positive, ranging from 0.02 to 0.29 (Shahdadi and Saghi, 2017). For Egyptian Barki sheep, the phenotypic correlations among the traits were reported 0.3 between BWT and WWT, 0.5 between BWT and pre-weaning average daily gain (ADG), and 0.92 between WWT and pre-weaning ADG (Sallam et al., 2018).

1. SUMMARY OF MATERIALS AND METHODS

The study was conducted in Doyogena district, Kembata Zone in the Central Ethiopia Region. The Doyogena district is situated at 7⁰ 20' N latitude and 37⁰ 50' E longitudes. The altitude ranges from 1900 to 2800 meters above sea level (m.a.s.l). The district was selected due to the existence of Doyogena sheep breed improvement program. The mean average annual rainfall is between 1200 and 1600 mm with an average mean temperature of 10 – 16 °C. Enset (*Ensete ventricosum*) based mixed crop-livestock production system is the dominating production system in the study area (Taye et al., 2016), which is entirely dependent on rainfall. Cattle, sheep, poultry, equine and goats are the major livestock species kept in the district.

The Doyogena sheep (formerly known as Adilo) is one of the thick, long, fat-tailed sheep breeds in the country. This breed is relatively large, twinning is common, and it has a variety of coat colors (Jimma et al., 2021). It is distributed across mid to high altitude regions within mixed crop-livestock production systems in the Central Ethiopia Region. The Hadiya, Kembata, and Halaba zones are the main distribution areas for Doyogena sheep. According to the CSA (2022),

the total sheep population is estimated at around 280,474 head, of which 57% are breeding females. The majority of farmers practice tethering during cropping season and allow their animals to graze on their farmland after harvesting crops. Improved forages, natural pasture, enset (*Ensete ventricose*) corm and tuber, and crop residues are the major animal feed resources (Taye et al., 2016; Habtegyorgis et al., 2022).

The former southern agricultural research institute (SARI), with Areka Agricultural Research Centre in partnership with the International Center for Agriculture Research in Dry Areas (ICARDA), established Doyogena sheep breeder cooperatives in 2013 in the Doyogena district of Kembata Zone. In the District, community based-breeding program was initially started in two villages: Anicha and Hawora. It later expanded into three more villages (Begedamu, Murassa and Serera) in 2014, two additional villages (Lemi and Gomora) in 2017 and one more (Serera women) in 2018. Currently a total of eight active breeder cooperatives are available in the district. The main objective of the breed improvement program is to increase the income of households through enhanced lamb growth, reduced mortality and increased number of lambs born per breeding ewe. Each member in breeder cooperatives contributing at least two breeding ewes, practicing good sheep management, and communicating with enumerators for data collection at different growth stages of the lambs.

Enumerators were hired for data collection when various events occur. Participant farmers keep newly born lambs until the selection period (six-month age) and bring the animals to the central place for selection to identify the best rams. A team of researchers and selection committee members have been involved in the selection process. Based on growth performance, estimated breeding value (EBV), and breeding objectives, the top 10% of rams have been selected. These

rams were purchased by the cooperatives and used to mate ewes, with about 20-30 organized in a mating group under cooperative members.

3.1. Genetic Parameter Estimation and Correlations among Traits

The data sources were the pedigree and performance records of Doyogena sheep that were gathered and kept in the Areka Research Center database over ten years (2013–2022). The traits collected were growth (birth weight, weaning weight, and weight at six months), reproductive (annual reproductive rate, lambing interval, litter weight at birth, size of litter at birth, litter weight at weaning, litter size at weaning, and postpartum weight of the ewe), and lamb survival (birth to weaning and survival birth to six months age (measured as 1 or 0 for a lamb alive or dead, respectively)). The annual reproductive rate and lambing interval were calculated using the available lamb records. Pedigree viewer software was used to avoid mistakes for recording like bisexuality, duplicate animals, and sire or dam of itself problems that were found in the dataset. Before the analysis, outliers identified by transforming extreme data points with z-scores beyond ± 3 standard deviations from the means were excluded to reduce bias in estimation and enhance result consistency. A total of 6505 records of BWT, 5017 records of WWT, and 3821 records of SMW of lambs born from 325 sires and 444 ewes, and 6525 records of reproductive and survival traits of individual phenotypic data were derived as outlined in Table 1 (Article I)

The general linear model (GLM) was employed to analyze growth and reproductive traits, while the logistic regression procedure was employed to analyze survival rates by using the SAS software (SAS, 2012). Fixed effects determined to be significant ($p < 0.05$) were taken in the next genetic analysis model. Fixed environmental effects taken into account during the analysis included season of birth in 2 classes (wet season from April to December and dry season from

November to March), lamb sex in 2 classes (male and female), birth type in 3 classes (single, twin, and triplet and above), ewe parity in 8 classes (ranging from 1 to ≥ 8), year of birth in 10 classes (2013–2022), and breeder cooperatives in 8 classes (Anicha, Begedamu, Gomora, Hawora, Lemi, Murasa, Serera, and Women’s). Variance components and genetic parameters for growth and reproductive traits were estimated using WOMBAT (Meyer, 2007) with multivariate genetic analysis models. Initially, a full multi-trait animal model was attempted for all twelve traits but encountered convergence issues. This led to the analyses, which produced six- and seven-trait with reasonable estimates and improved convergence (change in log L less than 5×10^{-4}). Random effects, including residuals, the permanent environment effect of dam for growth traits, the permanent environment effect of animals for reproductive traits, and the direct additive effect were all taken into consideration by the model. The average information-restricted maximum likelihood algorithm was applied in a multivariate mixed model to investigate lamb survival (Madsen and Jensen, 2013). For the analysis, DMU modules, specifically DMU1 and DMUAI were used. Growth traits and survival were found to have genetic correlations, which were estimated using DMUAI, which was derived from DMU1 data. A direct additive random effect was included in the model.

The model used for the analysis of growth and reproductive traits was

$$y = \mathbf{X}b + \mathbf{W}_1a + \mathbf{W}_2m + \mathbf{W}_3peA + \mathbf{W}_4peD + e$$

The model used for the analysis of lamb survival and growth traits was

$y = \mathbf{X}b + \mathbf{W}_1a + e$ where y = Vector of observation of the studied traits; b = vector of fixed effects; a = vector of direct additive genetic effects; m = vector of direct maternal genetic effects; peA = vector of permanent environment effects of the animal; peD = vector of permanent

environment effects of the dam; e = vector of residual effects. While \mathbf{X} , \mathbf{W}_1 , \mathbf{W}_2 , \mathbf{W}_3 , \mathbf{W}_4 =design matrices associating the fixed, direct additive, direct maternal, permanent environment effect of animal, and permanent environment effects of dam, respectively.

The heritability (h^2) was computed as the ratio of the animal variance to phenotypic variance. Whereas repeatability (r) was determined using the formula $r = (\sigma^2a + \sigma^2peA + \sigma^2peD) / \sigma^2p$, where σ^2a represents additive variance, σ^2peA represents a permanent environmental variance of the animal, σ^2peD represents a permanent environmental variance of the dam, and σ^2p represents phenotypic variance. Genetic trends for the traits were assessed by performing a weighted regression of the average breeding value of the animals based on the year of birth.

3.2. Study on flock dynamics, offtake-rate, and farmers' perception

For this study, five sheep breeder cooperatives implementing CBBP in Doyogena district, Kembata Zone were randomly selected from the existing eight cooperatives. The selection of 5 out of 8 breeder cooperatives over 60% was likely considered due to a balance of practical, statistical, and representativeness factors. The five selected CBBPs were Anicha-Sadicho, Murasa-Woyiramo, Hawora-Arara, Serera-Bukata and Lemi-Suticho. Primary data was captured through interviews, field observations, group discussions and monitoring animals from December 2021 to November 2022. Monitoring was done once a month, and information was collected by breeder cooperative enumerators. A semi-structured pre-tested questionnaire was prepared for the formal survey. One group with 8-12 members was organized for group discussion in each cooperative. The discussion was focused on farmers' perception towards the breeding program, lessons/knowledge acquired during the breeding program, sustainability and suitability of the program, flock management and problems encountered. Data focusing on-flock

size and structure, keeping breeding ram and mating system, flock dynamics (incoming and exiting routes of sheep), physical changes such as growth, conformation, survival, litter size, and coat color that farmers have recognized. In addition, change in income from sheep and its contribution to livelihood, and constraints they faced along with socio-economic characteristics were also collected through formal survey and used as a primary source.

Recorded data (number of animals selected, sold animal number and price of selling, members of cooperatives) were obtained from the secondary source and other additional information collected from cooperative's receipts, invoices, record books and case histories. Among total sheep producers in the study site, a total of 260 sheep producer households were included in the study, from which 130 respondents were selected to represent 358 CBBP members while the rest, 130 respondents were selected from non-CBBP members by using the simple random sampling technique based on the formula given by Yemane (1967):

$$n = \frac{N}{1+N(e)^2}$$

Where: n= sample size for the study; N= Total number of sheep producers (743) from selected sites and e is level of precision which was taken to be 5%.

$$n = \frac{743}{1+743(0.05)^2} = 260.0$$

The collected data were entered into an Excel sheet and checked for outliers before analysis. Statistical Analysis Software (SAS, 2012) was used for the analysis of the collected data. Descriptive statistics, including means, frequency, and percentile for flock size, flock dynamics, and benefits of sheep (trend of selected rams, CBBP member participation, income, and price of ram per kilogram weight), were conducted. Independent t-tests were carried out to compare

quantitative variables, including flock size and structure, and income from sheep, between CBBP members and non-members. Indices were employed to calculate the traits improved through selection, to assess sustainability mechanisms, and constraints of Doyogena CBBP according to the following formula:

Index = Σ of [4 for rank 1 + 3 for rank 2 + 2 for rank 3 + 1 for 4] given for particular qualitative variables divided by Σ of [4 for rank 1 + 3 for rank 2 + 2 for rank 3 + 1 for rank 4] for all variables considered (Kosgey, 2004).

To obtain the sheep offtake-rate, each parameter was calculated using the methods employed by Shigdaf et al. (2012) and Deribe et al. (2021).

$$\text{Offtake rate (\%)} = \frac{\text{sheep exit parmaters}}{\text{total flock size of sampled respondents}} \times 100$$

Sheep exit parameters (routes of sheep leaving mechanisms from the flock) are sale, slaughter, gift and shareholding-out. Total flock size of sample respondents was calculated using an average number animals at a period of monitoring start plus the end of monitoring.

The Poisson regression model was employed to assess the factors influencing flock dynamics, and the income obtained from sheep. Socio-economic characteristics of the respondents, such as gender, age, education, family size, and farm-land size, were hypothesized to positively or negatively influence the response variables (routes of sheep entry into and exit from the flock, and income) along with CBBP participation and flock size. The Poisson regression model was chosen for the analysis of count data due to its suitability. It can be estimated using the quasi-maximum likelihood approach and can address issues related to over-dispersion (Verbeek, 2004; Dubale and Yohannis, 2021). The model used for Poisson regression has been stated as follows:

$$\text{Log (y)} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7$$

Where $\log(y)$ is logarithm of predicated mean number of response variables (income, way of sheep entry to the flock and exit from the flock); y is the mean of the response variable, β_0 is intercept; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ and β_7 are the coefficients to be estimated. The coefficients represent the change in the logarithm of the expected value of the dependent variable for a one-unit change in each independent variable, holding other variables constant.

Independent variables are CBBP with levels participation level (1=member, 2= non-member), sex of respondent household head (1=male, 2=female), education (1=illiterate, 2= primary and above), age (in number), farm land size (in hectare), family size (in number), flock size (in number).

3.3. Devising scaling options for Doyogena sheep CBBP

3.3.1. Description of production unit flock

Doyogena sheep is distributed across mid to high-altitude regions within mixed crop and livestock production systems in the Central Ethiopia Region. Hadiya, Kembata, and Halaba zones are the main distribution areas for Doyogena sheep. Average household flock size is 4.0 head (Taye et al., 2016, Jimma et al., 2024), collectively distributed across 70,118 targeted households in the production unit. According to CSA (2022), the breeding females constituted approximately 57% (160,294) of the total population. For breed improvement, 5,343 improved rams are required, assuming a mating ratio of 30 ewes per ram. Under the prevailing production system where rams are utilized for a maximum of two years mating service with a 95% annual survival rate, then $5343 / (1+0.95) = 2,740$ improved young breeding rams (rR) would be needed annually to replace old rams following the more general formula of Mueller et al. (2018).

3.3.2. Current potential of Doyogena CBBPs

As of April 2025, there were eight active CBBPs available in Doyogena district. Each CBBP involved 180 households managing 841 sheep, including 378 breeding ewes. Key parameters are shown in Table 1. With 1.86 a reproduction rate at SMW to be expected to produce a total of approximately 351 male candidates for selection. However, only 223 are available at the time of selection of which 75 selected for breeding, as the remainders are sold before selection (Table 1: Manuscript III).

3.3.3. Increase breeding ewes per CBBP

A challenge observed in the Doyogena CBBP is that some members do not follow cooperative bylaws mandating the keeping of at least two breeding ewes per farmer (Jimma et al., 2024). This significantly impacts the rate of return and genetic progress. To address this, we evaluated an option to increase the number of breeding ewes per CBBP by 50%, raising the total to 534 to enhance the production of improved rams (Table 2: Manuscript III).

From 534 breeding ewes per CBBP were produced 169 breeding rams out of them 160 for production unit with similar selection procedures and proportion with the current CBBP. To generate a surplus of improved rams, two adjustments could enhance supply and adoption: encouraging farmers to keep all male lambs until selection by avoiding early selling and castration, and by increasing the proportion of visually acceptable rams from 90% to 95%. These changes would increase the number of young breeding rams available per CBBP and expand their utilization in production units (Table 2: Manuscript III).

3.3.4. Scaling strategies

The scaling strategies are structured into two tiers, involving the sheep CBBP as a nucleus and the surrounding flocks as the base population or production unit. The current CBBP practice as reference was used to model the five strategies: 1) Current CBBP practice, 2. Retain all candidates plus increase breeding females per CBBP to enhance improved ram selection (0.15), 3) The same as strategy 2 but keep current selection proportion of ram (0.34) to increase more number of improved rams per CBBP, 4. Mix of AI and natural mating based on Model 2. 5. Mix of AI and natural mating based on strategy 3 (Table 3: Manuscript III).

3.3.5. Breeding objective and selection criteria

Following farmer preferences documented by Taye (2016), the breeding objectives for Doyogena CBBPs include body size (SMW), litter size, and mothering ability. For this study, SMW was used as both the breeding objective and the selection criterion.

3.3.6. Additional information, genetic improvement duration and planning horizon (H)

Additional complementary information also collected from field and market included mating ratio, ram service year, proportion of selection focusing physical appearance, proportion of lambs attain selection, conception rate, cost of meat sheep, ear tag, ear tag applicators, weighing scale, enumerators salary, cost of materials used for AI (ewe handling equipment for inseminating, AI gun, sheath, AI straw extender, syringes, distilled water, soap, slides and cover slides, hormone for ewe synchronization, liquid thermometers, graduated cylinders and beakers). Fixed AI tools (ultrasound, water bath, generator, spectrophotometer, microscope, movable shade, artificial vagina, lighter and speculum) was assumed available in all CBBP sites through ICARDA support and not needed considering as cost.

3.3.7. Input parameters, description of scaling strategies and evaluation

3.3.7.1. Biological and cost parameters

To expand the reach of genetic improvement in Doyogena sheep distribution area, the primary strategy focuses on increasing the number of breeding ewes per CBBPs. Under the current practice (Strategy 1), the 378 breeding females in the CBBP, with a reproduction rate of 1.86, to be expected to produce a total of approximately 351 male candidates for selection. However, only 223 are available at the time of selection, as the remainders are sold beforehand.

This result in a selection proportion of 0.34 (75 selected out of 223 available, as shown in Table 1 and Table 4: Manuscript III. If all potential candidates were retained, the selection proportion would be higher intensity, at $75/351 = 0.21$. In the current model, 75 breeding sires are approved, and 69 of them are used in the base production unit. Strategy 2 (Table 2 and Table 4: Manuscript III) is developed by both increasing the number of breeding females per CBBP from 378 to 534 and retaining all possible male candidates. This is expected to yield $534 * 1.86 * 0.5 = 497$ male candidates. If the same number of sires (75) is selected for the nucleus and production units as in strategy 1, the selection proportion becomes 0.15. Strategy 3 involves increasing the number of improved rams per CBBP, similar to strategy 2, but it applies the higher selection proportion from the current practice (strategy 1: 0.34). This allows for the dissemination of more rams to the production unit, producing a total of 169 rams, 160 of which are disseminated to the production unit. The potential of artificial insemination (AI) to spread genetic superiority more broadly was also examined.

In strategy 4 and strategy 5, a combination of AI and natural mating (NM) was used (Table 5: Manuscript III), with ratios adjusted to account for their different conception rates (AI: 0.48,

NM: 0.90). In strategy 4 (similar to strategy 2), 66 sires are disseminated to the PU. Of these, 39.6 are produced for AI and 26.4 for NM. Sixty percent of the AI-derived sires are sold for breeding due to their high genetic progress, alongside 40% from NM. The selection proportion for natural mating was 0.15. In strategy 5 (similar to strategy 3), 160 sires were disseminated to the production unit. Of these, 96 were produced via AI and 64 via natural mating. Sixty percent of the AI-derived sires were sold for breeding, alongside 40% from NM. The selection proportion for natural mating was 0.34. Selection proportion was 0.024 used for AI for both model (model 4 and 5). Combined genetic progress and a cost-benefit analysis were presented for both strategies (4 and 5: Manuscript III).

In strategies 4 and 5), 0.02 proportions of sires were used for CBBP and PU for AI. It was assumed that a proportion (p) of rams purchased by production farmers annually would be used for AI at a ratio of MRAI ewes per ram, while the remainder would be used for natural mating at the standard rate (MR). The number of ewes inseminated depended on the duration of the breeding season and the availability of skilled personnel and resources.

3.3.7.2. Economic and genetic evaluation

Economic and genetic evaluations were conducted using the gene flow method to predict the benefits of different scaling options using an Excel spreadsheet (Amer et al., 2007; FAO, 2010; Mueller et al., 2019). The average genetic selection differential was calculated as $i \times SD \times h^2$, where i is the standardized selection differential, SD is the standard deviation of SMW, and h^2 is its heritability. Genetic gain was realized in lambs born one year after mating. The model accounted for the direct and maternal expression of improved genes across generations, with all incomes and costs discounted to their present values at year zero over a 20-year planning

horizon. Benefits were generated by selling improved young rams from the nucleus flock to production unit farmers at a 10% premium over the cost of meat animals; associated costs and incomes were allocated appropriately. Revenue and expense calculations for year one and beyond was used input parameters and trait values as of April 2025. Sensitivity analyses were conducted using a 7% discount rate. All monetary parameters were expressed in US dollars (\$). The impact of all models was measured at both the CBBP and production unit levels.

4. SUMMARY OF RESULTS

4.1. Estimation of genetic parameters

4.1.1. Overall phenotypic estimation of the traits

The list of observations under each trait along with the overall means and SD (standard deviations) is presented (Table 1: Article I). The overall mean values for BWT, WWT, and SMW were 3.07, 15.05, and 23.45 kg, respectively. The values of LI, ARR, LWB, LSB, LSW, LWW, and EPPW were 258 days, 2.18 lambs/ewe/year, 4.58 kg, 1.54 litter/ewe, 1.33 litter/ewe, 19.99 kg, and 30.80 kg, respectively. Lamb survival rate from birth to weaning and birth to six months for the same animals were 96% and 95%, respectively. Coefficients of variations (CV) for growth and reproductive traits ranged between 14.5% for SMW to 20.1% for BWT, and 15.9% for EPPW to 52.5% for ARR, respectively.

4.1.2. Non-genetic factors

Year of birth and breeder cooperative had a substantial ($p < 0.01$) influence on every trait that was studied (Table 2: Article I). The season of birth had a significant ($p < 0.01$) effect on both BWT and LSSM values. The effect of lamb sex was significant ($p < 0.01$) in growth (BWT, WWT, and SMW) and survival (PWLS and LSSM) traits. Birth type had a significant ($p < 0.01$) effect on

growth, survival, and certain reproductive traits. Except LI and PWLS, parity of ewe had a significant ($p < 0.01$) influence on all the traits under investigation.

4.1.3. Genetic parameters

Direct heritability estimates of the studied traits were moderate (0.21 - 0.37) for growth, low to moderate (0.03 - 0.24) for reproductive, and low (0.08 - 0.1) for lamb survival (Table 3). The estimates of direct heritability for growth, reproductive, and survival traits from multivariate analyses are mentioned in Table 3: Article I.

4.1.4. Correlations between traits

Correlations between body weights with other traits from multi-trait analysis are presented in Table 4: Article I. Birth weight (BWT) had positive but weak genetic correlation with WWT (0.14) and SMW (0.03). The genetic correlation between WWT and SMW was positive and moderate (0.30). The genetic correlations between BWT with LSB, LWB, EPPW, PWLS, and LSSM ranged from low (0.05) to high (0.96) and were positive. On the other hand, the genetic correlations between BWT and LSW, LWW, LI, and ARR were negative and varied from -0.25 for LI to -0.06 for LWW). Birth weight exhibited a strong correlation with LWB (0.96) and a moderate correlation with LSB (0.47).

Reproductive traits had positive and low genetic correlation with WWT, except LWW (0.38), which had a positive and moderate genetic correlation. The correlations between WWT with LSW, LWB, LSB, LI, ARR, EPPW, PWLS, and LSSM obtained in the current study were low and varied from 0.02 for ARR to 0.20 for LWB and EPPW. A moderate genetic correlation estimate was shown between SMW and LWB (0.32), and positive and low correlations were obtained between SMW and almost all the studied traits.

The phenotypic correlations between BWT and almost all the other studied traits were positive (Table 4: Article I). The lamb WWT had positive phenotypic correlations with, LWB, LWW, ARR, EPPW, PWLS, and LSSM. However, it had negative phenotypic correlations (-0.16 to -0.05) with LSB, LSW and LI. Pre-weaning lamb survival, LSSM, LSB, LSW and LI traits had a negative phenotypic correlations with SMW.

4.1.5. Genetic progress

Except BWT, the annual genetic progress in growth traits had exhibited positive and highly significant ($p < 0.001$) (Table 5: Article I). Most of reproductive and lamb survival traits had also showed a significant ($p < 0.001$) trend (Table 5: Paper I). LWB and BWT showed a negative and low genetic trend (Table 5: Article I). Figure 2: Article I illustrates the genetic trends for six-month weight (SMW) of Doyogena sheep under CBBP. The yearly genetic trends of SMW were -0.066, 0.089, 0.45, 0.24, 0.04, 0.07, 0.068, and 0.3 kg per year at Anicha, Begedamu, Gomora, Hawora, Lemi, Murasa, Serera, and Women's breeding cooperatives, respectively. Except Anicha cooperative, significant ($p < 0.01$) improvement and positive genetic progress have been achieved in Doyogena sheep breeder cooperatives. The increases of genetic trend of SMW were more pronounced in Gomora (0.44 kg/yr), Serera women (0.30 kg/yr), and Hawora (0.24 kg/yr) breeder cooperatives than others in Doyogena CBBPs.

Except Gomora cooperative, the annual genetic trend trends for LWW, LSB, and ARR had improved significantly ($p < 0.001$) over time. Figures 2c and 3: Article I Gomora breeder cooperative showed a negative trend in LSB and a positive and higher annual trend in SMW, and vice-versa for Anicha breeder cooperative, which was negative trend in SMW and positive trend

in LSB. ARR and LWW trends were significantly ($p<0.001$) higher in the Begedamu breeder cooperative others (Figures 4 and 5: Article I).

4.1.6. Inbreeding rate

The annual and overall inbreeding rate was 0.04% and 0.29%, respectively in Doyogena CBBP (Figure 6 and Table 5: Article I). The inbreeding values for Begedamu, Murasa, and Hawora cooperatives were 0.49, 0.35, and 0.31%, respectively, where it exhibited comparatively higher levels. In comparison, the women-led cooperative showed the lowest level of inbreeding (0.00%).

4.2. Study on flock dynamics, offtake-rate, and farmers' perception

4.2.1. Flock structure and dynamics

4.2.1.1. Flock structure

The least-square means (SE) of sheep composition per household in the Doyogena district are presented in Table 1: Article II. Overall flock size per household in the Doyogena district was 3.84, ranging from 1-14 heads. The castrated sheep had the smallest percentage in the flock with 1.3%. The higher proportion was recorded for breeding ewes (48.43%) followed by intact males aged 6 to 12 months (15.36%). Male and female lambs aged 3-6 months made up 7.03% and 5.73% of the total, respectively. The mean number of young lambs below 3 months of age, male lambs aged 3-6 months, intact male aged 6-12 months, female lambs aged 6-12 months, breeding rams, breeding ewes, and the number of lambs per household were higher ($p<0.05$) in CBBP members compared to non-members.

4.2.1.2. Flock dynamics and offtake-rate

Table 2: Article II shows the flock dynamics and offtake for the Doyogena district. In our study, we identified the major ways through which sheep enter and leave the flock in the study area. The primary routes of sheep entering flocks include the birth of lambs, gifts, shareholding-in (keeping animals for the benefit share obtained from those with a larger flock size), and purchases.

In the Doyogena district, both CBBP member and non-member households indicated that sheep entered flocks more frequently through birth (Table 2: Article II). Total entry was significantly affected by CBBP membership. CBBP membership had significant higher ($p < 0.05$) number of animals obtained through birth and shareholding-in than non-member. In the study district, 352 lambs were born during the 12-month period from December 2021 to November 2022. Of all entries, birth accounted the highest proportion of entry, with 240 (84.51%) lambs for CBBP members and 112 (75.68%) lambs for non-members. Additionally, the cooperatives acquired 39 (13.73%), 4 (1.41%), and 1 (0.35%) through purchasing, shareholding and gift, respectively.

