# EVALUATION OF SELECTION RESPONSE OF GROWTH AND REPRODUCTION TRAITS IN DIFFERENT OUT SCALED BONGA SHEEP COMMUNITY BASED BREEDING PROGRAMS IN KAFFA ZONE, ETHIOPIA

**MSc THESIS**

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**NOVEMBER, 2019**

**JIMMA, ETHIOPIA**

# EVALUATION OF SELECTION RESPONSE OF GROWTH AND REPRODUCTION TRAITS IN DIFFERENT OUT SCALED BONGA SHEEP COMMUNITY BASED BREEDING PROGRAMS IN KAFFA ZONE, ETHIOPIA

**Ebadu Areb Ahmed**

**A Thesis**

***Submitted to the department of Animal Science, Jimma University College of Agriculture and Veterinary Medicine, School of Graduate Studies. In Partial Fulfillment of the Requirements for the Degree of Master of Science in Animal Breeding and Genetics.***

**November, 2019**

**Jimma, Ethiopia**

## SCHOOL OF GRADUATE STUDIES

## JIMMA UNIVERSITY

## COLLEGE OF AGRICULTURE AND VETERINARY MEDICINE

## MSc THESIS APPROVAL SHEET

We, the undersigned, member of the Board of Examiners of the final open defense by **Ebadu Areb** have read and evaluated his/her thesis entitled **"Evaluation of Selection Response of Bonga Sheep Under out Scaled Community Based Breeding Program in Kefa Zone"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in **Animal Breeding and Genetics.**

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# DEDICATION

I dedicated this thesis manuscript to my father Areb Ahmed, my mother Munteha Yesuf, my brothers (Zeki, Nurmeded and Tofik), my sisters (Lubaba and Seada), my love Muna Habib and the last but not the least my daughter Ayla for encouragement, love and their partnership in the success of my life.

# STATEMENT OF AUTHOR

First, I declare that this thesis is my own work and that all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Breeding and Genetics at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University/College library to be made available to borrowers under rules of the Library.

I solemnly declare that this thesis has not been 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 manuscript in whole or in part may be granted by the head of the department or the Dean of the College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however permission must be obtained from the author.

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# BIOGRAPHICAL SKETCH

The author, Mr. Ebadu Areb, was born on January 03, 1992 at Enemore District, Gurage Zone, Southern Nation Nationalities and Peoples Regional State, Ethiopia from his father Mr. Areb Ahmed and his mother Mrs. Munteha Yesuf. He attended his primary and elementary education (Grade 1 to 8) in Gomshe Primary School from 1998 to 2006 and his secondary and preparatory education was attended at Gunchire Secondary and Preparatory School from 2007 to 2010. He then joined Dilla University, College of Agriculture and Computational Science in the department of Animal and Range Science in 2011 and obtained a BSc. degree in Animal and Range Science in July, 2013. Soon after graduation, he was employed by Debre Birhan University as a technical assistance and served for 3 months. He also employed by Gewane Technical Vocational Educational Training (TVET) college of Agriculture as lecturer for 5 months. Then the author had joined Southern Agricultural Research Institute (SARI) and served as Junior Animal Breeding Researcher for three years. In 2017/2018, he joined the School of Graduate Studies (SGS) of Jimma University to pursue his MSc. study in Animal Breeding and Genetics in the Collage of Agriculture and Veterinary Medicine (JUCAVM) department of Animal Science.

# ACKNOWLEDGMENTS

First, I would like to say Alhamdulilah. I have highly grateful thanks to my major advisor Prof. Manzoor Ahmed Kirmani, Jimma University for his guidance, assistance, and coherent writing. The Co-Advisor Dr. Tesfaye Getachew and Dr. Aynalem Haile, International Center for Agricultural Research in Dry Area (ICARDA) small ruminant research team express my deepest respect and sincere appreciation for their guidance, sound advice, their encouragement at all stages of my work. Especially Dr. Tesfaye Getachew I have no word to express feeling of his thanks for his friendship and open discussion, provide reading materials and provide training. For all of my advisors their utmost cooperation, concrete suggestions, excellent teaching and constructive criticism from the initial conception to the end of this work are highly appreciated. Also, I would like to thank Dr. Barbara Rischkowsky consultative group on International Agricultural Research in ICARDA for her discussion and guidance on methodology during initial stage of this work. I have special thanks for staff members of Jimma University Animal Science department Mohammed Aliy, Ahmed Seid, Zemene Worku, Abdo Mohammed and Metekiya Tamiru for their constructive comments.

I would like to thank the former Southern Agriculture Research Institute (SARI) Livestock Research Director Bereket Zeleke for providing study leave and funding for study. My special gratitude goes to all Bonga Agricultural Research Center (BARC) staffs for their encouragements and kind treatments during my study time. I have special thanks to the livestock research team of BARC (Tewabe Edimew, Muluken Zeleke, Dr. Fisseha Mengiste, Metsafe Mamiru, Dawit H/giorgis, Chernet Retie, Zelalem Abate, Kibreab Yosef, Tegbaru G/silase, Dekamu Fisseha, Tesfu Shegaw and Temesgen Tesfaye for your friendship, encouragement, assistance and participation as team of CBBP work. Also, I would like to thank enumerators and health experts of respective CBBP cooperatives (Tsegaye, Abate, Damtew, Legesse, Admasu, Adisu, Gizachew, Tekle, Tamiru, Hasabu, Gero, Gezahegn, Tamiru Bekele, Million, Matiyos, Asirat, Zewude, Demis, Nigatu, Abuye, Wubit, Tariku and Tekalegn) for their patient, obeying and hardworking. Also, I have thanks for data entering team for Fasika, Mehbuba and Ferehiwot. Heartfelt thanks for participant and non-participant community members who participate in this study. I have glad to thanks for Abiy G/mikael for his help and positive response.

Finally, my heartfelt thanks to my beloved family members for your unreserved caring, loving, supporting and encouraging me.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADG | Average Daily Gain |
| AFL | Age at First Lambing |
| AGIN | African Goat Improvement Network |
| BARC | Bonga Agricultural Research Center |
| BHS | Black Head Somali Sheep |
| BOKU | Austrian University of Natural Resources and Life Sciences |
| BWT | Birth Weight |
| CBBP | Community Based Breeding Program |
| CSA | Central Statistical Agency |
| EBI | Ethiopian Biodiversity Institute |
| EBV | Estimated Breeding Value |
| EIAR | Ethiopian Institute of Agricultural Research |
| ESAP | Ethiopian Society of Animal Production |
| ESGIP | Ethiopia Sheep and Goats Productivity Improvement Program |
| ETB | Ethiopian Birr |
| FAO | Food and Agricultural Organization of the United Nations |
| FAOSTAT | Food and Agricultural Organization of the United Nations, statistical division |
| gm | Gram |
| GO | Government Organization |
| ICARDA | International Center for Agricultural Research in Dry Areas |
| ID | Identification |
| ILCA | International Livestock Centre for Africa |
| ILRI | International Livestock Research Institute |
| Kg | Kilogram |
| Km | Kilometer |
| KNMI | Royal Netherlands Meteorological Institute |
| L | Liter |
| LI | Lambing Interval |
| LS | Litter size |
| Mm | Millimeter |
| NA | Not Available |
| NBE | National Bank of Ethiopia |
| NGO | Non-governmental Organization |
| NMWT | Nine Month Weight |
| RF | Rain Fall |
| SARI | Southern Agricultural Research Institute |
| SAS | Statistical Analysis System |
| SMWT | Six Month Weight |
| SNNPR | Southern Nation Nationalities and People Region |
| SPSS | Statistical Package for Social Science |
| WWT | Weaning Weight |
| YWT | Yearling Weight |

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# ABSTRACT

*The aim of the study was to evaluate genetic improvement and farmers perception in the out-scaled Bonga sheep community-based breeding programs (CBBPs) cooperatives. Body weights, average daily gain (ADG) and reproduction traits data collected between 2012 and 2018 from 14 out scaled Bonga sheep CBBPs and survey data collected from 322 households' interview and 43 focus group discussion of 7 communities (both CBBP participant and non-participant), were used for evaluation and farmer perception studies, respectively. Phenotypic performance was analyzed using the GLM procedures of SAS. Genetic parameters by univariate, bivariate, multivariate model for body weights, ADGs traits and age at first lambing (AFL), and repeatability models for lambing interval (LI) and litter size (LS) traits were undertaken by restricted maximum likelihood method with an animal model using WOMBAT software. Best model was chosen based on both likelihood ratio test (LRT) and Akakie information criteria (AIC). The overall least square mean ± SE of body weights in kg was 3.13±0.01, 16.07±0.07, 24.7±0.2, 30.4±0.4 and 34.04±0.84 for birth weight (BWT), weaning weight (WWT), six-month weight (SMWT), nine-month weight (NMWT) and yearling weight (YWT) respectively. For ADG from birth to weaning (ADG1), ADG from weaning to six-month (ADG2), ADG from six-month to nine-month (ADG3) and ADG from nine-month to yearling weight (ADG4) of the breed was 141.9±0.8, 98.65±2.4, 87.6±4.3 and 58.7±8.5gm/day, respectively. Also, reproductive traits of AFL, LI, annual reproductive rate (ARR), and LS least square mean ± SE was 375.2±12.5, 283.5±9.9, 2.31±0.05 and 1.45±0.01, respectively. Direct heritability estimates of univariate analysis from selected models were 0.56±0.03, 0.36±0.03, 0.22±0.04, 0.17±0.07 and 0.13±0.15 for BWT, WWT, SMWT, NMWT and YWT respectively. Similarly, for AFL, LI and LS were 0.07±0.19, 0.06±0.1, and 0.18±0.07. All studied traits have good response to selection except LS. SMWT is the selection trait and show positive trend for 11 CBBPs but negative trends for 3 of the CBBPs. Average inbreeding coefficient of Bonga sheep was 0.36% with 0.13% annual trend and 17% of amongst inbred animals. Implication of the result to future improvement program was continue selection, incorporate maternal line selection and consider her effect, conservation of prolific flocks, expanding the CBBP and continue market linkage. WWT and SMWT heritability values and importance of these traits approved the best option for selection age. Moderate to high estimated heritability and positive genetic trends indicated scope for further improvement of body weights and positive medium to high correlation among body weight expect correlated response. Further awareness creation on top ram using for those 3 CBBPs, strengthen rotation of top ram among and within CBBP cooperative to protect inbreeding, and always use breeding value for ram selection are among recommendations.*

**Keywords:** Bonga Sheep, Community-Based Breeding Program, Genetic gain, Genetic Parameters.

# 1. INTRODUCTION

Ethiopia follows agriculture led industrialization policy because more than 80% of the population depend on it (NBE, 2018). Based on the 2017/2018 data on agriculture provides about 34.9% of the gross domestic product (GDP) and 83.9% of total exports (NBE, 2018) of this and the livestock sector contributes up to 25.6% of the agricultural GDP and 10.5% of total Ethiopian foreign exchange earnings (NBE, 2018).

According to the Ethiopian Central Statistical Agency (CSA) (2017/2018), the total Ethiopian sheep population was estimated as 31.30 million. In the study by Gizaw *et al.* (2007) using microsatellite deoxyribonucleic acid (DNA) marker, nine sheep breeds were identified in the country being distributed in different agro-ecologies and production systems. The breeds identified were Bonga, Horro, Simien, Gumz, Washera, Arsi, Afar, Black head Somali (BHS) and Short fat tailed sheep (Sekota, Farta, Tikur, Wollo, and Menz). Ethiopian sheep breeds have immense potential to contribute to the livelihood of producers especially under low input, smallholder and pastoral production systems (Gizaw, 2008). The contributions are both tangible and intangible in nature. Some of the tangible benefits of sheep are immediate cash income, meat, milk, skin and manure while the intangible benefit includes social prestige among the community members (Adane and Girma, 2008). Moreover, sheep play great role in the economy of the country by being exportable items and thus, are sources of much needed foreign currency (Berhanu and Arendonk, 2006).

Bonga sheep is one of the well-known sheep breed in Ethiopia, geographically distributed in Kaffa, Bench Maji and Sheka zones of the Southern Nation Nationalities and Peoples Region (SNNPR) (Gizaw *et al.,* 2011). The breed is used for immediate cash income, meat production, social prestige and manure (Mestafe, 2015). It is one of the largest sheep breed in the country which is characterized by long and wide fat tailed with tapering and twisted end, both male and female are polled, short and smooth hair, mainly convex facial profile of male and all type of color but predominantly light red. The breed is known by its docile temperament, fattening potential, meat quality, fast growth and prolificacy (Duguma *et al*., 2011 and Mestafe, 2015).

There are three approaches used to date for small ruminant breeding programmes in Ethiopia which are cross-breeding and distribution of cross-breed rams from stations/ranches, selective breeding involving central nucleus schemes and community-based breeding programs (CBBPs). The first two were based on centralized nucleus which were not successful in Ethiopia and other developing countries while CBBPs generating genetic gain and economic benefits to smallholder farmers in Ethiopia (Haile *et al*, 2019).

In 2009, the International Center for Agricultural Research in 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 in Ethiopia initiated CBBP (Haile *et al*, 2019). In this program producers are involved in all steps of design and implementation of breeding programs and focus is given to indigenous sheep genetic resources in four breeds of sheep (Bonga, Afar, Horro and Menz) which representing different production system in Ethiopia (Duguma *et al.*, 2010; Mirkena *et al.*, 2012; Gutu *et al.*, 2015 and Haile *et al.*, 2019). This programme has attracted global interests and is also being scaled out in many places in Africa (Malawi, Uganda, Sudan, Tanzania, South Africa and Kenya) and others (Brazil, Iran, Mongolia, Bangladesh, Mexico, Peru, Australia, Bolivia, Vietnam, Argentina and New Zealand) (Mueller *et al.*, 2015 and Haile *et al.*, 2019).

There are 15 functional and /or licensed CBBP cooperatives in the four districts, namely Adiyo Kaka, Chena, Gesha, and Tello, of Kaffa zone of SNNPR, Ethiopia. Among the CBBP cooperatives Boqa - shuta from Adiyo Kaka is the first CBBP cooperative established by ICARDA, ILRI and BOKU in collaboration with Southern Agricultural Research Institute (SARI) of Bonga Agricultural Research Center (BARC). The data generated from Boqa-shuta CBBP cooperative was analyzed and reported as good improvement together with good participation of the community in operating the programme (Haile *et al*., 2018).

For accurate genetic evaluation and selection, estimates of genetic parameters for traits of importance should be known. In this regard, growth and reproductive traits are important, as they significantly influence the profitability of any sheep production enterprises (Abegaz and Duguma, 2000). In order to achieve the largest possible gains, a thorough evaluation of the programme is needed (Lamuno *et al.*, 2018). Besides, it is a relevant tool to show that the promised benefits for farmers can actually be achieved and that livestock breeding is a sustainable intervention strategy under CBBP. However, the data generated from out-scaled

CBBP cooperatives, in Kaffa zone has not been analyzed and / or evaluated for further decision making. Thus, the present study was proposed to analyze /evaluate the data at these out-scaled CBBP cooperatives with the following objectives:

### 1.1. General Objective

- To evaluate genetic improvement in the out-scaled Bonga sheep community-based breeding programs

### 1.2. Specific Objectives

- To identify the effect of non-genetic factors influencing growth and reproductive traits
- To estimate genetic parameters for growth and reproduction traits
- To evaluate inbreeding level and selection response for growth and reproductive traits
- To asses' farmers perception of community-based breeding programs
- To generate information for optimization of the on-going community-based breeding program.

# 2. LITERATURE REVIEW

## 2.1. Development of Breeding Program and Management Scheme

Breeding programs are defined as systematic and structured programs to change the genetic composition of a population based on objective performance criteria (FAO, 2010). The interacting components to be considered in its design includes description of production environment and production system, characterization of the available local genotype, definition of breeding objectives, identification of traits to be selected, decision about breeding methods and breeding population, and understanding of structure and organization of people involved (FAO, 2010; Sölkner and Wurzinger., 2010).

Genetic improvement programs of indigenous livestock in low and medium-input production systems contribute significantly to improved livestock productivity (Olivier *et al.*, 2002) as well as ensuring sustainable conservation strategies (Gizaw *et al.,* 2008; Mirkena *et al.*, 2010). There is an obstacle to the design and implementation of conservation-based selective breeding programs in the tropics is the lack of estimates of genetic parameters to predict genetic gains (Gizaw *et al.,* 2007). Therefore, information of genetic parameter estimation for different traits is useful in formulating breeding program since these parameters determine the direction and magnitude of genetic improvement (Haile, 2006). Accuracy of selection is an important feature for all breeding programs and genetic evaluation, with genetic gain influenced by the accuracy of the breeding values estimation and by the selection decisions taken by the breeder (McIntyre and Newman, 2016). The basic pre-requisite of any breed improvement program is a priori knowledge about the extent of variability, or more precisely, the additive genetic variability present within the population under study, association between traits and repeatability of the trait targeted (Haile, 2006).

## 2.2. Community Based Breeding Program (CBBP)

In CBBPs, community is both breeder and producer; being suggested as viable options for the genetic improvement programs of small ruminants in low-input smallholder production systems (Sölkner *et al.,* 1998; Kahi *et al.,* 2005; Gizaw and Getachew, 2009). It is a designed suitable breeding schemes that enable communities to implement breed improvement activities under uncontrolled village breeding practice. This designing and implementation of CBBP require a good understanding of the production system and importance of the different constraints, breeding objectives of the farmers and identifying the superior genotypes (Baker and Gray, 2003).

The CBBPs are an emerging way to improve both livestock populations and the livelihoods of their owners. It contributes to efficient utilization and conservation of animal genetic resources. This includes procedures for the selection and use of superior breeding stock and prediction of genetic progress under village conditions (Adisu *et al.,* 2015). This is because smallholder livestock breeders have used different phenotypic features including adaptive attributes to identify and select their breeds, strains or landraces for centuries (Rege, 2001). According to African Goat Improvement Network (AGIN) (2014), CBBP is distinct in a few important ways. Namely (i) farmers in this program helps to determine which genetic traits to select for and (ii) trained to incorporate these traits into their breeding practices. This may be explained by an example, they may select for animals that have twins often. Farmers who can identify traits that will be valuable in the long term are in a better position to decide which animals to keep or sell. For example, farmers often sell the fastest growing animals when they are young because it maximizes immediate income, but with training they may choose to keep these animals in order to promote the long-term genetic improvement of the flock. Farmers also pool their flocks with those of other farmers in their communities to create a bigger and more diverse gene pool, and they receive support to set up local recording systems to monitor the performance of their animals over time and continuously improve their resilience. Community-based breeding programs include substantial interaction between farmers and scientists as they evaluate different breeding options so that decisions on herd management are informed and collaborative. This participatory approach builds both capacity and buy-in among local farmers, who are less likely to return to familiar, traditional breeding practices when the programs end because they have ownership in the process of improving flock management and creating reliable record-keeping systems (AGIN, 2014).

The CBBP for indigenous sheep breeds in Ethiopia were started after detailed and comprehensive studies. Comprehensive characterization of the production system and market analysis in various agroecological zones were initially conducted (Gutu *et al.,* 2015). The first step in setting CBBP is to define objectives which are realistic and attainable. The methods employed in defining the breeding objectives in Ethiopia were choice experiments (Duguma, 2010) and own flock and group animal ranking experiments (Mirkena *et al.,* 2012). Findings from these studies and the participatory research with farmers revealed shortages of breeding rams, inbreeding and negative selections as some of the problems in sheep breeding practices, particularly for Bonga and Horro sheep breeds. Addressing these problems was, therefore, part of the objectives of the breeding programs.

Ethiopian government has accepted CBBP as the strategy of choice for genetic improvement of small ruminants as explicitly indicated in the "Ethiopian Livestock Master Plan" (Shapiro *et al.*, 2015). According to Haile *et al.* (2019) the second "Growth and Transformation Plan" of the Ethiopian government and the new World Bank Livestock and Fisheries sector development projects are adopting CBBP. The strategy of upscaling by the Government focuses on using the existing CBBPs as nucleus stock where genetic improvement is generated and disseminated. There are around 40 CBBPs each having around 80 households that are currently running in Ethiopia. These include Menz, Horro, Bonga, Washera, Doyogena and Atsbi sheep and Konso, Arsi and Abergelle goat (Haile *et al.*, 2019). The author further explained that genetic progress and socio- economic benefits have not been monitored and reported for most selection programmes. According to Haile *et al.* (2014), the overall growth trait of Bonga, Horro and Menz sheep is indicated in Table 1 from the year of 2009 to 2012.

**Table 1:Overall least square mean of growth traits for CBBP of different breeds (kg ± SE)**

| Breed | BWT | WWT | SMWT | ADG2 | ADG3 |
|---|---|---|---|---|---|
| Bonga | 3.42±0.051 | 14.8±0.226 | 21.0±0.7 | 0.13±0.002 | 0.05±0.005 |
| Horro | 3.12±0.129 | 11.7±0.548 | 17.3±0.8 | 0.09±0.006 | 0.06±0.009 |
| Menz | 2.27±0.043 | 9.3±0.619 | 13.7±0.3 | 0.08±0.007 | 0.04±0.003 |

The predicted genetic gains per year in yearling weight were differed among the breeds and ranged from 0.399 to 0.440 in Afar, 0.813 to 0.894 in Bonga, 0.850 to 0.940 in Horro and 0.616 to 0.699kg in Menz for different four schemes (scheme 1= 10% selection proportion and 2 years of ram used for breeding; scheme 2 = 10% selection proportion and 3 years of ram used for breeding; scheme 3 = 15% selection proportion and 2 years of ram used for breeding; and scheme 4 = 15% selection proportion and 3 years of ram used for breeding). The genetic gains per year in number of lambs born per ewe bred ranged from 0.009 to 0.010 lambs in both Bonga and Horro. The predicted genetic gain in the proportion of lambs weaned per ewe joined was nearly comparable in all breeds ranging from 0.008 to 0.011lamb. The genetic gain per year in milk yield of Afar sheep breed was in the order of 0.018 to 0.020L, while the genetic gain per generation for greasy fleece weight ranged from 0.016 to 0.024kg in Menz (Mirkena *et al.*,2012). The author further explained that strong selection and shorter duration of ram use for breeding were the preferred options. The expected genetic gains are satisfactory but largely rely on accurate and continuous pedigree and performance recording. Similarly, according to Haile *et al*. (2018) the phenotypic progress of litter size by CBBP for Bonga and Horro sheep breed is indicated in Table 2.

**Table 2: Phenotypic performance of litter size improvement for two sheep breeds ± SE**

| **Year** | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Over all |
|---|---|---|---|---|---|---|---|---|---|
| **Bonga** | 1.48± 0.039 | 1.53± 0.026 | 1.48± 0.022 | 1.58± 0.020 | 1.53± 0.018 | 1.54± 0.015 | 1.53± 0.013 | 1.61± 0.016 | 1.53± 0.008 |
| **Horro** | 1.28± 0.033 | 1.40± 0.020 | 1.37± 0.020 | 1.36± 0.023 | 1.35± 0.023 | 1.31± 0.024 | 1.37± 0.022 | 1.46± 0.039 | 1.36± 0.010 |

According to Dagnew *et al.* (2018) the response of genetic gain for Gumz sheep by two village-based and two central nucleus-based schemes namely a village-based breeding scheme with existing lambing (whole village sheep population), a village-based scheme with improved lambing (improved breeding management and estrous synchronization), central nucleus-based scheme with 5% nucleus size (5% of the total population of ewes and 5% rams were selected for future sire from nucleus flock) and central nucleus-based scheme with 10% nucleus size (10% of best rams each year selected at nucleus flocks for own use). The annual genetic gains per year in 6-month weight (kg) were differed across schemes and ranged from 0.154 to 0.171 in village-based scheme, and 0. 334 to 0.336 in central-based schemes. The annual genetic gain per year in number of lambs born per ewe bred ranged from 0.0017 to 0.0036% in both village and central nucleus-based scheme. The genetic gain in the proportion of lambs weaned per ewe was comparable across central nucleus-based scheme but little differed in village-based schemes and ranged from 0.0015 to 0.0016%.

### 2.3. Growth Traits

#### 2.3.1. Growth performance of Ethiopian sheep breeds

Phenotypic characterization includes describing of physical environment, morphometric characteristics, productive and reproductive characteristics of the breed (FAO, 2012). Morphometric measurements of indigenous sheep include phenotypic values like body weight, body length, heart/chest length, height at wither, tail length, tail width, ear length and hair length. The least square means of some morphometric measurement of indigenous adult sheep are summarized in Table 3.

**Table 3: The overall body size characteristics measured on adult sheep in kg and cm**

| Sheep type | Adult body weight (Kg) | Withers height | Body length | Heart girth | Ear length | Tail Length | Tail Width | Hair length |
|---|---|---|---|---|---|---|---|---|
| Adilo | 28.4 | 65.5 | 62.1 | 71.8 | 11.7 | 28.1 | 6.7 | 4.4 |
| Arsi Bale | 28.4 | 64.1 | 62.3 | 73.3 | 11.0 | 28.4 | 6.2 | 4.2 |
| Bonga | 36 – 40 | 66.7 | 69.4 | 73.5 | 9.8 | 25.9 | 8.1 | 2.9 |
| Farta | 25.4 | 67.9 | 65.7 | 72.0 | 9.9 | 22.9 | 9.6 | 7.5 |
| Gumz | 31 | 62.9 | 65.8 | 72.1 | 11.2 | 31.6 | 7.2 | 3.6 |
| Horro | 25 – 35 | 70.0 | 71.6 | 76.9 | 10.8 | 35.6 | 9.9 | 2.6 |
| Menz | 14.8 -38.5 | 57.5 | 58.5 | 65.7 | 6.8 | 17.0 | 7.9 | 7.9 |
| Sekota | 25.4 | 62.3 | 62.2 | 69.9 | 4.4 | 19.9 | 9.5 | 6.5 |
| Semien | 26.9 | 66.6 | 64.7 | 73.2 | 8.3 | 12.8 | 9.6 | 8.2 |
| Afar | 31 | 63.6 | 58.3 | 70.6 | 3.8 | 19.1 | 16 | 3.2 |
| Tikur | 25.4 | 64.1 | 69.7 | 35.9 | 6.8 | 17.3 | 8.9 | 7.4 |
| Washera | 32.8 | 69.4 | 66.7 | 74.1 | 10.6 | - | - | 6.3 |
| BHS | 27.9 | 63.3 | 59.9 | 71.5 | 9.6 | 14.7 | 14 | 4.0 |
| Wollo | 25.4 | 62.7 | 61.2 | 67.6 | 8.7 | 20.4 | 7.2 | 7.9 |

Source: (Gizaw, 2008; Gizaw, 2009 and Duguma *et al.*, 2010)

According to Mengestu (2008), growth rate of lambs during the early stages of growth is strongly influenced by genotype, mothering ability of the ewe, the environment under which the animals are maintained including the availability of adequate feed supply in terms of both quantity and quality, parity, pre-mating weight of the dam, type of birth, sex and season of birth of small ruminants. Birth weight of animals is one of the most key factors influencing the pre-weaning growth of the young and has a positive relationship with subsequent body weight gain (Kasahun, 2000; Gbangboche *et al.*, 2006; Berhanu and Aynalem, 2009; Taye *et al.*, 2009; Momoh *et al.*, 2013 Deribe *et al.*, 2014). Lambs which are heavier at birth are usually singles or those produced by ewes with larger body sizes under better management conditions. This showed that lambs heavier at birth have larger adult weight and higher growth capacity given proper management (Kasahun, 2000; Taye *et al.*, 2009) partially due to the carry over effect the heavier birth weight. The birth and weaning weights of some of the indigenous breeds/types have been shown in Table 4.

**Table 4: Birth and weaning weight of some sheep breeds in kg**

| Breed | Management | BWT | WWT | Source |
|---|---|---|---|---|
| Bonga | On-farm | 3.6 | 15.5 | Mestafe, 2015 |
| Arsi-Bale | On-farm | 2.89 | 12.23 | Getahun, 2008 |
| Adilo | On-farm | 2.3 | 10.4 | Deribe *et al.,* 2014 |
| Horro | On-station | 2.4 | 9.48 | Markos, 2006 |
| Washera | On-farm | 2.61 | 11.78 | Shigdafe *et al*., 2013 |
| Simien | On-farm | 2.97 | 11.76 | Surafel *et al.*, 2012 |
| Abera | On-farm | 2.8 | 12.3 | Marufa *et al.*, 2017 |
| Sekota | On-farm | 2.73 | 11.9 | Yiheyis *et al*., 2012 |
| Horro | On-station | 2.6 | 12.00 | Abegaz, 2002 |
| Horro | On-farm | 2.83 | 12.53 | Bekana, 2019 |
| Horro | On-station | 2.54 | 11.04 | Bekana, 2019 |

*Note: BWT = Birth Weight WWT = Weaning Weight*

### 2.3.2. Improvement of growth traits

Most scientists agreed that selection for growth should be based on traits which can be measured early in the animal life (Mekuriaw and Haile, 2014). It is generally agreed that more progress in weaning weight can be made by selection on post-weaning weight than pre-weaning weight, due to the higher direct heritability of the post-weaning weight and its high genetic correlation with the weaning trait in sheep (Atkins, 1986). The birth weight is important in improving survival of lambs. Therefore, selection of Afar and BHS lambs for birth weight can have significant impact on overall productivity (Yacob, 2008). Lambs with wider range of breeding value for traits conclude that selection of lambs for the next generation would lead to higher genetic progress in the flock (El-Arian *et al.,* 2008). Genetic trends in performance traits are important in that they allow for the evaluation of the efficiency of selection and management schemes (Ozder *et al.,* 2009). Estimates of genetic parameters and observed genetic trends confirm that selective breeding can lead to significant genetic improvement in Menz sheep (Gizaw *et al.,* 2007).

## 2.4. Reproductive Traits

### 2.4.1. Reproductive performance of Ethiopian sheep breeds

Reproduction in sheep is influenced by several factors like their genetic potential, nutritional status, environmental factors and health status. Reproductive performance description includes different traits like age at first lambing, lambing interval, litter size, number of lamb crop for productive stage of life and number of lambs weaned. Reproductive traits are difficult to measure, lowly heritable and are strongly influenced by management decisions, but traits like conception rate, litter size, young mortality and lambing interval are economically important traits (Notter, 2000; Mukasa *et al.*, 2002). The reproductive performance of indigenous sheep breeds/types is summarized in Table 5.

**Table 5: Reproductive performance of indigenous sheep breeds/types**

| Breed/Ecotype | AFL (days) | LI (days) | LS (lamb) | Source |
|---|---|---|---|---|
| Menz | 522.3±17.4 | 261±8.7 | 1.02 | Mirkena *et al.*,2012 and Tesfaye *et al.*, 2013 |
| Wollo | 434.1±21 | 227.1±9 | - | Tesfaye *et al.*, 2013 |
| Bonga | 438±75 | 255±48 | 1.37 | Mestafe, 2015 |
| Horro | 399±51 | 276±72 | 1.36 | Edea *et al*, 2012 |
| Washera | 457±4.76 | 303 | 1.05±0.09 | Mekuriaw *et al*., 2013 |
| BHS | 720 | 420 | 1.06 | Wilson, 2011 |
| Gumz | 410.1 | 199.2±33.9 | 1.17 | Abegaz, 2007 |
| Abera sheep | 387±7.8 | 288±7.2 | 1.5±0.003 | Marufa *et al.*, 2017 |
| Adilo | 438 | 372.9 | 1.5 | Deribe, 2009 |
| Arsi Bale | 381 | 234 | 1.7 | Tsedeke, 2007 |
| Horro | 491.17 | 264.58 | 1.32 | Bekana, 2019 |

*Note: AFL = Age at first lambing; LI = Lambing interval; LS= litter size; BHS = black head Somali*

### 2.4.2. Improvement of reproductive traits

Estimate of heritability under different models have shown that litter size has low to medium heritability (0.06-0.17) and the correlation between direct and maternal additive genetic effect is negative (-0.68) for Horro sheep (Abegaz and Duguma, 2000). Thus, genetic improvement for this trait could be difficult. As a result, improving the weight of ewes at mating could make sizable increase in litter size. In this regard, there could be about 2.5% additional lamb for 1kg increase in flock average weight at mating (Abegaz and Duguma, 2000). Twinning for Horro sheep was found to have medium heritability (0.15) and repeatability and moderate to high genetic correlation with number of lambs weaned, birth weight and weaning weight. These results suggested that twinning can be used as a selection criterion for improvement in productivity despite increase in lamb mortality with increase in twinning (Abegaz, 2002).

## 2.5. Estimate of Genetic Parameters

To determine optimal breeding strategies and to increase the efficiency of sheep production, knowledge of genetic parameters for weight traits at various ages and also the genetic relationships between the traits is needed (Behzadi *et al*., 2007). The author further explained that the most important environmental factors are year, sex, type of birth, age of dam, and age of lambs at weighing. Many random factors affect the growth of lambs. These factors include direct genetic effects, maternal genetic effects, and environmental factors, which affect both the lamb and its dam. Estimated genetic parameter include heritability, repeatability and correlation between traits (Yacob, 2008). Much more information on heritability, repeatability and genetic correlation estimates for growth and reproductive trait were not available for sheep in Ethiopian (Mekuriaw and Haile, 2014). Estimates of genetic parameters help to determine genetic variability in the population (El-Arian *et al.,* 2008). The potential for genetic improvement is largely depend on the genetic parameters of growth weight trait upon which selection may be applied (Hermiz *et al.,* 2009).

### 2.5.1. Heritability ($h^2$)

Heritability is defined as the proportion of genotypic variance to phenotypic variance that is due to heredity. The heritability of a trait is the proportion of variation among individuals in a population that is due to variation in the additive genetic effects (Falconer and Mackay, 1996). Obviously, heritability is important among several factors determining how much genetic improvement can be made in any trait (Haile, 2006). If individuals will be selected based on their phenotypic values, success in improvement can be predicted only from the knowledge of correspondence between phenotypic and the breeding values. This degree of correspondence is measured by heritability. Since the genotype values are determined by the additive effects of the genes, heritability estimation is necessary to obtain the best estimate of an individual's breeding value (Kanakaraj, 2001). Making a good comparison for alternative procedures in selection and management requires the estimations of genetic, phenotypic, and environmental trends (Mohammadi and Abdollahi, 2015). When the estimated heritability for studied trait is moderate, improving programs for that traits must be included improving environmental conditions with genetic improvement to achieved better results (El-Arian *et al.,* 2008). Comparison of heritability estimates for productive and reproductive traits show lower estimates for female reproductive than productive traits because female reproductive traits are highly influenced by the environment and it could be more improved through manipulation of production environment than selection (Chrilukovian, 2006).

**(I) Heritability for Growth Traits**

The interests in heritability of the different weights are simply in choosing the most adequate weight to use as a selection criterion to improve interested traits (Al-Shorepy, 1995). Body weight and rate of gain are among the most economically important and easily measured traits of sheep (Mekuriaw and Haile, 2014). The estimates of direct heritability were medium to high for both birth weight (0.18 to 0.32) and yearling weights (0.23 to 0.31) whereas the maternal heritability was medium (0.12 to 0.23) for birth weight but it was low (0.09) for yearling weight for Horro sheep (Abegaz *et al.*,2002). This indicate that faster genetic improvement through selection is possible for these traits and it should consider both direct and maternal heritability estimates. However, direct-maternal genetic covariances were found negative (-0.64±0.08 and -0.46±0.18) for birth weight and yearling weight, respectively, and thus caution should be made in making selection decisions. Heritability estimates for Menz and Horro were generally moderate at 0.22 vs 0.26 for birth weight (Markos, 2006). Heritability of productive traits of indigenous sheep are indicated in table 6.

**Table 6: Summary of heritability estimates of some Ethiopian sheep breeds/types**

| Trait | Breed | Method of estimation | $h^2a$ | $h^2m$ | Source |
|---|---|---|---|---|---|
| Birth weight | Afar | univariate analysis | 0.13 - 0.38 | 0.02 - 0.21 | Yacob, 2008 |
| | BHS | univariate analysis | 0.20 - 0.58 | 0.06 - 0.46 | Yacob, 2008 |
| | Horro | multi-trait analysis | 0.18 - 0.32 | 0.12 - 0.23 | Abegaz *et al.*, 2002 |
| | Menz | multi-trait analysis | 0.019±0.036 | NA | Gizaw *et al.*, 2014 |
| Weaning Weight | Afar | univariate analysis | 0.11 - 0.37 | 0.12 - 0.21 | Yacob, 2008 |
| | BHS | univariate analysis | 0.00 - 0.29 | 0.15 - 0.20 | Yacob, 2008 |
| | Horro | multi-trait analysis | 0.10 - 0.26 | 0.19 - 0.24 | Abegaz *et al.*, 2002 |
| | Menz | multi-trait analysis | 0.19±0.057 | 0.19 | Gizaw *et al.*, 2014 |
| Six-month weight | Afar | univariate analysis | 0.14 - 0.32 | 0.04 - 0.23 | Yacob, 2008 |
| | BHS | univariate analysis | 0.00 - 0.43 | 0.12 - 0.23 | Yacob, 2008 |
| | Horro | multi-trait analysis | 0.16-0.26 | 0.09 | Abegaz *et al.*, 2002 |
| | Menz | multi-trait analysis | 0.46±0.081 | 0.24 | Gizaw *et al.*, 2014 |
| Yearling weight | Afar | univariate analysis | 0.21 - 0.28 | 0.02 - 0.25 | Yacob, 2008 |
| | BHS | univariate analysis | 0.12 - 0.25 | 0.00 - 0.20 | Yacob, 2008 |
| | Horro | multi-trait analysis | 0.23 - 0.31 | 0.08 - 0.14 | Abegaz *et al.*, 2002 |
| | Menz | multi-trait analysis | 0.56 | NA | Gizaw *et al.*, 2007 |

*Note: $h^2a$ =direct heritability, $h^2m$ = maternal heritability, NA = Not Available*

A common finding is that more progress in weaning weight can be made by selection on post-weaning weight than on weaning weight itself, due to the higher direct heritability of the post-weaning weight and its high genetic correlation with direct components of weaning weight.

The high heritability estimates for productive traits were due to the high genetic variances attributed to these traits implying possibility of improvement through selection. Maternal heritability is a function of maternal variance that 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 declines as the lamb grows and becomes independent (Meyer, 1992).

**(II) Heritability for Reproductive Traits**

Fertility, litter size and lamb survival are components of the overall ewe reproduction traits. It appears that heritability estimates of these traits are rather low and reflect the generally small genetic variance for most reproductive traits. The estimate of direct heritability of fertility was 0.02±0.01 and 0.06 ±0.02 when service sire was considered as random and fixed respectively for Horro sheep (Abegaz, 2002). The heritability estimate for fertility is low throughout and it becomes much lower as a result of inclusion of service sire as a non-genetic random effect. The data were generated from a single sire-controlled mating system where assignment of rams to a group was done randomly after initial choice of rams to be used as sires. Due to this there was a need to include the serving ram as a random effect to separate its contribution to variation in ewe fertility (Abegaz, 2002). According to Gizaw *et al.* (2010b) heritability of fertility for Menz sheep was 0.04.

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 0.06 to 0.11 estimated by (Abegaz *et al.*,2002). The amount of direct additive and maternal heritability's for litter size were estimated 0.14 and 0.08, respectively for Iranian Kordi ewe (Saghi and Shahdadi, 2017). More over ratio of permanent environmental variance on phenotypic variance for the breed is 0.01 to 0.03 (Saghi and Shahdadi, 2017). The direct heritability of liter size for Lori-Bakhtiari sheep in Iran was 0.10±0.01(Vatankhah and Talebi, 2008). Litter size has medium heritability 0.16 to 0.19 than the other components traits like fertility 0.10 and survival rate 0.09 for Awassi sheep breed (Juma and Alkass, 2006).

### 2.5.2. Repeatability

Repeatability is the intraclass correlation between repeated records of an individual (Pickering *et al.,* 2012). It indicates the gain in accuracy that may be expected from the use of the mean multiple measurements instead of single measurement (Kanakaraj, 2001). Basically, repeatability value is greater than heritability value since repeatability estimates include the permanent maternal environmental variance in addition to additive genetic variance component (Abegaz and Duguma, 2000). The accuracy of repeatability estimates for reproductive traits were lower than heritability estimates for selection improvement because repeatability is a measures correlation between performances of traits in different parities (Vatankhah *et al.,* 2008). Estimated repeatability of twinning rate for Horro sheep is 0.16 (Abegaz *et al.,* 2002) while repeatability of fertility was 0.02 and 0.08 when service sire was considered random and fixed. The low repeatability values indicate that an animal evaluation for the traits based on repeated observations is more reliable than evaluation on a single observation.

### 2.5.3. Correlation

In the broadest sense correlation is any statistical association, though it commonly refers to the degree to which a pair of variables are linearly related. It is useful because they can indicate a predictive relationship that can be exploited in practice (Dietrich, 1991).

#### i. Genetic Correlation

Genetic correlations are a measure of genetic factors shared between two traits. When two traits are highly genetically correlated, the genes that contribute to the traits are usually co-inherited (Lynch and Walsh, 1998). The high genetic correlation (0.81) between weight at six-month and weight at one year indicates that breeding rams could be selected at an earlier age of six months and the correlated response can lead to significant genetic improvement in Menz sheep (Gizaw *et al.,* 2007). The higher genetic correlations indicated that indirect selection for correlated traits expressed late in life, like yearling weight, can be done through selection for earlier traits (Abegaz and Duguma, 2000).

In Afar and BHS sheep breeds had high genetic correlations between birth weight and weaning weight (0.73 and 0.86), six-month and yearling weights (0.95 and 0.65), respectively. This implies that genetic improvement of birth weight of lambs can improve their growth performance at later age. Genetic correlations among birth weight, weaning weight, twinning and number of lambs at weaning were in the range of 0.57 to 0.86 for Horro sheep (Abegaz, 2002). The genetic correlation of Awassi sheep between weaning weight and weight gain was high 0.72±0.95 (Haile *et al.,* 2018). Genetic correlations between reproductive traits of Iranian Kordi sheep were estimated to be positive and within the range of 0.09 to 0.96 (Saghi and Shahdadi, 2017). Genetic correlations between pairs of the studied traits for Egyptian Barki sheep were 0.4±0.01 (BWT and WWT), 0.12±0.01 (BWT and ADG) and 0.91±0.01 (WWT and ADG) (Sallam *et al*., 2018). Generally, the presence of strong correlations in some cases indicates that direct selection for one of the traits will result in concomitant improvement in correlated trait.

### ii. Phenotypic Correlation

Phenotypic correlations depend on both the correlation of additive genetic and environmental effects (Sebastia *et al*., 2018). For Horro sheep, the phenotypic correlation of birth weight with weaning weight, twinning and number of lambs at weaning were 0.37, 0.77 and 0.45, respectively (Abegaz, 2002). The author further reported that phenotypic correlation of litter size at birth with weaning weight and litter size at weaning was 0.26 and 0.45, respectively. Birth weight had medium phenotypic correlation with weaning weight and weight gain 0.44±0.02 and 0.25±0.19, respectively whereas weaning weight and weight gain had high 0.83±0.71 correlations for Awassi sheep (Haile *et al.,* 2018). Also, Iranian Kordi sheep phenotypic correlations between reproductive traits were estimated to be positive and within the range of 0.02 to 0.29 (Saghi and Shahdadi, 2017). Correlations between pairs of the studied traits of Egyptian Barki sheep were 0.3±0.01 (BWT and WWT), 0.5±0.01 (BWT and ADG) and 0.92±0.01 (WWT and ADG) for phenotypic correlation, respectively (Sallam *et al*., 2018).

## 2.6. Farmers Perception for Community Based Breeding Program

CBBP encourage beneficiaries to fully participate by the improvement program which enable farmers to believe their involvement helped them to have clear ideas on the breeding objectives and that their preferences were considered (Gutu *et al.,* 2015). Understanding preferred traits of sheep by farmers is helpful in matching genotypes with prevailing socioeconomic conditions and the production environment. Formation of CBBP breeders' cooperatives, understanding farmer preferences, setting breeding objective based on preference and interventions helped the breeding program to overcome sustainability of the program, challenges related to small flock size, performance recording and multiple production goals of smallholder farmers also helped to achieve genetic gains through CBBP. The author further explained that achievements of participating farmers have also attracted other farmers and members of the sheep breeders' CBBP cooperatives are growing. Getachew *et al.* (2016) reported that farmers in Ethiopia showed strong interest to adopt and implement breeding programs when they found them working and benefitting them. Comparison of sheep flock size owned by the participant and non-participant indicated that CBBP participants had larger flock sizes and the difference was significant for Bonga, Menz and Horro.

The percentage of the members CBBP in Bonga (72.5%) and Horro (65%) reporting mostly twin births of their ewes was much higher than for the ewes owned by non-participants (52.5% and 20% in Bonga and Horro, respectively) which case partly variation in flock size among the two participant and non-participants (Gutu *et al.*, 2015). According to Mengestu (2018) highland sheep under CBBP in Atsbi Wenberta district of Tigray region indicate that 58% of CBBP participant respondents thought body size of new-born lambs in their sheep flock showed improvement as result of the intervention and it was also evident from the interviews with non-members (52%) reported they perceived improvement in body size of sheep owned by CBBP members. The author also indicated that there is no improvement of twining but majority of CBBP participants (56%) reported that mutton consumption in the household had increased after the introduction of intervention. This increasing of consumption was related with improvement of income after intervention of the program.