The exit routes vary widely among members and non-members. CBBP members had significantly higher ($p < 0.05$) sheep exiting through sale, slaughter, and shareholding compared to non-members. Out of a 401 and 187 head of animals, approximately 59% and 75% of sheep left the flock due to sale in CBBP member and non-CBBP member households, respectively.

Gift and shareholding as an exit route accounted for 7.9% and 1.49% for CBBP members, respectively, while it was minimal for non-members. The members of the CBBP in the study district exhibited a higher ($p < 0.05$) offtake-rate at 36%, in contrast to non-cooperative members at 17% (Table 2: Article II).

4.2.1.3. Factors affecting dynamics of sheep entry routes

The CBBP participation, sex of the household heads, and flock sizes were found to influence the sheep entry routes (Table 3: Article II). The study revealed that the participation in the CBBP significantly ($p < 0.01$) influenced the entry routes of sheep into households. Particularly, farmers engaged in the CBBP demonstrated a significant positive correlation with the birth of lambs, indicating that program participants experienced a 44% increase in the number of animals entering their flocks through birth compared to non-participants. Additionally, the study highlighted the influence of flock sizes on sheep entry routes, showing that farmers with larger flocks are more likely ($p < 0.001$) to acquire animals through birth, with a 21% higher tendency compared to those with smaller flocks. This finding shows the importance of flock size management in optimizing sheep breeding outcomes.

Furthermore, the study identified the sex of household heads as a determinant factor in sheep acquisition patterns. Specifically, households with male heads are less likely to receive animals as gifts or for shareholding.

4.2.1.4. Factors affecting dynamics of sheep exit and offtake-rate

CBBP participation, gender, age, land size, and flock size of the households were shown to influence the off-take and sheep exit routes. Sheep exit through sale, slaughter, gift, and shareholding-out was significantly ($p < 0.05$) affected by CBBP participation (Table 4: Article II). The animal exits through sale among the CBBP members were significantly ($P < 0.01$) higher and 1.52 times more than non-members. Similarly, the number of animals slaughtered for household consumption was also higher ($p < 0.001$) for CBBP members. The number of slaughtered animals within a year by CBBP members was 2.4 times higher than that for non-members. The CBBP

participation significantly influenced the probability of sheep exit through shareholding and gifting ($p < 0.01$). The farmers who have larger farm land size had ($p < 0.01$) higher (1.66 times more) number of animals sale than who have smaller land size. Farm land size also significantly ($p < 0.01$) affected the probability of sheep exiting through death.

The influence of flock size was positive on the sale of animals, slaughter, death, and shareholding-out. Farmers with a larger flock size tended to sale a more number ($p < 0.001$) of animals and likewise had a higher ($p < 0.001$) probability of slaughtering sheep for home consumption.

4.2.2. Farmers' perception on benefits of Doyogena sheep CBBP

4.2.2.1. Trend of Doyogena CBBP and socio economic benefits

The CBBP has shown significant enhancements in various key indicators between 2014 and 2022. These findings collectively indicate positive trends and progress in the Doyogena CBBP. The growth in the number of selected rams (from 56 to 357 (Figure 1: Article II)) and participants (from 35 to 276 (Figure 2: Article II)) shows increasing engagement and interest in the program. The substantial increase in income, from ETB 474,000 (USD 24,126.60) to ETB 3,398,203 (USD 70,958.51) through ram sales (Figure 3: Article II), along with the rise in the price per kilogram of live weight (increasing from 70 to 180 (Figure 4: Article II)), further underscores the economic success and viability of the program throughout the studied period. These improvements underscore the positive influence of the Doyogena CBBP on the local economy and the livelihoods of program participants.

From the total candidate rams, 20% were selected for genetic improvement, with the top 10% reserved for serving ewes of the members and the remaining 10% distributed for genetic

improvement outside the CBBP sites. The higher ($p < 0.038$) number of participants providing breeding rams to the community every year might have contributed to producing more lamb crops through birth, which is vital for genetic improvement in a progressive manner and ensures the participation of members. The number of CBBP households participating in the scheme has increased from 35 in the year 2014 to 276 in the year 2022.

Breeding ram's price was set on weight basis by the CBBP committee members. The price of one-kilogram live weight of elite ram was ETB 70 in 2014 while it increased ($p < 0.01$) to ETB 180 in 2022 (Figure 4: Article II). A total income obtained by the sale of breeding rams was increased considerably ($p < 0.019$) from 474,000 ETB (24,126.6 USD) in the year 2014 to 3,398,203 ETB (70,958.51 USD) in 2022 (Figure 3: Article II). Each participant farmer earned an average of 7,728 to 12,312 ETB annually. The increment of income from the sale of breeding ram was because of the increase of farmers' participation providing breeding rams and strategy of community based breed improvement program.

4.2.2.2. Factors affecting annual income

Factors affecting the annual income obtained from sheep sales are indicated in Table 5; Article II. Income for CBBP members was positive and significantly ($p < 0.001$) higher than that of non-CBBP member households. The mean annual income per households from sheep sales were generated approximately 2,507 ETB for CBBP-member and 1,807 ETB for non-member (Table 6: Article II). This might be due to the consecutive training offered for CBBP participant households on the breed improvement program and flock performance improvement, which have ensured better market participation in selling elite rams and culling nonproductive animals among member farmers than non-members. The gender of the household head had a positive

influence on the yearly income generated from sheep ($p < 0.001$). This implies that male household heads sell 1.03 times higher number of animals than female household heads.

Respondents with lower educational level (illiterate) generated lower income from sale of sheep than those who had attended primary school and above. Farm-land size of the household had significant ($p < 0.0001$) influence on income, and the household head with larger land size generated 1.25 times more income than those having smaller land size. This is because of households with large land size keep large number of animals, subsequently more number of animal offers to sale. The number of sheep in the household's flock has a significant ($p < 0.0001$) and positive effect on the annual income generated from sheep sales.

4.2.2.3. Sheep income contribution on the livelihood of the farmers

In the study district, both groups of farmers (CBBP members and non-members) obtained income from sheep, enabling them to spend more on their basic needs and assets, including school expenses for their children, fertilizer and improved crop seed purchase, house building and maintenance, family cloth, and diet diversification. CBBP participants made significant contributions ($P < 0.05$) to their livelihoods through income obtained from sheep sales (Table 6: Article II). For instance, they constructed new house and maintained existing ones for their families. They also used the money to buy dairy cows, providing animal-source foods for family members and enabling slaughtering for home consumption.

4.2.2.4. Traits improved due to CBBP interventions

Traits improved through selection in the Doyogena sheep CBBPs are summarized in Table 7: Article II. All respondents among CBBP members perceived that improvements were made in

their sheep flock, with the largest impact seen in the growth performance of their sheep (1st). This was followed by improvements in coat color (2nd), litter-size (3rd), body size (4th), survival (5th), and lambing interval (6th).

The majority of respondents indicated that the coat color (light red and dark red) of the sheep was mentioned among improved trait due to the genetic improvement program. This enhancement reportedly increased market value, as buyers preferred these specific coat colors, leading to higher selling prices.

4.2.2.5. Sustainability mechanism of Doyogena CBBP

Sustainability options of Doyogena sheep is presented in Table 8: Article II. To maintain the sustainability of Doyogena CBBP, promoting cooperatives to form unions was the best course of action as explained by the respondents. This was closely followed by equally valuable responses such as setting up a credit facility and interacting with many stakeholders. The study showed that farmers understood working with cooperative or group is acceptable and improves their livelihoods.

4.2.2.6. Constraints affecting Doyogena CBBP

Major constraints encountered by members of the Doyogena CBBP are presented in Table 9: Article II. The major constraints mentioned were audit delaying (Index=0.175), the gap in keeping cooperative bylaw (Index=0.15), lack of trust in CBBP leaders (Index=0.139), lack of market demand for higher weighing rams (I=0.1389), aggressiveness of the breeding rams (Index=0.1134), lack of credit access (Index=0.1061), concentrate feed shortage (Index=0.093), and disease (0.0817).

The delay in auditing poses a significant challenge across all breeding cooperatives. In the CBBP, member farmers have the right to receive the results of cooperative audits on a yearly basis and benefit from the profits. Seed money for revolving purposes was provided to all cooperatives during the implementation period. At the cooperative formation, every participant paid a membership fee and share. Farmers pay a 100 birr margin per animal when they sale the selected rams to and out of the community for breeding.

However, in some cooperatives, members were unaware of their cooperative's financial progress over the last five to six years. The timely replacement of CBBP leaders by a new committee and the lack of interest from the woreda cooperative office in inspecting and auditing periodically were the main problems. The cooperative bylaws formulated during the establishment of CBBP were accepted by all participants and CBBP leaders to govern their breed improvement cooperative under the rule of the bylaws. However, the rules were not fully respected by the members of the CBBP. Some members do not follow to breeding ewe guidelines, cooperative leaders assigned by members are not trusted, and early selling of breeding rams and a shortage of concentrate feed are key bottlenecks in all Doyogena CBBP sites.

4.3. Scaling options

4.3.1. Economic benefits

In the current CBBP (strategy 1), the scenario with a 50% increase of ewes per CBBP (Strategy 2), and the scenario with a greater number of improved rams produced per CBBP (Strategy 3), the return on investment (ROI) for the base production units was \$52.6, \$72.6, and \$122 per \$1 invested, respectively (Table 6: Manuscript III). The higher ROI in these models results from their larger accumulated discounted benefits. However, the ROI for the nucleus unit was much

lower than that for the base units. The highest ROI for the base units was achieved by strategy 3 (\$122), a result driven by disseminating a larger number of rams to production units without a substantial increase in operational costs. The highest ROI for the Nucleus was in strategy 5 (8.5), which used the same selection proportion as model 3 but with the AI/NM mix, thereby balancing genetic gain and revenue generation (Table 7: Manuscript III).

4.3.2. Genetic Progress Trends

The annual genetic gain in SMW for the average Doyogena CBBP model 1 (Figure 2: Manuscript III) and Strategy 3 (Figure 4) were 0.12 kg and 0.1 kg in the nucleus and in base population, respectively. While Strategy 2 (Figure 3) achieved higher genetic progress (0.17 kg/year in the nucleus and 0.13 kg/year in base) using natural mating practice. The difference would be associated with replacement ram selection proportion. The highest nucleus-level genetic progress was achieved in Strategy 4 (0.21 kg per year and 27.88 kg weight at SMW), where a proportion of sires were produced through AI (Figure 5 and Table 7: Manuscript III).

This improvement reflects AI's role in amplifying selection intensity and genetic dissemination efficiency. Strategies 2 and 5 also outperformed the baseline strategy 1 in SMW, indicating that increasing breeding females and retaining all candidates has a positive effect (Table 6 and Table 7: Manuscript III). However, strategy 3, despite not achieving the highest genetic gains, delivered a competitive nucleus at SMW (26.00 kg) while maximizing dissemination, leading to exceptional economic outcomes.

5. GENERAL DISCUSSION

5.1. Estimation of genetic parameters

5.1.1. Non-genetic factors

The body weight traits (Table 1: Article I) of Doyogena sheep were found to be comparable to those of Bonga (BWT 3.1kg, WWT 16.1kg, and SMW 24.7kg) sheep breed under CBBP conditions in the Keffa zone of the Southwestern Ethiopia (Areb et al., 2021a) while the breed exhibited higher values for BWT and SMW compared to Menz sheep (BWT 2.76kg and SMW 14.1kg) in Amhara region (Haile et al., 2020). This might be attributed to genetic and environmental differences. The significant effects of sex on body weight could be explained by hormonal and physiological differences between male and female lambs (Deribe et al., 2014; Alemayehu et al., 2021). Single-born lambs showed higher body weights than twins and triplets, possibly due to prenatal and postnatal environments (Deribe et al., 2014). The influence of lambing year on reproductive traits has been reported by various scholars (Amou Posht-e-Masari et al., 2013; Boujenane et al., 2013; Mohammadabadi and Sattayimokhtari, 2013; Yavarifard et al., 2015; Tesema et al., 2020; Tera et al., 2021). The availability of selected rams, management practices, feed availability, and weather conditions could play a role for the variations observed. The increase in litter size with progressing parity might be associated with physiological maturity, dam age, uterine capacity, and maternal behavior traits (Mengiste et al., 2010; Momoh et al., 2013).

5.1.2. Genetic parameter estimates

There was a declining trend in the direct heritability of body weight traits in post-weaning. Unlike the current results, previous reports indicated that the heritability of growth traits tended

to increase with the age of animals (Bahreini et al., 2007; Ngere et al., 2017). The decline in the direct heritability of body weight traits in this study could be associated with higher phenotypic variances due to environmental factors such as management, early selling of animals, data structure, and the methods of monitoring community flocks, as suggested by Areb et al. (2021a).

The heritability of BWT for Doyogena sheep was in the range reported for different sheep breeds in Ethiopia. For example, Abegaz et al. (2002) reported a range of 0.18-0.32 for Horro sheep using a multi-trait analysis method, while Yacob (2008) reported a range of 0.18-0.38 for Afar and 0.2-0.58 for Black Head Somali sheep breeds using univariate analysis method. Moderate heritability of BWT for different exotic sheep breeds has been reported by Jafari et al. (2014) for Makuie sheep, Gamasaee et al. (2010) for Mehraban sheep, and Arthy et al. (2018) for Madras Red sheep. The moderate result of direct heritability estimates for BWT suggests that focusing selection on BWT would lead to genetic improvement, but care should be taken to avoid difficult birth as a result in BWT beyond the optimum value (Haile et al., 2020).

A moderate value of heritability estimates for WWT in the current study is in accordance with other studies. For instance, Yacob (2008) reported a range of 0.11-0.37 for Afar sheep and 0.00-0.29 for black head Somali sheep. However, higher and lower values reported by various authors, for example, Areb et al. (2021a) reported a value of 0.36 for Bonga sheep. Gizaw et al. (2007, 2014) reported values of 0.48, and 0.19 for Menz sheep. The SMW in the present study was moderately heritable and which is in close agreement with those reported for Mehraban (0.35) and Kourdi (0.32) sheep breeds by Gamasaee et al. (2010) and Shahdadi and Saghi (2017), respectively. Higher estimates of heritability for SMW were also reported for other sheep breeds in Ethiopia. For example, Haile et al. (2020), reported heritability values of 0.49 for Bonga and 0.59 for Horro sheep breeds. The moderate heritability estimates of WWT and SMW

indicate the existence of additive genetic variance for the traits, which could be used as selection criteria for Doyogena CBBPs. Moderate to high estimates of direct heritability of growth traits were found in many reports (Mekuriaw et al., 2014; Baneh et al., 2019; Haile et al., 2020).

The direct heritability of litter size traits (LSB and LSW) in Doyogena sheep was low (Table 3; Article I), consistent with previous estimates of LSB reported for Kermani sheep (0.06)(Mohammadabadi and Sattayimokhtari, 2013), for Iran black sheep (0.11) (Baneh et al., 2019), and for Bonga sheep (0.085) (Tera et al., 2021). The heritability estimate for LSW aligns with results observed in Santa Ines sheep (0.03) (Aguirre et al., 2017) but was lower compared to other sheep breeds, with values ranging between 0.07 and 0.21(Boujenane et al., 2013; Nabavi et al., 2014; Mohammadi et al., 2015). The potential for genetic improvement through selection for litter size traits (LSB and LSW) could be limited due to low heritability which has been confirmed by the current study. Doyogena sheep are one of the most prolific sheep breeds in Ethiopia (Habtegiorgis et al., 2022b). The prolificacy and lamb mortality have a higher correlation, resulting in low heritability of litter size traits (Gootwine, 2020). The differences in pre and post pregnancy management among sheep keepers, dam age, and the low correlations with selection traits could also be reasons for the low heritability of litter size traits. Improving management might led to improvements than selection focusing on litter size traits.

The ewes genetic potential for producing lamb birth weight described by LWB. The moderate estimate of direct heritability for LWB in the present study was consistent with the values reported by Vatankhah and Talebi (2008) for Iranian Lori-Bakhtiani sheep breed. Lower heritability for LWB than the current result was reported by various Authors (Ekiz et al., 2005; Mohammadi et al., 2013). The combined effects of reproductive and mothering ability of ewes, pre-weaning growth, and survival of lambs were indicated by LWW (Rashidi et al., 2011). Direct

heritability estimates for LWW in the current study was in the range of 0.03-0.4, which is in agreement with findings reported by several authors (Mokhtari et al., 2010; Mohammadi et al., 2012; Amou Posht-e-Masari et al., 2013). Thus, the moderate heritability of LWB and LWW indicate that considering the traits in the selection program would yield considerable improvement in the reproductive performance of Doyogena sheep.

The estimated heritability of LI for Doyogena ewes was in close agreement with those reported by Quesada et al. (2002). However, lower LI values were reported by Tera et al. (2021) and Aguirre et al. (2017) who recorded values of 0.009 and 0.04 for Bonga and Santa Ines sheep, respectively. The observed differences could be associated with breeds of sheep and environmental factors such as feed, health, and other factors. The heritability estimates in the current study for ARR is much lower than that of Bonga sheep (0.25) reported by Areb et al. (2021b). Generally, the estimates of heritability for most studied reproductive traits are low, and focusing on selection for improvements of these traits may not bring the desired genetic improvement within shorter period. In this study, the direct heritability of lamb survival rate in the growth stages such as birth to weaning and birth to six months of age were low (Table 3; Article I). Similar with our findings, several authors have also reported values within the range of 0.00 to 0.11 for different sheep breeds (Safari et al., 2005; Getachew et al., 2015; Besufkad et al., 2024). The reason of low estimates of direct heritability for lamb survival could be associated with different factors that cause death (Hosseini-Zadeh et al., 2018). Genetic improvement through direct selection of lamb survival may be difficult due to the small heritability. Looking for a positive association with traits that are used for direct selection and suitable lamb management options will bring improvements in lamb survival.

5.1.3. Correlations between growth traits

The weak genetic connection between BWT and WWT in the current study is in close agreement with the reports by Illa et al. (2020) for Nellore sheep. Consistent to the current study, a low genetic association between BWT and SMW for Bonga and Horro sheep breeds was reported (Haile et al., 2020). The estimates of genetic correlation between BWT and WWT in the current finding was lower compared with the values reported by Gowane et al. (2010a and 2010b) in Bharat Merino sheep. The low genetic correlation between BWT and other growth traits post-weaning could be associated with physiological difference, feed availability, health and management factors (Habtegiorgis et al., 2022a). Newborn lambs are more dependent on dam milk and grow faster until pre-weaning, while they grow slower after weaning and are fully exposed to environmental factors. The moderate genetic correlation estimate of WWT with SMW obtained in our study was in line with the findings of Gowane et al. (2010a) and Singh et al. (2016) for Bharat Merino and Marwari sheep, respectively. Therefore, the moderate genetic correlations between WWT and SMW indicates that selection focusing the tails (WWT or SMW) can bring improvement on post weaning growth traits. This could be used as a selection criterion for improvement in body weight traits.

5.1.4. Correlations between BWT and reproductive and survival traits

The BWT showed a moderate correlation with LSB and a high correlation with LWB (Table 3; Article I). Ventankaha and Telabi (2008) reported a high genetic correlation between BWT and LWB (0.98) for Lori-Bakhtiari sheep in Iran, which align with this finding. Such association is anticipated, as BWT is a component of the ewe LWB. The negative genetic correlations between BWT and LSW and LWW observed in this study were consistent with the findings of Mohammadi et al. (2013) for Makooei sheep (-0.14 vs -0.03) and Bromley et al. (2000) for

Colombian sheep (BWT-LSW -0.37). In line with the current results, several authors (Everett-Hincks et al., 2014; Nel et al., 2021) reported low genetic correlations between BWT and PWLS. The findings suggest that breeding for improved BWT would have a minimal impact on most traits studied, except for LSB, and LWB.

The phenotypic correlations between BWT and other traits were positive, except for the correlation between BWT and LI (Table 4; Article I). The low positive correlations between BWT and LSB and LSW reported by Safari et al. (2007) and Vatankhah and Talebi (2008) closely align with our findings. However, Mohammadi et al. (2013) observed negative phenotypic correlations between BWT and these traits.

5.1.5. Correlations between WWT with reproductive and survival traits

The genetic correlations between WWT and almost all studied traits were positive and low to medium (Table 4; Article I). These findings are consistent with the literature. For instance, Vatankhah and Talebi (2008) and Notter et al. (2018) reported low but positive correlations between WWT and both litter size at birth (LSB: 0.23 vs. 0.18) and litter size at weaning (LSW: 0.14 vs. 0.07). Furthermore, Boujenane et al. (2013) observed a comparable low correlation for litter weight at birth (LWB).

Mohammadi et al. (2013, 2014) reported moderate genetic correlations between WWT and LWW which accord with the current observations. These indicate that selection based on WWT would have a positive influence on genetic response in reproductive and survival traits. Litter weight at weaning (LWW) per ewe would have reasonable improvement due to moderately correlated responses with WWT.

Similar to our finding, the negative phenotypic correlations between WWT and litter size traits (LSB and LSW) were reported for crossbred ewes (Afolayan et al., 2008), and D'man sheep in Morocco (Boujenanea et al., 2021). Low and positive phenotypic associations of WWT with litter weight (LWB and LWW) traits align with the findings from various published reports (Safari et al., 2005; Vatankhahand Talebi, 2008; Mohammadi et al., 2013). In line with current findings, Notter et al. (2018) reported low correlations between post-weaning weight and LSB (0.20) and between post-weaning weight and LSW (0.11) for the Katahdin sheep breed. Likewise, Safari et al. (2005) reported averages of 0.17 and 0.06 between post-weaning weight and LSB and between post-weaning weight and LWW, respectively.

5.1.6. Correlations between SMW with reproductive and survival traits

In the current study, the genetic correlation estimates between SMW and the reproductive and survival traits were low (Table 4; Article I), except for SMW-LWB which was moderate. In line with our findings, Notter et al. (2018) reported low genetic correlations between post-weaning weight with LSB (0.20) and LSW (0.11) for the Katahdin sheep breed. Likewise, Safari et al. (2005) reported averages of 0.17 and 0.06 between post-weaning weight and LSB and between post-weaning weight and LWW, respectively. Vatankhah and Talebi (2008) reported a moderate genetic correlation between SMW and LWB for Lori-Bakhtiari sheep in Iran which was parallel with our finding. Hence, selection focusing on SMW to improve genetic merit in the traits would yield a positive and low to moderate genetic response for reproductive, and lamb survival traits. Jembere et al. (2016) also reported that village-based small ruminant improvement would have significant improvement on the growth and positively correlated traits through selection focused on WWT and SMW.

Low and negative phenotypic correlations between SMW with litter size traits (LSB and LSW) in the current study were in agreement with the findings of Afolayan et al. (2008), who observed negative and low correlation between SMW-LSB and SMW-LSW. The low and positive correlations between SMW and litter weight traits (LWB and LWW) of this work were in concurrence with Vatankhah and Talebi (2008), who reported low and positive phenotypic correlations between SMW-LWB and SMW-LWW. Low and negative phenotypic correlations between SMW with litter size traits (LSB and LSW) in the current study were in agreement with the findings of Afolayan et al. (2008), who observed negative and low correlation between SMW-LSB and SMW-LSW. The low and positive correlations between SMW and litter weight traits (LWB and LWW) of this work are in concurrence with Vatankhah and Talebi (2008), who reported low and positive phenotypic correlations between SMW-LWB and SMW-LWW.

5.1.7. Genetic trends and Inbreeding rate

Similar genetic progress for BWT in Baluchi sheep (-0.005 kg) and Santa Ines sheep (-0.001 kg) were found by Gholizadeh and Ghafouri-Kesbi (2015) and Aguirre et al. (2017), respectively. The possible reasons for the negative trend of BWT in Doyogena CBBPs were during the crop harvesting season: farmers allow their animals to graze on the farmland and have possibility for mixing flocks with non-member farmers, sometimes members purchase ewes from market, gap on breeding ram usage in some members, and gap on regular supervision by data collectors.

The genetic gains for WWT and SMW obtained in the current study using multi-trait analysis are comparable to those reported for Bonga (Areb et al., 2021a) and Abera sheep (Alemayehu et al., 2021). Lower estimates than the current values were reported for WWT (0.017) and SMWT (0.012) for Iranian native Ghezel sheep (Baneh et al., 2018), and the higher estimates than our

values were reported for Bonga and Horro sheep (Haile et al., 2020). The differences might be attributed to the fact that the latter were selected for more generations compared to the CBBP program in the current study.