# 3. MATERIALS AND METHOD

## 3.1. Description of Study Area

The study was conducted in four districts, namely Adiyo kaka, Chena, Gesha, and Tello, in Kaffa zone of SNNPR, Ethiopia. This zone is situated in the south western part of Ethiopia (7º 34´N latitude and 37º 6´E longitude) and is 467 km away from capital city; Addis Ababa. The area is characterized by mixed crop-livestock production system. It has one major rainy season that extends from May to October and dry season lasts from October to April (Mirkena *et al.*, 2012).

The climatic conditions influenced, both directly and indirectly, the productivity and reproductivity of sheep especially under small-scale extensive production system. The data on updated climatic condition from each district is not available, thus such climatic information (rainfall http://climexp.knmi.nl/select.cgi?field=cru4_pre; mean maximum and minimum temperature http://climexp.knmi.nl/select.cgi?field=cru4_tmp) was obtained from online source, namely climatic explorer information of KNMI (Royal Netherland Meteorological Institute national research and information center for meteorology). The climatic condition was collected within 50km for Adiyo kaka, Chena and Tello whereas for Gesha within 100km from the indicated coordination of Table 7 because one CBBP cooperative (Dirbedo) is far away from the capital town of the district. The detail of climatic characteristics for each district is shown in Table 7.

**Table 7: Average climatic condition of study area**

| Districts | Coordinate | Condition/year | Years | | | | | | | Altitude Range (masl) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | |
| Adiyo kaka | 7º 15N 36º 35E | $T_{max}$ (ºC) | 31.36 | 31.58 | 31.55 | 31.83 | 31.89 | 31.60 | 31.43 | 1600-3348 |
| | | $T_{min}$ (ºC) | 20.49 | 20.63 | 20.66 | 20.75 | 20.99 | 20.69 | 20.54 | |
| | | RF (mm) | 1600.7 | 1538.9 | 1507.1 | 1446.5 | 1508.1 | 1576.2 | 1562.9 | |
| Chena | 7º 15N 35º 45E | $T_{max}$ (ºC) | 30.02 | 30.28 | 30.17 | 30.7 | 30.32 | 30.19 | 29.93 | 1851-2020 |
| | | $T_{min}$ (ºC) | 16.19 | 16.81 | 16.52 | 16.77 | 17.21 | 16.64 | 16.29 | |
| | | RF (mm) | 1394.6 | 1269.1 | 1477.8 | 1408.3 | 1387.9 | 1078.5 | 1335.7 | |
| Gesha | 7 º 40N 35º 50E | $T_{max}$ (ºC) | 26.46 | 26.73 | 26.58 | 27.13 | 26.72 | 26.62 | 26.36 | 1900-2600 |
| | | $T_{min}$ (ºC) | 13.75 | 14.38 | 14.09 | 14.34 | 14.76 | 14.22 | 13.82 | |
| | | RF (mm) | 1721.3 | 1556.1 | 1790 | 1721 | 1741.1 | 1335.9 | 1638.5 | |
| Tello | 7º 00N 36º 20E | $T_{max}$ (ºC) | 30.61 | 30.72 | 30.76 | 30.95 | 31.05 | 30.77 | 30.69 | 1800-2900 |
| | | $T_{min}$ (ºC) | 20.49 | 20.59 | 20.60 | 20.78 | 20.98 | 20.66 | 20.51 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RF (mm) | 1990.7 | 2010 | 1865.9 | 1822.5 | 1935.4 | 2013.9 | 2032.2 |

The map of the study districts is given under Figure 1.

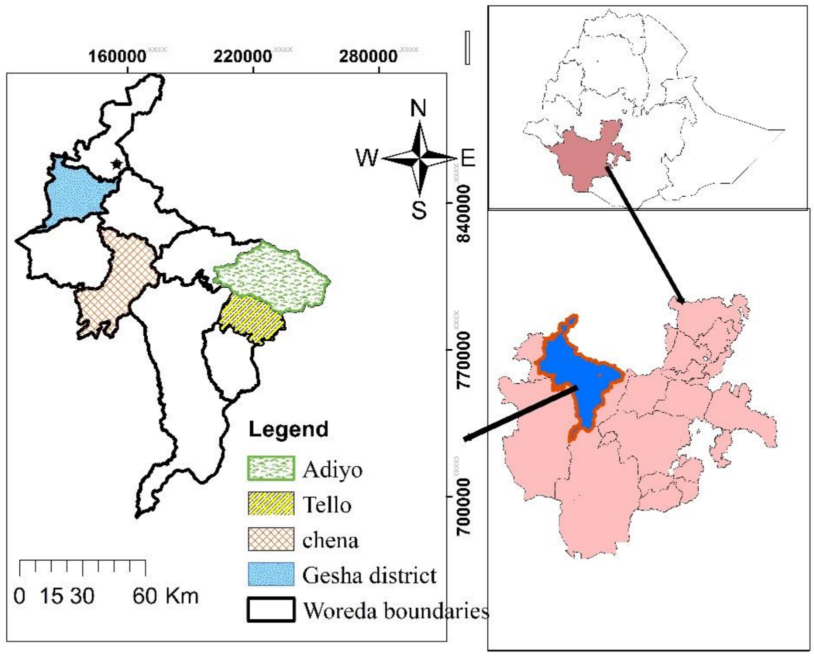



**Figure 1: Map of study area**

### 3.2. General Information and Flock Management

The animals were identified with a plastic ear tag. The ear tag contained code of CBBP cooperative, identification number (ID) of lamb and year of birth. The data for each lamb in recording book includes their sex, birth weight, weaning weight, six-month weight, nine-month weight, yearling weight, coat color, animal ID, sire ID, dam ID, birth date (date, month, and year), birth type, parity, cooperative name, and owners name. In addition of lamb recording book also inventory and ewe recording books are available. Inventory book include owners name, animal ID, sex of animal, birth type, coat color, age and lambing type at each parity. Also, ewe recording book include ewe ID, dam of ewe ID, sire of ewe ID, breeding ram ID, matting date, lambing date, parity, litter size, lamb ID, litter weight, post-partum weight, number of weaned and weight of weaned. One enumerator, who is a member of the community/CBBP cooperative and lives within the community, was employed for each sheep breeding CBBP cooperative for record-keeping and follow-up of the breeding programme. The flock being housed indoor at night in pens made up of bamboo walls and corrugated by any locally available roofing materials. Some participant members kept their flock around homestead at night. Flock were tethered especially adult male and females during crop cultivation period but after cultivation the sheep grazed freely and at times were mixed with neighbors' sheep. During free grazing in private lands, the adult male and female sheep were kept separate by tethering those adult males. However, this is not practiced by all farmers. Main feed source was pasture but additionally crop residue and kitchen leftover were used as source of feed. Feed availability and abundance vary with rainfall patterns. Comparatively huge amount of feed resources was available in rain season whereas less in quality and quantity during the dry season.

CBBP cooperatives were established and legalized by government for effective work of the program. All CBBP cooperatives are formal and registered by the government as “Bonga Sheep Breed Improvement and Multiplication Program cooperative”. Each CBBP cooperative has six committees, namely: main committee, control committee, credit and saving committee, capacity building committee, price determiner committee, and selection committee. The committees are responsible for effective functioning of the program and roles and responsibility are shared among the committees. However, among these committees only main committee and credit and saving committee were active. Selection and price determiner committee are a must for each selection program as a result main committee assign any member to cover their job when they are absent. The main reason of not working properly was poor linkage between CBBP cooperative with cooperative office of respective districts and poor initiation of CBBP cooperative management bodies to take accountability for their action. On the other hand, CBBP cooperative members were mainly focused on financial aspects by selling breeding rams but paid lower attention for breed improvement mechanism which may cause difficulties when market channel become inactive. One evidence for this is when market is inactive lambs was sold in market before selection result decrease in number of candidates.

A community-based breeding program is focused on identified traits of farmers before starting the program. In case of Bonga sheep the identified traits were growth rate, tail type, polled, twining rate and coat color of the breed (Duguma *et al.*, 2010). During selection these traits are incorporated. Even selection of sires was based on six-month weight but if morphologically having horn, black coat color and short tail were culled. Selection of sires was sometimes based on estimated breeding value (EBV). During selection without EBV the lambs are grouped based on litter size/birth type and selection is carried in each group. The reason of grouping was due to weight difference of lamb among birth type. Selection was carried out separately within for each

CBBP cooperative. Selection of male lambs during the initial stages of CBBP since 2009 was carried at six months of age but subsequently the selection is being carried at two stages; screening of heavy weaners at weaning (3-month) followed by selection at six months of age (post weaning). The reason of shifting in to two stage is selling of candidate lambs before six-month. This results in negative selection because it may cause loss of fast grower lambs and the number of candidate rams become decreased in numbers. The selection committee examines lambs for the conformation, coat colour, presence or absence of horn, tail type, birth type and pedigree of lamb during screening (at weaning) and then selects the heavy weaners phenotypically based on their body weight. Then after their selection, the breeder carries selection based on biological data recorded by the enumerators and physical observation. Ram lambs selected at weaning age was again selected at six months of age. The weaners screened at weaning are purchased by the respective CBBP cooperative after price determined by price determiner committee. These screened weaners are maintained by their owners, under strict vigilance of respective CBBP cooperative, till their sale either as breeding rams or for slaughter. Then the price after six months age estimated again and the profit (selling price - weaning weight purchasing price) has shared between CBBP cooperative and farmers on 50:50% basis. Rams culled at the age of six-month weight during post weaning selection are used for fattening by castrating immediately. The number of selection round and number of selected for pre and post (first stage and second stage) ram lamb and rams were presented in Table 8.

**Table 8: Number of selected ram lamb and rams under CBBP**

| CBBP cooperative | Round of selection | First stage selection | Second stage selection |
|---|---|---|---|
| Abeta | 13 | 284 | 220 |
| Alargeta | 12 | 572 | 445 |
| Angikolla | 9 | 153 | 136 |
| Buta | 17 | 739 | 665 |
| Dacha | 20 | 384 | 298 |
| Didifa | 12 | 310 | 284 |
| Dirbedo | 17 | 438 | 396 |
| Guta | 15 | 222 | 195 |
| Kicho | 15 | 287 | 259 |
| Meduta | 15 | 325 | 303 |
| Omashonga | 11 | 208 | 186 |
| Shosha | 19 | 536 | 512 |
| Wanabolla | 9 | 75 | 72 |
| Yama | 13 | 310 | 273 |
| **Total** | **197** | **4843** | **4244** |

The first top 10% of selected rams at 6-month of age known as "**Top Ram**" are used for breeding service within the community by rotating among different sire group and CBBP cooperatives. The member farmer brings their ewe/ewes, showing signs of estrus (heat), to top ram in the tethering area for individual mating. These top ram sires are managed by all members who are using it by buying rope for tethering, providing crop residue and kitchen leftover and tether any area of pasture of CBBP cooperative members. Top rams are used for 2-3 years. After breeding the sire was either castrated for mutton or sold as breeding ram to other community. Selected rams other than these 10% (top rams) are sold to other community in Southern Nation Nationalities and Peoples Region (SNNPR), Non-Governmental Organizations (NGOs), Governmental Organizations (GOs), higher education, cooperative association and private farms for breeding purpose. CBBP incorporate packages of the production which include in addition to breeding schemes health intervention, forage development and fattening system. To handle veterinary activities one health expert was employed for each district, who covers all CBBP cooperatives within the district and renders treatment and vaccinates the sheep. The fattening programme included capacity development and provision of feeding materials / supplements in some CBBP cooperatives members.

## 3.3. Data Collection

### 3.3.1. Performance and pedigree data

Performance and pedigree data for this study was collected from the on-farm 14 out-scaled Bonga sheep CBBPs which have been implemented in Kaffa zone (Table 9).

**Table 9: Establishment year and participant number in the different out scaled CBBPs**

| District | CBBP | Establishment year | Initial Members | | Initial total | Current members | | Current total |
|---|---|---|---|---|---|---|---|---|
| | | | male | Female | | Male | Female | |
| Adiyo Kaka | Alargeta | 2014 | 28 | 2 | 30 | 119 | 15 | 134 |
| | Angiokolla | 2014 | 103 | 2 | 105 | 64 | 3 | 67 |
| | Buta | 2012 | 52 | 6 | 58 | 173 | 27 | 200 |
| | Meduta | 2014 | 34 | 0 | 34 | 79 | 7 | 86 |
| Chena | Omashonga | 2014 | 13 | 4 | 17 | 50 | 7 | 57 |
| | Wanabolla | 2014 | 12 | 9 | 21 | 47 | 18 | 65 |
| Gesha | Abeta | 2012 | 39 | 2 | 41 | 73 | 4 | 77 |
| | Dirbedo | 2012 | 14 | 4 | 18 | 94 | 12 | 106 |
| | Didifa | 2014 | 43 | 4 | 47 | 51 | 8 | 59 |
| | Kicho | 2014 | 27 | 0 | 27 | 63 | 9 | 72 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tello | Dacha | 2012 | 28 | 4 | 32 | 72 | 13 | 85 |
| | Guta | 2014 | 27 | 3 | 30 | 65 | 6 | 71 |
| | Shosha | 2012 | 48 | 5 | 53 | 136 | 11 | 147 |
| | Yama | 2014 | 23 | 6 | 29 | 91 | 14 | 105 |
| **Total** | **14** | | **491** | **51** | **542** | **1177** | **154** | **1331** |

The type of data collected in CBBPs includes pedigree information, growth rate and reproductive traits. The collected body weight data were birth weight (BWT), weaning weight at 3-month (WWT), six-month weight (SMWT), nine-month weight (NMWT) and yearling weight (YWT). Suspended weighing scale having 50 kg capacity with accuracy of 100gm was used to record body weight. Similarly, for average daily gains (ADGs) are ADG from birth to weaning weight (ADG1), ADG from weaning to six-month (ADG2), ADG from six-month to nine-month (ADG3) and ADG from nine-month to yearling weight (ADG4), respectively. The reproductive performance data include age at first lambing (AFL), lambing interval (LI), annual reproductive rate (ARR) and litter size (LS). The detailed data structure and number of records for studied traits was indicated in Table 10.

**Table 10: Data structure for studied traits**

| Item | BWT | WWT | SMWT | NMWT | YWT | ADG1 | ADG2 | ADG3 | ADG4 | AFL | LI | LS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of animals | 22352 | 16565 | 5252 | 2504 | 700 | 16565 | 5220 | 1652 | 492 | 484 | 3894 | 22214 |
| No. of records | 16116 | 11470 | 4238 | 1351 | 563 | 11470 | 4214 | 1312 | 387 | 412 | 3841 | 11629 |
| No. of sires | 968 | 822 | 463 | 319 | 108 | 822 | 463 | 235 | 93 | 48 | 39 | 240 |
| No. of sires with records and progeny in data | 803 | 667 | 360 | 144 | 44 | 667 | 359 | 140 | 34 | 0 | 0 | 0 |
| No. of dams | 6647 | 5285 | 1037 | 966 | 74 | 5285 | 1028 | 250 | 47 | 46 | 142 | 768 |
| No. of dams with records and progeny in data | 891 | 549 | 126 | 16 | 1 | 549 | 126 | 15 | 1 | 22 | 128 | 768 |
| No. of animals with unknown sire | 11095 | 8502 | 2281 | 1417 | 367 | 8502 | 2261 | 668 | 223 | 327 | 3779 | 21472 |
| No. of animals with unknown dam | 6580 | 5323 | 2635 | 1183 | 542 | 5323 | 2625 | 1061 | 391 | 412 | 3643 | 20975 |
| No. of animals with both parents unknown | 6335 | 5161 | 1598 | 1160 | 312 | 5161 | 1588 | 561 | 203 | 285 | 3631 | 20972 |
| No. of animals w/out offspring | 14737 | 10458 | 3752 | 1219 | 518 | 10458 | 3729 | 1167 | 352 | 390 | 3713 | 21206 |
| No. of animals with offspring | 7615 | 6107 | 1500 | 1285 | 182 | 6107 | 1491 | 485 | 140 | 90 | 181 | 1008 |
| No. of animals with known paternal grandsire | 5774 | 3801 | 1206 | 443 | 54 | 3801 | 1205 | 409 | 54 | 0 | 0 | 0 |
| No. of animals with known paternal granddam | 8162 | 5512 | 1262 | 547 | 44 | 5512 | 1253 | 307 | 37 | 0 | 0 | 0 |
| No. of animals with known maternal grandsire | 963 | 529 | 107 | 17 | 1 | 529 | 107 | 16 | 1 | 8 | 6 | 68 |
| No. of animals with known maternal granddam | 1594 | 903 | 125 | 19 | 1 | 903 | 125 | 12 | 1 | 6 | 19 | 122 |

### 3.3.2. Farmers' perception survey

A survey was conducted to assess farmers perception about CBBPs. A structured questioner was prepared to address both participants involved in the program and non-participant farmers who were not involved in the CBBPs. Focus group discussion (FGD), formal interview and direct observation were carried to collect data from both groups of farmers (participant and non-participant). The questioners and discussion for participants focused on breed improvement through the program, economic importance of the program, type of improved traits, farmers flock trend and other management skill developed with the intervention of the program. Also, the questionaries' for non-participants was genetic improvement difference between participants and non-participants, type of ram they use, type of experience developed from participants, flock trend across year, economic difference between participant and non-participant and their interest to join the program (see Appendix F).

The farmers' survey was conducted in seven CBBP cooperatives selected randomly out of 14 CBBPs (Table 9). The selected CBBP cooperatives were Alargeta and Meduta from Adiyo Kaka; Wanabola from Chena; Abeta and Didifa from Gesha and Dacha and Yama from Tello Districts. The number of household samples was determined according to (Yamane, 1967);

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

Where:

n = is the sample size

N = total population size

e = is the level of precision

For randomly selected 7 CBBP cooperatives there are 611 farmer members (Table 9). Thus, the sample size (n) for Precision (e) of 7% because variability was observed during preliminary survey which makes to forced using 7% precision instead of 5%. The calculation was as under:

$611/\ 1+611(0.07^2) = 153$ farmers

Even if the determined sample size was 153 with 22 from members each CBBP cooperative, additionally each enumerator for each CBBP cooperative was included for interview. The same number of individuals were selected randomly from non-participant members. So, totally 7 CBBP cooperatives and 23 members from each CBBP cooperative a total of 161 members were included for participant. For non-participant from respective community 23 from each with a total of 161 farmers were randomly selected. From both participant and non-participant, a total of 322 farmers were interviewed to asses' farmers perception of the program.

### 3.4. Data Analysis

Different software and procedures or models were used for data analysis of phenotypic performance, genetic parameters and survey parts.

### 3.4.1. Phenotypic performance evaluation

The data which is taken with positive or negative deviation of actual date may affect performance of the breed. The objective of adjustments for any environmental differences are to remove performance differences that result because animals are treated differently. According to Inyangala *et al.* (1992) to reduce the biasness, weight measured at different age must be adjusted using the following formulae.

$$\text{Adjusted weaning weight (kg)} = \frac{90(\mathrm{W2} - \mathrm{W1})}{\mathrm{D}} + \mathrm{W1}$$

$$\text{Adjusted 6 month weight (kg)} = \frac{180(\mathrm{W3} - \mathrm{W1})}{\mathrm{D}} + \mathrm{W1}$$

$$\text{Adjusted 9 month weight (kg)} = \frac{270(\mathrm{W4} - \mathrm{W1})}{\mathrm{D}} + \mathrm{W1}$$

$$\text{Adjusted yearling weight (kg)} = \frac{365(\mathrm{W5} - \mathrm{W1})}{\mathrm{D}} + \mathrm{W1}$$

Where:

W1 = birth weight,

W2, W3, W4 and W5 = weight at 3, 6, 9 and 12 months

D = number of days between weighing date and date of birth

ADG is the change in body weight over time and is sometimes called as absolute growth rate (AGR). According to Fitzhugh and Taylor (1971) ADGs in gm/day is calculated as:

$$ADG = (W_{t2} - W_{t1}) / (t_2 - t_1)$$

Where:

$W_{t1}$ = body weights at $t_1$ ages in days

$W_{t2}$ = body weights at $t_2$ ages in days

$$\text{ADG from birth to weaning (g)} = \frac{(\mathrm{AWWt} - \mathrm{BWt})}{90} * 1000$$

$$\text{ADG from weanning to 6 month (g)} = \frac{\mathrm{A6MWt} - \mathrm{AWWt}}{90} * 1000$$

$$\text{ADG from 6 month to 9 month (g)} = \frac{\mathrm{A9MWt} - \mathrm{A6MWt}}{90} * 1000$$

$$\text{ADG from 9 month to yearling (g)} = \frac{\text{AYWt} - \text{A9MWt}}{90} * 1000$$

Where:

ADG = Average Daily Gain
BWt = Birth weight,
AWWt = Adjusted weaning weight at 90 days,
A6MWt = Adjusted 6 months weight at 180 days,
A9MWt= Adjusted 9 months weight at 270 days, and
AYWt = Adjusted yearling weight at 365 days

The effect of non-genetic factors like year of birth, lamb sex, type of birth, season of birth, dam parity, and CBBP cooperative on growth traits was considered. Whereas, for AFL trait year of birth, type of birth, season of birth, dam parity, and CBBP cooperative was included. Also, lambing year, lambing type, lambing season, dam parity and CBBP cooperative for ARR, LI, and LS was analyzed using the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS, 2012 ver. 9.3). All production and reproductive traits were considered as response factor and when significant means were separated using Adjusted Tukey-Kramer method in SAS. The statistical models fitted for growth and reproductive traits were:

**(I) Growth Traits:**

$$y_{ijklmno} = \mu + Y_i + S_j + T_k + B_l + C_m + D_n + e_{ijklmno}$$

Where:

$y_{ijklmn}$ = growth traits of each animal,

$\mu$ = overall mean,

$Y_i$ = effect of $i^{th}$ birth year (i = 1, 2…...7 from 2012 to 2018),

$S_j$ = effect of $j^{th}$ lamb sex (j = male and female),

$T_k$= effect of $k^{th}$ type of birth (k = single, twin, and ≥ triplet),

$B_l$ = effect of $l^{th}$ birth season (l = dry and wet),

$C_m$= effect of $m^{th}$ CBBP cooperatives (m = Abeta, Dirbedo, Guta, Yama, Dacha, Kicho, Didifa, Meduta, Alargeta, Angiokolla, Shosha, Omashonga and Wanabolla),

$D_n$ = effect of $n^{th}$ dam parity (n = 1, 2 …...≥7), and

$e_{ijklmno}$ = residual effect.

**(II) Reproductive Traits:**

**Model for Age at First Lambing (AFL)**:

$$y_{ijklmn} = \mu + Y_i + T_j + B_k + C_l + D_m + e_{ijklmn}$$

Where:

$y_{ijklmn}$ = AFL of each animal,

$\mu$ = overall mean

$Y_i$ = effect of $i^{th}$ birth year (i = 1, 2…...7 from 2012 to 2018),

$T_j$ = effect of $j^{th}$ birth type (j = single, twin, and ≥ triplet),

$B_k$ = effect of $k^{th}$ birth season (k = dry and wet),

$C_l$ = effect of $l^{th}$ CBBP cooperatives (l = Abeta, Dirbedo, Guta, Yama, Dacha, Kicho, Didifa, Meduta, Alargeta, Angiokolla, Shosha, Omashonga and Wanabolla),

$D_m$ = effect of $m^{th}$ dam parity (m = 1, 2, …...≥7), and

$e_{ijklmn}$ = residual effect.

**Model for Lambing Interval (LI)**:

$$y_{ijklmn} = \mu + Y_i + T_j + B_k + C_l + D_m + e_{ijklmn}$$

Where:

$y_{ijklmn}$ = LI of each animal,

$\mu$ = overall mean,

$Y_i$ = effect of $i^{th}$ lambing year (i = 1, 2…...7 from 2012 to 2018)

$T_j$ = effect of $j^{th}$ lambing type (j = single, twin, and ≥ triplet),

$B_k$ = effect of $k^{th}$ lambing season (k = dry and wet),

$C_l$ = effect of $l^{th}$ CBBP cooperatives (l = Abeta, Dirbedo, Guta, Yama, Dacha, Kicho, Didifa, Meduta, Alargeta, Angiokolla, Shosha, Omashonga and Wanabolla),

$D_m$ = effect of $m^{th}$ dam parity (m = 1, 2, …. ≥7), and

$e_{ijklmn}$ = residual effect

According to Wilson (1986), Mekuriaw *et al.* (2013) and Marufa *et al.*, (2017) ARR was computed as litter size multiplied by 365 divided by lambing interval (days). It is number of young produced per breeding female per year.

**Model for Annual Reproductive Rate (ARR) and Litter size (LS)**

$y_{ijklmn} = \mu + Y_i + B_k + C_l + D_m + e_{ijklmn}$

Where:

$y_{ijklmn}$ = ARR and LS of each animal,

$\mu$ = overall mean,

$Y_i$ = effect of $i^{th}$ lambing year (i = 1, 2…...7 from 2012 to 2018),

$B_k$ = effect of $k^{th}$ lambing season (k = dry and wet),

$C_l$ = effect of $l^{th}$ CBBP cooperatives (l = Abeta, Dirbedo, Guta, Yama, Dacha, Kicho, Didifa, Meduta, Alargeta, Angiokolla, Shosha, Omashonga and Wanabolla),

$D_m$ = effect of $m^{th}$ dam parity (m = 1, 2, …. ≥7), and

$e_{ijklmn}$ = residual effect

### 3.4.2. Genetic parameters and breeding value estimation

Pedigree viewer software (Birian and Sandy, 2015) version 6.5 was used to clean duplicates, bisexuality and sequencing animal. Also, R software version 3.4.3 was used for merging data for analysis (R Core Team, 2013). Genetic parameters for growth and reproductive traits were estimated by restricted maximum likelihood method with an animal model using WOMBAT software (Meyer, 2012). Restricted maximum likelihood methods have been used extensively to estimate (co)variance components for body weight in sheep (Nemutandani, 2016) because they can partition the phenotypic variance of a quantitative trait into additive genetic variance, environmental variance and other effects such as maternal, common environmental, or permanent environmental effects (Meyer, 1989).

Genetic parameters of growth and AFL traits estimated with univariate, bivariate, and multivariate analysis and LI and LS of reproductive traits were used repeatability animal models. Convergence was achieved by changing arbitrary starting value of variance for each traits of variance component. Six different type of models were used for genetic parameter estimation of growth and reproductive traits. These address additive effect of animal, maternal effect for lamb traits, maternal permanent environmental effect but for reproductive traits except AFL animal permanent environmental effect ($\mathbf{Z}_{3pe}$) considered instead of maternal permanent environmental effect ($\mathbf{Z}_{3c}$). The fixed effects included in the model were those found to have significant effect in the phenotypic least-square analyses by SAS.

The models are as follows:

**Model 1**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + e$

**Model 2**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + \mathbf{Z}_{3\ c} + e$

**Model 3**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + \mathbf{Z}_{2\ m} + e$ with Cov(a,m) = 0

**Model 4**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + \mathbf{Z}_{2\ m} + e$ with Cov(a,m) = $A\sigma_{am}$

**Model 5**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + \mathbf{Z}_{2\ m} + \mathbf{Z}_{3\ c} + e$ with Cov(a,m) = 0

**Model 6**: $\mathbf{Y} = \mathbf{X}_b + \mathbf{Z}_{1\ a} + \mathbf{Z}_{2\ m} + \mathbf{Z}_{3\ c} + e$ with Cov(a,m) = $A\sigma_{am}$

Where:

Y = growth and reproductive traits,

b = a vector contained fixed effects (birth year, CBBP cooperative, birth type, birth season, dam parity and lamb sex for growth traits; birth year for AFL; and lambing year, CBBP cooperative, lambing season and dam parity for LI and LS),

a = direct additive genetic effects,

m = maternal genetic effects for lamb traits,

c = maternal permanent environmental effect,

e = residual effect,

**X**= incidence matrices observations to b,

$\mathbf{Z}_1$= incidence matrices to a,

$\mathbf{Z}_2$ = incidence matrices to m,

$\mathbf{Z}_3$ = incidence matrices to c,

A = numerator relationship matrix between animals, and

$\sigma_{am}$ = covariance between direct and maternal genetic effects.

Incidence matrices are that relate the effect to the records. All models include an additive direct effect and this was the only random factor in Model 1. Model 2 included the maternal permanent environmental effect, fitted as an additional random effect. Model 3 include an additive maternal effect fitting as a second random effect.

Model 4 was the same as Model 3, but allowed for a direct maternal covariance (Cov(a,m)). Model 5 and Model 6 include both additive, maternal and maternal permanent environmental effects, ignoring and fitting, respectively, direct-maternal covariance.

Generally, the (co)variance structure for studied traits was as follows:

$$\mathbf{Var}\begin{Bmatrix} \mathbf{a} \\ \mathbf{m} \\ \mathbf{c} \\ \mathbf{e} \end{Bmatrix} = \begin{Bmatrix} \mathbf{A\sigma^2}\boldsymbol{a} & \mathbf{A\sigma am} & \mathbf{0} & \mathbf{0} \\ \mathbf{A\sigma am} & \mathbf{A\sigma^2}\boldsymbol{m} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{Id\sigma^2 c} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{In\sigma^2}\boldsymbol{e} \end{Bmatrix}$$

According to Fadili *et al.* (2000) the (co)variance structure of the random effects in the analysis were:

$V(a) = A\sigma^2_a$, $V(m) = A\sigma^2_m$, $V(c) = Id\sigma^2_c$, $V(e) = In\sigma^2_e$, $Cov(a,m) = A\sigma_{am}$

where:

A = numerator relationship matrix between animals,

$\sigma_a^2$ = direct additive genetic variance,

$\sigma_m^2$ = maternal additive genetic variance,

$\sigma_{am}$ = direct-maternal additive genetic covariance,

$\sigma_c^2$ = maternal permanent environnemental variance,

$\sigma_e^2$ = residual variance,

Id = identity matrices of an order equal to the number of dams, and

In = identity matrices of an order equal to the number of records.

Estimates of additive direct ($h^2_a$) and additive maternal ($h^2_m$) heritability and ratio of maternal permanent environmental variance with phenotypic variance ($c^2$) were calculated as ratios of estimates of additive direct ($\sigma_a^2$), additive maternal ($\sigma_m^2$) and maternal permanent environmental ($\sigma_c^2$) variances to the phenotypic variance ($\sigma_p^2$), respectively.

Total heritability was calculated according to the following equation (Willham, 1972):

$$h^2{}_t = \frac{\sigma^2{}_a + 0.5\sigma^2{}_m + 1.5\sigma_{am}}{\sigma^2{}_p}$$

According to the $h^2_t$ formula, when direct-maternal genetic covariance is positive and presence of maternal genetic effects increases the total heritability and the potential response to selection (Kesbi and Eskandarinasab, 2008). Heritability ranging from < 0.1 are considered as low while heritability ranging 0.1 to 0.3 and above 0.3 are considered as medium and high, respectively (Berhanu, 2000).

Genetic correlations between the traits must be taken into consideration when the breeding plan is drawn up, as unfavorable correlations could lead to unwanted selection responses in correlated traits (Olivier and Greyling, 2011). The genetic correlation between direct and maternal genetic effects ($r_{am}$) was estimated as the ratio of the estimates of the $\sigma_{am}$ to the product of the square roots of the estimates of $\sigma^2_a$ and $\sigma^2_m$.

$$r_{am} = \frac{\sigma_{am}}{\sqrt{\sigma 2a * \sigma 2m}}$$

Genetic and phenotypic correlations were estimated using bivariate and direct additive multivariate analysis. The genetic correlation ($r_g$) between traits were estimated as following Falconer and Mackay (1996):

$$rg = \frac{\sigma_{a12}}{\sqrt{\sigma^2 a1 * \sigma^2 a2}}$$

Where: $\sigma_{a12}$ = genetic covariance between the traits 1 and 2,

$\sigma^2{}_{a1}$ = genetic variance for trait 1, and

$\sigma^2{}_{a2}$ = genetic variance for trait 2.

Similarly, phenotypic correlation ($r_p$) between traits were estimated as:

$$rp = \frac{\sigma_{a12}}{\sqrt{\sigma^2 a1 * \sigma^2 a2}}$$

Where:

$\sigma_{a12}$ = phenotypic covariance between the traits 1 and 2,

$\sigma^2{}_{a1}$ = phenotypic variance for trait 1, and

$\sigma^2{}_{a2}$ = phenotypic variance for trait 2.

Correlation is categorized as low or weak (<0.3), medium (0.3 to 0.7) and high (strong) (0.7 to 1) (Ratner, 2009).

Repeatability was estimated for this study for litter size (LS) and lambing interval (LI) traits. The repeatability (r) is the fraction of the repeated observation variance, which is the sum of additive genetic variance and animal permanent environmental variance of a trait to total phenotypic variance (Mokhtari *et al.*, 2010):

$$r = \frac{\sigma^2{}_a + \sigma^2{}_{pe}}{\sigma^2{}_p}$$

where:

$\sigma^2_a$ = additive genetic variance;

$\sigma^2_{pe}$ = animal permanent environmental variance

$\sigma^2_p$ = phenotypic variance

Repeatability was categorized as lowly repeatable ($r < 0.2$), moderately repeatable ($0.2 < r < 0.4$) and highly repeatable ($r > 0.4$).

The annual genetic trend of studied traits was computed as the regression coefficients of the trait's values on the year of birth, after adjusting the records for the non-genetic effects. Evaluating additive genetic gains over time is an appropriate method to assess the efficiency of the breeding programs. The effectiveness of selection is typically measured by the rate of genetic gain that results. Genetic trends were estimated by averaging the predicted breeding values within the year (Kariuki *et al*., 2010). Genetic gain was calculated by deducting estimated breeding value (EBV) from 2018 to 2012 i.e. end of the year **-** beginning year of the program (Amarilho-Silveira *et al*., 2018).

### 3.4.3. Model selection

To determine the most appropriate model, both likelihood ratio tests (LRT) and Akakie information criteria (AIC) were used for each trait. The significance of model comparison was done from univariate analysis of animal models with and without including the effects as a random effect and compare the final log-likelihoods (Maximum log L) by chi-square distribution for $\alpha = 0.05$ with one degree of freedom (Wilson *et al.,* 2010). An effect was considered to have a significant influence when its inclusion caused a significant increase in log likelihood, compared with the model in which it was ignored.

$$\chi^2_{1df} = 2(L(\mathbf{x})_f - L(\mathbf{x})_r)$$

The LRT was distributed as a $\chi^2$ statistic with degrees of freedom equal to ($p_f - p_r$).

Where:

LRT =loglikelihood Ratio Test,

$L(\mathbf{x})_f$ =maximum likelihood for full model,

$L(\mathbf{x})_r$ = maximum likelihood for reduced model,

$P_f$ =parameter for full model, and

$P_r$ = parameter for reduced model.

The degree of freedom is obtained by deducting the number of parameters from full model to reduced model. If the chi-square distribution value is significance at ($p < 0.05$) the full model is best fit the data (Wilson *et al.,* 2010). Using LRT, only models that differ by at least one parameter are comparable, i.e., comparison of model 2 with model 3 and model 4 with model 5 is not feasible by LRT because both models include the same number of parameters which is 3 and 4 respectively. For this reason, the Akaike information criterion (AIC) of Akaike (1974) was computed to rank the models. Let p denote the number of random (co)variance parameters to be estimated and Log L is the maximum likelihood, then the information criterion is defined as:

$$AIC = -2\text{Log } L + 2p$$

The model yielding the smallest AIC value fits the data best (Akaike, 1974).

### 3.4.4. Analysis of farmers' perception

The collected data from both participant and non-participant farmers was analyzed by statistical package for social science (SPSS) version 20 (IBM, 2011). Descriptive statistics were applied for analysis particularly mean and frequency distribution whereas focus group discussion was open ended and used for discussion purpose.

Indices were calculated to provide rankings of the type of improved traits and constraineds faced.

Index = Sum of (3 X number of households ranked first + 2 X number of households ranked second + 1 X number of households ranked third) given for an individual improved trait divided by the sum of (3 X number of households ranked first + 2 X number of households ranked second + 1 X number of households ranked third) for overall improved traits. Then after index calculation ranking was done. Similar procedure was done for major constraints of CBBP.

Mann-Whitney U test was used to test significance of non-parametric test for selling price of sheep at different age and sex group for participant and non-participant community members. The reason of using Mann-Whitney U test is the collected data was independent and not normally distributed because interviewee replied frequent price values based on local market.

# 4. RESULTS AND DISCUSSION

## 4.1. Non-genetic Factors Affecting Growth and Reproductive Traits

### 4.1.1. Growth traits

#### (A) Body Weights

The effects of non-genetic factors on growth traits were identified and included year of birth, CBBP cooperative, lamb sex, birth season, birth type and dam parity. The ANOVA and least square means for body weights are presented in appendix A, Tables 1 to 5 and Table 11, respectively. The overall least square means ± standard errors of 3.13±0.01, 16.07±0.07, 24.7±0.2, 30.4±0.4 and 34.04±0.84 were obtained for BWT, WWT, SMWT, NMWT and YWT of Bonga sheep respectively (Table 11). The results also showed that these body weights ranged from 1 to 4.9, 7.5 to 31, 11 to 41.5, 20 to 52, and 18 to 62kgs for BWT, WWT, SMWT, NMWT and YWT, respectively. Body weights of Bonga sheep obtained at different ages in this study was comparable with Horro, Rutana (desert ecotype of Sudan sheep) Gumz cross, and exotic Pure Dorper sheep breeds reported in the range of 3.12±0.129 to 3.22±0.06kg for BWT (Haile *et al*., 2014 and Yohannes *et al.* 2018) respectively, 16.18±0.35kg for WWT, 24.30±0.59 for SMWT and 34.43±0.79kg for YWT (Ayele *et al.*, 2015). However, it was higher than the values ranged from 2.27±0.043 to 2.84±0.06kg for BWT, 8.98±0.24 to 14.8±0.226kg for WWT, 13.7±0.3 to 23.8±0.16 kg for SMWT, 19.96±0.35kg for NMWT and 16.9±0.45 to 26.9±3.98kg for YWT for BHS, ecotype of Jimma zone, Afar, Farta, previous study of Bonga, Horro, Menz, Atsbi highland, and Gumz sheep breeds reported in the literatures (Yacob, 2008; Berhanu and Aynalem, 2009; Wilson, 2011; Shigdafe *et al*., 2013; Haile *et al*., 2014; Mengestu, 2018; and Yohannes *et al.*, 2018) respectively. The result of the study was higher than Dorper-Afar (50%) cross, Dorper-Menz (50%) cross and Rutana-Gumz (50%) cross reported in the range of 2.57±0.06 to 2.77±0.04kg for BWT, 9.45±0.87 to 13.03±0.22kg for WWT, 13.18±0.97 to 17.45±0.29kg for SMWT, 21.91±0.37kg for NMWT and 24.96±3.77 to 31.33±0.56kg for YWT (Ayele *et al.*, 2015 and Yohannes *et al.*, 2018) respectively. Bonga sheep had higher body weights than some exotic sheep breeds like Rutana, West African Dwarf Djallonke, Somali Arab of northern Somalia and Red Masai sheep breeds reported in the range of 2.2 to 2.8kg for BWT, 10.5 to 14.40±0.23kg for WWT, 18.93±0.29kg for SMWT, 23.29±0.37kg for NMWT and 22 to 27.62±0.36kg for YWT (Gbangboche *et al.,* 2006; Wilson, 2011 and Yohannes *et al.* 2018) respectively. Least square mean of Bonga sheep BWT was lower than previous study of the same breed 3.42±0.051kg (Haile *et al*., 2014) may be due to higher sample size use for current study, exotic Pure Dorper sheep BWT 3.39±0.08 (Ayele *et al.*, 2015) and Rutana exotic sheep BWT 3.71±0.07 (Yohannes *et al.*, 2018). One of the reasons of lower BWT than previous study may be due to sample size difference that more records was used for current study. The detailed result of phenotypic performance for each studied trait by considering each fixed effect for each CBBP cooperatives was presented in (APPENDIX D Table 14 to 27).

**(I) Year of Birth**

The year of birth showed significant difference ($P< 0.001$) for BWT, WWT, SMWT, NMWT and YWT (Table 11). The body weights, under study, showed fluctuating trend over the years. The possible reason for this may be variation in the environmental conditions, number of record difference (sample size), availability of forage, feeding and other managemental conditions over the last seven years (2012 to 2018). Difference observed in weights measured at different age between years may be a reflection of difference in feed availability, between years caused by variation in total annual precipitation and the distribution of rain fall (Duguma, 2001).