Checking the genetic progress in each CBBP cooperative, focusing on selection age and reproductive traits will be important to know the direction of the program. The positive annual genetic progress for SMW in most breeder cooperatives of Doyogena CBBPs is in line with previous reports in Abera (Alemayehu et al., 2021) and Bonga sheep (Areb et al., 2021a). The higher annual genetic trend of SMW and the negative and decreasing trend of LSB in the Gomora breeder cooperative might indicate a focus more on phenotypic base selection rather than breeding value, which favors animals born single rather than multiple births. On the other hand, the positive lower genetic trend in the Lemi breeder cooperative might be associated with the recently joined breeder cooperative, which uses low selection intensity of breeding rams, and gaps in awareness. Other findings reported by Jimma et al. (2024) indicate that considering multiple births is crucial for maintaining genetic diversity and increasing productivity. The reasons for negative trends of SMW in the Anicha breeder cooperative were the selection of rams for mating based on physical appearances which are influenced by management, inaccuracies in data recording, mixed flocks, uncontrolled mating, inadequate follow-up on breeding rams, and fattening un-castration of rams not fitting for breeding (Areb et al., 2021a; Alemayehu et al., 2021; Baneh et al., 2018). Therefore, special consideration is needed to fill the gap among breeder cooperatives. The positive and considerable annual genetic gain of reproductive traits in most breeder cooperatives of this study implies that selection based on SMW have made positive and indirect influence on the traits. However, variations among breeder cooperatives have existed and it might be associated with the use of selected ram, way

of data recording, and management. Thus, there is a need to implement an indirect selection method that considers growth, reproductive, and survival traits, enhancing the effectiveness of management, consistent monitoring, and follow-up by data collectors. In agreement with the present study, positive genetic changes for LSB and ARR have also been reported for Horro (Endris et al., 2022) and Bonga sheep (Areb et al., 2021b), respectively. Unlike the current study, the negative genetic trend for prolificacy (LSB, LSW, and LWW) was reported by Aguirre et al. (2017) for Sant Inês sheep in Brazil.

The annual inbreeding rate in the findings of this study was lower than the recommended level (0.5-1%) mentioned by FAO (2010). Higher levels of inbreeding rate than the current study (0.29%) have been reported for Bonga CBBPs (0.34) and Menz sheep (0.31) (Haile et al., 2020). The reason for the lower inbreeding rate of sheep in the current study might be due to the timely utilization of selected rams, implementation of ram rotation, and castrating of unselected ones in Doyogena CBBP.

5.2. Study on flock dynamics, offtake-rate, and farmers' perception

5.2.1. Flock structure

The distribution of flock structure reflects the management choices made by producers, based on their production goals (Gizaw et al., 2010). At the CBBP level, keeping fast-growing lambs has reduced lamb mortality while increasing litter sizes, resulting in significant improvements in flock structure and size (Haile et al., 2014; 2020). In the present study, the average flock size was lower than the values reported by Tibbo et al. (2006) for Bonga (11.3), Horro sheep (8.2), and that of Abebe (1999) for Menz sheep. However, it was comparable to that of Taye (2016), reported in the same study district. The shortage of land for grazing could be one of the reasons

for the low flock size in the study area. Gutu et al. (2015) have reported that the flock size of sheep for CBBP member households was higher than non-member households for Bonga, Horro, and Menz sheep, which was similar to the current study. The higher proportion of breeding ewes in the flock is an opportunity for a high number of lamb productions and the need for sustainable household income in the study district. The finding is comparable to the findings reported by Luke (2010), Shenkute et al. (2010), Tasew et al. (2014), and Amare et al. (2019). According to the bylaw of the cooperatives every CBBP member is expected to keep at least two breeding ewes with a good maternal record for genetic improvement for the next generation.

The reason of higher proportion of intact ram aged 6-12 months could be in the CBBPs, keeping male lambs until selection is mandatory and which increase the possibility of getting best-performing animals to be parents for the next generation. In some cases, CBBP members keep selected lambs that were 2–6 months after selection until they get a better market. Retaining breeding ewes and keeping male lambs until selection would enhance selection intensity and improves genetic progress (Haile et al., 2020).

The control mating practice in Doyogena CBBP is attributed to the presence of CBBP. Intensive selection of breeding rams, combined with the acquisition of knowledge by CBBP members through participatory training and direct program involvement, could positively contribute to the success. Our findings are consistent with a similar report by Asrat et al. (2021) for Bonga sheep (25 to 30 breeding ewes), and that the current study ratio is higher than that reported by Haile (2021) for Horro sheep (1 to 6.34) at the CBBP.

5.2.2. Flock dynamics and offtake-rate

Parallel to the current study, Kocho et al. (2011) and Deribe et al. (2014) reported that the primary route of entry for sheep in the Alaba zone of southern Ethiopia was birth. The authors'

reports also demonstrated that shareholding is an essential method of strengthening the flock within the sheep farming community, consistent with the present study. The reason of higher proportion of sheep sale in non-member is that there is no binding rule that can prevent early sales, which could be a potential reason for negative selection in the flock. On the other hand, the cooperative bylaw encourages producers to keep the best-performing animals. Animals with low performance have exited the flock through sale. Reports of other studies confirm that the sale was the major exit route for sheep in central Ethiopia (Legesse et al., 2008; Kocho et al., 2011). In contrast to CBBP participants, non-participants tended to sale animals at younger ages, aligning with findings from Deribe et al. (2021) and Kocho et al. (2011), who noted that in Alaba district, sheep and goat keepers sold their animals before reaching breeding age. The off-take rate (53.8%) in this study is higher than other research endeavors. For instance, CSA (2020) reported an off-take rate of 30.8%, while Shigdaf et al. (2012) documented rates of 25.3% and 32.8% for sheep in Farta and Lay Giant districts, respectively. The higher offtake-rate in the current study can be attributed to the existence of breed improvement cooperatives, the strategic culling of unproductive animals, the implementation of fattening practices tailored for festivals, disseminating improved rams, and collaboration within the group leading to improved market opportunities. Furthermore, the percentage of sheep sales (18.7%) and slaughter (11.3%) reported by CSA (2020) was comparatively lower and consistent with our findings, respectively.

5.2.3. Factors affecting sheep dynamics of sheep entry and exit routes

The reason of male heads were less likely accept of animals likely to accept animals as gifts or for shareholding may be attributed to cultural or gender-specific roles and preferences within the community. Additionally, the household heads those who have smaller family sizes are less inclined to purchase sheep, with a significant association to the scarcity of labor. This aligns with

other reports by Legesse et al. (2008) and Budisatria et al. (2007), who indicated that labor shortages can be a limiting factor in small-scale livestock keeping, particularly in contexts where family members are essential contributors to farming activities.

Sale, slaughter, shareholding and gift were the main exit routes and significantly higher in CBBP members than non-members. This might be associated with the higher number of sheep produced through birth for the CBBP member households due to the use of different production packages and the existence of breeding cooperatives (Rekik et al., 2016; Esayas and Jane, 2019; Jane, 2019). This ensures better market participation of CBBP members than non-members. The higher slaughtering of animals could be attributed to the larger flock size of CBBP members. Similar findings reported by Gutu et al. (2015) and Haile et al. (2020), who reported changes in the number of sheep sold per year and the consumption of mutton as a result of CBBP membership compared to non-CBBP members for Bonga, Horro, and Menz sheep in CBBP sites. The gender of the head of the household exerted a favorable influence on animal sales, with males showing a significantly higher tendency to sale animals compared to households led by women. This aligns with the findings of Ashenaf et al. (2013), who reported that women are primarily responsible for managing tasks such as feeding, herding, and cleaning, while males take on the role of decision-makers in terms of purchasing and selling sheep. Households led by women frequently accept animals instead of selling them, driven by financial difficulties. Debesa (2020) reported that poor market participation, limited technical skill and financial resources affect the role of women compared to men in small ruminant value chain, which was agree with this study.

Sales were significantly and negatively affected by the respondents' ages. This demonstrates that younger individuals are more involved in the production of sheep and sale than the older

household head, and it offers young farmers looking for work the chance to take part in sheep breeding. This in line with Ayele et al. (2003), who got negative association between age of households and beef cattle market participation. However, it contrasts the finding of Dubale and Yohannis (2021), who found that the older people were more enthusiastic to participate in sheep market than the younger people. The lower probability of animal exit through death in farmers having small land size may be attributed that keeping small number of animals and manages their animals by practice tethering in roadside and land-demarked areas most of the year. The feed shortages in the dry season and drought period are the main reasons of sheep exit through death (Addis, 2015; Habte et al., 2019).

5.2.4. Trend and benefits of Doyogena CBBP

The upward trends in ram selection, farmer participation, and income generation reflect the Doyogena CBBP's success in improving livelihoods and fostering genetic progress. The increase in participants and breeding rams highlights growing trust in the program, likely driven by awareness and multi-stakeholder engagement. The substantial income growth underscores the program's economic viability, aligning with findings from Haile et al. (2023), who reported similar income increases (20%) in established Ethiopian CBBPs. The price surge for breeding rams (ETB 70 to 180/kg) and total income growth (ETB 474,000 to 3,398,203) can be attributed to community-based breeding practices and expanded farmer participation. These outcomes in line with trends in other Ethiopian CBBPs (Gutu et al., 2015; Areb et al., 2021c), where economic incentives and genetic gains boosted membership. The program's structure, which reserves top-tier rams for members while distributing others externally, ensures sustained genetic improvement and broader community benefits. Increased household participation (35 to 276) reflects the program's ability to attract farmers through tangible rewards, as noted by Bhuiyan et

al. (2017) and Kaumbata et al. (2021). The participatory approach, which empowers smallholders in breed improvement, aligns with Mirkena et al. (2012) and Haile et al. (2018), who emphasized farmer engagement as critical to CBBP success.

5.2.5. Factors affecting annual income

The higher income observed among CBBP members aligns with previous studies (Kassa et al., 2021; Areb et al., 2021c; Gutu et al., 2015; Haile et al., 2020), which attribute this advantage to targeted training on breed improvement, flock management, and market strategies. These programs likely enhance members' ability to sell elite rams and cull unproductive animals more effectively than non-members. The gender disparity in income may reflect sociocultural or resource-access barriers limiting female-headed households' participation in markets or flock management. Male-headed households' higher sales volume suggests a need for interventions to empower female producers. The positive effect of education aligns with findings by Kassa et al. (2021) and Areb et al. (2021c), as education likely improves producers' capacity to adopt improved breeding practices and engage in strategic sales. Larger farmland size likely supports higher livestock numbers, enabling households to maintain larger flocks and generate more income through sales. This underscores the role of land access in smallholder livestock economies. Similarly, flock size directly drives income, as larger flocks provide more animals for sale, reinforcing the importance of sustainable flock management practices to optimize productivity.

5.2.6. Traits improved due to CBBP intervention

The perceived improvements in growth performance and coat color align with findings from Areb et al. (2021c), who identified these traits as important in Bonga sheep CBBPs. Coat color, a

culturally significant factor in Ethiopian livestock markets, directly influences buyer preferences and pricing, as corroborated by studies in Bonga (Kassa et al., 2021) and northern Ethiopian highlands (Beneberu et al., 2011). Cultural and traditional beliefs often prioritize specific coat colors for slaughter, underscoring its economic relevance. Improvement in litter size in Doyogena CBBPs aligns with results in Bonga and Horro CBBPs, where 72.5% and 65% of members, respectively, noted twin births (Gutu et al., 2015). This improvement may stem from selective breeding favoring genes associated with multiple births. Enhanced performance traits likely result from integrated activities, including elite ram selection, controlled mating and improved health and nutrition interventions (Mirkena et al., 2012; Weldemariam and Mezgebe, 2020). Such practices align with broader evidence from Eastern and Southern Africa, where systematic selection has improved growth rates, reduced lambing intervals, and lowered mortality (Haile et al., 2023).

5.2.7 Constraints and Sustainability mechanism of Doyogena CBBP

The constraints mentioned by CBBP members across breeding cooperatives were likely similar to those reported by Areb et al. (2021c) for Bonga and Gutu et al. (2015) for Bonga, Menz, and Horro CBBP. Creating strong link among stakeholders for timely audits and extension support, improving communication channels between cooperative leaders and members to increase awareness of financial progress and decisions affecting the cooperative, provide training and support for cooperative leaders to ensure smooth transitions and effective leadership and arrange awareness creation meeting. By addressing these issues, Doyogena CBBP cooperatives can enhance their efficiency, transparency, and overall success in achieving their breeding objectives. Community based breeding program is an important tool for effective utilization of genetic resources. Hence, strengthening the breeding cooperatives and promoting the cooperative to

union may help to get more credit access, ensure market participation at domestic and international level, improve bargaining power and develop strong stakeholder integration. Other scholars also mentioned similar sustainability mechanisms for different CBBPs (Mirkena, 2010; Muller et al., 2015; Haile et al., 2018a, 2019).

5.3. Devising CBBP scaling options

5.3.1. Establishing additional CBBP and breeding objective traits

To cover the whole Doyogena sheep distribution area in breed improvement program forming 9 (17 - 8) new CBBP would be needed. Guidelines for the establishment of new CBBP were presented in detail by Haile et al. (2018a) and Mueller et al. (2021). During CBBP, it is crucial to carefully consider farmers' breeding objectives and trait preferences, existing infrastructure, ensure decisions and active participation in various activities, and clear ownership structures (Muller et al, 2015; Haile et al., 2020).

Community based improvement programs in low input system target few important traits (Haile et al, 2018a). In Doyogena CBBP growth, twining, and mothering ability were among objective traits (Habtegiorgis et al., 2021; Jimma et al., 2024). However selection was primarily based on estimated breeding value of SMW. Thus SMW was taken as unique breeding objective and selection criterion due to its relevance in Doyogena CBBPs. Other important traits, such as body conformation, coat color other than black, presence of horns, scrotal circumference, and sexual libido were assessed by the selection committee during visual appraisal.

5.3.2. Scaling strategies

Up and out scaling options of Doyogena sheep breed improvement process is involve to identify the best scaling strategy and way of addressing the feasible scaling that suits for the mixed crop livestock production system.

The higher accumulated discounted benefits and returns on investment in the base-level Strategies (1, 2, and 3) compared to the combined AI-supported strategies (Strategies 4 and 5) may be attributed to the lower costs associated with purchasing breeding rams and supervision. Strategy 3, which achieved the highest returns and accumulated benefits, was associated with an increase in breeding ewes per Community-Based Breeding Program (CBBP) and the dissemination of a large number of breeding rams from the nucleus flock. A greater number of ewes per household within a CBBP led to higher productivity. This also improved the chances of identifying large number superior rams for the next generation and reduced the impacts of inbreeding (Gizaw et al., 2013; Muller et al., 2019).

The higher genetic progress (0.17 kg/year at nucleus and 0.13 kg/year at base) revealed in Strategy 2 using natural mating practice associated with the result of applying higher selection intensity. Using higher selection intensity in genetic improvement would result in higher genetic gain similar with the current study also reported (Galukande et al., 2013; Desalegn et al., 2022). In the combined AI-supported strategies (Strategy 4 and 5), the higher genetic progress for SMW over the 20-year period compared to the other strategies assumed negligible effects from potential management and environmental changes during this timeframe. Similarly, when improved rams from the reference CBBP were disseminated to production units and used alongside AI, greater genetic progress in SMW was achieved compared to natural mating. This

predicted genetic progress aligns with the gains projected for Menz sheep (Mueller et al., 2019). The superior progress associated with AI is likely due to the use of genetically superior ram semen (Alvares et al., 2015).

The AI-based strategies (Strategy 4 and 5) produced higher trait levels, but their economic returns varied. For instance, Strategy 4's high genetic progress did not translate into the highest ROI, partly due to increased AI costs. Conversely, Strategy 5 demonstrates that integrating AI into a high-dissemination framework can yield strong cumulative benefits (\$353,757 in the production unit) while maintaining solid genetic progress. The economic superiority of Strategy 3 highlights the importance of maximizing ram dissemination to production units, even at slightly lower genetic progress rates.

6. SUMMARY AND CONCLUSION

6.1. Summary

This comprehensive study evaluated a ten-year (2013–2022) Community-Based Breeding Program for Doyogena sheep, assessing its genetic, phenotypic, and socioeconomic impacts, and options for scalability. The study aimed to estimate genetic parameters for growth, reproduction, and survival traits; assess morphological changes in the sheep and socioeconomic benefits for farmers, including flock dynamics; and develop and evaluate strategies for scaling up/out the program by analyzing genetic gains and economic returns.

Data on 12 traits such as birth weight (BWT), weaning weight (WWT), weight at six months (SMW), annual reproductive rate (ARR), lambing interval (LI), litter weight at birth (LWB), litter size at birth (LSB), litter weight at weaning (LWW), litter size at weaning (LSW), ewe

post-partum weight (EPPW), pre-weaning lamb survival (PWLS), and lamb survival up to six months (LSSM) were analyzed using advanced statistical models (REML, multi-trait animal model). A survey of 260 farmers (130 CBBP members, 130 non-members) captured perceptions and flock data. Five scaling strategies were modeled for genetic progress and economic return. Growth traits showed moderate heritability, while reproductive and survival traits had low heritability. Significant positive annual genetic trends were observed for most traits, proving the CBBP's effectiveness for genetic improvement. Positive genetic correlations were found between growth traits and reproduction/survival, indicating selection for growth can improve other important traits. Concerning socioeconomic and flock dynamics Impact, CBBP members had larger flock sizes, higher birth rates, and a significantly higher off-take rate (36.45% vs. 17.35%) than non-CBBP members, meaning they sold more animals for income. Farmers reported noticeable improvements in growth, coat color, litter size, survival, and lambing interval due to the program. The CBBP directly increased members' annual income from sheep, which was used for household needs, maintenance, and dietary diversity. Among CBBP scaling strategies, those incorporating Artificial Insemination (AI) (Strategy 4) achieved the highest genetic progress (27.88 kg at nucleus level). A strategy focusing on maximizing dissemination through natural mating (strategy 3) yielded the highest Return on Investment (ROI) at the production unit level. The AI-based strategies (Strategies 4 and 5) produced higher SMW, but their economic returns varied. While strategy 4 accelerated genetic gains, its higher costs did not translate to the best economic returns. The strategy integration with AI can accelerate genetic progress, optimal economic outcomes depend on effective candidate retention, dissemination strategies, and aligning breeding models with operational capacity. Thus, Doyogena CBBP successfully improved sheep genetics, increased farmer incomes, and enhanced livelihoods. To ensure long-

term sustainability and maximize impact, litter weight traits should be included along with growth traits in the breeding objective, scaling strategies must be tailored to local operational capacity, financial constraints, and breeding goals.

6.2. Conclusion

The heritability estimates obtained for the studied traits indicate that the response to selection for body weight (growth traits) and litter weight traits (LWB and LWW) were more pronounced than other traits. The low heritability for most reproductive and survival traits attributed to the significant impact of environmental factors, suggesting limited potential for improvement via selection alone. The medium heritability and moderate genetic correlations between growth (WWT and SMW) and litter weight (LWB and LWW) traits suggest that incorporating these traits into the selection index could lead to improvements in the performance of the breed. The CBBP was effective and well-accepted by participants, CBBP members had larger flock size, higher lamb production, and greater income from sheep than non-participants. The CBBP scaling strategy integration with AI can accelerate genetic progress, optimal economic outcomes depend on effective candidate retention, dissemination strategies, and aligning breeding models with operational capacity.

7. RECOMMENDATIONS

- The litter weight traits identified here should be included along with growth traits in the selection index and optimizing Doyogena sheep breeding program are recommended to achieve the best outcomes for sustainable use.

- To ensure sustainability, efforts should focus on improving stakeholder integration, advancing breeding cooperatives, and creating awareness among farmers.
- Policy and Scaling Recommendations
 - ✓ Targeted AI Expansion – AI should be prioritized in high capacity CBBPs where genetic gain is the primary objective and operational capacity can handle semen distribution.
 - ✓ Candidate Retention Strategies – Preventing premature sale of male candidates significantly enhances selection intensity and long-term genetic progress.
 - ✓ Strategic Adoption
 - Retain all candidates plus increase breeding females per CBBP but keep current selection proportion of ram (0.34) for maximizing short-to-medium term economic impact and wide-scale dissemination (scaling strategy 3; Manuscript III).
 - Strategy 5 for a balanced approach when both genetic improvement and high economic returns are desired (AI + NM (based on strategy 3)).

8. SCOPE FOR FUTURE WORK

1. Monitor the long-term socioeconomic (e.g., livelihood resilience, gender equity) and environmental impacts of scaled-up CBBPs on farming communities and ecosystems.
2. Undertake genomic studies to identify potential genetic markers associated with key traits like litter weight and survival, which could enhance the accuracy of selection.

9. LIMITATIONS OF THE PRESENT WORK

- The inconsistency and lack of accuracy of collected data on CBBP level resulted from awareness differences of among data collectors in some CBBPs of Doyogena sheep.

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Research Article

Exploring Genetic Parameters and Correlations Among Growth, Reproductive, and Survival Traits in Doyogena Sheep

Addisu Jimma ^{1,2}, Aberra Melesse ¹, Aynalem Haile,³ and Tesfaye Getachew³

¹School of Animal and Range Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia

²Animal Research Directorate, Areka Agricultural Research Center, P.O. Box 79, Areka, Ethiopia

³International Center for Agricultural Research in the Dry Areas, P.O. Box 5689, Addis Ababa, Ethiopia

Correspondence should be addressed to Addisu Jimma; addisj2003@gmail.com

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In central Ethiopia region, the community-based breeding program (CBBP) for improving Doyogena sheep has utilized growth traits as a primary selection criterion since its establishment. Growth, reproduction, and survival traits play a vital role in the overall productivity, so it is critical to evaluate how these traits changing overtime. This study purposed to examine variance components, genetic parameters for growth, reproductive, and survival traits, and correlations between growth and other economically important traits in Doyogena CBBPs. The data was gathered over 10 years (2013–2022) and traits considered were birth weight (BWT), weaning weight (WWT), weight at 6 months (SMW), annual reproductive rate (ARR), lambing interval (LI), litter weight at birth (LWB), litter size at birth (LSB), litter weight at weaning (LWW), litter size at weaning (LSW), ewe postpartum weight (EPPW), preweaning lamb survival (PWLS), and lamb survival up to 6 months (LSSM). Using a restricted maximum likelihood procedure, WOMBAT software was used to analyze the traits in a multitrait animal model. The values for additive heritability estimates for BWT, WWT, SMW, LSB, LWB, LSW, LWW, LI, ARR, EPPW, PWLS, and LSSM were 0.37, 0.26, 0.21, 0.10, 0.24, 0.03, 0.22, 0.15, 0.12, 0.14, 0.10, and 0.08, respectively. The majority of performance traits show positive and significant ($p < 0.001$) annual genetic trends in breeder cooperatives, indicating the feasibility of breed improvement programs. Positive and low to moderate genetic correlations were observed between growth (WWT and SMW) with most of the reproduction and lamb survival traits. The medium heritability and the moderate correlations between growth and litter weight traits (LWB and LWW) suggest the importance of considering litter weight in addition to growth traits in selection processes. In conclusion, optimizing the Doyogena sheep breeding program and improving management conditions are recommended to achieve the best outcomes and ensure long-term sustainability.

1. Introduction

Small ruminants are reared under various agroecologies and are a vital species of livestock in Ethiopia, with an estimated figure of about 42.9 and 52.5 million sheep and goats, respectively [1]. Small holder producers drive their immediate needs for family members from sheep sales. During crop failure and environmental risk, sheep are often seen as a valuable asset that can be used as insurance. They also fulfill a variety of socioeconomic and cultural roles [2]. However, Gizaw et al. [3] list several limiting factors for low efficiency. The lack of a proper improvement program and top-to-bottom procedures was the primary cause of inefficient productivity per animal [3].

An effective strategy that suits low-input farming systems for enhancing livestock species, particularly small ruminants, is a community-based breeding program (CBBP) [4]. This program follows a participatory manner toward developing breeding objectives and desired characters, designing appropriate breed improvement frameworks tailored to diverse farming systems, collecting trait data through enumerators, selecting sires for mating based on genetic merits and physical appearance, and facilitating communal utilization of selected sires [5]. These initiatives aimed to improve productivity and maximize smallholder producers' revenue.

Evaluation reports of CBBPs demonstrate improvements in productivity (such as multiple births, better growth, and reduced lamb mortality) and a significant increase in the annual income of smallholder farmers [6, 7]. In Ethiopia, there are over 130 CBBPs across different sheep and goat breeds, engaging around 13,000 producers and deriving benefits from the schemes [8]. Since 2013, the former Southern Agricultural Research Institute (SARI) in collaboration with International Center for Agricultural Research in the Dry Areas (ICARDA) launched CBBPs for different sheep breeds in different zones of the region. Doyogena sheep CBBPs is among the most successful breed improvement programs, with eight strong cooperatives and more than 1200 members.

Doyogena sheep breed is known for its long fatty tail, large in size, fast growth, multiple births, horned, and diverse coat colors [9, 10]. According to CSA [1], Doyogena sheep were estimated at around 298,675 heads and Kembata, and neighboring zones are the main distribution areas for Doyogena sheep in the Central Ethiopia Region [11].

The advancement of genetics and optimization of the Doyogena CBBPs are vital for maximizing revenues and ensuring the long-term sustainability of the program. While the program initially focused on improving the growth trait, specifically utilizing 6-month weight (SMW) as a selection criterion [12, 13], it is essential to recognize the significance of other important characteristics like reproduction and survival. In sheep farming, growth is an economically vital trait as it directly influences the profitability of the enterprise [14, 15]. However, solely emphasizing growth without considering other traits can lead to an imbalanced breeding program. Reproduction and survival traits play an essential role in the overall productivity and efficiency of the breeding program [16, 17]. By incorporating these traits into the selection criteria, the program can aim for a more comprehensive improvement of the Doyogena sheep breed.

Previous evaluations of the Doyogena sheep breed focused on an individual trait in isolation using univariate analysis [12, 18]. However, they failed to capture the potential interrelationships and genetic correlations between different traits. This limitation hindered the program from fully understanding the complex genetic architecture of the breed and optimizing the selection process. In a breed improvement program, the economic value of the final product generally depends on multiple traits, as highlighted by Bernardo [19]. To address this limitation, the current study suggests using a multivariate analysis approach to uncover relationships between growth, reproduction, and survival traits. This holistic perspective aims to enhance the breeding program's effectiveness by considering multiple traits simultaneously [20].