**Table 11: Least square means (±SE) for all body weight traits by different fixed effects**

| Fixed effect | N | BWT | N | WWT | N | SMWT | N | NMWT | N | YWT |
|---|---|---|---|---|---|---|---|---|---|---|
| **Overall** | **16116** | **3.13±0.01** | **11470** | **16.07±0.07** | **4238** | **24.7±0.2** | **1351** | **30.4±0.4** | **563** | **34.04±0.84** |
| CV % | | 17.6 | | 15.9 | | 14.8 | | 12.4 | | 15 |
| Range (kg) | | 1- 4.9 | | 7.5 – 31 | | 11 - 41.5 | | 20 – 52 | | 18 - 62 |
| **Year** | p-value | <.0001 | | <.0001 | | 0.0049 | | <.0001 | | 0.0007 |
| 2012 | 322 | 2.98±0.03$^{d}$ | 178 | 16.1±0.2$^{abcd}$ | 45 | 24.7±0.6$^{ab}$ | 10 | 34.9±1.3$^{a}$ | 16 | 31.4±1.7$^{c}$ |
| 2013 | 801 | 3.02±0.02$^{d}$ | 539 | 15.8±0.13$^{bcd}$ | 207 | 24.0±0.3$^{b}$ | 34 | 29.9±0.8$^{bc}$ | 63 | 33.3±1.1$^{bc}$ |
| 2014 | 2605 | 3.2±0.01 $^{a}$ | 1939 | 16.2±0.1$^{a}$ | 887 | 24.6±0.2$^{b}$ | 287 | 30.4±0.4$^{b}$ | 122 | 35.6±0.9$^{ab}$ |
| 2015 | 3816 | 3.1±0.01$^{bc}$ | 2957 | 15.8±0.1$^{cd}$ | 1222 | 24.8±0.2$^{b}$ | 447 | 29.1±0.4$^{c}$ | 142 | 36.3±0.9$^{a}$ |
| 2016 | 3959 | 3.05±0.01$^{ab}$ | 3180 | 15.7±0.1$^{d}$ | 1267 | 24.6±0.2$^{b}$ | 441 | 29.0±0.4$^{c}$ | 197 | 35.1±0.9$^{abc}$ |
| 2017 | 3073 | 3.10±0.01 $^{c}$ | 2248 | 16.0±0.1$^{abc}$ | 599 | 25.2±0.2$^{a}$ | 132 | 28.8±0.5$^{c}$ | 23 | 32.6±1.4$^{bc}$ |
| 2018 | 1540 | 3.16±0.01$^{ab}$ | 429 | 16.3±0.14 $^{a}$ | 11 | 25.1±1.2$^{ab}$ | - | - | - | - |
| **Coop** | p-value | <.0001 | | <.0001 | | <.0001 | | <.0001 | | <.0001 |
| Abeta | 1721 | 3.06±0.01$^{de}$ | 1071 | 15.1±0.1$^{de}$ | 156 | 23.5±0.4$^{d}$ | 98 | 27.9±0.5$^{c}$ | 50 | 31.0±1.1$^{c}$ |
| A.geta | 1460 | 3.3±0.01$^{b}$ | 1242 | 17.6±0.1$^{a}$ | 673 | 24.1±0.3$^{cd}$ | 272 | 30.3±0.4$^{b}$ | 63 | 33.1±1$^{c}$ |
| A.kola | 620 | 3.6±0.02$^{a}$ | 427 | 17.9±0.15$^{a}$ | 99 | 26.4±0.4$^{b}$ | - | - | 11 | 41.8±1.9$^{a}$ |
| Dacha | 1611 | 3.1±0.01$^{c}$ | 1252 | 14.5±0.1$^{ef}$ | 714 | 23.2±0.3$^{d}$ | 413 | 29.4±0.4$^{b}$ | 186 | 32.5±0.8$^{c}$ |
| Didifa | 1086 | 2.8±0.02$^{g}$ | 664 | 17.1±0.1$^{b}$ | 167 | 25.9±0.4$^{b}$ | 8 | 31.4±1.4$^{b}$ | 35 | 35.8±1.2$^{b}$ |
| D.bedo | 1731 | 3.1±0.01$^{cd}$ | 1150 | 17.6±0.1$^{a}$ | 417 | 24.0±0.3$^{cd}$ | 190 | 29.3±0.4$^{b}$ | 40 | 31.9±1.1$^{c}$ |
| Guta | 1122 | 2.9± 0.02$^{g}$ | 605 | 15.8±0.1$^{c}$ | 165 | 25.8±0.4$^{b}$ | 77 | 31.9±0.6$^{b}$ | - | - |
| Kicho | 1074 | 3.0±0.01$^{ef}$ | 826 | 14.7±0.1$^{de}$ | 477 | 23.4±0.3$^{d}$ | 3 | 28.5±2.3$^{bc}$ | 31 | 33.9±1.2$^{bc}$ |
| M.uta | 1412 | 3.0± 0.01$^{ef}$ | 1006 | 14.5±0.1$^{ef}$ | 418 | 22.7±0.3$^{de}$ | 117 | 30.0±0.5$^{b}$ | 17 | 34.9±1.5$^{bc}$ |
| O.hoga | 897 | 3.3±0.02$^{b}$ | 710 | 15.4±0.1$^{cd}$ | 116 | 26.0±0.4$^{b}$ | - | - | 15 | 39.2±1.6$^{a}$ |
| Shosha | 1632 | 3.3±0.01$^{b}$ | 1183 | 16.7±0.1$^{b}$ | 505 | 25.3±0.3$^{bc}$ | 126 | 31.3±0.5$^{b}$ | 101 | 32.2±0.9$^{bc}$ |
| W.lla | 745 | 3.3±0.02$^{b}$ | 531 | 14.2±0.1$^{f}$ | 87 | 22.7±0.5$^{de}$ | - | - | - | - |
| Yama | 1005 | 3.0±0.02$^{ef}$ | 803 | 17.8±0.1 $^{a}$ | 244 | 28.2±0.3$^{a}$ | 47 | 33.6±0.7$^{a}$ | 14 | 37.6±1.7$^{ab}$ |
| **Season** | p-value | 0.4288 | | 0.0249 | | 0.0968 | | 0.0873 | | 0.5291 |
| Dry | 7924 | 3.1±0.01 | 5707 | 16.1±0.07 | 2063 | 24.8±0.2 | 735 | 30.5±0.4 | 327 | 33.9±0.9 |
| Wet | 8192 | 3.09±0.01 | 5763 | 16.0±0.07 | 2175 | 24.6±0.2 | 616 | 30.2±0.4 | 236 | 34.20.9 |
| **Sex** | p-value | <.0001 | | <.0001 | | <.0001 | | <.0001 | | <.0001 |
| Male | 10555 | 3.2±0.01 | 7639 | 16.7±0.07 | 2985 | 26.5±0.2 | 1010 | 33.2±0.4 | 453 | 37.7±0.8 |
| Female | 5561 | 3.0±0.01 | 3831 | 15.4±0.07 | 1253 | 22.9±0.2 | 341 | 27.5±0.5 | 110 | 30.4±1.0 |
| **B. type** | p-value | <.0001 | | <.0001 | | <.0001 | | <.0001 | | 0.0111 |
| Single | 7146 | 3.47±0.03$^{a}$ | 5281 | 17.6±0.05$^{a}$ | 2172 | 25.9±0.2$^{a}$ | 718 | 31.4±0.4$^{a}$ | 311 | 35.2±0.8$^{a}$ |
| Twin | 8554 | 3.1±0.008$^{b}$ | 5916 | 15.9±0.05$^{b}$ | 1966 | 24.6±0.2$^{b}$ | 599 | 30.8±0.4$^{b}$ | 238 | 33.7±0.7$^{b}$ |
| ≥ Triple | 416 | 2.7±0.03$^{c}$ | 273 | 14.6±0.16$^{c}$ | 100 | 23.7±0.4$^{c}$ | 34 | 28.8±0.8$^{c}$ | 14 | 33.2±1.7$^{b}$ |
| **Parity** | p-value | <.0001 | | 0.0003 | | 0.8529 | | 0.5259 | | 0.7386 |
| 1 | 6795 | 3.07±0.01$^{b}$ | 3097 | 15.7±0.07$^{d}$ | 1130 | 24.3±0.2 | 372 | 30.3±0.5 | 174 | 33.7±0.9 |
| 2 | 4177 | 3.11±0.01$^{a}$ | 3067 | 15.9±0.07$^{c}$ | 1193 | 24.3±0.2 | 383 | 30.3±0.5 | 162 | 33.5±0.9 |
| 3 | 2417 | 3.10±0.01$^{a}$ | 2830 | 15.9±0.07$^{c}$ | 1044 | 24.4±0.2 | 345 | 30.3±0.5 | 136 | 33.8±0.9 |
| 4 | 1241 | 3.11±0.02$^{a}$ | 968 | 16.0±0.1$^{c}$ | 327 | 24.7±0.3 | 99 | 30.0±0.6 | 37 | 33.0±1.2 |
| 5 | 716 | 3.09±0.02$^{ab}$ | 644 | 16.1±0.12$^{bc}$ | 246 | 24.8±0.3 | 72 | 30.4±0.6 | 28 | 33.9±1.2 |
| 6 | 433 | 3.08±0.02$^{ab}$ | 405 | 16.5±0.15$^{ab}$ | 139 | 25.5±0.4 | 37 | 30.7±0.7 | 11 | 35.4±1.9 |
| ≥ 7 | 337 | 3.08±0.02$^{ab}$ | 459 | 16.4±0.14$^{b}$ | 159 | 25.1±0.4 | 43 | 30.5±0.7 | 15 | 35.2±1.6 |

*Where: coop =CBBP cooperatives; B.type = Birth type; A.geta =Alargeta; A.kola = Angiokola; D.bedo = Dirbedo; M.uta =Meduta; O.honga = Omashonga; W.lla = Wanabolla; Means with different letter in column within fixed effects are significantly different (P<0.05)*

### (II) CBBP Cooperative Effect

The cooperatives showed highly significant (P<0.0001) effect on all body weights measured (BWT, WWT, SMWT, NMWT, YWT). Perusal of results in Table 11 showed that BWT, WWT and YWT were heaviest in the lambs of Angiokola cooperatives whereas lambs of Yama cooperative had highest SMWT and NMWT. The lowest weights at birth, weaning, six months, nine months and one year were recorded in the lambs of Didifa, Wanabolla, Wanabolla, Abeta and Abeta cooperatives, respectively. The variation in the body weights among the cooperatives may possibly be due to the differences in the flock management practices, availability of feed / fodder and other environmental conditions among the cooperatives.

**(III) Season of Birth**

The results in Table 11 showed that season of birth had no significant influence on the body weights under study except WWT ($P = 0.0249$). The reason of non-significance of birth season ($P>0.05$) may be due feed resource is not a crucial problem of the area. Similarly, Haile *et al.* (2013) explained that feed availability in quality and quantity is the major challenge in all production systems (Afar, Menz, and Horro) except in Bonga. Year of birth had significance influence on body weight but season didn't because good season and bad season were cancelling each other.

**(IV) Sex of Lamb**

The sex of lamb exhibited highly significant effect on all the body weights (Table 11). The male lambs were heavier than female lambs in all body weights. This result was in agreement with the report of Markos (2006). The possible reason for heavier weight in male sex may be due to the effect of hormones and physiological function in the two sexes. The heavier body weight of ram lambs than their female counter parts in early life such as weaning weights and six-month weights may be due to greater birth weights and growth rate of male lambs.

**(V) Type of Birth**

Type of birth had significant effect ($P< 0.01$) on all body weights except yearling weight (Table 11). Perusal of Table 11 showed that a uniform trend was exhibited in the body weights among singles, twins and triplets wherein the body weights of single born lambs were highest and triplets lowest. The result was in agreement with Markos (2006) who state that single born lamb was higher than multiple birth due to the inability of ewes to provide sufficient nourishment for the development of fetuses and extra milk for lambs or competition for resources. Similarly, Gamasaee *et al*. (2010) mentioned that the significant effect of birth type on body weight can be explained by limited uterine space during pregnancy, nutrition of dam especially during last pregnancy and competition for milk suckling between multiple birth lambs during birth to weaning.

**(VI) Dam Parity**

The effect of dam parity was significant (P<0.001) on birth weight and weaning weight but non-significant on SMWT, NMWT and YWT. In the birth weight all pair-wise differences were non-significant except parity 1-2, 1-3 and 1-4 which were significant. However, in WWT the pair-wise differences were significant except parities 2-3, 2-4, 2-5, 3-4, 3-5, 5-6, 5-7 and 6-7 parities. The results further showed that lambs born to first parity dams were lower in respective body weights compared to other parities. The possible reason for this may be ascribed to the younger age of first parity dams coupled with their inexperience in mothering of lambs. The result is in agreement with London and Weniger (1996) maiden ewes are still growing therefore the competition between foetal growth and maternal growth could be result smaller body weight of lambs than latter delivered lambs. Also, the reproductive organs of first parity ewes are less developed to bear large foetus in which case the physiology adjusts the foetal size (Markos, 2006). This might be explained by the fact that young dams that had not reached adult size continued to grow during pregnancy and thus competed with the fetus for available nutrients (Duguma, 2001).

**(B) Body Weight Gains**

The effects of non-genetic factors on body weight gains (ADG1, ADG2, ADG3 and ADG4) were identified and included year of birth, CBBP cooperative, lamb sex, birth season, birth type and dam parity. The ANOVA and least square means of these body weight gains are presented in appendix B Table 6 to 9 and Table 12, respectively. The overall mean ADG1, ADG2, ADG3 and ADG4 (Table 12) for Bonga sheep were 141.9±0.8, 98.65±2.4, 87.6±4.3 and 58.7±8.5gm/day, respectively. The present results of body weight gains in Bonga breed was comparable with Dorper and Egyptian Rahmani sheep breeds reported in the range of 142.93±3.89 to 148.499±42.1 gm/day for ADG1 (Ayele *et al.,* 2015 and Radwan and Shalaby, 2017) respectively and 90.76±40.4 gm/day for ADG2 (Radwan and Shalaby, 2017). However current result was higher than Arsi Bale, Adilo, BHS, previous study of Bonga, Horro, Menz, and Gumz breeds of Ethiopia reported in the range of 98.2±0.96 to 102.01gm/day for ADG1, 46.34±3.29 to 90 gm/day for ADG2 and 37.5±0.71 to 60±9 gm/day for ADG3 (Getahun, 2008; Yacob, 2008; Haile *et al.,* 2014; and Yohannes *et al.,* 2018). Also, Bonga sheep had higher ADG than Dorper-Afar (50%) cross, Dorper-Menz (50%) cross, Rutana lambs, and Rutana-Gumz cross breeds reported in the range of 73.19±10.89 to 118.05±2.67 gm/day for ADG1 and 52.15±3.36 to 59.01±3.44 gm/day for ADG2 (Ayele *et al.*, 2015 and Yohannes *et al.*, 2018), respectively.

**Table 12: Least square means for all average daily gains (± SE) by different fixed effects**

| Fixed effect | N | ADG1 | N | ADG2 | N | ADG3 | N | ADG4 |
|---|---|---|---|---|---|---|---|---|
| **Overall** | **11470** | **141.9±0.8** | **4214** | **98.65±2.4** | **1312** | **87.6±4.3** | **387** | **58.7±8.5** |
| CV% | | 19.6 | | 40.6 | | 55.4 | | 60.9 |
| Range (gm) | | 33 – 293 | | 5 – 422 | | 2 - 388 | | -85 - 206 |
| **Year** | p-value | <.0001 | | <.0001 | | <.0001 | | 0.1919 |
| 2012 | 178 | 145.7±2.3$^{a}$ | 45 | 100.7±5.8$^{ab}$ | 9 | 150.6±12.8$^{a}$ | - | - |
| 2013 | 539 | 140.7±1.5$^{ab}$ | 205 | 89.0±3.0$^{c}$ | 33 | 95.9±7.8$^{b}$ | 15 | 66.2±11.8 |
| 2014 | 1939 | 142.6±1.0$^{a}$ | 879 | 91.1±1.9$^{c}$ | 280 | 82.8±4.2$^{b}$ | 93 | 61.6±7.0 |
| 2015 | 2957 | 139.5±0.8$^{ab}$ | 1213 | 96.4±1.8$^{b}$ | 438 | 65.8±3.9$^{c}$ | 119 | 50.8±6.6 |
| 2016 | 3180 | 139.1±0.9$^{b}$ | 1262 | 97.5±1.8$^{b}$ | 431 | 66.4±3.9$^{c}$ | 151 | 47.4±6.3 |
| 2017 | 2248 | 141.7±0.9$^{a}$ | 599 | 104.8±2.2$^{a}$ | 131 | 64.0±4.7$^{c}$ | 9 | 39.3±13.5 |
| 2018 | 429 | 143.8±1.6$^{a}$ | 11 | 111±11.2$^{a}$ | - | - | - | - |
| **Coop** | p-value | <.0001 | | <.0001 | | <.0001 | | 0.8570 |
| Abeta | 1071 | 131.0±1.2$^{e}$ | 156 | 98.8±3.7$^{bc}$ | 93 | 63.1±4.9$^{d}$ | 43 | 56.1±9.1 |
| A.geta | 1242 | 156.2±1.2$^{b}$ | 672 | 77.5±2.7$^{d}$ | 272 | 75.7±4.2$^{cd}$ | 63 | 61.7±9.2 |
| A.kolla | 427 | 156.2±1.6$^{b}$ | 98 | 102.5±4.5$^{bc}$ | - | - | - | - |
| Dacha | 1252 | 123.5±1.1$^{gh}$ | 713 | 100.0±2.7$^{bc}$ | 408 | 72.0±3.9$^{cd}$ | 183 | 62.0±8.3 |
| Didifa | 664 | 155.9±1.4$^{b}$ | 167 | 102.9±3.7$^{b}$ | 7 | 232.0±14.2$^{a}$ | - | - |
| D.bedo | 1150 | 158.8±1.2$^{b}$ | 416 | 77.6±2.9$^{d}$ | 187 | 65.0±4.1$^{d}$ | 32 | 54.4±10.0 |
| Guta | 605 | 141.4±1.4$^{d}$ | 164 | 105.3±3.7$^{b}$ | 75 | 80.8±5.6$^{bc}$ | - | - |
| Kicho | 826 | 128.6±1.3$^{ef}$ | 477 | 95.3±2.8$^{c}$ | 3 | 56.1±21.3$^{bcd}$ | - | - |
| Meduta | 1006 | 125.9±1.2$^{fg}$ | 413 | 90.6±2.9$^{c}$ | 114 | 88.9±4.7$^{b}$ | 16 | 60.2±11.9 |
| O.shong | 710 | 133.0±1.3$^{e}$ | 111 | 118.3±4.1$^{a}$ | - | - | - | - |
| Shosha | 1183 | 147.8±1.1$^{c}$ | 503 | 91.1±2.8$^{c}$ | 119 | 76.4±4.9$^{cd}$ | 36 | 52.3±9.9 |
| W.lla | 531 | 119.1±1.5$^{h}$ | 83 | 104.4±4.7$^{b}$ | - | - | - | - |
| Yama | 803 | 166.9±1.3$^{a}$ | 241 | 118.0±3.3$^{a}$ | 44 | 65.9±6.6$^{cd}$ | 14 | 57.7±12.4 |
| **Season** | p-value | 0.0387 | | 0.8155 | | 0.7505 | | 0.6609 |
| Dry | 5707 | 142.4±0.9 | 2052 | 98.8±2.4 | 716 | 87.9±4.5 | 239 | 59.2±8.6 |
| Wet | 5763 | 141.3±0.9 | 2162 | 98.5±2.5 | 606 | 87.3±4.4 | 148 | 58.2±8.8 |
| **Sex** | p-value | <.0001 | | <.0001 | | <.0001 | | 0.0147 |
| Male | 7639 | 147.7±0.8 | 2971 | 107.8±2.4 | 987 | 95.7±4.3 | 301 | 68.5±8.4 |
| Female | 3831 | 136.0±0.9 | 1243 | 89.5±2.6 | 335 | 79.5±4.7 | 86 | 48.8±9.2 |
| **B. type** | p-value | <.0001 | | 0.0102 | | 0.0267 | | 0.8814 |
| Single | 5281 | 154.9±0.7$^{a}$ | 2160 | 94.8±2.2$^{b}$ | 705 | 88.9±4.0$^{b}$ | 217 | 53.7±8.8 |
| Twin | 5916 | 140.4±0.7$^{b}$ | 1954 | 97.3±2.2$^{a}$ | 584 | 93.4±3.9$^{a}$ | 162 | 49.5±8.6 |
| ≥ Triple | 273 | 130.3±1.8$^{c}$ | 100 | 103.9±4.2$^{a}$ | 33 | 80.5±7.4$^{b}$ | 8 | 72.8±13.8 |
| **Parity** | p-value | 0.2416 | | 0.0006 | | 0.1807 | | 0.6565 |
| 1 | 5052 | 142.5±0.8 | 1812 | 94.0±2.3$^{c}$ | 561 | 90.6±4.3 | 159 | 61.5±8.6 |
| 2 | 2947 | 141.6±0.9 | 1069 | 97.5±2.4$^{b}$ | 301 | 86.3±4.5 | 86 | 62.3±8.7 |
| 3 | 1455 | 143.5±1.0 | 566 | 98.0±2.7$^{b}$ | 207 | 89.1±4.8 | 67 | 60.8±9.3 |
| 4 | 917 | 142.0±1.2 | 335 | 97.2±3.0$^{bc}$ | 104 | 88.1±5.4 | 32 | 61.9±10.0 |
| 5 | 559 | 141.6±1.4 | 222 | 94.5±3.3$^{bc}$ | 79 | 81.2±5.8 | 22 | 56.6±10.9 |
| 6 | 345 | 142.9±1.7 | 132 | 107.5±3.9$^{a}$ | 48 | 81.4±6.7 | 12 | 57.2±12.9 |
| ≥ 7 | 195 | 138.7±2.2 | 78 | 101.8±4.7$^{abc}$ | 24 | 96.4±8.5 | 9 | 50.3±13.6 |

*Where: coop =CBBP cooperatives; B.type = Birth type; A.geta =Alargeta; A.kola = Angiokola; D.bedo=Dirbedo; M.uta =Meduta; O.honga = Omashonga; W.lla = Wanabolla; Means with different letter in column within fixed effects are significantly different (P<0.05)*

The year of birth showed highly significant effect on ADG1, ADG2 and ADG3 whereas it was non-significant for ADG4 (Table 12). The body weight gains, under study, showed fluctuating trend over the years. The possible reason for this may be variation in the environmental conditions, number of record difference, availability of forage, feeding and other managemental conditions over the seven years (2012 to 2018).

The CBBP cooperatives showed highly significant ($P<0.0001$) effect on all body weight gains (ADG1, ADG2, ADG3) except ADG4. Perusal of results in Table 12 showed that ADG1, ADG2 and ADG3 was heaviest in the lambs of Yama, Omashonga and Didfa cooperatives, respectively, whereas lambs of Wanabolla, Alargeta and Kicho cooperative had lowest body weight gains at these stages, respectively. The variation in the body weight gains among the cooperatives may possibly be due to the differences in the flock management practices, availability of feed / fodder and other environmental conditions among the cooperatives.

The results in Table 12 showed that season of birth had no significant influence on the average daily gain under study except ADG1. The sex of lamb exhibited highly significant ($P<0.0001$) effect on ADG1, ADG2 and ADG3 whereas it was significant on ADG4 (Table 12). The body weight gain was higher in male lambs than female lambs at all stages. The type of birth had highly significant effect on ADG1 whereas it was significant on ADG2 and ADG3. The effect on ADG4 was non-significant (Table 12). The effect of dam parity was significant at ($P=0.0006$) on ADG2 whereas it was non-significant on ADG1, ADG3 and ADG4. In ADG2 all pair-wise differences were non-significant except parity of 1-2, 1-3, 1-6, 2-6, 3-6, 4-6 and 5-6 which were significant. The results further showed that lambs born to first parity dams showed lowest ADG2 whereas ADG2 was highest in lambs born to six parity dams. The possible reason for lower ADG2 in first parity dams may be ascribed to the younger age of first parity dams coupled with their inexperience in mothering of lambs.

### 4.1.2. Reproductive traits

Productivity in any sheep enterprise where meat is the main product can be measured in terms of total weight of lambs weaned per ewe. This trait depends on fertility, litter size, weight (growth) of individual lambs, mothering ability and survival (Abegaz, 2002). The ANOVA and least square means of reproductive traits are presented in appendix B Table 10 to 13 and Table 13, respectively.

**(I) Age at First Lambing (AFL)**

The overall least square mean ± standard error and coefficient of variation of AFL for Bonga ewe was 375.2±12.5 days and 19.8% respectively. AFL is an important reproduction trait as greater population turnover and more rapid genetic progress can be obtained when sheep produce their first offspring at an earlier rather than later age. Early maturing females are known to have a relatively long and fruitful reproductive life (Ayele and Urge, 2019). AFL was significantly affected at (P=0.0354) by birth year but not affected by CBBP cooperatives, dam parity, birth season and birth type of ewe through influence of breeding program. Similarly, Ayele and Urge (2019) stated that year of birth of lamb influence age at first lambing through their effect on feed supply and quality. In the previous study by Edea *et al.* (2012) and Mestafe (2015) AFL of Bonga was 447±93 and 438±75 days, respectively but the current study was slightly shorter. AFL was decreasing across year from 423.5±24.4 in 2012 to 361.4±14.4 days in 2017. This indicate that the breeding program had contribution for shortening the number of days required for AFL. This is due to selection of fast grower rams and using them as a breeding ram result fast grower progeny even if reproductive traits are lowly heritable traits and better management difference due to skill development across year. The majority of studies reported for AFL of the Ethiopian sheep within the range of 330 to 480 days (Ayele and Urge, 2019).

AFL of Bonga sheep obtained in this study was comparable with Horro, West African sheep and Abera sheep ecotype that ranged from of 387±7.8 to 399±51days (Edea *et al.,* 2012; Musa *et al.,* 2015 and Marufa *et al.,* 2017) respectively. The current result was shorter than Menz, Wollo, Awassi crossbred with local around Debre Berhan area ewes, Begayt, and Atsbi highland sheep breeds reported in the range of 461.6 to 731.67±0.3 days (Tesfaye *et al.,* 2013; Ashebir *et al.,* 2016 and Mengestu, 2018) respectively. Also, shorter than local ecotype of Jimma zone, BHS, Washera, Tumelie (believed as cross of Wollo and Afar sheep) local ewe around eastern Amhara region, Tumelie-Dorper cross breeds, and Dawuro and Gamo Gofa zone ecotype reported in the range of 404±65.4 to 720 days (Berhanu and Aynalem, 2009; Wilson, 2011; Mekuriaw *et al.,* 2013; Lakew *et al.,* 2014 and Asrat *et al.,* 2018). Similarly, Bonga sheep had shorter AFL than exotic sheep breed like West African Dwarf Djallonke, Iranian Afshari sheep, Red Masai and Egyptian Rahmani sheep reported within the range of 540 to 691.45±15.45 days (Gbangboche *et al.,* 2006; Mohammadi *et al.,* 2011, Wilson, 2011 and Radwan and Shalaby, 2017) respectively.