Through the exploration of genetic associations among traits, the breeding scheme can identify animals that exhibit desirable characteristics across multiple traits. This integrated approach ensures that the selection process considers the interplay among growth, reproduction, and survival, leading to a more balanced and optimal breeding strategy. By selecting animals through improved genetic capability for all these traits, the program can enhance the overall productivity, adaptability, and profitability of the Doyogena sheep breed. The knowledge

gained from the multivariate analysis will guide the development of more efficient breeding schemes, enabling the selection of animals with superior genetic merit across a range of economically important traits. Therefore, the objectives of the current study were to investigate genetic parameters for growth, reproduction, and survival as well as associations among growth and other economically important traits in Doyogena CBBPs.

2. Materials and Methods

2.1. Description of the Study Area. Doyogena sheep CBBPs are found in the Doyogena district, situated in the Kembata zone of the Central Ethiopia Region. This district's coordinates are between 7°20' N latitude and 37° 32' 50" E longitudes. Since 2013, the CBBPs have been established in eight breeder cooperatives (Anicha, Begedamu, Gomora, Hawora, Lemi, Murasa, Serera, and Women's). The area farming system is based on mixed crop–livestock production, with enset (*Ensete ventricose*) being a significant crop. The altitude varies from 1900 to 2800 m above sea level, with minimum and maximum temperatures of 10 and 16°C, respectively. The average annual rainfall is 1400 mm, mostly occurring from April to December [21].

2.2. Description of the Breeding Program and Animal Management. Since 2013, ICARDA and Areka Agricultural Research Center (ARC) has collaborated to implement the CBBP for Doyogena sheep. Improving growth rate, twinning, and mothering abilities were the main objective traits. Doyogena sheep are considered in CBBP due to their fast growth, common multiple births, diverse and attractive coat color (Figure 1), good fattening ability, and play a great role for livelihood of farmers next to cattle [9, 10].

In the Doyogena CBBPs, each breeder cooperative member managed their animals on an individual level. The average flock size per household was reported to be 4.67 [13]. Monitoring and performance data recording were regularly done by enumerators. A unique identification number was given for each animal with a plastic ear tag and newborn lambs were weighed within 24 h after birth. Weaning weight (WWT) was measured at 90 days and SMW at 180 days of age on the exact dates. Rams were selected at 6 months of age from each breeder cooperative based on breeding values and phenotypic information. The selection committee who were assigned by cooperative members approved the selection after checking the scrotum normality, body conformation, sexual libido, coat color, and horn of the selected rams. Mating of sheep was controlled and year-round, with each mating group including 20–30 ewes for a single ram. The breed improvement program and breeding ram selection procedures are described in detail [7]. The majority of farmers practice tethering during cropping season and allow their animals to graze on their farmland after harvesting crops. Improved forages, natural pasture, enset (*Ensete ventricose*) corm and tuber, and crop residues are the major animal feed resources [9, 18].

2.3. Data Collection and Management. The data sources were the pedigree and performance records of Doyogena sheep that



FIGURE 1: Doyogena sheep (a) breeding ram and (b) ewe with twin born lambs.

TABLE 1: Data structure of growth, reproductive, and survival traits of Doyogena sheep.

Traits	N	M ± SD	CV (%)
Growth traits			
Birth weight (kg)	6505	3.07 ± 0.62	20.1
Weaning weight (kg)	5017	15.05 ± 2.51	16.7
6 month weight (kg)	3821	23.45 ± 3.40	14.5
Reproductive traits			
Lambing intervals (in days)	1306	258 ± 94.68	36.7
Annual reproductive rate (number)	1304	2.18 ± 1.14	52.5
Litter weight at birth (kg)	4384	4.58 ± 1.65	36.2
Litter size at birth (number)	4384	1.54 ± 1.59	36.4
Litter size at weaning (number)	2905	1.33 ± 0.51	38.34
Litter weight weaning (kg)	2905	19.99 ± 7.52	37.6
Ewe postpartum weight (kg)	5242	30.82 ± 4.90	15.9
Lamb survival traits			
Preweaning survival	6529	0.96 ± 0.02	—
Birth to 6 month survival	6529	0.954 ± 0.03	—

Note: M, overall means; N, number of observation.
Abbreviations: CV, coefficient of variation; SD, standard deviation.

were gathered and kept in the Areka Research Center database over ten years (2013–2022). The traits collected were growth (birth weight (BWT), WWT, and weight at six months), reproductive (annual reproductive rate (ARR), lambing interval (LI), litter weight at birth (LWB), size of litter at birth, litter weight at weaning (LWW), and postpartum weight of the ewe), and survival (measured as 1 or 0 for a lamb alive or dead, respectively). The ARR and LI were calculated using the available lamb records. Pedigree viewer software was used to avoid mistakes for recording like bisexuality, duplicate animals, and sire or dam of itself problems that were found in the dataset. Before the analysis, outliers identified by transforming extreme data points with z -scores beyond ± 3 standard deviations from the means were excluded to reduce bias in estimation and enhance result consistency. A total of 6505 records of BWT, 5017 records of WWT, and 3821 records of SMW of lambs born from 325 sires and 444 ewes, and 6525 records of reproductive and survival traits of individual phenotypic data were derived as outlined in Table 1.

2.4. Data Analysis. The general linear model (GLM) was employed to analyze growth and reproductive traits, while the logistic regression procedure was employed to analyze survival rates by using the SAS software [22]. Fixed effects determined to be significant ($p < 0.05$) were taken in the following genetic analysis model. Fixed environmental effects taken into account during the analysis included season of birth in two classes (wet season from April to December and dry season from November to March), lamb sex in two classes (male and female), birth type in three classes (single, twin, and triplet and above), ewe parity in eight classes (ranging from 1 to ≥ 8), year of birth in 10 classes (2013–2022), and breeder cooperatives in eight classes (Anicha, Begedamu, Gomora, Hawora, Lemi, Murasa, Serera, and Women's). Variance components and genetic parameters for growth and reproductive traits were estimated using WOMBAT [23] with multivariate genetic analysis models. Initially, a full multitrait animal model was attempted for all 12 traits, but encountered convergence issues. This led to the

TABLE 2: Nongenetic factors affecting growth, reproductive, and survival traits of Doyogena sheep.

Nongenetic factors	p-Value											
	BWT	WWT	SMW	LI	ARR	LWB	LSB	LSW	LWW	EPPW	PWLS	LSSM
Sex	0.001	0.001	0.001	0.058	Na	Na	Na	Na	Na	Na	0.003	0.006
Birth type	0.001	0.001	0.001	0.670	Na	0.001	Na	Na	0.001	0.001	0.006	0.001
Parity	0.001	0.001	0.005	0.732	0.01	0.001	0.001	0.001	0.001	0.001	0.091	0.016
Season	0.001	0.79	0.51	0.114	0.055	0.324	0.12	0.905	0.96	0.49	0.596	0.004
Cooperatives	0.001	0.001	0.001	0.026	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.001
Year	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0001

Note: SMW, weight at 6 month.

Abbreviations: ARR, annual reproductive rate; BWT, birth weight; EPPW, ewe postpartum weight; LI, lambing interval; LSB, litter size at birth; LSSM, lamb survival birth to six month; LSW, litter size at weaning; LWB, litter weight at birth; LWW, litter weight at weaning; NA, not applicable; PWLS, preweaning lamb survival; WWT, weaning weight.

analyses, which produced six- and seven-trait with reasonable estimates and improved convergence (change in log L less than 5×10^{-4}). Random effects, including residuals, the permanent environment effect of dam for growth traits, the permanent environment effect of animals for reproductive traits, and the direct additive effect were all taken into consideration by the model. The average information-restricted maximum likelihood algorithm was applied in a multivariate mixed model to investigate lamb survival [24]. For the analysis, DMU modules, specifically DMU1 and DMUAI were used. Growth traits and survival were found to have genetic correlations, which were estimated using DMUAI, which was derived from DMU1 data. A random effect that used in the model was a direct additive.

The model used for the analysis of growth and reproductive traits was:

$$y = Xb + W_1a + W_2m + W_3peA + W_4peD + e.$$

The model used for the analysis of lamb survival and growth traits was $y = Xb + W_1a + e$ where y = vector of observation of the studied traits; b = vector of fixed effects; a = vector of direct additive genetic effects; m = vector of direct maternal genetic effects; peA = vector of permanent environment effects of the animal; peD = vector of permanent environment effects of the dam; e = vector of residual effects. While X , W_1 , W_2 , W_3 , W_4 = design matrices associating the fixed, direct additive, direct maternal, permanent environment effect of animal, and permanent environment effects of dam, respectively.

The heritability (h^2) was computed as the ratio of the animal variance to phenotypic variance. Whereas repeatability (r) was determined using the formula $r = (\sigma^2a + \sigma^2peA + \sigma^2peD) / \sigma^2p$, where σ^2a represents additive variance, σ^2peA represents a permanent environmental variance of the animal, σ^2peD represents a permanent environmental variance of the dam, and σ^2p represents phenotypic variance. Genetic trends for the traits were assessed by performing a weighted regression of the average breeding value of the animals based on the year of birth.

3. Results

3.1. Overall Phenotypic Estimation of the Traits. The list of observations under each trait along with the overall means and standard deviations (SDs) is presented in Table 1. The overall mean values for BWT, WWT, and SMW were 3.07, 15.05, and 23.45 kg, respectively.

The values of LI, ARR, LWB, litter size at birth (LSB), litter size at weaning (LSW), LWW, and ewe postpartum weight (EPPW) were 258 days, 2.18 lambs/ewe/year, 4.58 kg, 1.54 L/ewe, 1.33 L/ewe, 19.99 kg, and 30.80 kg, respectively. Lamb survival rate (LSR) from birth to weaning and birth to 6 months for the same animals were 96% and 95%, respectively. Coefficients of variations (CVs) for growth and reproductive traits ranged between 14.5% for SMW to 20.1% for BWT, and 15.9% for EPPW to 52.5% for ARR, respectively.

3.2. Nongenetic Factors. Year of birth and breeder cooperative had a substantial ($p < 0.01$) influence on every trait that was studied (Table 2). The season of birth had a significant ($p < 0.01$) effect on both BWT and LSSM values. The effect of lamb sex was significant ($p < 0.01$) in growth (BWT, WWT, and SMW) and survival (preweaning lamb survival [PWLS] and LSSM) traits. Birth type had a significant ($p < 0.01$) effect on growth, survival, and certain reproductive traits. Except LI and PWLS, parity of ewe had a significant ($p < 0.01$) influence on all the traits under investigation.

3.3. Genetic Parameters. Direct heritability estimates of the studied traits were moderate (0.21–0.37) for growth, low to moderate (0.03–0.24) for reproductive, and low (0.08–0.1) for lamb survival (Table 3). The estimates of direct heritability for growth, reproductive, and survival traits from multivariate analyses are mentioned in Table 3.

3.4. Correlations Between Traits. Correlations between body weights with other traits from multitrait analysis are presented in Table 4. BWT had positive weak genetic correlation with WWT (0.14) and SMW (0.03). The genetic correlation between WWT and SMW was positive and moderate (0.30). The genetic correlations between BWT with LSB, LWB, EPPW, PWLS, and LSSM ranged from low (0.05) to high (0.96) and were positive. On the other hand, the genetic correlations between BWT with LSW, LWW, LI, and ARR were negative

TABLE 3: Estimates of direct heritability for growth, reproductive, and survival traits from multitrait analyses.

Traits	Variance components						h^2_a	Pe ² D	Pe ² A	h^2_m	re
	σ^2_e	σ^2_a	σ^2_m	σ^2_{peA}	σ^2_{peD}	σ^2_p					
Growth											
Birth weight	0.1	0.09	0.014	—	0.05	0.25	0.37 ± 0.03	0.19 ± 0.01	—	0.20 ± 0.05	—
Weaning weight	2.12	1.22	1.37	—	0.89	4.71	0.26 ± 0.03	0.18 ± 0.22	—	0.29 ± 0.02	—
Weight at 6 month	4.75	1.85	0.64	—	2.57	8.79	0.21 ± 0.04	0.17 ± 0.06	—	0.07 ± 0.07	—
Reproductive											
Litter size at birth	0.11	0.03	0.05	0.01	—	0.33	0.10 ± 0.03	—	0.03 ± 0.01	0.14 ± 0.02	0.12
Litter weight at birth	0.23	0.24	0.26	0.29	—	1.03	0.24 ± 0.03	—	0.28 ± 0.01	0.25 ± 0.05	0.51
Litter size at weaning	0.09	0.05	0.04	0.1	—	1.79	0.03 ± 0.01	—	0.06 ± 0.00	0.02 ± 0.01	0.08
Litter weight at weaning	17.36	12.12	5.52	10.76	—	55.1	0.22 ± 0.04	—	0.19 ± 0.01	0.1 ± 0.02	0.36
Lambing interval	4224.9	1691.7	1081.5	4088.6	—	11,087	0.15 ± 0.08	—	0.36 ± 0.07	0.09 ± 0.05	0.52
Annual reproductive rate	0.53	0.1	0.07	0.24	—	0.77	0.12 ± 0.08	—	0.31 ± 0.07	0.1 ± 0.06	0.44
Ewe postpartum weight	1.2	1.51	4.645	1.33	—	10.82	0.14 ± 0.03	—	0.12 ± 0.003	0.43 ± 0.02	0.46
Lamb survival											
Preweaning survival	0.001	0.004	—	—	—	0.04	0.10 ± 0.06	—	—	—	—
Survival birth to 6 month	0.003	0.003	—	—	—	0.04	0.08 ± 0.04	—	—	—	—

Note: σ^2_e , residual variance; σ^2_a , direct additive genetic variance; σ^2_m , maternal additive genetic variance; σ^2_{peA} , animal permanent environment; σ^2_{peD} , dam permanent environment; σ^2_p , phenotypic variance; h^2_a , direct heritability; pe²D, ratio of permanent environmental variance to phenotypic variance of dam; pe²A, ratio of permanent environmental variance to phenotypic variance of animal; h^2_m , maternal heritability. Abbreviation: re, repeatability.

TABLE 4: Genetic (r_g) and phenotypic (r_p) correlations of growth with other trait from multitrait analyses.

Trait	BWT		WWT		SMW	
	r_g	r_p	r_g	r_p	r_g	r_p
BWT	—	—	0.14 ± 0.04	0.13 ± 0.02	0.03 ± 0.04	0.10 ± 0.02
WWT	—	—	—	—	0.30 ± 0.04	0.14 ± 0.02
LSB	0.47 ± 0.11	0.15 ± 0.02	0.04 ± 0.12	-0.16 ± 0.03	0.08 ± 0.14	-0.06 ± 0.02
LWB	0.96 ± 0.03	0.57 ± 0.01	0.20 ± 0.09	0.11 ± 0.02	0.32 ± 0.12	0.09 ± 0.02
LSW	-0.16 ± 0.10	0.05 ± 0.01	0.10 ± 0.13	-0.1 ± 0.001	0.07 ± 0.14	-0.02 ± 0.01
LWW	-0.06 ± 0.11	0.17 ± 0.02	0.38 ± 0.1	0.33 ± 0.02	0.05 ± 0.14	0.08 ± 0.02
LI	-0.25 ± 0.16	-0.05 ± 0.03	0.02 ± 0.18	-0.05 ± 0.03	0.16 ± 0.22	-0.02 ± 0.01
ARR	-0.13 ± 0.16	0.06 ± 0.03	0.02 ± 0.19	0.034 ± 0.03	0.04 ± 0.22	0.03 ± 0.03
EPPW	0.26 ± 0.07	0.21 ± 0.01	0.20 ± 0.09	0.13 ± 0.02	-0.07 ± 0.11	0.05 ± 0.02
PWLS	0.06 ± 0.12	0.03 ± 0.013	0.05 ± 0.16	0.14 ± 0.02	0.19 ± 0.03	-0.06 ± 0.022
LSSM	0.05 ± 0.13	0.03 ± 0.01	0.07 ± 0.17	0.12 ± 0.02	0.20 ± 0.20	-0.05 ± 0.02

Note: r_g , genetic correlation; r_p , phenotypic correlation; LSSM, lamb survival birth to 6 month; SMW, weight at 6 month. Abbreviations: ARR, annual reproductive rate; BWT, birth weight; EPPW, ewe postpartum weight; LI, lambing interval; LSB, litter size at birth; LSW, litter size at weaning; LWB, litter weight at birth; LWW, litter weight at weaning; NA, not applicable; PWLS, preweaning lamb survival; WWT, weaning weight.

and varied from -0.25 for LI to -0.06 for LWW. BWT exhibited a strong correlation with LWB (0.96) and a moderate correlation with LSB (0.47).

Reproductive traits had positive and low genetic correlation with WWT, except LWW (0.38), which had a positive and moderate genetic correlation. The correlations between WWT with LSW, LWB, LSB, LI, ARR, EPPW, PWLS, and LSSM obtained in the current study were low and varied from 0.02 for ARR to 0.20 for LWB and EPPW. A moderate genetic correlation estimate was shown between SMW and LWB (0.32) and positive and low correlations were obtained between SMW and almost all the study traits.

The phenotypic correlations between BWT and almost all the other studied traits were positive (Table 4). The lamb WWT had positive phenotypic correlations with, LWB, LWW, ARR, EPPW, PWLS, and LSSM. However, it had negative phenotypic correlations (-0.16 to -0.05) with LSB, LSW, and LI. PWLS, LSSM, LSB, LSW, and LI traits had a negative phenotypic correlations with SMW.

3.5. Genetic Progress. Except BWT, the annual genetic progress in growth traits had exhibited positive and highly significant ($p < 0.001$; Table 5).

Most of reproductive and lamb survival traits had also showed a significant ($p < 0.001$) trend (Table 5). LWB and

TABLE 5: Genetic trends and inbreeding rate over year for growth, reproduction, and survival traits in Doyogena sheep CBBPs.

Parameters	Trend per year	p-Value
Birth weight (kg)	-0.019	0.0001
Weaning weight (kg)	0.073	0.0001
6 month weight (kg)	0.149	0.002
Litter weight at birth (kg/year)	-0.0004	0.0001
Litter weight at weaning (kg/year)	0.0297	0.09
Litter size at birth (lamb/year)	0.003	0.0001
Litter size at weaning (lamb/year)	0.0045	0.0001
Lambing interval (days/year)	0.9	0.559
Annual reproductive rate (lambs/ewe/year)	0.016	0.002
Ewe postpartum weight (kg)	0.012	0.001
Preweaning lamb survival (lamb/year)	0.0004	0.001
Birth to 6 month lamb survival (lamb/year)	0.0008	0.0001
Inbreeding level (%)	0.036	0.02

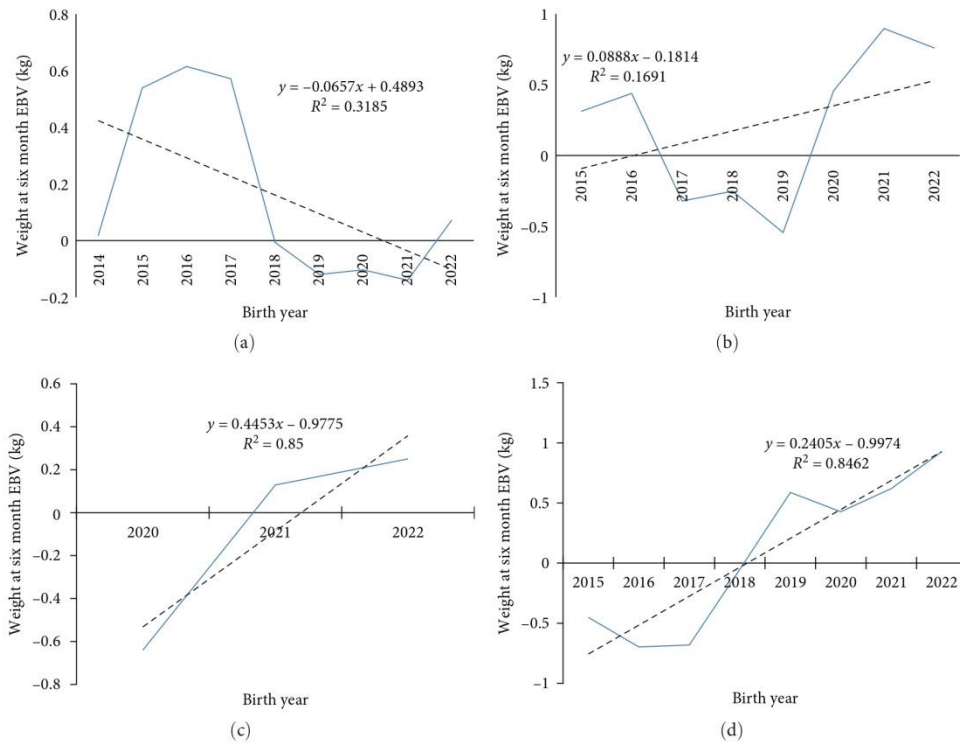


FIGURE 2: Continued.

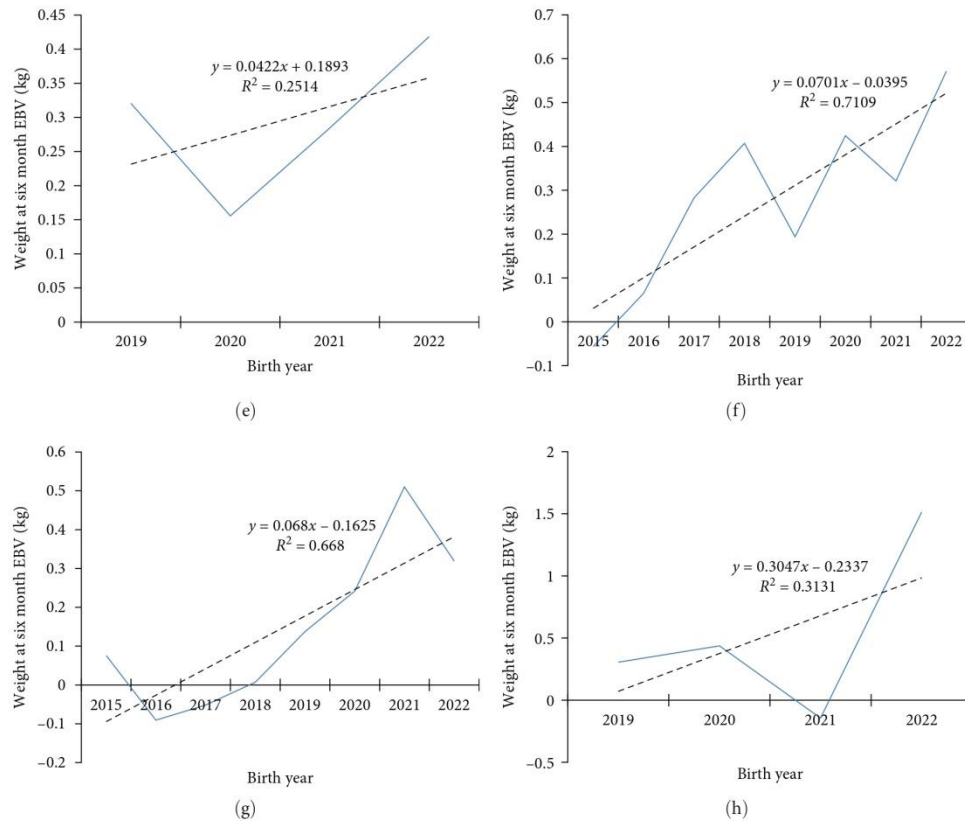


FIGURE 2: Direct genetic trend of weight at 6 month (SMW) for Anicha (a), Begedamu (b), Gomora (c), Hawora (d), Lemi (e), Murasa (f), Serera (g), and Women (h) sheep breeding cooperatives in Doyogena.

BWT showed a negative and low genetic trend (Table 5). Figure 2a-h illustrates the genetic trends for SMW of Doyogena sheep in CBBP. The yearly genetic trends of SMW were -0.066 , 0.089 , 0.45 , 0.24 , 0.04 , 0.07 , 0.068 , and 0.3 kg per year at Anicha, Begedamu, Gomora, Hawora, Lemi, Murasa, Serera, and Women's breeding cooperatives, respectively. Except Anicha cooperative, significant ($p < 0.01$) improvement and positive genetic progress have been achieved in Doyogena sheep breeder cooperatives. The increases of genetic trend of SMW were more pronounced in Gomora (0.45 kg/yr), Serera women (0.30 kg/yr), and Hawora (0.24 kg/yr) breeder cooperatives than others in Doyogena CBBPs. Except Gomora cooperative, the annual genetic trend trends for LWW, LSB, and ARR had improved significantly ($p < 0.001$) overtime. In Figures 2c and 3, Gomora breeder cooperative showed a negative trend in LSB and a positive and higher annual trend in SMW and vice-versa true for Anicha breeder cooperative. ARR and LWW trended were significantly ($p < 0.001$) higher in the Begedamu breeder cooperatives others (Figures 4 and 5).

3.6. Inbreeding Rate. The annual and overall inbreeding rate was 0.04% and 0.29% , respectively, in Doyogena CBBP (Figure 6 and Table 5). The inbreeding values for Begedamu, Murasa, and Hawora cooperatives were 0.49% , 0.35% , and 0.31% , respectively, while it exhibited comparatively higher levels. In comparison, the women-led cooperative showed the lowest level of inbreeding (0.00%).

4. Discussion

4.1. Nongenetic Factors. The body weight traits (Table 1) of Doyogena sheep (local breed) in Kembata zone of Central Ethiopia Region were found to be comparable to those of Bonga (BWT 3.1 kg, WWT 16.1 kg, and SMW 24.7 kg) sheep breed under CBBP conditions in the Keffa zone of the Southwestern Ethiopia [25], while the breed exhibited higher values for BWT and SMW compared to Menz sheep (BWT 2.76 kg and SMW 14.1 kg) in Amhara region (Northern part of Ethiopia) [7]. This might be attributed to the genetic difference between the breeds and their production

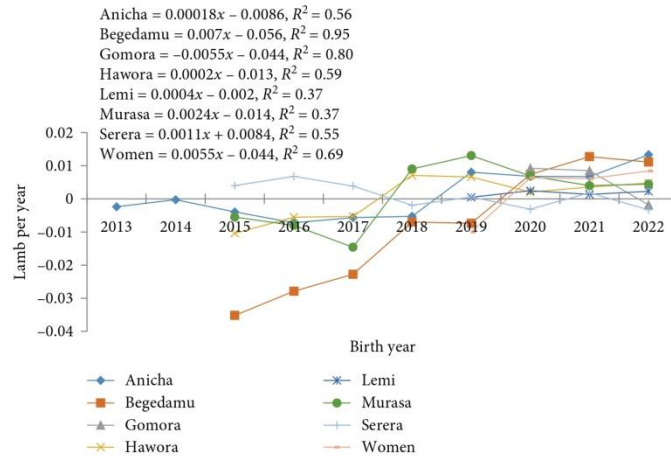


FIGURE 3: Genetic trend of litter size at birth (LSB) for each breeder cooperatives across year.

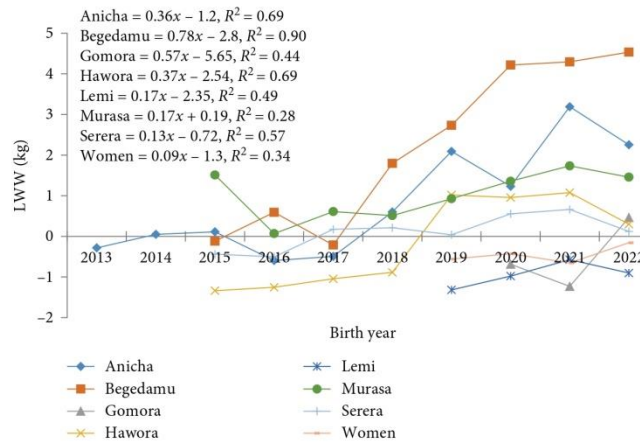


FIGURE 4: Genetic trend of litter weight at weaning (LWW) for each breeder cooperative across year.

environment variability. The significant effects of sex on body weight could be explained by hormonal and physiological differences between male and female lambs [26, 27]. Single-born lambs showed higher body weights than twins and triplets, possibly due to prenatal and postnatal environments [26]. The influence of lambing year on reproductive traits has been reported by various scholars [16, 28–31]. The availability of selected rams, management practices, feed availability, and weather conditions could play a role for the variations observed. The increase in litter size across different parities might be associated with physiological maturity, dam age, uterine capacity, and maternal behavior traits [14, 18].

4.2. Genetic Estimates. In advanced age, there was a declining trend in the direct heritability of body weight traits. Unlike the current results, previous reports indicated that the heritability of growth traits tended to increase with the age of animals [32, 33]. The decline in the direct heritability of body weight traits in this study could be associated with higher phenotypic variances due to environmental factors such as management, early selling of animals, data structure, and the methods of monitoring community flocks, as suggested by Areb et al. [25].

The heritability of BWT for Doyogena sheep was in the range reported for different sheep breeds in Ethiopia. For example, Abegaz [34] reported a range of 0.18–0.32 for Horro sheep using a multi-trait analysis method, Yacob [35] reported

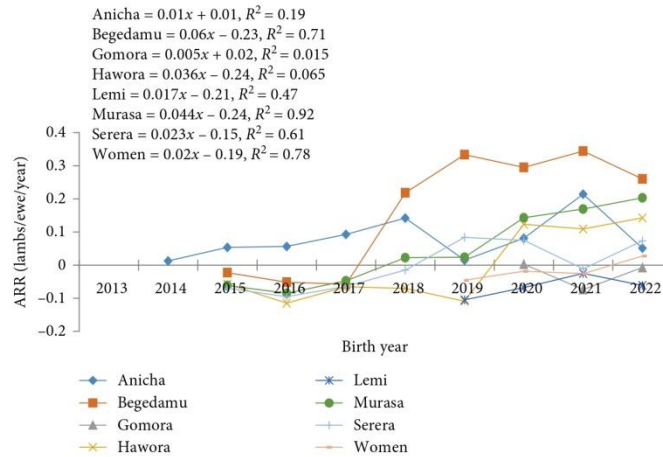


FIGURE 5: Genetic trend of annual reproductive rate (ARR) for each breeder cooperatives.

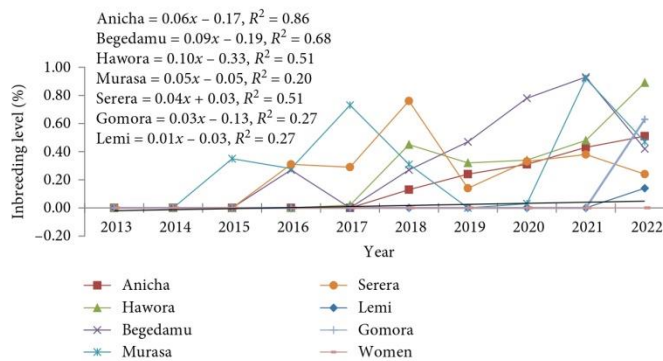


FIGURE 6: Inbreeding rate in each breeder cooperatives over years.

a range of 0.18–0.38 for Afar and 0.2–0.58 for black head Somali sheep breeds using univariate analysis method. Moderate heritability of BWT for different exotic sheep breeds has been reported by Arthy et al. [36] for Madras Red sheep, Jafari et al. [37] for Makuie sheep, and Gamasae et al. [38] for Mehraban sheep. The moderate result of direct heritability estimates for BWT suggests that focusing selection on BWT would lead to genetic improvement, but might be care taken to avoid the difficulty of birth impact of improvements in BWT beyond the optimum value [7].

A moderate value of heritability estimates for WWT in the current study was similar with other studies. For instance, Yacob [35] reported a range of 0.11–0.37 for Afar sheep and 0.00–0.29 for BHS. However, higher and lower values reported by authors. For example, Areb et al. [25] reported a value of 0.36 for Bonga sheep. Gizaw et al. [39, 40] reported values of 0.48 and 0.19 for Menz sheep in different period. The SMW in

the present study was moderately heritable and which is in close agreement with the values for Mehraban (0.35) and Kourdi (0.32) sheep breeds as reported by Gamasae et al. [38] and Shahdadi and Saghi [41], respectively. However, higher estimates of heritability for SMW were reported for other sheep breeds in Ethiopia. For example, Haile et al. [7], reported heritability values of 0.49 for Bonga and 0.59 for Horro sheep breeds. The moderate heritability estimates of WWT and SMW indicate the existence of additive genetic variance for the traits, which could be used as selection criteria for Doyogena CBBPs. Moderate to high estimates of direct heritability of growth traits were found in many reports [7, 42, 43].

The direct heritability of litter size traits (LSB and LSW) in Doyogena sheep was low (Table 3) and consistent with previous reports of LSB for other sheep breeds, such as Kermani sheep (0.06) [30], Iran black sheep (0.11) [43], and Bonga sheep

(0.085) [44]. The heritability estimate for LSW aligns with results observed in Santa Ines sheep (0.03) [45] but was lower compared to other sheep breeds, with values ranging between 0.07 and 0.21 [29, 46, 47]. The potential for genetic improvement through selection for litter size traits (LSB and LSW) could be limited due to low heritability which has been confirmed by the current study. Doyogena sheep are one of the most prolific sheep breeds in Ethiopia [48]. The prolificacy and lamb mortality have a higher correlation, resulting in low heritability of litter size traits [49]. The differences in pre and post pregnancy management among sheep keepers, dam age, and the low correlations with selection traits could also be reasons for the low heritability of litter size traits. Improving management might be led to improvements than selection focusing litter size traits.

The ability of ewes to produce lambs BWT, regardless of the number of lambs born, can be indicated by LWB. The moderate estimate of direct heritability for LWB in the present study was parallel with the values reported by Vatankhah and Talebi [50], who observed the value for LWB of 0.23 for Lori-Bakhtiani sheep in Iran. Lower heritability for LWB than the current result was reported in different findings [51, 52]. The combined effects of reproductive and mothering ability of ewes, preweaning growth, and survival of lambs were indicated by LWW [53]. Direct heritability estimates for LWW in the current study was in the range of 0.03–0.4, as reported by several authors [28, 54, 55]. Thus, the moderate heritability of LWB and LWW indicate that considering the traits in the selection program would yield considerable improvement in the reproductive performance of Doyogena sheep.

The estimated heritability of LI for Doyogena ewes (Table 3) was in close agreement with those reported by Quesada et al. [56]. However, lower LI values were reported by Tera et al. [44] and Aguirre et al. [45], who recorded values of 0.009 and 0.04 for Bonga and Santa Ines sheep, respectively. The observed differences would be associated with breeds of sheep and environmental factors such as feed, health, and other factors [44]. The heritability estimate in the current study for ARR (Table 3) is much lower than that for Bonga sheep (0.25) reported by Areb et al. [57]. Generally, the estimates of heritability for most studied reproductive traits are low and focusing on selection for improvements of these traits may not bring the desired genetic improvement within shorter period. In this study, the direct heritability of LSR in the growth stages such as birth to weaning and birth to 6 months of age were low (Table 3). Similar with our finding, several reports have also reported values within the range of 0.00–0.11 for different sheep breeds [58–60]. The reason of low estimates of direct heritability for lamb survival could be associated with different factors that cause death [61]. Genetic improvement through direct selection of lamb survival may be difficult due to the small heritability. Looking for a positive association with traits that used for direct selection and suitable lamb management options will bring improvements in lamb survival.

4.3. Correlations Between Traits

4.3.1. Correlations Between Growth Traits. The weak genetic connection between BWT and WWT in the current study is in

close agreement with the reports by Illa et al. [62] for Nellore sheep. Consistent to the current study, a low genetic association between BWT and SMW for Bonga and Horro sheep breeds was reported [7]. The estimates of genetic correlation between BWT and WWT in the current finding was lower compared with the values reported by Gowane et al. [63, 64] in Bharat Merino sheep. The low genetic correlation between BWT and other growth traits at an advanced age could be associated with physiological difference, feed availability, health, and management factors [48]. Newborn lambs are more dependent on dam milk and grow faster until preweaning, while they grow slower after weaning and are fully exposed to environmental factors. The moderate genetic correlation estimate of WWT with SMW obtained in our study was in line with the findings of Gowane et al. [63] and Singh et al. [65] in Bharat Merino and Marwari sheep, respectively. Therefore, the moderate genetic correlations between WWT and SMW indicate that transferable genes responsible for increasing WWT also increase SMW. This could be used as a selection criterion for improvement in body weight traits.

4.3.2. Correlations Between BWT and Other Traits. The BWT showed a moderate correlation with LSB and a high correlation with LWB (Table 4). Vatankhah and Talebi [50] reported a high genetic correlation between BWT and LWB (0.98) for Lori-Bakhtiani sheep in Iran, which align with this finding. Such association is anticipated, as BWT is a component of the ewe LWB. The negative genetic correlations between BWT and LSW and LWW observed in this study were consistent with the findings of Mohammadi et al. [52] for Makooei sheep (−0.14 vs. −0.03) and Bromley et al. [66] for Colombian sheep (BWT-LSW −0.37). Contrary to this study, Afolayan et al. [67] reported a moderate (0.34) correlation between BWT and LWW. In line with the current results, several authors [68, 69] reported low genetic correlations between BWT and PWLS. The findings suggest that breeding for improved BWT would have a minimal impact on most traits studied, except for LSB and LWB.

The phenotypic correlations between BWT and other traits were positive, except for the correlation between BWT and LI (Table 4). The low positive correlations between BWT and LSB and LSW reported by Safari et al. [70] and Vatankhah and Talebi [50] closely align with our findings. However, Mohammadi et al. [52] observed negative phenotypic correlations between BWT and these traits.

4.3.3. Correlations Between WWT and Other Traits. The genetic correlations between WWT and almost all study traits were positive and low to medium (Table 4). Similar to the present study, Vatankhah and Talebi [50] and Notter et al. [71] reported positive and low genetic correlations between WWT and LSB (0.23 vs. 0.18) and LSW (0.14 vs. 0.07). Boujenane et al. [72] also reported low correlation between WWT and LWB. Mohammadi et al. [52] and Mohammadi et al. [73] reported moderate genetic correlations between WWT and LWW which were parallel with our value. These indicate that selection based on WWT would have a positive influence on genetic response in reproductive and survival traits. LWW per

ewe would have reasonable improvement due to moderately correlated responses between WWT.

Similar to our finding, the negative phenotypic correlations between WWT and litter size traits (LSB and LSW) were reported for crossbred ewes [67] and D'man sheep in Morocco [72]. Low and positive phenotypic associations of WWT with litter weight (LWB and LWW) traits align with findings from various published reports [50, 52, 58]. In line with our findings, Notter et al. [71] reported low correlations between post-WWT and LSB (0.20) and between post-WWT and LSW (0.11) for the Katahdin sheep breed. Likewise, Safari et al. [58] reported averages of 0.17 and 0.06 between post-WWT and LSB and between post-WWT and LWW, respectively.

4.3.4. Correlations Between SMW and Other Traits. In current study, the genetic correlation estimates between SMW and the reproductive and survival traits were low (Table 4), except for SMW–LWB which was moderate. In line with our findings, Notter et al. [71] reported low genetic correlations between post-WWT with LSB (0.20) and LSW (0.11) for the Katahdin sheep breed. Likewise, Safari et al. [58] reported averages of 0.17 and 0.06 between post-WWT and LSB and between post-WWT and LWW, respectively. Vatankhah and Talebi [50] reported a moderate genetic correlation between SMW and LWB for Lori-Bakhtiari sheep in Iran which was parallel with our finding. Hence, selection focusing on SMW to improve genetic merit in the traits would yield a positive and low to moderate genetic response for reproductive, and lamb survival traits. Jemberé et al. [74] also reported that village-based small ruminant improvement would have significant improvement on the growth and positively correlated traits through selection focused on WWT and SMW.

Low and negative phenotypic correlations between SMW with litter size traits (LSB and LSW) in the current study were in agreement with the findings of Afolayan et al. [67], who observed negative and low correlation between SMW–LSB and SMW–LSW. The low and positive correlations between SMW and litter weight traits (LWB and LWW) of this work were in concurrence with Vatankhah and Talebi [50], who reported low and positive phenotypic correlations between SMW–LWB and SMW–LWW.

4.4. Genetic Trends and Inbreeding Rate. Similar genetic progress for BWT in Baluchi sheep (–0.005 kg) and Santa Ines sheep (–0.001 kg) were found by Gholizadeh and Ghafouri-Kesbi [75] and Aguirre et al. [45], respectively. The possible reasons for the negative trend of BWT in Doyogena CBBPs were during the crop harvesting season: farmers allow their animals to graze on the farmland and have possibility for mixing flocks with non-member farmers, sometimes members purchase ewes from market, gap on breeding ram usage in some members, and gap on regular supervision by data collectors.

The genetic gains for WWT and SMW obtained in the current study using multitrait analysis are comparable to those reported for Bonga [25] and Abera sheep [27]. Lower estimates than the current values were reported for WWT (0.017) and SMWT (0.012) for Iranian native Ghezel sheep [76]. As well as, the higher estimates than our values were reported for Bonga

and Horro sheep [7]. The differences might be attributed to the fact that the latter were selected for more generations compared to the CBBP program in the current study.

Checking the genetic progress in each CBBP cooperative, focusing on selection age and reproductive traits will important to know the direction of the program. The positive annual genetic progress for SMW in most breeder cooperatives of Doyogena CBBPs is in line with previous reports in Abera and Bonga sheep [25, 27]. The higher annual genetic trend of SMW and the negative and decreasing trend of LSB in the Gomora breeder cooperative might indicate a focus more on phenotypic base selection rather than breeding value, which favors animals born single rather than multiple births. On the other hand, the positive lower genetic trend in the Lemi breeder cooperative might be associated with the recently joined breeder cooperative, which uses low selection intensity of breeding rams, and gaps in awareness. Other findings reported by Jimma et al. [13] indicate that considering multiple births is crucial for maintaining genetic diversity and increasing productivity. The reasons for negative trends of SMW in the Anicha breeder cooperative were the selection of rams for mating based on physical appearances which are influenced by management, inaccuracies in data recording, mixed flocks, uncontrolled mating, inadequate follow-up on breeding rams, and fattening un-castration of rams not fitting for breeding [25, 27, 76]. Therefore, special consideration is needed to fill the gap among breeder cooperatives. The positive and considerable annual genetic gain of reproductive traits in most breeder cooperatives of this study implies that selection based on SMWT have made positive and indirect influence on the traits. However, variations among breeder cooperatives have existed and it was might associated with the use of selected ram, way of data recording, and management. Thus, there is a need to implement an indirect selection method that considers growth, reproductive, and survival traits, enhancing the effectiveness of management, consistent monitoring, and follow-up by data collectors. In agreement with the present study, positive genetic changes for LSB and ARR have also been reported for Horro [77] and Bonga sheep [57], respectively. Unlike the current study, the negative genetic trend for prolificacy (LSB, LSW, and LWW) was reported by Aguirre et al. [45] for Sant Inês sheep in Brazil.

The annual inbreeding rate in the findings of this study was lower than the recommended level (0.5%–1%) mentioned by FAO [78]. Higher levels of inbreeding rate than the current study (0.29%) have been reported for Bonga CBBPs (0.34) and Menz sheep (0.31) [7]. The reason for the lower inbreeding rate of sheep in the current study might be due to the timely utilization of selected rams, implementation of ram rotation, and castrating of unselected ones in Doyogena CBBP.

5. Conclusions

This study revealed that Doyogena sheep breeder cooperatives have demonstrated significant genetic progress in performance traits as a consequence of selection focused on lamb body weight traits. This highlights the importance of CBBPs as an effective strategy for small sheep keepers to improve the breed.

The heritability estimates obtained for the study traits indicate that the response to selection for body weight (growth traits) and litter weight traits (LWB and LWW) were more pronounced than other traits. The low heritability for most reproductive and survival traits attributed to the significant impact of environmental factors, suggesting limited potential for improvement via selection alone. BWT exhibited a moderate genetic correlation with LSB and a high genetic correlation with LWB. However, BWT showed low genetic correlations with growth and survival traits, and negative and low genetic correlations with most reproductive traits. The genetic correlations between WWT with SMW and LWW were moderate and positive, while correlations between WWT with reproductive and survival traits were positive and low. Similarly, SMW demonstrated a moderate correlation with LWB and positive and low with most reproductive and survival traits. The medium heritability and moderate genetic correlations between growth (WWT and SMW) and litter weight (LWB and LWW) traits suggest that incorporating these traits into the selection index could lead to improvements in the performance of the breed. Furthermore, enhancing management practices could be particularly effective in improving traits with low direct heritability estimates.

Data Availability Statement

The data are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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Evaluating Flock Dynamics, Offtake-rate, and Farmers' Perception on Benefits of Community Based Breeding Program in Doyogena District, Central Ethiopia

ADDISU JIMMA^{1,2*}, ABERRA MELESSE¹, AYNALEM HAILE³, TESFAYE GETACHEW³

¹School of Animal and Range Sciences, Collage of Agriculture, Hawassa University, P.O. Box 05, Hawassa, Ethiopia;

²Areka Agricultural Research Centre (ARC), P.O. Box 79, Areka, Ethiopia; ³International Center for Agricultural Research in the Dry Areas, P.O. Box c/o ILRI 5689, Addis Ababa, Ethiopia

Abstract | The community-based breeding program (CBBP) is currently active in implementing indigenous breed improvement strategies to achieve genetic progress, economic benefits, and livelihood improvements for smallholders in the pioneer sheep breed improvement cooperatives in Ethiopia. Although the Doyogena sheep CBBP is one of the well-performing breeding cooperatives, there is a lack of up-to-date information regarding farmer perspectives on morphological and reproductive changes (such as conformation, coat color, litter size, growth, and lambing interval), socio-economic benefits, off-take, flock structure, and trends since the CBBP started. To address this gap, a study involving 260 randomly selected farmers, with 130 being CBBP members and 130 non-members owning sheep from similar locations, was conducted. The results revealed significant differences ($p < 0.05$) in various aspects between CBBP members and non-members. CBBP participants showed higher numbers of lambs below 3 months, male lambs between 3-6 months, intact males between 6-12 months, breeding rams, mature ewes, and the mean flock size of sheep at the household level. The major routes of sheep entry into the flocks were birth (81%), and purchase (17%). The total number of entries and births was higher ($p < 0.05$) in CBBP members (284 vs. 240) than in non-members (148 vs. 112). The off-take rate, representing the proportion of sheep exits from the flock, was significantly higher ($p < 0.05$) in CBBP members (36.45%) compared to non-members (17.35%). Factors such as CBBP participation, gender of the household head, age, flock size, and farm land size influenced flock dynamics and off-take rates. The CBBP was attributed to performance improvements in traits such as growth, coat color, litter size, survival, and lambing interval. Moreover, the program had a positive influence on economic benefits, as CBBP members reported higher annual income from sheep-related activities. This income played a crucial role in supporting farmers' livelihoods, contributing to house maintenance and providing food for households. In conclusion, the study highlights the positive influence of the Doyogena CBBP on farmers' livelihoods, thus suggesting the need to scale up the program to benefit a broader community.

Keywords | CBBP, Doyogena-sheep, Flock dynamics, Offtake-rate, Performance traits, Scaling up

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***Correspondence** | Addisu Jimma, School of Animal and Range Sciences, Collage of Agriculture, Hawassa University, P.O. Box 05, Hawassa, Ethiopia; Email: addisj2003@gmail.com

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INTRODUCTION

Community-based breeding program (CBBP) was initiated in 2009 in Ethiopia, focusing on four distinct

sheep breeds: Bonga, Menz, Afar, and Horro. These breeds were selected to represent different agro-ecologies and production systems, as outlined by Haile et al. (2014). The primary objectives of this program were enhancing sheep

productivity and income of smallholders. The preliminary evaluation results of the CBBP have revealed several positive outcomes. Mainly, negative selection has been inverted, breeding rams are retained within the community flock, control mating practices have been adopted, and contributing to improvements in performance traits. Moreover, the selling of selected rams has been carried out at prices higher than the local market, indicating economic benefits for the participants (Haile et al., 2014).

In addition to the core breeding activities, the program has integrated complementary initiatives. These include the introduction of improved forages and feeding options, disease management strategies, and the application of biotechnology tools such as artificial insemination. Furthermore, efforts have been made to facilitate better market access for breeding rams and fattened sheep. Various studies and reports, including those by Rekek et al. (2016), Esayas and Jane (2019), Kassie (2019), and Jane (2019), have documented the design and implementation of these comprehensive activities, contributing to the overall success of the community-based breeding program in Ethiopia.

The community-based breeding program (CBBP) for Doyogena sheep has been actively underway in the Kembata Zone of the Central Ethiopia region since 2013. This program builds upon the promising outcomes observed in previous CBBPs. Evaluation studies, which specifically focused on genetic gain, genetic progress, and the phenotypic performance of growth and some reproductive traits in Doyogena sheep, have shown prominent improvements (Addisu et al., 2021; Kebede et al., 2020, 2022). The documented achievements, as presented in various workshops (<https://cgspagegiar.org/handle/10568/92538>), further highlighted the success of the program. These positive developments have driven Doyogena CBBP into a phase of significant progress, attracting attention from institutions that are working on small ruminants.

The success or failure of any genetic improvement program depends on the intuitive knowledge of farmers (Kosgey et al., 2006). However, to achieve successful outcomes, it is important to incorporate participatory implementation supported by empirical data. The implementation process, technical and socioeconomic evaluations for first generation CBBPs, particularly for Bonga, Menz and Horro sheep have been conducted with the participation of sheep producers (Gutu et al., 2015, Haile et al., 2020). However, such information are lacking for Doyogena CBBPs. Therefore, the objectives of this study are to assess flock dynamics, explore farmers' perceptions regarding morphological and reproductive changes in sheep, examine the socio-economic benefits, and identify constraints associated with Doyogena sheep CBBPs.

DESCRIPTION OF THE STUDY AREA

The study was conducted at Doyogena district, Kembata Zone in the Central Ethiopia Region. The Doyogena district is situated at 7° 20' N latitude and 37° 50' E longitudes. The altitude ranges from 1900 to 2800 meters above sea level. The mean average annual rainfall is between 1200 and 1600 mm with an average mean temperature of 10–16 °C. Enset (*Ensete ventricosum*) based mixed crop-live-stock production system is the dominating production system in the study area (Taye et al., 2016), which is entirely dependent on rainfall. Cattle, sheep, poultry, equine and goats are the major livestock species kept in the district.

DESCRIPTION OF THE BREEDING PROGRAM AND BREEDER COOPERATIVES

For this study, five sheep breeder cooperatives implementing community-based breeding program (CBBP) in Doyogena district, Kembata Zone were randomly selected from the existing eight cooperatives. The five selected CBBPs included Anicha-Sadicho, Murasa-Woyiramo, Hawora-Arara, Serera-Bukata and Lemi-Suticho, all of which have been implementing CBBPs since 2013. The main objective of the breed improvement program is to increase the income of households through enhanced lamb growth, reduced mortality and increased number of lambs born per breeding ewe. The major criteria for enrollment as CBBP member include sheep holding and willingness to pay membership fee (110 ETB). The CBBP has a bylaw that includes paying a membership share, which is 50 ETB, and each member can buy 10–20 shares, contributing at least two breeding ewes, practicing good sheep management, and communicating with enumerators for data collection at different growth stages of the lambs.