**(II) Lambing Interval (LI)**

The overall least square mean ± standard error lambing interval of Bonga sheep in the present study was 283.5±9.9 days. The current LI reported comparable with the 267.6±63.9 days reported by Edea *et al.* (2012) and 255±48 days reported by Mestafe (2015) for the same breed. Results from the past research showed that the LI for most Ethiopian indigenous sheep managed under traditional management were between 210 and 300days (Ayele and Urge, 2019).

LI of Bonga sheep was comparable with local ecotype of Jimma zone, Horro, Washera, Menz, Tumelie local ewe, Begayt, Abera sheep ecotype, and Atsbi highland sheep breeds reported within the range of 256.60±0.3 to 303 days (Berhanu and Aynalem, 2009; Edea *et al*, 2012; Mekuriaw *et al.*, 2013; Haile *et al.*, 2014; Lakew *et al.*, 2014; Ashebir *et al.*, 2016; Marufa *et al.*, 2017; and Mengestu, 2018). Also, related with Iranian Afshari sheep, Red Masai, Awassi-local cross ewe, and Tumelie-Dorper cross breed reported within the range of 286.3 to 306.24±10.16 days (Mohammadi *et al.*, 2011; Wilson, 2011; Tesfaye *et al.*, 2013; and Lakew *et al.*, 2014) respectively. Bonga sheep breed had shorter LI than BHS 420 days (Wilson, 2011) and Menz-Awassi cross 329.4±15.1days (Tesfaye *et al.*, 2013). The result was longer than some indigenous and other breeds like West African Dwarf Djallonke, Arsi Bale, Wollo, Wollo-Corriedale cross, Wollo-Awassi cross, West African sheep breed, and arithmetic mean of Dawuro and Gamo Gofa zones ecotype reported within 207±20.7 to 249.7±18 days (Gbangboche *et al.*, 2006; Tsedeke, 2007; Tesfaye *et al.*, 2013; Musa *et al.*, 2015; and Asrat *et al.*, 2018) respectively. In pastoral area like Afar, Somali, Borena and some areas of Tigray region tie the sheath of ram to protect mating of ewe and avoid lambing in unfavorable condition which result long LI and AFL.

Table 13 showed that LI was significantly influenced by lambing year ($P<0.0133$), CBBP cooperative at ($P <0.0155$), season of lambing ($p<0.0001$) and dam parity ($P<0.0359$), however, the influence of lambing type was non-significant. The pair wise comparison of LI among years showed significant differences among 2012-2015, 2012-2017, 2015-2016 and 2016-2017 years only. The results also showed that LI was decreasing from 302.3±11.6 days in 2012 to 272.3±5.5 days in 2017 thereby indicating that selective breeding under CBBP and management activities was yielding positive results. The Kicho cooperative had shortest LI than others, which was 272±10.9 days, and the longest was recorded from Guta cooperative, which was 294.9±11.4 days. The difference of LI across cooperative was mainly due to variation in the management activities like close follow up of heat sign and feeding management. The LI was shorter in wet season (278.0±10.0 days) compared to dry season (289.1±10.0 days). Even though literatures reported that no feed shortage when compared with other area but the current study indicate that there is short LI in wet season than dry season (Table 13). The perusal of results on effect of dam parity showed that LI among all parties were non-significant except parity 1-5 which was significant. The LI was longer in first parity ewes (294.6±10.1 days) whereas it was shorter in fifth parity ewes (272.8±11.3 days). The possible reason for longer LI in first parity dams may be ascribed to the younger age of first parity dams coupled with their poor development. Reproductive traits like AFL and LI are highly influenced by regular supervision for heat sign because the animal in the study area was mainly tethering on private land (Haile *et al.*, 2013) and mainly controlled breeding system.

**Table 13: Least square means for all reproductive traits (± SE) by different fixed effects**

| **Fixed effect** | **N** | **AFL** | **Fixed effect** | **N** | **LI** | **N** | **LS** | **N** | **ARR** |
|---|---|---|---|---|---|---|---|---|---|
| **Overall** | **412** | **375.2±12.5** | **Overall** | **3841** | **283.5±9.9** | **11629** | **1.45±0.01** | **3841** | **2.31±0.05** |
| CV % | | 19.8 | CV % | | 30.5 | | 36.62 | | 38.84 |
| Range | | 255- 540 | Range | | 170 - 539 | | 1- 4 | | 0.68 - 5.56 |
| **Birth Year** | | 0.0354 | **Lambing year** | | 0.0133 | | 0.6594 | | <.0001 |
| 2012 | 13 | 423.5±24.4$^{b}$ | 2012 | 71 | 302.3±11.6$^{b}$ | 233 | 1.47±0.03 | 71 | 2.30±0.06$^{bc}$ |
| 2013 | 35 | 375.7±17.0$^{ab}$ | 2013 | 252 | 284±7.4$^{ab}$ | 597 | 1.45±0.02 | 252 | 2.37±0.04$^{ab}$ |
| 2014 | 105 | 393.2±11.5$^{b}$ | 2014 | 864 | 279.3±5.3$^{ab}$ | 1926 | 1.42±0.01 | 864 | 2.35±0.03$^{ab}$ |
| 2015 | 123 | 399.8±10.5$^{b}$ | 2015 | 1103 | 280±5.0$^{a}$ | 2702 | 1.45±0.01 | 1103 | 2.23±0.03$^{bc}$ |
| 2016 | 80 | 387.4±12.4$^{ab}$ | 2016 | 983 | 287.6±5.0$^{b}$ | 2823 | 1.44±0.01 | 983 | 2.17±0.03$^{bc}$ |
| 2017 | 56 | 361.4±14.4$^{a}$ | 2017 | 568 | 272.3±5.5$^{a}$ | 2228 | 1.44±0.01 | 568 | 2.21±0.03$^{bcd}$ |
| 2018 | - | - | 2018 | - | - | 1120 | 1.45±0.01 | - | - |
| **Coop** | | 0.4130 | **Coop** | | 0.0155 | | <.0001 | | <.0001 |
| Abeta | 62 | 389.2±15.6 | Abeta | 486 | 275.3±10.5$^{ab}$ | 1292 | 1.42±0.01$^{bc}$ | 486 | 2.21±0.06$^{ab}$ |
| A.geta | 39 | 389.1±17.2 | A.geta | 270 | 287.9±11.2$^{ab}$ | 1046 | 1.48±0.01$^{b}$ | 270 | 2.38±0.06$^{a}$ |
| A.kola | 15 | 375.6±24.1 | A.kola | 95 | 273±13.4$^{ab}$ | 451 | 1.46±0.02$^{bc}$ | 95 | 2.48±0.08$^{a}$ |
| Dacha | 45 | 380.1±17.1 | Dacha | 471 | 281.6±10.5$^{ab}$ | 1229 | 1.38±0.01$^{c}$ | 471 | 2.14±0.06$^{b}$ |
| Didifa | 17 | 370.2±23.1 | Didifa | 240 | 292±11.2$^{ab}$ | 767 | 1.44±0.02$^{bc}$ | 240 | 2.23±0.06$^{ab}$ |
| D.bedo | 32 | 358.9±17.9 | D.bedo | 354 | 283.7±10.8$^{ab}$ | 1182 | 1.42±0.01$^{bc}$ | 354 | 2.29±0.06$^{ab}$ |
| Guta | 22 | 399.9±21.3 | Guta | 301 | 294.9±11.4$^{b}$ | 844 | 1.39±0.01$^{c}$ | 301 | 2.19±0.06$^{ab}$ |
| Kicho | 41 | 344.8±17.5 | Kicho | 317 | 272.0±10.9$^{a}$ | 761 | 1.45±0.02$^{bc}$ | 317 | 2.43±0.06$^{a}$ |
| Meduta | 47 | 372.3±16.2 | Meduta | 380 | 279.6±10.8$^{ab}$ | 1011 | 1.43±0.02$^{bc}$ | 380 | 2.30±0.06$^{ab}$ |
| O.honga | 14 | 364.3±24.1 | O.honga | 203 | 286.9±11.5$^{ab}$ | 591 | 1.57±0.02$^{a}$ | 203 | 2.42±0.06$^{a}$ |
| Shosha | 27 | 376.3±18.5 | Shosha | 355 | 287.8±10.8$^{ab}$ | 1168 | 1.47±0.01$^{b}$ | 355 | 2.31±0.06$^{ab}$ |
| W.lla | 33 | 381.6±18.4 | W.lla | 172 | 294±11.9$^{ab}$ | 551 | 1.48±0.02$^{bc}$ | 172 | 2.25±0.06$^{ab}$ |
| Yama | 18 | 375.4±22.1 | Yama | 197 | 277.3±11.6$^{ab}$ | 736 | 1.43±0.02$^{bc}$ | 197 | 2.34±0.06$^{ab}$ |
| **Birth Season** | | 0.4765 | **Lambing Season** | | <.0001 | | 0.1822 | | 0.0022 |
| Dry | 182 | 372.3±12.8 | Dry | 1760 | 289.1±10.0 | 5665 | 1.45±0.009 | 1760 | 2.27±0.05 |
| Wet | 230 | 378.2±13.4 | Wet | 2081 | 278.0±10.0 | 5964 | 1.44±0.007 | 2081 | 2.34±0.05 |
| **Birth type** | | 0.3275 | **Lambing type** | | 0.2564 | | | | |
| Single | 203 | 377.3±11.3 | Single | 2355 | 277.7±9.4 | | NA | | NA |
| Twin | 196 | 386.9±11.0 | Twin | 1437 | 281.7±9.2 | | | | |
| ≥ Triple | 13 | 361.5±24.3 | ≥ Triple | 49 | 291.2±15.3 | | | | |
| **Dam parity** | | 0.9797 | **Dam parity** | | 0.0359 | | 0.0008 | | <.0001 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 110 | 369.8±14.1 | 1 | 1411 | 294.6±10.1[b] | 3193 | 1.40±0.008[b] | 1411 | 1.56±0.05[d] |
| 2 | 124 | 366.9±13.7 | 2 | 1073 | 287.6±10.1[ab] | 3160 | 1.42±0.009[ab] | 1073 | 2.30±0.05[bc] |
| 3 | 92 | 372.2±13.9 | 3 | 563 | 288.9±10.2[ab] | 2908 | 1.42±0.01[ab] | 563 | 2.21±0.06[c] |
| 4 | 35 | 379.5±17.3 | 4 | 381 | 288.2±10.7[ab] | 956 | 1.48±0.01[a] | 381 | 2.34±0.06[bc] |
| 5 | 23 | 378.7±19.5 | 5 | 199 | 272.8±11.3[a] | 583 | 1.46±0.01[a] | 199 | 2.46±0.06[ab] |
| 6 | 20 | 379.3±20.7 | 6 | 134 | 275.4±12.3[ab] | 407 | 1.46±0.02[ab] | 134 | 2.61±0.07[a] |
| ≥ 7 | 8 | 381.0±30.4 | ≥ 7 | 80 | 277.2±13.7[ab] | 422 | 1.48±0.03[a] | 80 | 2.67±0.08[a] |

*Where: coop =CBBP cooperatives; B.type = Birth type; A.geta =Alargeta; A.kola = Angiokola; D.bedo= Dirbedo; O.honga = Omashonga; W.lla = Wanabolla and NA= not applicable; Means with different letter in column within fixed effects are significantly different (P<0.05)*

**(III) Litter Size (LS)**

The overall least square mean ± standard error for LS of Bonga sheep was 1.45±0.01lambs and the coefficient of variation was 36.62% in the present study. The percentage of twins and above were 40.13%. Similarly, the percentage of ewes having twins in tropical sheep breeds, generally range between 0 and 50% (Gatenby, 1986) and while under traditional management conditions the percentage tends to fall below 10%. The current result was higher than result of previous study reported by Edea *et al.* (2012). The author reported twining rate of 39.9% and 36% were obtained for Bonga and Horro sheep breeds, respectively. Twining is one of the most important reproductive parameters affecting the productivity of a dam and thereby the profitability of the producer. Litter size is a trait that depends on ovulation rate and is affected by the number of fertilized oocytes. The higher the ovulation rate, the more oocytes will be available for fertilization during the estrous and increase the possibility of more litters (Drouilhet *et al.,* 2013). The current result was higher than results of previous studies 1.4, 1.34, and 1.37 but lower than 1.53±0.008 (Edea *et al.,* 2012; Mirkena *et al.*,2012; Mestafe, 2015; and Haile *et al*., 2018) respectively. Similarly, Gutu *et al.* (2015) assessment of twining rate by questioner interview report indicated that 72.5% of respondents replied that their flock most of the time lambing twin. According to Girma (2008) LS of tropical breeds varies between 1.08 and 1.75 with the average of 1.38. The current study was in agreement with tropical breed LS expectation. LS of Bonga sheep obtained in this study was higher than Gumz, local ecotype of Jimma zone, BHS, Menz, Washera, Horro, and Atsbi highland sheep breeds reported in the range of 1.02 to 1.36±0.01 (Abegaz, 2007; Berhanu and Aynalem, 2009; Wilson, 2011; Mirkena *et al.*,2012; Mekuriaw *et al.,* 2013; Haile *et al*., 2018; and Mengestu, 2018) respectively. Additionally, Bonga sheep breed had higher LS than West African Dwarf Djallonke sheep, Iranian Afshari, Red Masai, Tumelie-Dorper cross and West African sheep breed reported in the range of 1.05 to 1.4±0.5 (Gbangboche *et al.,* 2006; Mohammadi *et al.,* 2011; Wilson, 2011; Lakew *et al.*,2014; and Musa *et al.,* 2005) respectively. According to literature Bonga sheep had lower LS than Arsi Bale, Adilo, Abera sheep ecotype, and arithmetic mean of Dawuro and Gamo Gofa zones ecotype 1.5 to 1.7 (Tsedeke, 2007; Deribe, 2009; Marufa *et al.,* 2017 and Asrat *et al.*,2018). Ibrahim (1998) reported that litter size can be increased 10-40% by improving the nutrition management of the pre-mating ewe or by treatment with gonadotropins. According to Abegaz *et al.* (2002), a kilogram (kg) increase of ewes body weight at mating could improve twining (LS) by about 2.5%.

Perusal of LS in the cooperatives, under study, showed that Omashonga cooperative had higher (1.57±0.02) LS whereas the lower (1.38±0.01) LS was observed from Dacha cooperative. The difference of LS across cooperative was mainly due to variation in the management activities across cooperatives. In the study area multiple lambs were treated artificially by providing additional milk and milk product and suckling was controlled deliberately to avoid suppression of either of the lamb. The influence of dam parity showed that all possible pairs showed non-significant differences except 1-4 parity, 1-5 parity and 1-$\geq$ 7 parity which were significant. Ewes falling under first parity had lowest (1.40±0.008) LS whereas ewes falling under $\geq$ 7 parity had highest (1.48±0.03) LS. The possible reason for lower LS in first parity dams may be ascribed to the younger age of first parity dams coupled with their poor development.

**(IV) Annual Reproductive Rate (ARR)**

The overall least square mean ± standard error of ARR was 2.31±0.05 lambs/ewe/year and the coefficient of variation was 38.84% in the present study. ARR is among the productivity measurement traits using different reproductive parameters (Mekuriaw *et al.*, 2013). The result obtained in the current study was higher than the 1.9 reported for same breed (Metsafe, 2015). Moreover, it was higher than the various study results reported in the literature for various indigenous sheep breeds (Washera, sheep ecotype in Jimma zone, Tumelie local sheep, Adilo, Kofele ecotype and Tumelie-Dorper cross) which ranged from 1.37 to 1.89 (Mekuriaw *et al.*,2013; Berhanu and Aynalem, 2009; Lakew *et al*., 2014; Siegmund *et al.*, 2008, Lakew *et al*., 2014 and Bekana K, 2019). The detailed result of phenotypic performance for each studied trait by considering each fixed effect for each CBBP cooperatives was presented in (APPENDIX D Table 14 to 27).

Perusal of effect of lambing year on ARR showed highest in the year 2013 and 2014 (2.37±0.04 and 2.35±0.03, respectively) whereas the lowest ARR was in 2016 (2.17±0.03) lambs/ewe/year. This indicates that litter size or number of progenies per year was decreasing due to attention was given for growth trait improvement.

Similarly, for CBBP cooperatives on ARR showed highest ARR of 2.48±0.08 was exhibited by Angikolla cooperatives whereas lowest ARR of 2.14±0.06 was from Dacha CBBP cooperative. The differences of ARR across cooperative was mainly due to variation in the management activities across cooperatives. Ewes that have lambed in dry season had lower ARR than those that lambed in wet season (2.27±0.05 vs. 2.34±0.05, respectively. This is mainly due to availability of green forages during wet season and lower LI in wet season.

The result of dam parity that there was a gradual increase in ARR from 1.56±0.05 (First parity) to 2.67±0.08 (≥ 7 parity). This result was corresponding to the gradual increase in the LS in succeeding parities observed in present study (Table 13). The effect of parity on ARR was also reported by Berhanu and Aynalem (2009) and Mekuriaw *et al.* (2013) who reported that ewes in their early parity showed a smaller ARR than ewes in the middle parities.

### 4.2. (Co)variance Component and Genetic Parameter Estimation

According to Tamioso *et al.* (2013) development of effective genetic assessments and accurate selection of rams required in calculation of genetic parameters of studied traits enable the breeder to predict weather these traits respond to genetic improvement and can use as selection criteria or not.

#### 4.2.1. Heritability estimate

**(A) Body Weights**

The number of sires and dams for the studied data were 968 and 6647 respectively (Table 10). Thus, on average based on data of BWT, there were 16.65 and 2.42 progenies per sire and dam, respectively. The data set was comparable with Gizaw *et al.* (2014) who used that on average, 15.8 and 22.4 progenies per sire in the village and nucleus data sets of Menz sheep, respectively. Data structure of body weights is shown in Table 10. The proportion of dams with record and progeny in the data for BWT, WWT, SMWT, NMWT and YWT was 13.4%, 10.4%, 12.15%, 1.66% and 1.35%, respectively. While for number of sires with record and progeny had high proportion than number of dams. It was 82.95%, 81.14%, 77.75%, 45.14% and 40.74% for BWT, WWT, SMWT, NMWT and YWT, respectively.

The estimates of (co)variance components and genetic parameter estimates for growth traits (Univariate analyses) along with estimated maximum likelihood and AIC (Akakie information criteria) values for six models for each body weight were presented in Table 14. The estimates of variance components and corresponding genetic parameters for the traits under the most suitable model are shown in bold format in the same Table (Table 14).

Perusal of results in Table 14 showed that direct heritability ($h^2_a$) from six models ranged from 0.3 to 0.57, 0.22 to 0.44, 0.22 to 0.36, 0.17 to 0.37, and 0.12 to 0.42 for BWT, WWT, SMWT, NMWT and YWT, respectively. Similarly, maternal heritability ($h^2_m$) were 0.003 to 0.52, 0.0 to 0.44, 0.15 to 0.31, 0.0 to 0.67 and 0.37 to 0.41 for BWT, WWT, SMWT, NMWT and YWT, respectively. Total heritability ($h^2_t$) estimated from direct, maternal and direct-maternal covariance were between the range of 0.19 to 0.47, 0.13 to 0.58, 0.23 to 0.38, 0.06 to 0.29, and 0.13 to 0.42 for BWT, WWT, SMWT, NMWT and YWT respectively.

The perusal of results (Table 14) showed that fitting simultaneously both maternal permanent environmental effect and maternal genetic effect in addition to direct effect resulted in more accuracy for BWT and WWT. Whereas, for SMWT, NMWT and YWT traits maternal genetic effect in addition of direct additive effect (model 3) was significantly different ($P<0.05$). So, model 6 was found to be the best model for BWT and WWT, and model 3 was the best model for SMWT, NMWT and YWT. The addition of covariance between direct and maternal genetic effect to model 5 improved the LRT and AIC values for BWT and WWT but not for SMWT, NMWT and YWT.

**Table 14: Estimates of (co)variance components and genetic parameter estimates for body weight traits from univariate analyses**

| Trait | Model | $\sigma^2_a$ | $\sigma^2_m$ | $\sigma^2_e$ | $\sigma^2_c$ | $\sigma^2_p$ | $\sigma_{am}$ | $h^2_a$ | $h^2_m$ | $c^2$ | $h^2_t$ | $r_{am}$ | log L | AIC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BWT | 1 | 0.16 | - | 0.18 | - | 0.34 | - | 0.47 | - | - | 0.47 | - | 1143.742 | 1141.742 |
| | 2 | 0.10 | - | 0.17 | 0.07 | 0.34 | - | 0.3±0.02 | - | 0.2±0.01 | 0.29 | - | 1332.979 | 1329.979 |
| | 3 | 0.10 | 0.07 | 0.17 | - | 0.34 | - | 0.29±0.02 | 0.2±0.01 | - | 0.40 | - | 1307.131 | 1304.131 |
| | 4 | 0.20 | 0.18 | 0.12 | - | 0.35 | -0.14 | 0.57±0.03 | 0.52±0.02 | - | 0.23 | -0.74±0.02 | 1414.890 | 1410.890 |
| | 5 | 0.10 | 0.001 | 0.17 | 0.07 | 0.35 | - | 0.3±0.02 | 0.003±0.03 | 0.2±0.03 | 0.29 | - | 1332.959 | 1328.959 |
| | **6** | **0.20** | **0.12** | **0.12** | **0.05** | **0.35** | **-0.13** | **0.56±0.03** | **0.34±0.05** | **0.15±0.03** | **0.19** | **-0.84±0.04** | **1423.953** | **1418.953** |
| WWT | 1 | 3.22 | - | 4.11 | - | 7.33 | - | 0.44±0.02 | - | - | 0.44 | - | -16797.29 | -16799.29 |
| | 2 | 1.62 | - | 4.03 | 1.67 | 7.32 | - | 0.22±0.02 | - | 0.23±0.01 | 0.22 | - | -16671.157 | -16674.157 |
| | 3 | 3.22 | 2.06 | 2.06 | - | 7.33 | - | 0.44±0.02 | 0.28±0.004 | - | 0.58 | - | -16797.29 | -16800.29 |
| | 4 | 2.59 | 3.26 | 3.47 | - | 7.37 | -1.94 | 0.35±0.03 | 0.44±0.03 | - | 0.18 | -0.67±0.06 | -16664.062 | -16668.062 |
| | 5 | 1.62 | 0.001 | 4.03 | 1.67 | 7.31 | - | 0.22±0.02 | 0.0±0.05 | 0.23±0.05 | 0.22 | - | -16671.16 | -16675.16 |
| | **6** | **2.50** | **1.52** | **3.48** | **1.39** | **7.36** | **-1.54** | **0.36±0.03** | **0.2±0.07** | **0.19±0.05** | **0.13** | **-0.79±0.1** | **-16658.043** | **-16663.043** |
| SMWT | 1 | 5.14 | - | 9.35 | - | 14.5 | - | 0.36±0.04 | - | - | 0.35 | - | -7717.475 | -7719.475 |
| | 2 | 3.28 | - | 9.06 | 2.07 | 14.42 | - | 0.23±0.04 | - | 0.14±0.02 | 0.23 | - | -7703.799 | -7706.799 |
| | **3** | **3.09** | **2.13** | **9.19** | **-** | **14.41** | **-** | **0.22±0.04** | **0.15±0.02** | **-** | **0.29** | **-** | **-7703.708** | **-7706.708** |
| | 4 | 4.02 | 3.48 | 8.59 | - | 14.44 | -1.64 | 0.28±0.06 | 0.24±0.07 | - | 0.23 | -0.44±0.2 | -7702.635 | -7706.635 |
| | 5 | 3.28 | 4.53 | 4.53 | 2.04 | 14.42 | - | 0.23±0.04 | 0.31±0.007 | 0.14±0.02 | 0.38 | - | -7703.799 | -7707.799 |
| | 6 | 4.00 | 3.27 | 8.59 | 0.18 | 14.44 | -1.59 | 0.28±0.06 | 0.23±0.15 | 0.01±0.1 | 0.23 | -0.44±0.2 | -7702.63 | -7707.63 |
| NMWT | 1 | 3.91 | - | 11.05 | - | 14.96 | - | 0.26±0.07 | - | - | 0.26 | - | -2495.051 | -2497.051 |
| | 2 | 2.55 | - | 8.59 | 3.90 | 15.05 | - | 0.17±0.07 | - | 0.26±0.05 | 0.17 | - | -2483.313 | -2486.313 |
| | **3** | **2.54** | **3.77** | **8.75** | **-** | **15.06** | **-** | **0.17±0.07** | **0.25±0.05** | **-** | **0.29** | **-** | **-2484.61** | **-2487.61** |
| | 4 | 5.60 | 10.14 | 6.67 | - | 16.03 | -6.38 | 0.37±0.1 | 0.67±0.15 | - | 0.06 | -0.85±0.15 | -2479.17 | -2483.17 |
| | 5 | 2.55 | 0.001 | 8.59 | 3.90 | 15.05 | | 0.17±0.07 | 0.0±0.35 | 0.26±0.35 | 0.17 | - | -2483.313 | -2487.313 |
| | 6 | 5.32 | 7.55 | 6.79 | 1.70 | 16.03 | -5.34 | 0.35±0.1 | 0.50±0.45 | 0.11±0.38 | 0.06 | -0.84±0.3 | -2478.981 | -2483.981 |
| YWT | 1 | 12.74 | - | 17.35 | - | 30.09 | - | 0.42±0.15 | - | - | 0.42 | - | -1223.527 | -1225.527 |
| | 2 | 3.81 | - | 14.36 | 11.85 | 30.02 | - | 0.13±0.15 | - | 0.39±0.1 | 0.13 | - | -1218.626 | -1221.626 |
| | **3** | **3.79** | **11.92** | **14.30** | **-** | **30.02** | **-** | **0.13±0.15** | **0.39±0.1** | **-** | **0.32** | **-** | **-1218.484** | **-1221.484** |
| | 4 | 3.53 | 11.14 | 14.47 | - | 30.04 | 0.90 | 0.12±0.19 | 0.37±0.41 | - | 0.35 | 0.14 | -1218.484 | -1222.484 |
| | 5 | 3.8 | 11.92 | 14.31 | 0.003 | 30.02 | - | 0.13±0.15 | 0.39 | 0.0 | 0.33 | - | -1218.484 | -1222.484 |
| | 6 | 3.97 | 12.39 | 14.20 | 0.001 | 30.02 | 0.56 | 0.13 | 0.41 | 0.0 | 0.37 | 0.08 | -1218.485 | -1223.485 |

$\sigma^2_a$, $\sigma^2_m$, $\sigma^2_e$, $\sigma^2_c$, $\sigma^2_p$: variance of direct, maternal, residual, maternal permanent environment and phenotypic respectively; $\sigma_{am}$ covariance between direct and maternal; $h^2_a$, $h^2_m$, $h^2_t$: heritability of direct, maternal and total respectively; $c^2$: ratio of maternal permanent environmental variance to phenotypic variance; $r_{am}$: genetic correlation between direct and maternal; log L: maximum loglikelihood AIC: Akakie information criteria.

Perusal of variance components of the best fitted model of each body weight indicated that 57, 34, 21.44, 16.87 and 12.62% of the total variations comprised of direct additive variance ($\sigma^2_a$) for BWT, WWT, SMWT, NMWT and YWT, respectively. Similarly, the contribution of the maternal additive component ($\sigma^2_m$) to the total phenotypic variance was 34.29, 20.65, 14.78, 25.03 and 39.71% for BWT, WWT, SMWT, NMWT and YWT, respectively. The maternal permanent environmental variance ($\sigma^2_c$) contribution to the total phenotypic variance was 14.29 and 18.89%, for BWT and WWT, respectively whereas the contribution of covariance between direct additive and maternal variance ($\sigma_{am}$) was -37.14% for BWT and -20.92% for WWT. Estimates of ratio of maternal permanent environmental variance to phenotypic variance ($c^2$) is not as informative as maternal heritability ($h^2_m$), however, in order to obtain accurate estimates of $h^2_m$, estimation of ($\mathbf{c^2}$) is necessary as exclusion of the maternal permanent environmental effects could cause maternal heritability to be overestimated (Kesbi and Baneh, 2012).

Univariate mixed model genetic analysis for Bonga sheep from selected model revealed that direct heritability estimates 0.56±0.03 for BWT, 0.36±0.03 for WWT, 0.22±0.04 for SMWT, 0.17±0.07 for NMWT and 0.13±0.15 for YWT (Table 14). The possible reason for the observed decreasing trend in the direct heritability estimates from BWT to YWT may be ascribed to the data structure, culling during selection and sale of rams either before taking yearling weight or even, sometimes, before NMWT as these may possibly minimize the diversity of these traits. Similarly, Matika *et al*. (2003) explained that the low estimates of heritability may be due to the stringent culling of animal might have reduced the observed genetic variation and management factors predisposing animals' environment. As Kesbi and Baneh (2012) explanation estimation of heritability is affected by several factors such as genetic structure of the population, management conditions and method of estimation, so it appears difficult to compare current results with results from the literature. However, BWT heritability of Bonga sheep was higher than other Ethiopian sheep breeds like univariate analysis Afar and BHS and multi-traits analysis of Horro and Menz were 0.13 to 0.38 (Yacob, 2008), 0.20 to 0.58 (Yacob, 2008), 0.18 to 0.32 (Abegaz *et al.*, 2002) and 0.019±0.036 (Gizaw *et al.*, 2014), respectively. Comparison of WWT heritability with the same authors of above Ethiopian sheep of Afar, BHS, Horro and Menz were 0.11 to 0.37, 0.0 to 0.29, 0.10 to 0.26 and 0.19±0.057 respectively was slightly higher. But lower heritability was estimated for SMWT and YWT than mentioned in other Ethiopia breeds which are 0.14 to 0.32, 0.00 to 0.43, 0.16 to 0.26 and 0.46±0.081 for SMWT and 0.21 to 0.28, 0.12 to

0.25, 0.23 to 0.31, and 0.56 for YWT respectively of Afar, BHS, Horro and Menz breeds. Similarly, the current study of direct heritability was higher than the 0.14 and 0.26 for BWT and WWT of Horro sheep, respectively and lower for YWT 0.36 by using random regression model (Abegaz *et al.*, 2010).

Maternal heritability for BWT, WWT, SMWT, NMWT and YWT from selected models were 0.34±0.05, 0.20±0.07, 0.15±0.02, 0.25±0.45, and 0.39±0.1, respectively. the result showed that larger maternal heritability of YWT than BWT which may be positive covariance between direct and maternal genetic effect but negative association for BWT. Maternal heritability of BWT trait was higher than Ethiopia Afar, BHS, and Horro sheep 0.02 to 0.21(Yacob, 2008), 0.06 to 0.46 (Yacob, 2008), and 0.12 to 0.23 (Abegaz *et al.*, 2002). Related estimates were recorded for WWT and SMWT 0.12 to 0.21, 0.15 to 0.20 and 0.19 to 0.24 and 0.04 to 0.23, 0.12 to 0.23, 0.09 and 0.24 for Afar, BHS, Horro and Menz sheep, respectively. But, Bonga sheep maternal heritability of YWT trait was higher than those Ethiopian sheep breeds 0.02 to 0.25, 0.00 to 0.20 and 0.08 to 0.14 for Afar, BHS, and Horro sheep breeds, respectively.

Estimated direct heritability of Bonga sheep was higher than Egyptian Barki sheep BWT 0.07 and WWT 0.15 (Sallam *et al*., 2018), on-station Dorper sheep in Kenya 0.18, 0.28, 0.21, 0.14 and 0.29 for BWT, WWT, SMWT, NMWT and YWT respectively (Kariuki *et al*., 2010), on station Sabi sheep of Zimbabwe direct heritability 0.27 and 0.38, and maternal heritability estimates of 0.24 and 0.09 for BWT and WWT respectively (Assan *et al*., 2002) and Morocco Sardi sheep direct heritability BWT 0.07 and WWT 0.05 and maternal heritability of BWT 0.13 (Boujenane and Diallo, 2017). The breed had higher direct heritability than Turkish Merino lamb BWT 0.08 and WWT 0.12 but lower for YWT 0.25 (Ozcan *et al.*, 2005). Also, high maternal heritability than Turkish Merino lamb of BWT, WWT and YWT 0.09, 0.04 and 0.03 respectively (Ozcan *et al.*, 2005). The differences among reported estimates indicate that wide genetic diversity of populations; besides, variations in data structure, choice of models, management and environmental conditions would have influenced the differences between estimations reported in the literature for sheep breeds. Based on the selected model (best fitted model) the estimates of direct heritability ($h^2_a$) for traits studied were medium to high and ranged between 0.13 for YWT and 0.56 for BWT and for maternal genetic heritability ($h^2_m$) were medium to high and ranged between 0.15 for SMWT and 0.39 for YWT. Higher heritability indicates that high with in variation of the breed and will better response during genetic improvement through selection for these traits. So, it should consider both direct and maternal heritability estimates. The moderate **$c^2$** estimate for birth and weaning weight indicates that the importance of maternal environment and maternal care at birth of the lamb but declined as the animal became independent of mother but contributed towards the variation. Maternal genetic effects expressed during gestation and lactation were expected to have a diminishing influence on weight as lambs became older (Prakash *et al.,* 2012).

Total heritability ($h^2_t$) from most suitable (best fitted) model of the trait was 0.19 for BWT, 0.13 for WWT, 0.29 for SMWT, 0.29 for NMWT and 0.32 for YWT. Estimates of $h^2_t$ value was to predict phenotypic response to selection (Kesbi and Baneh, 2012). Willham (1972) advocated that where maternal genetic effects are present, the potential response to selection might be better expressed by $h^2_t$. However, if there is negative covariance between direct and maternal genetic effects, which is the case in the present study for BWT, WWT, SMWT and NMWT phenotypic response to selection may be diminished (Wolf *et al.,* 1998). Current result of $h^2_t$ for BWT and WWT was lower than on-station Sabi sheep of Zimbabwe 0.77 and 0.69 respectively (Assan *et al*., 2002). As shown in Table 14, estimates of $h^2_t$ for SMWT, NMWT and YWT are higher than estimates of $h^2_a$, indicating that phenotypic response to selection would be higher than that predicted using estimates of $h^2_a$. The medium to high estimates of heritability in this study show the presence of high heritable variation in the growth traits of Bonga sheep breed.

A negative covariance between direct and maternal genetic effect indicates different ranking of individuals when the maternal contribution is omitted in the evaluation procedure (Bayeriyar *et al.,* 2011). Cundiff (1972) postulated that from an evolutionary point of view, the negative covariance between direct and maternal genetic effects prevents species from becoming increasingly larger. Maniatis and Pollott (2003) explained that the proportion of dams having their own record and the number of progenies per dam influence the estimation of covariance components. The authors further indicated during Suffolk lamb's data analysis explained that a high negative correlation between direct and maternal effects was the reason of a small number of progenies per dam and limited information from the dam herself which is the same for current study. Safari *et al*. (2007) given that the average number of progenies per dam was at least 4 and 40% of the dams had records. In the current study the number of progenies per dam for YWT was 7.6 which may the case of positive covariance between direct and maternal effects.

The genetic correlation between direct and maternal genetic effects ($r_{am}$) ranged from -0.85 to 0.14 for BWT, WWT, SMWT, NMWT and YWT. The $r_{am}$ was carrying negative sign for all body weights except YWT. The $r_{am}$ values showed a gradual decrease in magnitude from BWT to SMWT. However, the $r_{am}$ value increased for NMWT. The negative $r_{am}$ indicated that direct genetic effect and maternal effect were antagonistic for BWT, WWT, SMWT and NMWT. An antagonism between direct and maternal genetic effects for lamb growth traits an individual's genes for growth and those of its dam for a maternal ability might be due to natural selection for an intermediate optimum (Tosh and Kemp,1994). According to Maniatis and Pollott (2003), estimation of the correlation between direct and maternal genetic effects is dependent on key pedigree relationships. It is essential to have a high proportion of dams and maternal grand dams with their own records. Because, the data set used for the present study was collected over only 7 years, it could lack the optimum pedigree structure for accurate and reliable estimates of direct-maternal covariance components. As a means of avoiding problems related with low heritability, selection can be applied for traits which have a higher heritability and at the same time have a high correlation with the traits of interest (Abegaz, 2002). So, in the case of the current study for Bonga sheep either WWT or SMWT based selection result improvement because of high heritability and medium to strong correlation.

**(B) Average Daily Gains (ADGs)**

The data structure of ADGs as indicated in Table 10 the proportion of dams with record and progeny in the data for ADG1, ADG2, ADG3 and ADG4 was 10.39%, 12.26%, 6% and 2.13%, respectively. While for number of sires with record and progeny had high proportion than number of dams. It was 81.14%, 77.54%, 59.57% and 36.59% for ADG1, ADG2, ADG3 and ADG4 respectively. The estimates of (co)variance components and genetic parameter estimates for average daily gains (Univariate analyses) along with estimated maximum likelihood (log L) values for six models for each average daily gain were presented in Table 15. The estimates of variance components and corresponding genetic parameters for the traits under the most suitable model are shown in bold format in the same Table (Table 15).

All variance components $\sigma^2_{a,}$ $\sigma^2_{m,}$ $\sigma^2_c$ for pre-weaning average daily gain traits were higher than post-weaning traits. Also, $\sigma^2_a$ had higher variance than $\sigma^2_m$ and $\sigma^2_c$ but percentage contribution of $\sigma^2_m$ and $\sigma^2_c$ were vary based on models. Direct heritability for studied ADGs as indicated in Table 15 was 0.23 to 0.44, 0.19 to 0.28, 0.06 to 0.13 and 0.06 to 0.09 for ADG1, ADG2, ADG3 and ADG4 respectively. Similarly, for maternal heritability was 0.002 to 0.42, 0.0 to 0.14, 0.0 to 0.13 and 0.009 to 0.05 for ADG1, ADG2, ADG3 and ADG4 respectively. Total heritability was between the range of 0.15 to 0.44, 0.16 to 0.28, 0.01 to 0.08, and 0.07 to 0.10 for ADG1, ADG2, ADG3 and ADG4, respectively.

The Covariance between direct and maternal genetic effects, maternal genetic and maternal permanent environmental components in addition to direct additive genetic effect were important for ADG1 (Model 6 is best fitted model for ADG1). However, model 2 was found to be the best fitted model for ADG2, thereby indicating that both direct additive and maternal permanent environmental effect were important contributors for this trait whereas maternal genetic component and covariance between direct and maternal genetic effects had no significance contribution to ADG2. The chi-square distribution results further showed that maternal genetic component, covariance between direct and maternal genetic effects and maternal permanent environmental component were found to have a non-significant contribution ($P > 0.05$) to ADG3 and ADG4 (Post-weaning body weight gains) and model 1 was the best fitted model for these two traits indicating that effect of animal's own genes of direct additive genetic effect would be enough for genetic evaluation of post weaning gain weight in present sheep flock.

**Table 15: Estimates of (co)variance components and genetic parameter estimates for (ADGs) from univariate analyses**

| Trait | Model | $\sigma^2_a$ | $\sigma^2_m$ | $\sigma^2_e$ | $\sigma^2_c$ | $\sigma^2_p$ | $\sigma_{am}$ | $h^2_a$ | $h^2_m$ | $c^2$ | $h^2_t$ | $r_{am}$ | log L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADG 1 | 1 | 382.4 | - | 488.2 | - | 870.6 | - | 0.44±0.02 | - | - | 0.44 | - | -44127.892 |
| | 2 | 211.7 | | 480.1 | 176.8 | 868.6 | - | 0.24±0.02 | - | 0.20±0.01 | 0.24 | - | -44029.043 |
| | 3 | 196.8 | 176.14 | 495.6 | - | 868.6 | - | 0.23±0.02 | 0.20±0.01 | - | 0.33 | - | -44038.285 |
| | 4 | 325.3 | 364.35 | 413.4 | - | 874.3 | -228.7 | 0.37±0.04 | 0.42±0.04 | - | 0.19 | -0.66±0.06 | -44017.041 |
| | 5 | 211.4 | 2.014 | 480.2 | 175.9 | 868.6 | - | 0.24±0.03 | 0.002±0.04 | 0.20±0.04 | 0.24 | - | -44029.041 |
| | **6** | **317.3** | **222.12** | **415.4** | **115.4** | **873.4** | **-196.9** | **0.36±0.04** | **0.25±0.07** | **0.13±0.05** | **0.15** | **-0.74±0.08** | **-44016.908** |
| ADG 2 | 1 | 384.1 | - | 979.0 | - | 1363.1 | - | 0.28±0.04 | - | - | 0.28 | - | -17215.799 |
| | **2** | **261.9** | **-** | **955.2** | **140.69** | **1357.8** | **-** | **0.19±0.04** | **-** | **0.10±0.03** | **0.19** | **-** | **-17208.395** |
| | 3 | 259.0 | 132.51 | 966.1 | - | 1357.6 | - | 0.19±0.04 | 0.1±0.02 | - | 0.24 | - | -17209.511 |
| | 4 | 290.1 | 189.01 | 944.4 | - | 1358.3 | -65.2 | 0.21±0.05 | 0.14±0.07 | - | 0.21 | -0.28±0.3 | -17209.303 |
| | 5 | 261.9 | 0.004 | 955.3 | 140.63 | 1357.8 | - | 0.19±0.04 | 0.0±0.1 | 0.10±0.1 | 0.19 | - | -17208.395 |
| | 6 | 289.8 | 9.28 | 937.4 | 172.04 | 1359.7 | -48.8 | 0.21±0.05 | 0.006±0.15 | 0.13±0.12 | 0.16 | -0.94 | -17208.202 |
| ADG 3 | **1** | **106.7** | **-** | **1200.3** | **-** | **1307.0** | **-** | **0.08±0.06** | **-** | **-** | **0.08** | **-** | **-5366.948** |
| | 2 | 79.73 | - | 1167.7 | 55.65 | 1306.5 | - | 0.06±0.06 | - | 0.04±0.05 | 0.06 | - | -5366.619 |
| | 3 | 94.54 | 20.09 | 1192.1 | - | 1306.8 | - | 0.07±0.06 | 0.02±0.05 | - | 0.08 | - | -5366.905 |
| | 4 | 167.0 | 171.42 | 1136.6 | - | 1316.1 | -158.9 | 0.13±0.09 | 0.13±0.14 | - | 0.01 | -0.94±0.4 | -5366.56 |
| | 5 | 75.75 | 0.004 | 1175.1 | 55.68 | 1306.5 | - | 0.06±0.06 | 0.0±0.27 | 0.04±0.28 | 0.06 | - | -5366.619 |
| | 6 | 171.2 | 61.34 | 1145.1 | 93.56 | 1373.8 | -97.5 | 0.12±0.09 | 0.04±0.41 | 0.07±0.32 | 0.04 | -0.95 | -5366.7 |
| ADG 4 | **1** | **104.6** | **-** | **1021.4** | **-** | **1126.0** | **-** | **0.09±0.16** | **-** | **-** | **0.09** | **-** | **-1549.902** |
| | 2 | 80.70 | - | 988.3 | 56.89 | 1125.9 | - | 0.07±0.17 | - | 0.05±0.14 | 0.07 | - | -1549.822 |
| | 3 | 80.33 | 58.13 | 987.4 | - | 1125.9 | - | 0.07±0.17 | 0.05±0.13 | - | 0.10 | - | -1549.819 |
| | 4 | 78.79 | 52.73 | 988.6 | - | 1126.3 | 6.2 | 0.07±0.24 | 0.05±0.42 | - | 0.10 | 0.10 | -1549.818 |
| | 5 | 81.36 | 35.83 | 987.1 | 21.78 | 1126.1 | - | 0.07±0.19 | 0.03±0.002 | 0.02±0.14 | 0.09 | - | -1549.82 |
| | 6 | 72.09 | 9.84 | 994.2 | 26.48 | 1126.4 | 23.8 | 0.06±0.24 | 0.009±0.004 | 0.02±0.41 | 0.10 | 0.89 | -1549.819 |

$\sigma^2_a$, $\sigma^2_m$, $\sigma^2_e$, $\sigma^2_c$, $\sigma^2_p$: variance of direct, maternal, residual, maternal permanent environment and phenotypic respectively; $\sigma_{am}$ covariance between direct and maternal; $h^2_a$, $h^2_m$, $h^2_t$: heritability of direct, maternal and total respectively; $c^2$ ratio of maternal permanent environmental variance to phenotypic variance; $r_{am}$ genetic correlation between direct and maternal; log L: maximum loglikelihood

The $h^2_a$ from selected best model (best fitted model) was range from low to high which were 0.36, 0.19, 0.08 and 0.09 for ADG1, ADG2, ADG3 and ADG4, respectively. Medium to high direct heritability ($h^2_a$) for ADG1 and ADG2 indicate that additive genetic effect constitutes the most part of phenotypic variation; and proposing modest genetic improvement would be predicted through direct selecting method. Increase variation among lambs in their own additive genes for gain weight traits suggested increase genetic selection and possibility for future improvement (Radwan and Shalaby, 2017). The low estimates of heritability for ADG3 and ADG4 (0.08 and 0.09, respectively) traits in this study may be attributed to the high phenotypic and residual variance arising from a large environmental variation as indicated in the range of daily gains of Table 12 and Table 15.