Enumerators were hired by the former Southern Regional Bureau of Agriculture for data collection when various events occur. Participant farmers keep newly born lambs until the selection period (six-month age) and bring the animals to the central place for selection to identify the best rams. A team of researchers and selection committee members have been involved in the selection process. Based on growth performance, estimated breeding value (EBV), and breeding objectives, the top 10% of rams have been selected. These rams were purchased by the cooperatives and used to mate ewes, with about 20–30 organized in a mating group under cooperative members.

SOURCES AND PROCEDURES OF DATA COLLECTION

Two sources of data were used for the study: primary and secondary. Primary data was captured through interviews, field observations, group discussions and monitoring animals from December 2021 to November 2022.

A semi-structured pre-tested questionnaire was prepared for the formal survey. One group with 8-12 members was organized for group discussion in each cooperative. The discussion was focused on farmers' perception towards the breeding program, lessons/knowledge acquired during the breeding program, sustainability and suitability of the program, flock management and problems encountered. Data focusing on-flock size and structure, keeping breeding ram and mating system, flock dynamics (incoming and exiting routes of sheep), biological changes such as growth, conformation, survival, litter size, and coat color that farmers have recognized. In addition, change on income from sheep and its contribution to livelihood, and constraints they have faced along with socio-economic characteristics were also collected through formal survey and used as a primary source. Recorded data (number of animal selected, sold animal number and price of selling, members of cooperatives) were obtained from the secondary source and other additional information collected from cooperative's receipts, invoices, record books and case histories. Among total sheep producers in the study site, a total of 260 sheep producer households were included in the study, from which 130 respondents were selected to represent 358 CBBP members while the rest, 130 respondents were selected from non-CBBP members by using the simple random sampling technique based on probability proportional, following Yamane's (1967) formula:

$$n = \frac{N}{1 + N(e)^2}$$

Where: n= sample size for the study; N= Total number of sheep producers (743) from selected sites and e is level of precision which was taken to be 5%.

$$n = \frac{743}{1 + 743 (0.05)^2} = 260.0$$

DATA ANALYSIS

The collected data were entered into an Excel sheet and checked before analysis. Statistical Analysis Software (SAS, 2012) was used for the analysis of the collected data. Descriptive statistics, including means, frequency, and percentile for flock size, flock dynamics, and benefits of sheep (trend of selected rams, CBBP member participation, income, and price of ram per kilogram weight), were conducted. Independent t-tests were carried out to compare quantitative variables, including flock size and structure, and income from sheep, between CBBP members and non-members. Indices were employed to calculate the traits improved through selection, to assess sustainability mechanisms, and constraints of Doyogena CBBP using method mentioned by Kosgey (2004). To obtain the sheep offtake rate, each parameter was calculated using the

methods employed by Shigdaf et al. (2012) and Deribe et al. (2021).

$$\text{offtake rate (\%)} = \frac{\text{sheep exit parameters}}{\text{total flock size of sampled respondents}} \times 100$$

Sheep exit parameters (routes of sheep leaving mechanisms from the flock) are sale, slaughter, gift and share-holding-out.

The Poisson regression model was employed to assess the factors influencing flock dynamics, and the income obtained from sheep. Socio-economic characteristics of the respondents, such as , gender, age, education, family size, , and farm land size, were hypothesized to positively or negatively influence the response variables (routes of sheep entry into and exit from the flock, and income) along with CBBP participation and flock size. The Poisson regression model was chosen for the analysis of count data due to its suitability. It can be estimated using the quasi-maximum likelihood approach and can address issues related to over-dispersion (Dubale and Yohannis, 2021; Verbeek, 2004). The model used for Poisson regression is as follows: $\text{Log}(y) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_6x_6 + \beta_7x_7$

Where log(y) is logarithm of predicated mean number of response variables (income, way of sheep entry to the flock and exit from the flock); y is the mean of the response variable, β_0 is intercept; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ and β_7 are the coefficients to be estimated. The coefficients represent the change in the logarithm of the expected value of the dependent variable for a one-unit change in each independent variable, holding other variables constant.

Independent variables are CBBP with levels participation level (1=member, 2= non-member), sex of respondent household head (1=male, 2=female), education (1=illiterate, 2= primary and above), age (in number), farm land size (in hectare), family size (in number), flock size (in number).

RESULTS AND DISCUSSION

FLOCK STRUCTURE AND DYNAMICS

Flock structure: The least-square means (SE) of sheep composition per household in the Doyogena district are presented in Table 1. Overall flock size per household in the Doyogena district was 3.84, ranging from 1-14 heads. The castrated sheep had the smallest percentage in the flock, with 1.3%, the higher proportion was recorded for breeding ewes (48.43%) followed by intact males aged 6 to 12 months (15.36%).

Male and female lambs aged 3-6 months made up 7.03% and 5.73% of the total, respectively. The mean number of

young lambs below 3 months of age, male lambs aged 3-6 months, intact male aged 6-12 months, female lambs aged 6-12 months, breeding rams, breeding ewes, and the number of lambs per household were higher ($p < 0.05$) in CBBP members compared to non-members.

The distribution of flock structure reflects the management choices made by producers, based on their production goals (Solomon et al., 2010). At the CBBP level, keeping fast-growing lambs has reduced lamb mortality while increasing litter sizes, resulting in significant improvements in flock structure and size (Haile et al., 2014; 2020). In the present study, the average flock size was lower than the values reported by Tibbo et al. (2006) for Bonga (11.3), Horro sheep (8.2), and that of Abebe (1999) for Menz sheep. However, it was comparable to that of Teye (2016), reported in the same study district. The shortage of land for grazing could be one of the reasons for the low flock size in the study area. Gutu et al. (2015) have reported that the flock size of sheep for CBBP member households was higher than non-member households for Bonga, Horro, and Menz sheep, which was similar to the current study. The higher proportion of breeding ewes in the flock is an opportunity for a high number of lamb productions and the need for sustainable household income in the study district. The finding is comparable to the findings reported by Luke (2010), Shenkute et al. (2010), Tasew et al. (2014), and Amare et al. (2019). According to the bylaw of the cooperatives every CBBP member is expected to keep at least two breeding ewes with a good maternal record for genetic improvement for the next generation.

The proportion of intact ram aged 6-12 months was higher than from all except breeding ewes. The reason could be in the CBBPs, keeping male lambs until selection is mandatory and which increase the possibility of getting best-performing animals to be parents for the next generation. In some cases, CBBP members keep selected lambs that were 2-6 months after selection until they get a better market. Retaining breeding ewes and keeping male lambs until selection would enhance selection intensity and improves genetic progress (Haile et al., 2020).

The breeding ram to ewes ration in the study site was 1:24, and farmers practiced year-round breeding with control mating. This practice is attributed to the presence of CBBP. Intensive selection of breeding rams, combined with the acquisition of knowledge by CBBP members through participatory training and direct program involvement, could positively contribute to the success. Our findings are consistent with a similar report by Asrat et al. (2021) for Bonga sheep (25 to 30 breeding ewes), and that the current study ratio is higher than that reported by Aynalem (2021) for Horro sheep (1 to 6.34) at the CBBP.

Flock dynamics and offtake rate: Table 2 shows the flock dynamics and offtake for the Doyogena district. In our study, we identified the major ways through which sheep enter and leave the flock in the study area. The primary methods of sheep entering flocks include the birth of lambs, gifts, shareholding-in (keeping animals for the benefit share obtained from those with a larger flock size), and purchases.

In the Doyogena district, both CBBP member and non-member households indicated that sheep entered flocks more frequently through birth (Table 2). Total entry was significantly affected by CBBP membership. Similarly, membership exerted significant difference only on birth and shareholding-in among routes of entry. In the study district, 352 lambs were born during the 12-month period from December 2021 to November 2022. Of all entries, birth accounted the highest proportion of entry, with 240 (84.51%) lambs for CBBP members and 112 (75.68%) lambs for non-members. Additionally, the cooperatives acquired 39 (13.73%), 4 (1.41%), and 1 (0.35%) through purchasing, shareholding and gift, respectively. Similarly, 36 (24.32%) were entered through purchases for non-members. Parallel to the current study, Kocho et al. (2011) and Deribe et al. (2014) reported that the primary route of entry for sheep in the Alaba zone of southern Ethiopia was birth. The authors' reports demonstrated that shareholding is an essential method of strengthening the flock within the sheep farming community, consistent with the present study.

The exit routes vary widely among members and non-members. CBBP members had significantly higher ($p < 0.05$) sheep exiting through sale, slaughter, and shareholding compared to non-members. Out of a 401 and 187 sheep flock, approximately 59% and 75% of sheep left the flock due to sale in CBBP member and non-CBBP member households, respectively. The reason of higher proportion of sheep sale in non-member is that there is no binding rule that can prevent early sales, which could be a potential reason for negative selection in the flock. On the other hand, the cooperative bylaw encourages producers to keep the best-performing animals. Animals with low performance have exited the flock through sale. Reports of other studies confirm that the sale was the major exit route for sheep in central Ethiopia (Legesse et al., 2008; Kocho et al., 2011).

Gift and shareholding as an exit route accounted for 7.9 and 1.49% for CBBP members, respectively, while it was minimal for non-members.

The overall off-take rate for Doyogena sheep was 53% (Table 2). The members of the CBBP in the study dis-

district exhibited a higher off-take rate at 36%, in contrast to non-cooperative members at 17%. This higher off-take rate in the breed improvement cooperative can be attributed to the strategic culling of unproductive animals, the implementation of fattening practices tailored for festivals, disseminating improved rams, and collaboration within the group leading to improved market opportunities. In contrast, non-participants tended to sale animals at younger ages, aligning with findings from Deribe et al. (2021) and Kocho et al. (2011), who noted that in Alaba district, sheep and goat keepers sold their animals before reaching breeding age. The off-take rate (53.8%) in this study is higher than other research endeavors. For instance, CSA (2020) reported an off-take rate of 30.8%, while Shigdaf et al. (2012) documented rates of 25.3% and 32.8% for sheep in Farta and Lay Giant districts, respectively. Furthermore, the percentage of sheep sales (18.7%) and slaughter (11.3%) reported by CSA (2020) was comparatively lower and consistent with our findings, respectively.

Factors affecting dynamics of sheep entry routes: The CBBP participation, sex of the household heads, and flock sizes were found to influence the sheep entry routes (Table 3). The study revealed that the participation in the CBBP significantly ($p < 0.01$) influenced the entry routes of sheep into households. Particularly, farmers engaged in the CBBP demonstrated a significant positive correlation with the birth of lambs, indicating that program participants experienced a 44% increase in the number of animals entering their flocks through birth compared to non-participants. This suggests that the CBBP plays a vital role in enhancing the reproductive outcomes within the sheep breeding cooperatives. Additionally, the study highlights the influence of flock sizes on sheep entry routes, showing that farmers with larger flocks are more likely ($p < 0.001$) to accept animals through birth, with a 21% higher tendency compared to those with smaller flocks. This finding shows the importance of flock size management in optimizing sheep breeding outcomes.

Furthermore, the study identified the sex of household heads as a determinant factor in sheep acquisition patterns. Specifically, households with male heads are less likely to accept animals as gifts or for shareholding. This observation may be attributed to cultural or gender-specific roles and preferences within the community. Additionally, the household heads those who have smaller family sizes are less inclined to purchase sheep, with a significant association to the scarcity of labor. This aligns with existing literature, such as reports by Legesse et al. (2008) and Budisatria et al. (2007), who indicated that labor shortages can be a limiting factor in small-scale livestock keeping, particularly in contexts where family members are essential contributors to farming activities.

Factors affecting dynamics of sheep exit and offtake rate:

As shown in Table 4, CBBP participation, gender, age, land size, and flock size of the households were shown to influence the offtake and sheep exit routes. Sheep exit through sale, slaughter, gift, and shareholding-out was significantly ($p < 0.05$) affected by CBBP participation. The animal exits through sale in the CBBP members were significantly ($P < 0.01$) higher and 1.52 times more than non-members. This might be associated with the higher number of sheep produced through birth for the CBBP member households due to the use of different production packages and the existence of breeding cooperatives (Rekik et al., 2016; Esayas and Jane, 2019; Jane, 2019). This ensures better market participation of CBBP members than non-members. Similarly, the number of animals slaughtered for household consumption was also higher ($p < 0.001$) for CBBP members.

The number of slaughtered animals within a year in CBBP members was 2.4 times higher than that in non-members. This result aligns with previous findings by Gutu et al. (2015) and Haile et al. (2020), who reported changes in the number of sheep sold per year and the consumption of mutton as a result of CBBP membership compared to non-CBBP members for Bonga, Horro, and Menz sheep in CBBP sites. The CBBP participation significantly influenced the probability of sheep exit through shareholding and gifting ($p < 0.01$). This could be attributed to the larger flock size of CBBP members. In Doyogena CBBP, the CBBP members provided for other members of CBBP, particularly those with a small number of sheep for shareholding. This might be advantage to keep better-performing animals in breeding cooperative. Shortage of labor and feed could be the reason for animal exit through shareholding.

The gender of the head of the household exerted a favorable influence on animal sales, with males showing a significantly higher tendency to sale animals compared to households led by women ($p < 0.001$). This aligns with the findings of Ashenaf et al. (2013), who reported that women are primarily responsible for managing tasks such as feeding, herding, and cleaning, while males take on the role of decision-makers in terms of purchasing and selling sheep. Households led by women frequently accept animals instead of selling them, driven by financial difficulties. Debesa (2020) reported that poor market participation, limited technical skill and financial resources affect the role of women compared to men in small ruminant value chain, which is agree with this study.

Table 1: Least square means (SE) of flock size and percentage of flock structure at CBBP member and non-member.

Sheep flock composition	CBBP member		Non-member		Overall		P-value
	N=130	%	N=130	%	N=260	%	
Lambs below 3 months	0.62 ±0.09	13.37	0.28±0.05	9.3	0.45±0.07	11.72	0.001
Male lambs between 3-6 Mths	0.460 ±0.07	9.85	0.24±0.05	8	0.27±0.06	7.03	0.01
Female lambs between 3-6 Mths	0.25 ±0.05	5.35	0.18±0.04	6	0.22±0.05	5.73	0.319
Female lambs between 6-12 Mths	0.23 ±0.048	4.93	0.12±0.04	4	0.18±0.04	4.9	0.0001
Male lambs between 6-12Mths	0.81 ±0.09	17.34	0.38±0.05	12.1	0.59±0.07	15.4	0.0001
Breeding rams	0.11±0.03	2.36	0.05±0.02	1.6	0.08±0.03	2.9	0.02
Breeding ewes	2.03 ±0.08	43.47	1.68±0.05	56	1.86±0.07	48.44	0.003
Castrated	0.07±0.027	1.49	0.02±0.01	0.6	0.05±0.02	1.32	0.128
Fattened	0.09±0.04	1.93	0.04±0.02	1.3	0.07±0.03	1.82	0.187
Overall flock size	4.67 ±0.20		3.0 ±0.08		3.84±0.14		0.0001

N =number of respondents; Mths=months

Table 2: The proportion of dynamics and offtake rate of sheep flock (%) in CBBP membership.

Parameter	CBBP-member		Non-member		Overall		χ ²
	N=130	%	N=130	%	N=260	%	
Incoming reason							
Birth	240	84.51	112	75.68	352	81.48	29.893***
Gift-in	1	0.35	0	0.00	1	0.23	1.004
Shareholding-in	4	1.41	0	0.00	4	0.93	4.062*
Purchase	39	13.73	36	24.32	75	17.36	7.00
Total entry	284	100	148	100	432	100	30.267***
Exiting reason							
Death	40	9.97	16	8.56	56	9.52	7.028
Sale	238	59.35	140	74.87	378	64.29	31.64***
Slaughter	83	20.7	28	14.97	111	18.88	23.0***
Predator	2	0.5	-	-	2	0.34	2
Gift-out	6	1.49	-	-	6	1.02	6
Shareholding out	32	7.98	3	1.6	35	5.95	12.5*
Total exit	401	100	187	100	588	100	41.12***
Offtake-rate	359	35.97	171	17.13	530	53.1	42.78***

N=number of animals, *, ** and *** the proportion of dynamics b/n CBBP level significant at p <0.05, p<0.01 and p<0.001 respectively.

Table 3: Coefficients (standard errors) and exponential values of Poisson regression for factors contributing sheep entry routes in Doyogena district.

Factors	Birth		Purchase		Gift and shareholding in	
	Coef.(SE)	Exp(B)	Coef.(SE)	Exp(B)	Coef.(SE)	Exp(B)
CBBP participation	0.363(0.13)**	1.44	0.021(0.26)	1.02	-	
Gender	0.052(0.12)	1.05	-0.318(0.25)	0.73	-1.743(1.03)*	0.17
Family size	0.002(0.02)	1.00	-0.083(0.05)*	0.92	-0.249(0.24)	0.78
Flock size	0.187(0.23)***	1.21	0.058(0.06)	1.06	-0.213(0.27)	0.81
Log likelihood	-372.454		-193.019		-18.520	
Chi- square	114.891		6.676		12.433	

*, ** and *** mean coefficient significant at the level of p <0.05, p<0.01 and p<0.001 respectively

Sales were significantly and negatively affected by the respondents' ages. This demonstrates that younger individuals are more involved in the production of sheep and sale than the older household head, and it offers young farmers looking for work the chance to take part in sheep breeding. This in line with Ayele et al. (2003), who got negative association between age of households and beef cattle market participation. However, it contrasts the finding of Dubale and Yohannis (2020), who found that the older people were more enthusiastic to participate in sheep market than the younger people. As a result, they sell more number of sheep in the market.

The farmers who have larger farm land size had ($p < 0.01$) higher (1.66 times more) number of animals sale than who have smaller land size. Farm land size also significantly ($p < 0.01$) affected the probability of sheep exiting through death. The study confirm that the report indicated by Terfa (2012), who reported that the number of sheep owned significantly and positively affected the intensity of sheep market participation.

The household with a small land size manages their animals by practice tethering in roadside and land-demarcated areas most of the year. The feed shortages in the dry season and drought period are the main reasons of sheep exit through death (Addis, 2015; Habite et al., 2019). The influence of flock size was positive on the sale of animals, slaughter, death, and shareholding-out. Farmers with a larger flock size tended to sale a greater number ($p < 0.001$) of animals and likewise had a higher ($p < 0.001$) probability of slaughtering sheep for home consumption. This agrees with the finding reported by Mapiliyao et al. (2012).

FARMERS' PERCEPTION ON BENEFITS OF DOYOGENA SHEEP CBBP

Trend of Doyogena CBBP and socio economic benefits
 The Doyogena Community-Based Breeding Program (CBBP) has shown significant enhancements in various key indicators between 2014 and 2022. These findings collectively indicate positive trends and progress in the Doyogena CBBP. The growth in the number of selected rams (from 56 to 357; Figure 1) and participants (from 35 to 276; Figure 2) shows increasing engagement and interest in the program. The substantial increase in income, from ETB 474,000 (USD 24,126.60) to ETB 3,398,203 (USD 70,958.51) through ram sales (Figure 3), along with the rise in the price per kilogram of live weight (increasing from 70 to 180; Figure 4), further underscores the economic success and viability of the program throughout the studied period. These improvements underscore the positive influence of the Doyogena CBBP on the local economy and the livelihoods of program participants.

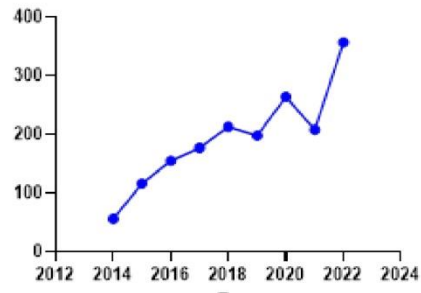


Figure 1: Number of breeding ram disseminated

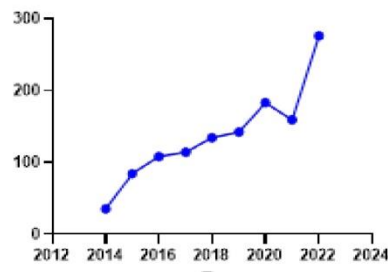


Figure 2: Number of CBBP participants

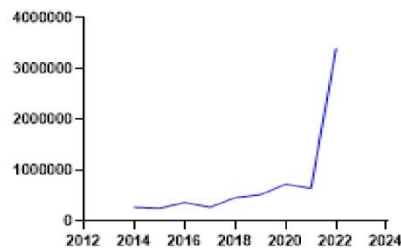


Figure 3: Trend of sheep income across year

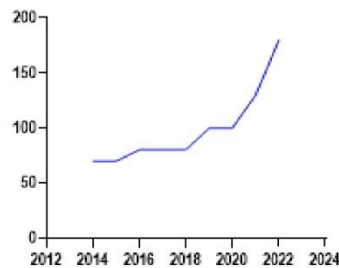


Figure 4: Trend of Price of sheep per kg live weight
 Note: At the study period (2022) 1USD = 47.89 ETB and at year of 2014 1USD = 19.65ETB

From the total candidate rams, 20% were selected for genetic improvement, with the top 10% reserved for serving

ewes of the members and the remaining 10% distributed for genetic improvement outside the CBBP sites. A comparable trend to the current study in various production systems and sheep breeds at the CBBP was reported (Gutu et al., 2015; Haile et al., 2020; Arab et al., 2021; Asrat et al., 2021).

The higher ($p < 0.038$) number of participants providing breeding rams to the community every year might have contributed to producing more lamb crops through birth, which is vital for genetic improvement in a progressive manner and ensures the participation of members. The CBBP ensures better participation of smallholder farmers in the breed improvement process and rewards them with better benefits (Merkina et al., 2012; Haile et al., 2018; Getachew et al., 2020). The number of CBBP households participating in the scheme has increased from 35 in the year 2014 to 276 in the year 2022. This might be due to the awareness level of farmers because of the multi-stockholder participation on various activities in the CBBP site. According to Markina et al. (2012), a large number of animal owners and increased participants contributed to the success of the program. Moreover, an increase in the membership of CBBP over time was due to improved benefits and the attraction of the scheme (Bhuiyan et al., 2017; Kaumbata et al., 2021; Wurzinger et al., 2021). Similarly, Gutu et al. (2015) and Arab et al. (2021) observed that the number of participant farmers in different CBBPs in Ethiopia showed increasing trends.

Breeding ram's price was set on weight basis by the CBBP committee members. The price of one-kilogram live weight of elite ram was sold at a prize of ETB 70 in 2014 while it increased ($p < 0.01$) to ETB 180 in 2022. A total income obtained by the sale of breeding rams was increased considerably ($p < 0.019$) from 474,000 ETB (24,126.6 USD) in the year 2014 to 3,398,203 ETB (70,958.51 USD) in 2022 (Figure 4). Each participant farmer earned an aver-

age of 7,728 to 12,312 ETB annually. The increment of income from the sale of breeding ram was because of the increase of farmers' participation providing breeding rams and strategy of community based breed improvement program. In concurrent to the present study, Haile et al. (2023) reported an increase of 20% on average in the previously established CBBP on Horro, Menz and Bonga sheep since 2009.

Factors affecting annual income: Factors affecting the annual income obtained from sheep sales are indicated in Table 5. Income for CBBP members was positive and significantly ($p < 0.001$) higher (over 48%) than that of non-CBBP member households. This might be due to the consecutive training offered for CBBP participant households on the breed improvement program and flock performance improvement, which have ensured better market participation in selling elite rams and culling nonproductive animals among member farmers than non-members. The findings reported by Kassa et al. (2021) and Areb et al. (2021) for Bonga sheep; Gutu et al. (2015) for Bonga, Horro, and Menz sheep; and Haile et al. (2020) for Bonga and Menz sheep breeding finds similarity with the current study.

The gender of the household head had a positive influence on the yearly income generated from sheep ($p < 0.001$). This implies that male household heads sell 1.03 times higher number of animals than female household head.

Respondents with lower educational level (illiterate) generated lower income from sale of sheep than those who had attended primary school and above. This due to education improves the knowledge of sheep producers to involve breed improvement activity and sale more number of animals. Kassa et al. (2021) and Areb et al. (2021), for Bonga sheep for breeding reported parallel with our findings.

Table 4: Coefficients (SE) and exponential values of Poisson regression for factors contributing sheep exit routes from the flock in Doyogena district.

Factors	Response variables							
	Sale		Slaughter		Death		shareholding out	
	Coef.(SE)	Exp(B)	Coef.(SE)	Exp(B)	Coef.(SE)	Exp(B)	Coef.(SE)	Exp(B)
CBBP	0.417(0.12)**	1.52	0.858(0.24)***	2.358	0.37(0.34)	1.449	1.863(0.64)**	6.443
Gender	0.277(0.02)*	1.32	-0.114(0.21)	0.892	-0.665(0.30)	0.514	0.266(0.43)	1.305
Age	-0.019(0.01)**	0.98	-0.001(0.01)	0.999	0.002(0.01)	1.002	-0.016(0.02)	0.984
Land size	0.508(0.18)**	1.66	0.015(0.38)	1.015	0.984(0.46)*	2.675	-1.175(0.87)	0.309
Flock size	0.073(0.03)**	1.08	0.133(0.42)***	1.142	0.173(0.06)**	1.189	0.251(0.07)**	1.285
Log likelihood	-395.676		-208.089		-136.150		-84.800	
Chi- square	64.421		39.437		25.479		39.878	

*, ** and *** mean coefficient significant at the level of $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively

Table 5: Factors influencing the annual income generated from sheep sale.

Parameter	Coefficient	Std. Error	Exp(B)	P-value
CBBP participation level	0.391	0.0022	1.48	0.000
Gender of household head	0.026	0.0022	1.03	0.001
Education				
Illiterate	0.016	0.0027	1.016	0.001
Primary school	0.018	0.0023	1.018	0.000
Age of respondents	-0.010	0.0001	0.99	0.024
Family size	0.020	0.0004	0.98	0.002
Land size	0.222	0.0033	1.25	0.000
Flock size	0.059	0.0004	1.06	0.000
Log likelihood		-292827.756		
Log likelihood ratio chi- square		98407.947		

Table 6: Contribution of income obtained from sheep (ETB) on the livelihoods of CBBP and non CBBP member.

Sheep income contribution	Mean ± SD				P-value
	N	Member	N	Non-member	
School fee and input	62	1518.2±1259	29	1396.6±1462.7	0.645
Fertilizer for crop production	58	1763.6±1278.4	38	1765.6 ±1446.2	0.606
Improved crop seed	48	1443.8±1081.9	28	2204.3± 1446.4	0.560
House building and maintenance	25	6743.2±5443	16	2596.9±2471.4	0.001
Family cloth	59	1821.4±1317.9	33	1607.9 ± 1019.8	0.425
For home consumption (variety of diet)	50	4309.6±7114.7	29	1679.3± 1635.38	0.040

N= number of respondents

Table 7: Traits improved due to selection in the CBBP of Doyogena sheep improvement program.

Traits improved	Respondent rank						Index	Rank
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6		
Growth	46	40	26	8	5	5	0.2183	1
Color	24	24	18	20	20	21	0.2065	2
Litter size	21	17	19	40	19	11	0.1613	3
Body size	13	25	27	18	23	19	0.1521	4
Survival	18	13	14	25	24	30	0.1454	5
Lambing-interval	7	9	25	13	33	37	0.1164	6

Table 8: Sustainability mechanism of Doyogena CBBP mentioned by members.

Mechanism	Rank1	Rank2	Rank3	Index	Rank
Promoting cooperatives to Union	71	10	27	0.403	1
Creating credit access from micro-finance	19	48	40	0.299	2
Engaging multi stakeholders to the program	20	47	38	0.298	3

Farm land size of the household had significant ($p < 0.0001$) influence on income, and the household head with larger land size generated 1.25 times more income than those having smaller land size. This is because of households with large land size keep large number of animals, subsequently more number of animal offers to sale. The number of sheep in the household's flock has a significant ($p < 0.0001$) and positive effect on the annual income generated from sheep

sales.

SHEEP INCOME CONTRIBUTION ON THE LIVELIHOOD OF THE FARMERS

In the study district, both groups of farmers (CBBP members and non-members) obtained income from sheep, enabling them to spend more on their basic needs and assets, including school expenses for their children, fertilizer and

improved crop seed purchase, house building and maintenance, family cloth, and diet diversification. CBBP participants made significant contributions ($P < 0.05$) to their livelihoods through income obtained from sheep sales (Table 6). For instance, they constructed new house and maintained existing ones for their families. They also used the money to buy dairy cows, providing animal-driven nutrition for family members and enabling slaughtering for home consumption. A report by *Kebede et al. (2022)* indicated that in the some districts of this study, farmers participating in CBBP benefited from sheep income, allowing them to provide a varied diet for their families and construct houses for both themselves and their animals. In the Alaba zone, farmers used the income obtained from the sale of small ruminants to purchase inputs for crop production, cloth, and the family's diet, as well as to cover educational expenses for the children (*Deribe et al., 2021*), which is similar to the findings of this study.

TRAITS IMPROVED DUE TO CBBP INTERVENTIONS

Traits improved due to selection in the CBBP site for Doyogena sheep are shown in Table 7. All respondents among CBBP members perceived that improvements were made in their sheep flock, with the largest impact seen in the growth performance of their sheep (1st). This was followed by improvements in coat color (2nd), litter-size (3rd), body size (4th), survival (5th), and lambing interval (6th).

The majority of respondents indicated that the coat color (light red and dark red) of the sheep was mentioned among improved trait due to the genetic improvement program. This improvement resulted in fetching a better price when selling the sheep due to the buyers' preference for the specific color. These findings align with those of *Areb et al. (2021)*, who reported that growth and coat color were the most important traits for the CBBP of Bonga sheep. Coat color is among the most influential factors determining sheep prices in the Bonga CBBP (*Kassa et al., 2021*) and sheep in the highland of northern Ethiopia (*Beneberu et al., 2011*). In many Ethiopian livestock markets, the color of live animals sold for slaughter plays a significant role due to various cultural and traditional beliefs. The improvement of litter size of Doyogena sheep of the current study in line with the finding, *Gutu et al. (2015)* reported that a percentage of CBBP members in Bonga (72.5%) and Horro (65%) mostly reported twin births in their ewes. The improvement in litter size may be associated with the selection favoring the trait responsible for multiple births. The enhancement of performance traits, as a result of the best ram selection, controlled mating practices integrated with feeding, and health intervention activities, could be the reason (*Mirkena et al., 2012*) and (*Weldemariam et al., 2020*). Moreover, reported evidence indicated that appropriate selection improved performance on growth rate,

lambing interval and reduced mortality in all communities of Eastern and Southern Africa (*Haile et al., 2023*). Hence, selection of elite animals brought improvement on most economical important traits and coat color of the animals.

SUSTAINABILITY MECHANISM OF DOYOGENA CBBP

Sustainability options of Doyogena sheep presented in Table 8. To maintain the sustainability of Doyogena CBBP, promoting cooperatives to form unions was the best course of action as reported by the respondents. This was closely followed by equally valuable responses such as setting up a credit facility and interacting with many stakeholders. The study showed that farmers understood working with cooperative or group is acceptable and improves their livelihoods. Community based breeding program is an important tool for effective utilization of genetic resources. Hence, strengthening the breeding cooperatives and promoting the cooperative to union may help to get more credit access, ensure market participation at domestic and international level, improve bargaining power and develop strong stakeholder integration. Other scholars mentioned additional sustainability mechanisms for different CBBPs (*Merкина, 2010; Muller et al., 2015; Haile et al., 2018, 2019*).

CONSTRAINTS AFFECTING DOYOGENA CBBP

Major constraints encountered by the members of the Doyogena CBBP are presented in Table 9. The major constraints mentioned were audit delaying (Index=0.175), the gap in keeping cooperative bylaw (Index=0.15), lack of trust in CBBP leaders (Index=0.139), lack of market demand for higher weighing rams (I=0.1389), aggressiveness of the breeding rams (Index=0.1134), lack of credit access (Index=0.1061), concentrate feed shortage (Index=0.093), and disease (0.0817).

The delay in auditing poses a significant challenge across all breeding cooperatives. In the CBBP, member farmers have the right to receive the results of cooperative audits on a yearly basis and benefit from the profits. Seed money for revolving purposes was provided to all cooperatives during the implementation period. At the beginning cooperative formation, every participant paid a membership fee and share. Farmers pay a 100 birr margin per animal when they sale the selected rams to and out of the community for breeding.

However, in some cooperatives, members were unaware of their cooperative's financial progress over the last five to six years. The timely replacement of CBBP leaders by a new committee and the lack of interest from the worda cooperative office in inspecting and auditing periodically were the main problems. The cooperative bylaws formulated during the establishment of CBBP were accepted by all

Table 9: Major challenges of Doyogena sheep reported by CBBP members.

Constraints	R1	R2	R3	R4	R5	R6	R7	R8	Index	Rank
Delay auditing	38	30	22	13	10	9	6	2	0.1754	1
Gap on keeping bylaw	19	25	22	20	17	14	6	5	0.152	2
Lack of trusts on CBBP leader	16	17	19	24	20	15	10	4	0.1395	3
Lack of market demand	15	23	19	20	19	11	8	7	0.1389	4
Aggressiveness of breeding ram	13	13	12	16	17	17	13	20	0.1134	5
Lack of credit access	10	9	17	14	16	15	19	17	0.1061	6
Concentrate feed shortage	10	7	9	12	11	21	25	20	0.093	7
Disease	9	6	8	6	12	18	23	29	0.0817	8

participants and CBBP leaders to govern their breed improvement cooperative under the rule of the bylaws. However, the rules were not fully respected by the members of the CBBP. Some members do not follow to breeding ewe guidelines, cooperative leaders assigned by members are not trusted, and early selling of breeding rams and a shortage of concentrate feed are key bottlenecks in all Doyogena CBBP sites. The constraints mentioned by CBBP members across breeding cooperatives are nearly similar. The results were likely similar to those reported by Areb et al. (2021) for Bonga sheep and Gutu et al. (2015) for Bonga, Menz, and Horro CBBP.

Creating strong link among stakeholders for timely audits and extension support, improving communication channels between cooperative leaders and members to increase awareness of financial progress and decisions affecting the cooperative, provide training and support for cooperative leaders to ensure smooth transitions and effective leadership and arrange awareness creation meeting. By addressing these issues, Doyogena CBBP cooperatives can enhance their efficiency, transparency, and overall success in achieving their breeding objectives.

CONCLUSION

The CBBP participants working with group in the district generally confirmed the effectiveness, acceptability, and suitability of the breed improvement program. Sheep income contributed significantly to the improvement of the livelihood of farmers, especially for house building and providing food for their households. The CBBP participants had comparatively higher flock size, number of lambs born, and income from the sale of animals, and slaughter for home consumption compared to non-CBBP participants. The CBBP members perceived improvements in growth, coat color, litter size, lamb survival, and lambing interval. The number of selected rams, participant farmers, number of animals sold, and income have shown an increasing trend since the establishment of CBBP. However, the study identified several constraints in the Doyogena CBBP, including audit delays, gaps in bylaw compliance, a

lack of trust in CBBP members and committees, and the aggressiveness of breeding rams. To ensure sustainable genetic improvement and effective utilization of resources, efforts should focus on improving stakeholder integration, advancing breeding cooperatives to a union level, and creating awareness among farmers. By involving more farmers in the CBBP and implementing genetic improvement programs, there is a great potential to increase farmers' income in the Doyogena sheep CBBP and beyond.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

NOVELTY STATEMENT

We declare that this article is our original work and that we have duly acknowledged all sources of material used in this study.

AUTHOR CONTRIBUTIONS

Idea and research protocol: Addisu Jimma, Aynalem Haile, Aberra Melesse, and Tesfaye Getachew
 Data collection, analyzing, writing the original draft and revising the final: Addisu Jimma
 Checking statistical analysis, reviewing, and editing: All authors
 Approved the final paper: All authors.

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Paper III. Devising up and out-scaling options for Doyogena sheep community-based breeding programs in Central Ethiopia

Addisu Jimma^{1,2}, Aberra Melesse², Aynalem Haile³, Tesfaye Getachew³ & Joaquin Mueller⁴

Areka Agricultural Research Centre, P.O. Box 79, Areka, Ethiopia¹

School of Animal and Range Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia²

International Center for Agricultural Research in the Dry Areas, P.O. Box 5689, Addis Ababa, Ethiopia³

National Institute for Agricultural Technology (INTA), P.O. Box 277, Bariloche, Argentina⁴

Abstract

This study devised scaling options for the Doyogena Community-Based Breeding Programs (CBBPs). The proposed strategies were: 1, Current CBBP practice. 2. Retain all candidate animals and increase the number of breeding females per CBBP to enhance improved ram selection, 3. The same as Strategy 2 but maintain the current selection proportion of rams to increase the number of improved rams disseminated per CBBP, 4. A mix of artificial insemination (AI) and natural mating based on strategy 2, 5. A mix of AI and natural mating based on strategy 3. Genetic progress and economic returns for Doyogena sheep were calculated using the gene flow method, based on field and market data. The analysis assumed a two-tier breeding program structure consisting of a nucleus flock and the surrounding production flocks. The six-month weight (SMW) served as both the breeding objective and the selection criterion. Among the strategies, Strategy 3 showed the highest return on investment (ROI) at the production unit (\$122), while Strategy 5 showed the highest ROI in the nucleus unit (\$8.5). Strategy 5 achieved the highest accumulated discounted benefits in both the nucleus (\$62,847) and base units (\$353,757). The highest genetic progress at the nucleus level was achieved in strategy 4 (27.88 kg), where a proportion of sires were produced through AI. Strategy 2 and 5 also outperformed the baseline Strategy 1 in trait levels, indicating that increasing the number of breeding females and retaining all candidates has a positive effect. However, strategy 3, despite not achieving the highest genetic gains, delivered a competitive nucleus trait level (26.00 kg) while maximizing dissemination, leading to exceptional economic outcomes. The AI-based strategies 4 and 5 produced higher trait levels, but their economic returns varied. Strategy 4's high genetic progress did not translate into the highest ROI, partly due to increased AI costs. The strategy integration with AI can accelerate genetic progress, optimal economic outcomes depend on effective candidate retention, dissemination strategies, and aligning breeding models with operational capacity. Policymakers and practitioners should tailor adoption strategies to their specific genetic improvement targets, financial constraints, and infrastructural readiness to ensure that both genetic and economic goals are met sustainably.

1. Introduction

In Ethiopia, small ruminant production plays a substantial role in supporting the livelihoods of smallholder farmers (Lemma, 2014). Enhancing productivity through improved management, healthcare, and genetic advancement is critical for raising the living standards of producers, as emphasized by Shapiro et al. (2015). One of the most effective and context appropriate approaches for livestock genetic improvement in smallholder systems is the Community-Based Breeding Program (CBBP) (Gutu et al., 2015; Haile et al., 2019). In many developing countries, CBBPs have emerged as a practical and sustainable strategy, particularly among smallholder farmers managing indigenous small ruminant breeds (Mueller et al., 2015). These programs empower communities to lead selective breeding efforts, ensuring genetic improvement while maintaining adaptation traits critical for resilience and productivity in low-input systems.

Community-Based Breeding Programs (CBBPs) were introduced in Ethiopia in 2009, targeting four indigenous sheep breeds including Bonga, Menz, Afar, and Horro across diverse agro-ecologies (Haile et al., 2019). Designed to enhance flock productivity, these programs combine selective breeding, improved nutrition, and strengthened animal health services. A core feature of CBBPs is their integration of scientific methods with farmers' indigenous knowledge. Farmers, organized in cooperatives, collectively identify priority traits and participate in the selection process, using both estimated breeding values and visual appraisal by elected selection committees (Gutu et al., 2015; Haile et al., 2018). With technical support from researchers, communities also establish local recording systems to track performance data, enabling participatory and evidence-based flock management. This strong collaboration between scientists and smallholder farmers is central to the success of CBBPs, as documented in practical guidelines (Haile et al., 2018) and evaluations across developing countries (Mueller et al., 2015).

The Doyogena sheep breed improvement program, initiated in 2013, was established after the initial cohort of CBBPs and has since become one of the most successful and well progressing programs in the country. The preliminary evaluation of the programs show that farmers increased breeding awareness by keeping fast-growing animals for breeding and culling unproductive or inferior ones for slaughter which minimized unwanted mating. In addition, farmers have started keeping sheep as the main source of income and selling selected rams with better price (Jimma et al., 2024). Improvements were observed in growth performance traits such as birth, weaning and six-month weight (Habtegiorgis et al., 2020; Jimma et al., 2021). The encouraging performance of Doyogena sheep CBBPs started attracting various institutions to work with small ruminants (Abebe et al., 2018). The program has also triggered a significant demand for improved rams from neighboring communities and institutions seeking quality genetics. While the CBBP in Doyogena has served as a successful pilot dedicated to producing improved genotype, expanding its reach by linking with Production Units (PUs) and addressing the broader Doyogena sheep population is essential to maximize genetic impact and ensure breed-wide improvement.

According to CSA (2022), Doyogena (Adilo) sheep were estimated at 280,474; with about 57% being breeding females and found in Kembata and adjacent zones of central Ethiopia. To expand the reach and impact of ongoing genetic improvement efforts, the Ministry of Agriculture (MoA), has launched two key strategic documents: the National Red Meat Strategy and the CBBP Scaling Manual (MoA, 2024a; MoA, 2024b). These documents provide a national roadmap for scaling CBBPs, aiming to strengthen institutional coordination, enhance genetic gains, and improve the livelihoods of smallholder sheep and goat producers across the country. This initiative creates an opportunity to increase productivity, maximize benefits, ensure sustainable breed improvement techniques, and enhance livestock genetic quality. Small

ruminant producers will have better access to improved genotypes and healthier animals through the expansion of breed improvement initiatives.

Despite the success of the Doyogena CBBP in demonstrating measurable genetic improvement and economic benefits, its contribution remains limited in scale relative to the broader Doyogena sheep population. Currently, improved rams produced by the program are insufficient to meet the growing demand from production units and surrounding communities. Moreover, the program lacks a systematic strategy for scaling up ram supply or replicating the model in other potential areas. There has been little empirical analysis of alternative scaling pathways, particularly in terms of their genetic and economic trade-offs. This gap necessitated a closer examination of feasible up- and out-scaling options such as using current CBBP, increased breeding ewes per CBBPs, increasing number of rams per CBBP for production unit, and combined strategy (using AI and natural mating) evaluated through economic and genetic impacts. The study was thus designed to identify technically sound and economically viable strategies for expanding the reach and impact of CBBPs beyond their current boundaries.

2. Material and Methods

2.1. Target breed and current Doyogena CBBP potential

The community-based Doyogena sheep breed improvement program was established in 2013 by ICARDA in collaboration with Areka Agricultural Research Center in Doyogena district former Kembata Tembaro (current Kembata) zone of Southern nation nationality people

region(SNNPR) (current Central Ethiopia region).

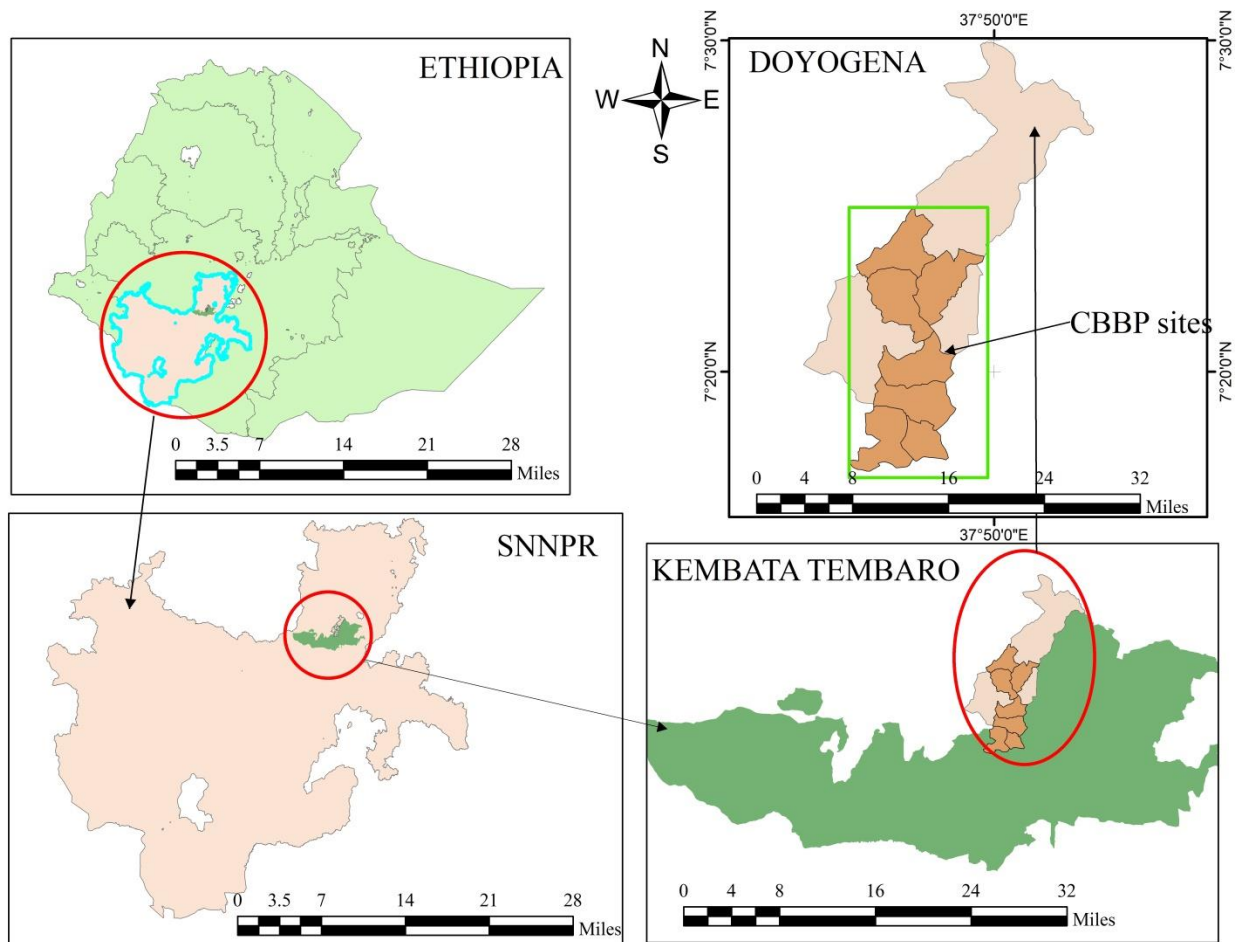


Figure 1. Map of study sites

The Doyogena sheep (formerly known as Adilo) breed is one of the thick and long fat-tailed sheep types in the country. The breed is relatively large in size, with twinning being common, and it possesses various coat colors. It is distributed across mid- to high-altitude regions within mixed crop and livestock production systems in the Central Ethiopia Region. Hadiya, Kembata, and Halaba zones are the main distribution areas for Doyogena sheep. Average household flock size is 4.0 head (Taye et al., 2016, Jimma et al., 2024), collectively distributed across 70,118 targeted households in the production unit. According to CSA (2022), the breeding females constituted approximately 57% (**160,294**) of the total population. For breed improvement, 5,343

improved rams are required, assuming a mating ratio of 30 ewes per ram. Under the prevailing production system where rams are utilized for a maximum of two years mating service with a 95% annual survival rate, then $5343 / (1+0.95) = 2,740$ improved young breeding rams (rR) would be needed annually to replace old rams following the more general formula of Mueller et al. (2018).

2.2. Current Doyogena CBBP potential

As of April 2025, there were eight ongoing CBBPs in Doyogena district (Figure 1). Each CBBP involved 180 households managing 841 sheep, including 378 breeding ewes. Key parameters are shown in Table 1: Manuscript III. With 1.86 a reproduction rate at SMW to be expected to produce a total of approximately 351 male candidates for selection. However, only 223 are available at the time of selection of which 75 selected for breeding, as the remainders are sold before selection (Table 1).

Table 1. Current potential of Doyogena CBBP

Parameters	Current Potential	Source
Number of CBBPs	8	
Average number of breeding ewes (E)	378	
Conception rate (CR)	0.90	Field information
Litter size (LS)	1.54	Jimma et al., 2025
Mating ratio (females/male) (MR)	30	Current practice
Lambing interval (days) (LI)	258	Jimma et al., 2025
Lambing frequency per year (LF)	1.41	365/LI
Number of lambs born per year (LB)	738.71	$E*LF*CR*LS$
Male lamb proportion (MP)	0.50	Field information
Number of male lambs born (MB)	369.36	$LB*MP$
Ram service years (RSY)	2	From ongoing Doyogena CBBPs

Average number of breeding rams(M)	12.6	E/MR
Ram survival proportion per year (YSP)	0.95	Field information
Average number of replacement ram needed per year in a CBBP (rR)	6.46	$M / (1+YSP)$
Survival until selection (SS)	0.95	Jimma et al., 2025
Annual reproductive rate on SMW (ARR)	1.86	$LF*CR*SS*LS$
Number of lambs at measurement per year (LM)	350.89	$MB*SS$
Proportion of lambs attain until selection(pU)	0.635	Field information
Number of lambs at selection per year (Ls)	223.	$LM*(pU)$
Proportion of selected rams on measurement (pM)	0.41	Best EBV
Selected based on measurement (SM)	83.4	$Ls*pM$
Proportion of selection based on physical (pA)	0.90	Practice in Doyogena CBBP
Number of breeding rams selected (S)	75.1	$SM*pA$
Rams ready for production unit	69	$S-rR$

2.3. Increase breeding ewes per CBBP

A challenge observed in the Doyogena CBBP is that some members do not follow cooperative bylaws mandating the keeping of at least two breeding ewes per farmer (Jimma et al., 2024). This significantly impacts the rate of return and genetic progress. To address this, we evaluated an option to increase the number of breeding ewes per CBBP by 50%, raising the total to 534 to enhance the production of improved rams (Table 2: Manuscript III).

From 534 breeding ewes per CBBP were produced 169 breeding rams out of them 160 for production unit with similar selection procedures and proportion with the current CBBP. To generate a surplus of improved rams, two adjustments could enhance supply and adoption: encouraging farmers to keep all male lambs until selection by avoiding early selling and castration, and by increasing the proportion of visually acceptable rams from 90% to 95%.

Table 2. Increased breeding ewes per CBBP

Parameters	Increased number of ewes	Increased number of ram	Source
Average number of breeding ewes per CBBp (E)	534	534	
Number of lambs at measurement per year (LM)	496.62	496.62	534x1.86x0.5
Proportion of lambs attain at selection	99%	100%	
Number of lambs at selection per year (Ls)	491.65	496.62	
Proportion of selected rams on measurement (pM)	0.17	0.36	Best EBV
Selected based on measurement (SM)	83.58	178.7	Ls*pM
Proportion of selection based on physical (pA)	0.90	0.95	Increased for ram production from 67 to 95%
Number of breeding rams selected (S)	75 0.	169	SM*pA
Rams ready for production unit	66	160	S-rR
Number of CBBP needed		17	2740/160
Additional CBBP needed		9	17-8(current CBBP)

These changes would increase the number of young breeding rams available per CBBP and expand their utilization in production units (Table 2: Manuscript III).

2.4. Scaling strategies

The scaling strategies are structured into two tiers, involving the sheep CBBP as a nucleus and the surrounding flocks as the base population or production unit. The current CBBP practice as reference was used to model the five strategies: 1) Current CBBP practice, 2. Retain all candidates plus increase breeding females per CBBP to enhance improved ram selection (0.15), 3) The same as strategy 2 but keep current selection proportion of ram (0.34) to increase more number of improved rams per CBBP, 4. Mix of AI and natural mating based on Model 2. 5. Mix of AI and natural mating based on strategy 3 (Table 3: Manuscript III).

Table 3. Scaling strategies analyzed

Model	Main Change	Breeding Females	Selection Proportion	Key Distinction
1	Current practice	378	0.34	Many candidates sold before selection
2	Retain all candidates + increase breeding females	534	0.15	Larger female base, more male candidates
3	Same as Model 2 but keep current selection proportion	534	0.34	Higher dissemination of rams
4	AI + NM (based on Model 2)	534	0.15	Mix of AI and natural mating, AI produces 60% of breeding sires
5	AI + NM (based on Model 3)	534	0.34	Higher dissemination with AI/NM combination

2.5. Breeding objective and selection criteria

Following farmer preferences documented by Taye (2016), the breeding objectives for Doyogena CBBPs include body size (SMW), litter size, and mothering ability. For this study, SMW was used as both the breeding objective and the selection criterion.

2.6. Additional information, genetic improvement duration and planning horizon (H)

Additional complementary information also collected from field and market included mating ratio, ram service year, proportion of selection focusing physical appearance, proportion of lambs attain selection, conception rate, cost of meat sheep, ear tag, ear tag applicators, weighing scale, enumerators salary, cost of materials used for AI (ewe handling equipment for inseminating, AI gun, sheath, AI straw extender, syringes, distilled water, soap, slides and cover slides, hormone for ewe synchronization, liquid thermometers, graduated cylinders and beakers). Fixed AI tools (ultrasound, water bath, generator, spectrophotometer, microscope, movable

shade, artificial vagina, lighter and speculum) was assumed available in all CBBP sites through ICARDA support and not needed considering as cost.

2.7. Input parameters, description of scaling strategies and evaluation

2.7.1. Biological and cost parameters

To expand the reach of genetic improvement in Doyogena sheep distribution area, the primary strategy focuses on increasing the number of breeding ewes per CBBPs. Under the current practice (Strategy 1), the 378 breeding females in the CBBP, with a reproduction rate of 1.86, to be expected to produce a total of approximately 351 male candidates for selection. However, only 223 are available at the time of selection, as the remainders are sold beforehand.

This result in a selection proportion of 0.34 (75 selected out of 223 available, as shown in Table 1 and Table 4: Manuscript III. If all potential candidates were retained, the selection proportion would be higher intensity, at $75/351 = 0.21$. In the current model, 75 breeding sires are approved, and 69 of them are used in the base production unit. Strategy 2 (Table 2 and Table 4: Manuscript III) is developed by both increasing the number of breeding females per CBBP from 378 to 534 and retaining all possible male candidates. This is expected to yield $534 * 1.86 * 0.5 = 497$ male candidates. If the same number of sires (75) is selected for the nucleus and production units as in strategy 1, the selection proportion becomes 0.15. Strategy 3 involves increasing the number of improved rams per CBBP, similar to strategy 2, but it applies the higher selection proportion from the current practice (strategy 1: 0.34). This allows for the dissemination of more rams to the production unit, producing a total of 169 rams, 160 of which are disseminated to the production unit. The potential of artificial insemination (AI) to spread genetic superiority more broadly was also examined.

Table 4. Biological and cost parameters

Parameters	Strategy 1	Strategy 2	Strategy 3
Parameters in base			
Average Nr of ewes	378	534	534
Annual reproduction rate at SMW age	1.86	1.86	1.86
Initial average SMW, kg	23.5	23.5	23.5
CV of SWT	0.15	0.15	0.15
Replacement rams selected on SMW	0.34	0.15	0.34
Rams selected for breeding	76	78	178
Rams need in nucleus	6	9	9
Replacement ewes selected on SMW	1.00	1.00	1.00
Heritability	0.22	0.22	0.22
Additional cost			
Various during first year, \$	458	512	512
Various annually, \$	479	585	585
Economic parameters			
Value of 1 kg live weight at SMW, \$	2.82	2.82	2.82
Planning horizon, years	20	20	20
Discount rate	0.07	0.07	0.07
Parameters in PU			
Nr of young rams from Nucleus	69	69	162
Mating ratio	30	30	30
ARR at SWT	1.86	1.86	1.86
Initial average SMW, kg	23.5	23.5	23.5
Additional cost of supervision	200.	200	200.00
Total supervision cost, \$	200	200	200
Additional cost of an improved ram	455	456	1071

In strategy 4 and strategy 5, a combination of AI and natural mating (NM) was used (Table 5: Manuscript III), with ratios adjusted to account for their different conception rates (AI: 0.48,

Table 5. Strategies combined with AI

Parameters	Strategy 4		Strategy 5	
	NM	AI	NM	AI
Parameters in Nucleus				
Nr of ewes	342	400	342	400
Annual reproduction rate at SWT	1.86	1.00	1.86	1.00
Initial average SWT, kg	23.5	23.5	23.5	23.5
CV of SWT	0.15	0.15	0.15	0.15
Replacement rams selected on SWT	0.15	0.02	0.34	0.02
Replacement ewes selected on SWT	1.00	1.00	1.00	1.00
Heritability of SWT	0.22	0.22	0.22	0.22
Additional cost				
Various during first year, \$	229	229	229	229
Various annually, \$	222	222	222	222
Various with AI during first year, \$	0	400	0	400
Various with AI annually, \$	0	200	0	200
Economic parameters				
Value of 1 kg live weight at SWT, \$	2.82	2.82	2.82	2.82
Planning horizon, years	20	20	20	20
Discount rate	0.07	0.07	0.07	0.07
Parameters in PU				
Nr of young rams from Nucleus	27.6	41.4	67.6	101.4
Mating ratio, nr of ewes / ram / year	30	200	30	200
Annual reproduction rate at SWT	1.86	1.00	1.86	1.00
Initial average SWT, kg	23.5	23.5	23.5	23.5
Additional cost of an improved ram, \$ (supervision) and AI	200.00	0.50	200.00	0.50
Total supervision cost, \$	200	4140	200	10,140
Additional cost of an improved ram -	183	274.35	447.99	671.98
Nucleus income per year				

NM: 0.90). In strategy 4 (similar to strategy 2), 66 sires are disseminated to the PU. Of these, 39.6 are produced for AI and 26.4 for NM. Sixty percent of the AI-derived sires are sold for breeding due to their high genetic progress, alongside 40% from NM. The selection proportion for natural mating was 0.15. In strategy 5 (similar to strategy 3), 160 sires were disseminated to the production unit. Of these, 96 were produced via AI and 64 via natural mating. Sixty percent of the AI-derived sires were sold for breeding, alongside 40% from NM. The selection proportion for natural mating was 0.34. Selection proportion was 0.024 used for AI for both model (model 4 and 5). Combined genetic progress and a cost-benefit analysis were presented for both strategies (4 and 5: Manuscript III).

In strategies 4 and 5), 0.02 proportions of sires were used for CBBP and PU for AI. It was assumed that a proportion (p) of rams purchased by production farmers annually would be used for AI at a ratio of MRAI ewes per ram, while the remainder would be used for natural mating at the standard rate (MR). The number of ewes inseminated depended on the duration of the breeding season and the availability of skilled personnel and resources.

2.8. Economic and genetic evaluation

Economic and genetic evaluations were conducted using the gene flow method to predict the benefits of different scaling options using an Excel spreadsheet (Amer et al., 2007; FAO, 2010; Mueller et al., 2019). The average genetic selection differential was calculated as $i \times SD \times h^2$, where i is the standardized selection differential, SD is the standard deviation of SMW, and h^2 is its heritability. Genetic gain was realized in lambs born one year after mating. The model accounted for the direct and maternal expression of improved genes across generations, with all incomes and costs discounted to their present values at year zero over a 20-year planning horizon. Benefits were generated by selling improved young rams from the nucleus flock to

production unit farmers at a 10% premium over the cost of meat animals; associated costs and incomes were allocated appropriately. Revenue and expense calculations for year one and beyond was used input parameters and trait values as of April 2025. Sensitivity analyses were conducted using a 7% discount rate. All monetary parameters were expressed in US dollars (\$). The impact of all models was measured at both the CBBP and production unit levels.

3. Results

3.1 . Economic benefits

The genetic progress and economic outcomes for the five models are presented in Tables 6 and 7. In the current CBBP (strategy 1), the scenario with a 50% increase ewes per CBBP (strategy 2), and the scenario with a greater number of improved rams produced per CBBP (strategy 3), the return on investment (ROI) for the production units was \$52.6, \$72.6, and \$122 per \$1 invested, respectively (Table 6). The higher ROI in these models results from their larger accumulated discounted benefits. However, the ROI for the nucleus unit was much lower than that for the base units.

The highest ROI for the base units was achieved by strategy 3 (\$122), a result driven by disseminating a larger number of rams to production units without a substantial increase in operational costs.

Table 6. Genetic progress and economic outcome in nucleus and production unit.

Results	Strategy 1		Strategy 2		Strategy 3	
	CBBP	PU	CBBP	PU	CBBP	PU
SMW, kg	26.0	25.2	27.1	25.9	26.0	25.2
Annual income, \$	5519	37638	10751	51918	8210	87277
Discounted annual income, \$	1426	9726	2778	13417	2122	22554
Accumulated discounted income, \$	29899	122028	55193	168325	47031	282964
Annual costs, \$	479	200	585	200	585	200
Discounted annual costs, \$	124	52	151	52	151	52
Accumulated discounted costs, \$	6006	2319	7297	2319	7297	2319
Discounted annual benefit, \$	1303	9675	2627	13365	1970	22502
Accumulated discounted benefit, \$	23892	119709	47896	166006	39734	280645
Return on investment, \$	5.0	52.6	7.6	72.6	6.4	122.0

PU: production unit

The highest ROI for the Nucleus was in strategy 5 (8.5), which used the same selection proportion as strategy 3 but with the AI/NM mix, thereby balancing genetic gain and revenue generation (Table 7).

Table 7. Strategies with AI support (60% AI and 40% natural)

Results	Strategy 4		Strategy 5	
	CBBP	PU	CBBP	PU
SMW, kg	27.88	26.46	27.19	25.99
Annual income, \$	13134	75495	12321	113403
Discounted annual income, \$	3394	19509	3184	29306
Accumulated discounted income, \$	67528	244765	71175	367669
Annual costs, \$	644	1200	644	1200
Discounted annual costs, \$	167	310	167	310
Accumulated discounted costs, \$	8329	13913	8329	13913

Discounted annual benefit, \$	3228	19199	3017	28995
Accumulated discounted benefit, \$	59199	230852	62847	353757
Return on investment, \$	8.1	17.6	8.5	26.4

3.2 Genetic Progress Trends

The annual genetic gain in SMW for the average Doyogena CBBP strategy 1(Figure 2) and strategy 3(Figure 4) were resulted kg/year 0.12 kg at the nucleus and 0.1 kg at base. While the strategy 2(Figure 3) was achieved higher genetic progress (0.17 kg/year at nucleus and 0.13 kg/year at base) was obtained than strategy 1 and strategy 3 using natural mating strategy. The difference would be associated with replacement ram selection proportion. The highest nucleus-level genetic progress was achieved in **strategy 4** (0.21kg per year and 27.88 kg weight at SMW), where a proportion of sires were produced through AI (Figure 5 and Table 9).

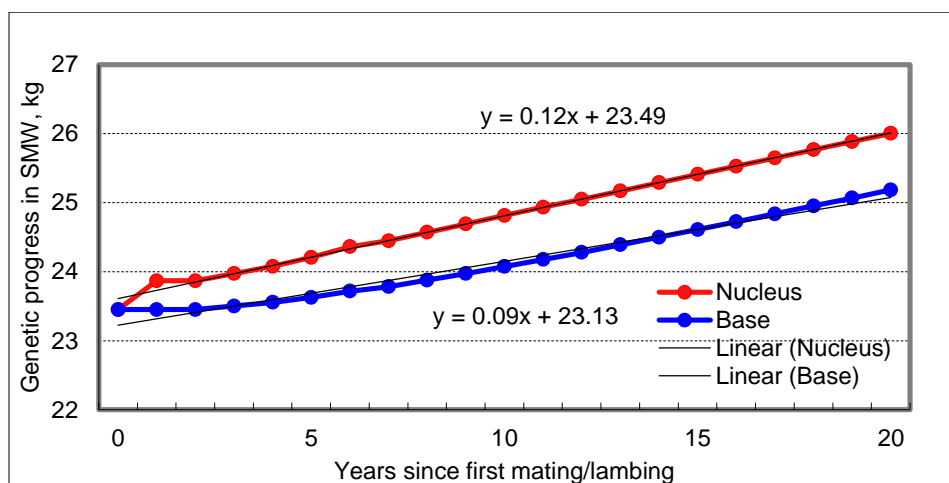


Figure 2. Genetic progress of current practice (Strategy 1)

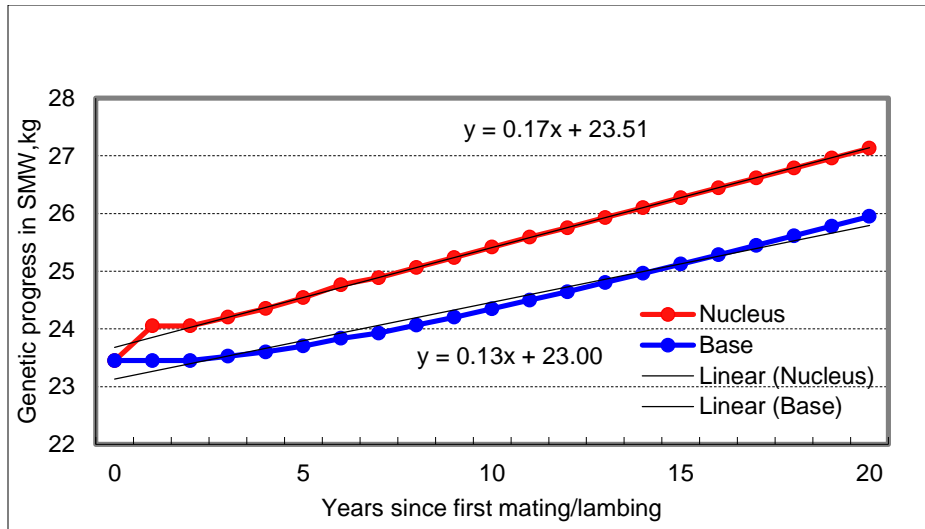


Figure 3. Genetic progress of strategy 2

This improvement reflects AI's role in amplifying selection intensity and genetic dissemination efficiency. Strategies 2 and 5 also outperformed the baseline strategy 1 in trait levels, indicating that increasing breeding females and retaining all candidates has a positive effect (Table 6 and Table 7). However, **strategy 3**, despite not achieving the highest genetic gains, delivered a competitive nucleus SMW trait (26.00 kg) while maximizing dissemination, leading to exceptional economic outcomes.

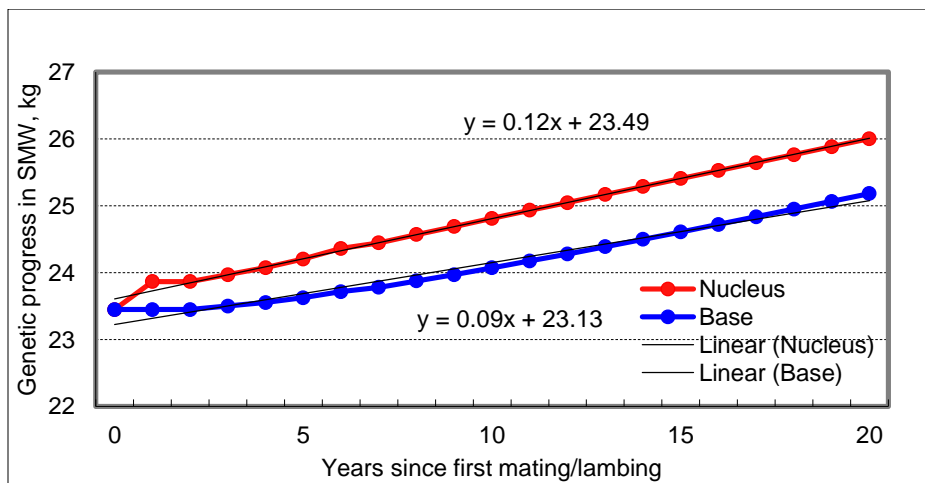


Figure 4. Genetic progress of strategy 3.

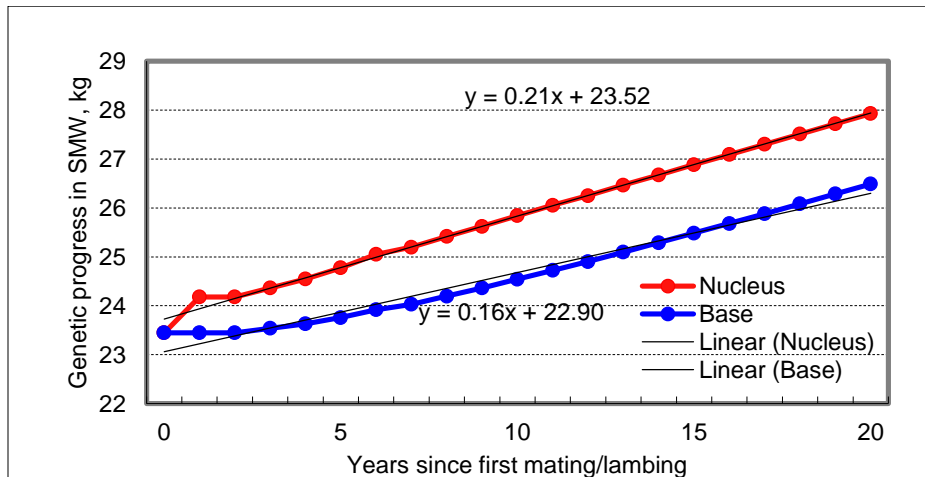


Figure 5. Genetic progress of strategy 4(AI with natural mating)

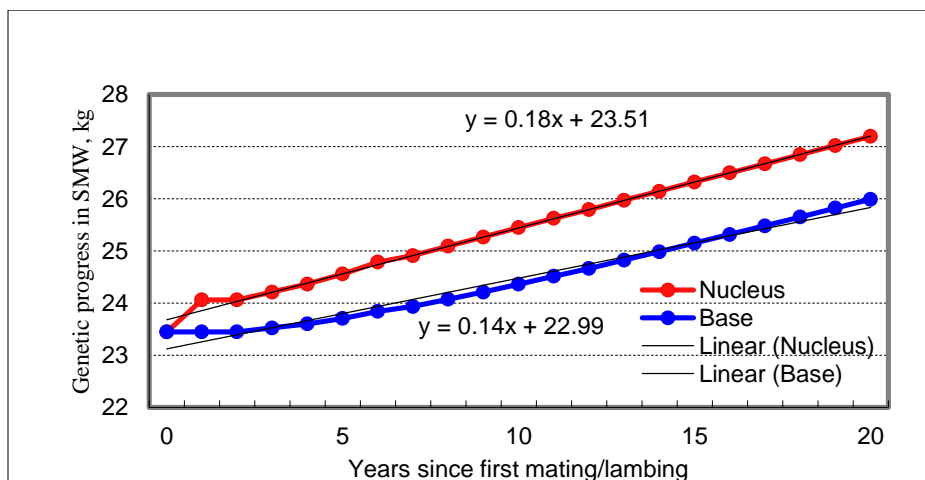


Figure 6. Genetic progress of strategy 5(AI with natural mating)

4. Discussion

4.1 Establishing additional CBBP and breeding objective traits

To cover the whole Doyogena sheep distribution area in breed improvement program forming 9 (17 - 8) new CBBP would be needed. Guidelines for the establishment of new CBBP were

presented in detail by Haile et al. (2018) and Mueller et al. (2021). During CBBP, it is crucial to carefully consider farmers' breeding objectives and trait preferences, existing infrastructure, ensure decisions and active participation in various activities, and clear ownership structures (Muller et al, 2015; Haile et al., 2020).

Community based improvement programs in low input system target few important traits (Haile et al, 2018). In Doyogena CBBP growth, twining, and mothering ability were among objective traits (Habtegiorgis et al., 2021; Jimma et al., 2024). However selection was primarily based on estimated breeding value of SMW. Thus SMW was taken as unique breeding objective and selection criterion due to its relevance in Doyogena CBBPs. Other important traits, such as body conformation, coat color other than black, presence of horns, scrotal circumference, and sexual libido were assessed by the selection committee during visual appraisal.

4.2 Scaling strategies

Scaling options of Doyogena sheep breed improvement process is involve to identify the best scaling strategy and way of addressing the feasible scaling that suits for the mixed crop livestock production system.

The higher accumulated discounted benefits and returns on investment in the production unit strategies (1, 2, and 3) compared to the combined AI-supported strategies (strategies 4 and 5) may be attributed to the lower costs associated with purchasing breeding rams and supervision. Strategy 3, which achieved the highest returns and accumulated benefits, was associated with an increase in breeding ewes per CBBP and the dissemination of a large number of breeding rams from the nucleus flock. A greater number of ewes per household within a CBBP led to higher

productivity. This also improved the chances of identifying large number of superior rams for the next generation and reduced the impacts of inbreeding (Gizaw et al., 2013; Muller et al., 2019).

The higher genetic progress (0.17 kg/year at nucleus and 0.13 kg/year at base) revealed in strategy 2 using natural mating practice associated with the result of applying higher selection intensity. Using higher selection intensity in genetic improvement would result in higher genetic gain similar with the current study also reported (Galukande et al., 2013; Desalegn et al., 2022).

In the combined AI-supported strategies (strategies 4 and 5), the higher genetic progress for six-month weight (SMW) over the 20-year period compared to the other strategy assumed negligible effects from potential management and environmental changes during this timeframe. Similarly, when improved rams from the reference CBBP were disseminated to production units and used alongside AI, greater genetic progress in SMW was achieved compared to natural mating. This predicted genetic progress aligns with the gains projected for Menz sheep (Mueller et al., 2019). The superior progress associated with AI is likely due to the use of genetically superior ram semen (Alvares et al., 2015).

The AI-based strategies (4 and 5) produced higher SMW trait levels, but their economic returns varied. For instance, Strategy 4's high genetic progress did not translate into the highest ROI, partly due to increased AI costs. Conversely, Strategy 5 demonstrates that integrating AI into a high-dissemination framework can yield strong cumulative benefits (\$353,757 in the base unit) while maintaining solid genetic progress. The economic superiority of strategy 3 highlights the importance of maximizing ram dissemination to production units, even at slightly lower genetic progress rates.

5 Conclusion

Different scaling-up and scaling-out options for Doyogena CBBPs were evaluated based on selection for SMW. The options included: the current CBBP practice (strategy 1); retaining all candidate animals and increasing the number of breeding females per CBBP to enhance improved ram selection (strategy 2); maintaining the current selection proportion of rams to increase the number of improved rams disseminated per CBBP (strategy 3); a mix of artificial insemination (AI) and natural mating based on strategy 2 (strategy 4); and a mix of AI and natural mating based on strategy 3 (strategy 5) for supplying improved rams to production units and nucleus flocks to enhance genetic improvement and economic benefits. This comparative analysis demonstrates that while AI integration can accelerate genetic progress, optimal economic outcomes depend on effective candidate retention, dissemination strategies, and aligning breeding models with operational capacity. Policymakers and practitioners should tailor adoption strategies to their genetic improvement targets, financial constraints, and infrastructural readiness, ensuring that both genetic and economic goals are met sustainably.

Policy and Scaling Recommendations

- **Targeted AI Expansion** – AI should be prioritized in high-capacity CBBPs where genetic gain is the primary objective and operational capacity can handle semen distribution.
- **Candidate Retention Strategies** – Preventing premature sale of male candidates significantly enhances selection intensity and long-term genetic progress.
- **Strategic Adoption**
 - **Scaling strategy 3** for maximizing short-to-medium term economic impact and wide-scale dissemination.

- **Scaling strategy 5** for a balanced approach when both genetic improvement and high economic returns are desired.

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12. BIOGRAPHY

Mr. ADDISU JIMMA was born on May 11, 1982, in Damot Gale woreda Bodditi town of Wolaita Administrative Zone from his father Ato Jimma Falita and his mother W/o Beyenech Wajago. He attended his elementary education at Hawassa Tabour Elementary and Junior Secondary school and his Senior Secondary education at Hawassa Addis ketema and Areka secondary school. He joined Alage ATVET in 2002 and was awarded a Diploma in Animal Science in 2004. Soon after graduation he was employed by the Ministry of Agriculture as Developing Agent at Wolaita zone in Soddo Zuria woreda and served for two years and four months. In January 2007 he was employed by the Areka Agricultural Research Center and served as Technical Assistant for three years.

He joined the Wolaita Sodo University in 2007 and was awarded with a BSc of Degree in Animal and Range Sciences in October 2010. In October 2014, he joined the Graduate Study program of the School of Animal and Range Sciences of Hawassa University and was graduated with M.Sc. degree in the specialization of Animal Breeding in October 2016. After completion of his BSc and MSc study, he worked in Areka Research Center where he served as researcher in animal breeding until the date of starting PhD study.

In October 2019/20, he joined Hawassa university school of graduate studies to pursue his PhD in Animal Breeding and Genetics in the School of Animal and Range Sciences. At present, Mr Addisu is married and has three children.