Bonga sheep had higher direct, maternal heritability and ratio of maternal permanent environmental to phenotypic variance of ADG1 than Turkish Merion lamb 0.11, 0.04 and 0.09 respectively (Ozcan *et al.*,2005), direct heritability of Egyptian Barki sheep 0.16 (Sallam *et al*., 2018) and Morocco Sardi sheep ADG1 and ADG2 were 0.01 and 0.05, respectively (Boujenane and Diallo, 2017).

**(C) Reproductive Traits**

The data structure of reproductive traits as indicated in Table 10 the proportion of dams with record and progeny in the data for AFL, LI and LS was 47.83%, 90.14% and 100% respectively. The estimates of (co)variance components and genetic parameter estimates for reproductive traits along with estimated maximum likelihood (log L) and AIC (Akakie information criteria) values for six models were presented in Table 16. The estimates of variance components and corresponding genetic parameters for the traits under the most suitable model are shown in bold format in the same Table (Table 16). Direct heritability ($h^2_a$) for studied reproductive traits from different models, as indicated in Table 16, was 0.0 to 0.07, 0.06 to 0.13 and 0.06 to 0.18 for AFL, LI and LS, respectively. Similarly, maternal heritability ($h^2_m$) was ranged between 0.19 to 0.4, 0.0 to 0.008 and 0.12 to 0.15 for AFL, LI and LS respectively. Also, for ratio of maternal permanent environmental variance to phenotypic variance ($c^2$) for AFL was 0.0 to 0.2 and ratio of animal permanent environmental variance to phenotypic variance ($pe^2$) was 0.09 to 0.51 and 0.24 to 0.45 for LI and LS, respectively. Total heritability ($h^2_t$) was between the range of 0.02 to 0.11, 0.06 to 0.09 and 0.09 to 0.10 for AFL, LI and LS respectively.

**Table 16: Components of (co)variance and genetic parameter estimate for reproductive traits from univariate analysis (±SE)**

| Trait | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|
| **Age at first lambing (AFL)** | | | | | | |
| $\sigma^2_a$ | **389.22** | 90.10 | 0.15 | 332.93 | 0.05 | 332.09 |
| $\sigma^2_m$ | - | - | 1277.9 | 2354.9 | 1148.7 | 2357.7 |
| $\sigma^2_e$ | **5538.4** | 4621.0 | 4653.8 | 4107.8 | 4598.4 | 4108.1 |
| $\sigma^2_c$ | - | 1222.3 | - | - | 185.48 | 0.1468 |
| $\sigma^2_p$ | **5927.6** | 5933.4 | 5931.8 | 5914.7 | 5932.7 | 5914.5 |
| $\sigma_{am}$ | - | - | - | -881.02 | - | -883.58 |
| $h^2_a$ | **0.07±0.19** | 0.02±0.2 | 0.0±0.2 | 0.06±0.3 | 0.0±0.2 | 0.06±0.3 |
| $h^2_m$ | - | - | 0.22±0.2 | 0.4±0.3 | 0.19±0.4 | 0.4±0.9 |
| $c^2$ | - | 0.2±0.2 | - | - | 0.03±0.4 | 0.0±0.5 |
| $h^2_t$ | **0.07** | 0.02 | 0.11 | 0.03 | 0.10 | 0.03 |
| $r_{am}$ | - | - | - | -0.99 | - | -0.99 |
| log L | **-1973.922** | -1973.554 | -1973.332 | -1973.011 | -1973.332 | -1973.01 |
| AIC | **-1975.922** | -1976.554 | -1976.332 | -1977.011 | -1977.332 | -1978.01 |
| **Lambing interval (LI)** | | | | | | |
| $\sigma^2_a$ | 467.83 | **472.0** | 471.55 | 948.25 | 462.81 | 891.68 |
| $\sigma^2_m$ | - | - | 0.03 | 59.909 | 0.02 | 45.94 |
| $\sigma^2_e$ | 6927.7 | **3147.1** | 6924.0 | 6412.6 | 6302.5 | 3236.8 |
| $\sigma^2_{pe}$ | - | **3776.5** | - | - | 630.25 | 3236.8 |
| $\sigma^2_p$ | 7395.6 | **7395.6** | 7395.6 | 7182.4 | 7395.5 | 7208.8 |
| $\sigma_{am}$ | - | - | - | -238.34 | - | -202.40 |
| $h^2_a$ | 0.06±0.1 | **0.06±0.1** | 0.06±0.1 | 0.13±0.2 | 0.06±0.1 | 0.12±0.2 |
| $h^2_m$ | - | - | 0.0±0.1 | 0.008±0.1 | 0.0±0.1 | 0.006±0.1 |
| $pe^2$ | - | **0.51±0.1** | - | - | 0.09±0.002 | 0.45±0.2 |
| $h^2_t$ | 0.06 | **0.06** | 0.06 | 0.09 | 0.06 | 0.08 |
| $r_{am}$ | - | - | - | -1 | - | -1 |
| r | - | **0.57** | - | - | - | - |
| log L | -18969.651 | **-18969.651** | -18969.651 | -18969.572 | -18969.651 | -18969.569 |
| AIC | -18971.651 | **-18972.651** | -18972.651 | -18973.572 | -18973.651 | -18974.569 |
| **Litter size (LS)** | | | | | | |
| $\sigma^2_a$ | 0.02 | 0.02 | 0.01 | 0.04 | 0.01 | **0.04** |
| $\sigma^2_m$ | - | - | 0.03 | 0.03 | 0.03 | **0.03** |
| $\sigma^2_e$ | 0.24 | 0.12 | 0.21 | 0.18 | 0.10 | **0.09** |
| $\sigma^2_{pe}$ | - | 0.12 | - | - | 0.10 | **0.09** |
| $\sigma^2_p$ | 0.26 | 0.26 | 0.26 | 0.24 | 0.26 | **0.24** |
| $\sigma_{am}$ | - | - | - | -0.02 | - | **-0.02** |
| $h^2_a$ | 0.09±0.04 | 0.09±0.04 | 0.06±0.05 | 0.18±0.07 | 0.06±0.05 | **0.18±0.07** |
| $h^2_m$ | - | - | 0.12±0.03 | 0.15±0.03 | 0.12±0.03 | **0.15±0.03** |
| $pe^2$ | - | 0.45±0.04 | - | - | 0.24±0.003 | **0.37±0.007** |
| $h^2_t$ | 0.09 | 0.09 | 0.09 | 0.10 | 0.09 | **0.10** |
| $r_{am}$ | - | - | - | -0.53±0.08 | - | **-0.53±0.08** |
| r | - | 0.54 | - | - | - | **-** |
| log L | 1767.991 | 1767.991 | 1771.369 | 1774.644 | 1771.369 | **1774.644** |
| AIC | 1765.991 | 1764.991 | 1768.369 | 1770.644 | 1767.369 | **1769.644** |

M1, M2, M3, M4, M5 and M6 : model 1, 2, 3, 4, 5 and 6; $\sigma^2_a$, $\sigma^2_m$, $\sigma^2_e$, $\sigma^2_c$, $\sigma^2_{pe}$, $\sigma^2_p$: variance of direct, maternal, residual, maternal permanent environment, animal permanent environment and phenotypic respectively; $\sigma_{am}$: covariance between direct and maternal; $h^2_a$, $h^2_m$, $h^2_t$ heritability of direct, maternal and total respectively; $c^2$: ratio of maternal permanent environmental variance to phenotypic variance; $pe^2$: ratio of animal permanent environment to phenotypic variance; $r_{am}$: genetic correlation between direct and maternal; r: repeatability; AIC: Akakie information system; log L: maximum loglikelihood

The comparison of models showed that model 1, 2 and 6 were most appropriate fit models based on log likelihood ratio test (LRT) for AFL, LI and LS, respectively. The variance component from selected best fit model of direct additive ($\sigma^2_a$), maternal genetic ($\sigma^2_m$), permanent animal environment ($\sigma^2 p_e$) and covariance between direct animal and maternal effect ($\sigma_{am}$) accounted for 16.6, 12.5, 37.5 and -8.3%, respectively, of total variance for LS whereas for LI 6.38 and 51.06% of total variance was contributed by direct additive and animal permanent environmental component. Similarly, variance component of direct additive ($\sigma^2_a$) contributed 6.56% of variation to total variance for AFL. Direct heritability from selected models for AFL, LI and LS were 0.07±0.19, 0.06±0.1 and 0.18±0.07 respectively. These results showed that both AFL and LI were strongly influenced by environmental effects. The ratio of animal permanent environmental variance to phenotypic variance was higher for repeatable traits (LS and LI) which was 0.37 and 0.51, respectively, in the present study. This indicated that improving animal environment would result in improvement program of these traits. Similarly, Lôbo *et al.* (2009) explained that low heritability estimated for these traits were expected. Direct genetic selection within the breed for AFL and LI may therefore not bring about much improvement. However, productivity estimates are aggregate traits and a small improvement in these traits would mean sizeable gain in terms of overall change in the other traits and is usually realized with concurrent change in all components.

Higher estimate direct heritability of LS was estimated from Bonga sheep than Horro sheep 0.15 (Abegaz *et al.,* 2002), Iranian Lori-Bakhtiari sheep 0.10±0.01(Vatankhah and Talebi, 2008), Awassi sheep 0.16 to 0.19 (Juma and Alkass, 2006), and British Suffolk and Texel sheep 0.06 to 0.13 (Janssens *et al*., 2004). Also, higher than on-station Iranian Zandi Sheep 0.14 (Mohammadi *et al*., 2012), on-station Brazilian Santa Ines sheep 0.12±0.014 (Aguirre *et al*., 2017), on-station Columbia sheep 0.09 (Hanford *et al*., 2002), and Iranian native Kordi sheep of direct additive, maternal heritability and ratio of permanent environmental variance on phenotypic variance 0.14, 0.08 and 0.01 to 0.03 respectively (Saghi and Shahdadi, 2017). Lower heritability of LS was estimated than on-station Zimbabwe Sabi sheep by using ASREML 0.26 (Matika *et al*., 2003). Current result has lower heritability of AFL than Brazilian Santa Ines sheep 0.13±0.10 (Aguirre *et al*., 2017) and related with LI 0.04±0.017 (Aguirre *et al*., 2017). Lôbo *et al.* (2009) estimated 0.04 and 0.06 for AFL and LI from multibreed meat sheep population (types of sheep breed listed in detail Lôbo *et al.*, 2009) in Brazil. Average heritability for AFL and LI were low 0.07 and 0.02, respectively for Iranian Lori-Bakhtiari sheep (Abdoli *et al*., 2019).

### 4.2.2. Correlation estimate

The estimates of correlations coefficients (genetic and phenotypic correlation coefficients) among growth traits and litter size, using multi-variate, analysis was shown in Table 17. Perusal of Table 17 showed that both Phenotypic and genetic correlations among body weights were positive. The BWT showed positive but low genetic correlation with WWT, SMWT, NMWT and YWT (0.204, 0.225, 0.246 and 0.113, respectively). Similarly, the phenotypic correlation of BWT with other four body weight was positive but low (0.002, 0.009, 0.005 and 0.024 for WWT, SMWT, NMWT and YWT, respectively). The lower estimates of the additive direct correlation ($r_g$) among birth weight and subsequent body weights indicated that selection for latter weight would not immediately lead to increased birth weight.

**Table 17: Direct additive genetic below diagonal and phenotypic above diagonal correlation**

| Traits | BWT | WWT | SMWT | NMWT | YWT | ADG1 | ADG2 | ADG3 | ADG4 | LS |
|---|---|---|---|---|---|---|---|---|---|---|
| BWT | - | 0.002 (0.010) | 0.009 (0.014) | 0.005 (0.02) | 0.024 (0.033) | 0.003 (0.010) | 0.008 (0.015) | 0.000 (0.024) | 0.025 (0.043) | -0.025 (0.009) |
| WWT | 0.204 (0.056) | - | 0.515 (0.012) | 0.403 (0.019) | 0.308 (0.033) | 0.923 (0.002) | -0.202 (0.016) | -0.106 (0.026) | -0.028 (0.046) | -0.309 (0.009) |
| SMWT | 0.225 (0.076) | 0.610 (0.048) | - | 0.736 (0.011) | 0.492 (0.029) | 0.482 (0.012) | 0.694 (0.008) | -0.277 (0.026) | -0.111 (0.046) | -0.182 (0.014) |
| NMWT | 0.246 (0.086) | 0.414 (0.065) | 0.896 (0.036) | - | 0.644 (0.027) | 0.389 (0.019) | 0.490 (0.017) | 0.391 (0.021) | -0.160 (0.046) | -0.130 (0.022) |
| YWT | 0.113 (0.111) | 0.191 (0.094) | 0.457 (0.101) | 0.606 (0.099) | - | 0.277 (0.033) | 0.356 (0.032) | 0.300 (0.036) | 0.604 (0.027) | -0.098 (0.035) |
| ADG1 | 0.065 (0.057) | 0.916 (0.007) | 0.579 (0.050) | 0.413 (0.067) | 0.159 (0.095) | - | -0.200 (0.016) | -0.082 (0.026) | -0.070 (0.046) | -0.236 (0.010) |
| ADG2 | 0.192 (0.094) | -0.188 (0.076) | 0.583 (0.056) | 0.668 (0.070) | 0.486 (0.126) | -0.168 (0.078) | - | -0.241 (0.026) | -0.074 (0.046) | 0.065 (0.016) |
| ADG3 | 0.040 (0.145) | -0.319 (0.125) | -0.056 (0.147) | 0.387 (0.125) | 0.457 (0.178) | -0.278 (0.126) | 0.246 (0.189) | - | -0.080 (0.044) | 0.049 (0.026) |
| ADG4 | -0.018 (0.141) | -0.086 (0.122) | -0.070 (0.145) | 0.007 (0.160) | 0.785 (0.060) | -0.134 (0.123) | 0.082 (0.182) | 0.238 (0.253) | - | 0.029 (0.047) |
| LS | -0.094 (0.045) | -0.298 (0.033) | -0.133 (0.051) | 0.044 (0.065) | 0.115 (0.085) | -0.228 (0.035) | 0.180 (0.065) | 0.230 (0.108) | 0.111 (0.103) | - |

Values in bracket are standard errors

This (lack of strong correlation between BWT and later weights) is particularly advantageous, because selection for each trait could be affected without much change in BWT. This is so because,

if the associations were strong, selection for WWT or SMWT would also increase BWT, which m ay be associated with dystocia and loss of productivity (Haile *et al*., 2018).

The WWT showed positive and medium genetic and phenotypic correlation with SMWT (0.610 and 0.515, respectively) whereas similar coefficients with NMWT and YWT were low to medium and positive (0.414 and 0.403 for NMWT; 0.191 and 0.308 for YWT, respectively). This showed that selection involving SMWT will result in concomitant improvement in weaning weight and vice-versa. However, selection for WWT may not result in appreciable improvement in YWT. The possible reason may be that NMWT and YWT are not influenced by the pre-weaning environment especially mothering ability of dam. The SMWT showed highest positive genetic and phenotypic correlation with NMWT (0.896 and 0.736, respectively) but its correlations with YWT were medium (0.457 and 0.492, respectively). Similarly, NMWT showed medium positive genetic and phenotypic correlation with YWT (0.606 and 0.644, respectively). The positive and higher correlation among post-weaning body weights indicated that these could be used developing appropriate selection strategy in Bonga sheep.

The genetic correlation of BWT with ADG1, ADG2, ADG3 and ADG4 ranged from 0.065, 0.192, 0.040 and -0.018, respectively, and corresponding estimates of phenotypic correlation ranged from 0.003, 0.008, 0.000 and 0.025, respectively. These estimates were low indicating any selection based on birth weight will not result in any improvement in body weight gains. This may possibly be ascribed to the role of environment, especially pre- and postnatal environment, on birth weight. The genetic correlation of WWT were positive and high with ADG1 (0.916) whereas similar with ADG2, ADG3 and ADG4 were negative and low to medium (-0.188, -0.319 and -0.086). The corresponding phenotypic correlation coefficient showed similar trend wherein these were positive and high with ADG1 (0.923) but negative and low with ADG2, ADG3 and ADG4 (-0.202, -0.106, and -0.028). Similarly, genetic correlation of SMWT were positive and medium with ADG1 and ADG2 (0.579 and 0.583) whereas values with ADG3 and ADG4 were negative and low (-0.056 and -0.070).

The corresponding phenotypic correlation coefficient showed similar trend wherein these were positive with ADG1 and ADG2 (0.482 and 0.694, respectively) but negative and low with ADG3 and ADG4 (-0.277 and -0.111). The genetic correlation of NMWT were positive with ADG1, ADG2, ADG3 and ADG4 (0.413, 0.668, 0.387 and 0.007, respectively) whereas the corresponding phenotypic correlation coefficient showed similar trend wherein these were positive with ADG1, ADG2 and ADG3 (0.389, 0.490 and 0.391, respectively) but negative and low with ADG4 (-0.160). The genetic correlation of YWT were positive with ADG1, ADG2, ADG3 and ADG4 (0.159, 0.486, 0.457 and 0.785, respectively) whereas the corresponding phenotypic correlation coefficient showed similar trend wherein these were positive with ADG1, ADG2, ADG3 and ADG4 (0.277, 0.356, 0.300 and 0.604, respectively). Better positive and strong genetic and phenotypic correlation was estimated in Kenya from on-station data of Dorper sheep WWT-SMWT, SMWT-NMWT, SMWT-YWT and NMWT-YWT were 0.90, 0.95, 0.65, and 0.86 and 0.78, 0.80, 0.69, and 0.83 respectively (Kariuki *et al*., 2010). The genetic correlation of SMWT-NMWT for Iranian Baluchi sheep was 0.96 (Gholizadeh and Farhad, 2015). Negative and small phenotypic correlation was estimated form Morocco Sardi sheep BWT-ADG1 -0.01 but positive and medium correlation WWT-ADG1 0.66 for phenotypic correlation and for genetic correlation BWT-ADG1 0.23±0.34 and WWT-ADG1 0.79±0.14 (Boujenane and Diallo, 2017).

Multi-variate analysis of phenotypic correlations between body weights with LS were negative and have low to medium correlation. Negative medium phenotypic correlation was between LS-WWT -0.309±0.009. The genetic correlation between selection traits of body weight for WWT-LS and SMWT-LS was -0.298±0.033 and -0.133±0.051 respectively. This may be one of the reasons for positive body weight genetic gain and negative genetic gain of litter size across years of the CBBPs (Figure 2 and 7) respectively.

Bivariate correlation analysis was done for AFL-LS and LI-LS. Correlation of AFL-LS was -0.660±0.03 and 0.030±0.052 for genetic and phenotypic correlation. Also, correlation between LI-LS was 0.844±0.850 and 0.023±0.016 for genetic and phenotypic correlation. Both AFL and LI have medium and strong respectively but opposite sign correlation with LS.

### 4.2.3. Repeatability (r) estimates

The animal permanent environmental effect was considered for LI and LS instead of maternal permanent environment because they are repeatable traits. The estimate of repeatability of LI and

LS was 0.57 and 0.54, respectively, for Bonga sheep. It indicated that the breed will perform like current status of reproductive performance for these two traits in future. High repeatability indicates that culling of animals on the basis of performance in single or only few initially available records could be done. The result was much higher than Horro sheep for litter size 0.12 (Abegaz *et al*, 2002) and Pelibuey ewes of southeastern México 0.06±0.20 and 0.12±0.04 for LI and LS respectively (Jansses *et al*., 2015). If repeatability estimates of traits were higher than heritability estimate showed that the traits were influenced by non-additive genetic effects and permanent environmental effects and to improve these traits one should improve environmental effects or management of flock in first step (Bayeriyar *et al.*, 2011).

## 4.3. Genetic Gain and Annual Trend

### 4.3.1. Growth traits

**(A) Body Weights**

Estimated breeding value (EBV) was estimated from selected best fit models among six different models for each trait. EBV for different growth traits were obtained by WOMBAT output of RnSolution_animal for direct additive, RnSolution_maternal for maternal EBV and Rnsolution_permanent maternal environment to get maternal permanent environmental trend. The direct genetic gain (kg), maternal genetic gain (kg) and maternal permanent environment trend of body weight traits is presented in Table 18. The means of breeding values for different years plotted against the year of birth, to show the genetic trend for body weights at different ages, are shown in Figure 2.

**Table 18: Genetic gain of body weight traits in kg**

| Traits | Direct genetic gain | Maternal genetic gain | Maternal permanent environment trend |
|---|---|---|---|
| BWT | 0.0254 | -0.0246 | -0.00198 |
| WWT | 0.1471 | -0.0048 | 0.1788 |
| SMWT | 0.3103 | 0.0776 | - |
| NMWT | 0.3837 | -0.0870 | - |
| YWT | 0.1599 | 0.7516 | - |

Perusal of results in Table 18 and Figure 2 showed that EBVs was positive for all direct genetic effect for BWT, WWT, SMWT, NMWT and YWT. The genetic gain with annual increasing value for each body weight were 0.0254 with 0.0021kg, 0.1471 with 0.0285kg, 0.3103 with

0.0587kg, 0.3837 with 0.0811kg and 0.1599 with 0.0205kg for BWT, WWT, SMWT, NMWT and YWT, respectively. The highest genetic gain (0.3837 with 0.0811kg) due to direct genetic effect across birth year was obtained for NMWT. The annual genetic trends for WWT, SMWT and NMWT are statistically highly significance at ($P<0.0001$) whereas non-significance for BWT and YWT ($P>0.05$). The reason of non-significance may be due to no maternal effect consideration during selection for BWT and limited sample size for YWT. The results indicated that annual direct genetic trends for body weight of growth traits showed good response to selection in these traits.

The maternal genetic gain (Table 18 and Figure 2) were positive for SMWT and YWT but negative for BWT, WWT and NMWT. The genetic gain with annual trend for BWT, WWT, SMWT, NMWT and YWT were -0.0246 with -0.0028kg, -0.0048 with -0.0035kg, 0.0776 with 0.0201kg, -0.087 with -0.0203kg and 0.7516 with 0.0918kg respectively. The annual maternal genetic trend of body weights across birth year of lamb was significance at ($P<0.01$) for BWT, WWT, and SMWT respectively but non-significance for NMWT and YWT. Negative maternal genetic trends were showed for BWT, WWT and NMWT may be due to negative correlations between direct and maternal effects. But for SMWT even having negative direct-maternal correlation there is a positive annual genetic trend. The reason of means of the estimated breeding values for the maternal effect for some body weight show negative trend, demonstrating that maternal effect doesn’t had been take into consideration in the selection process by breeders.

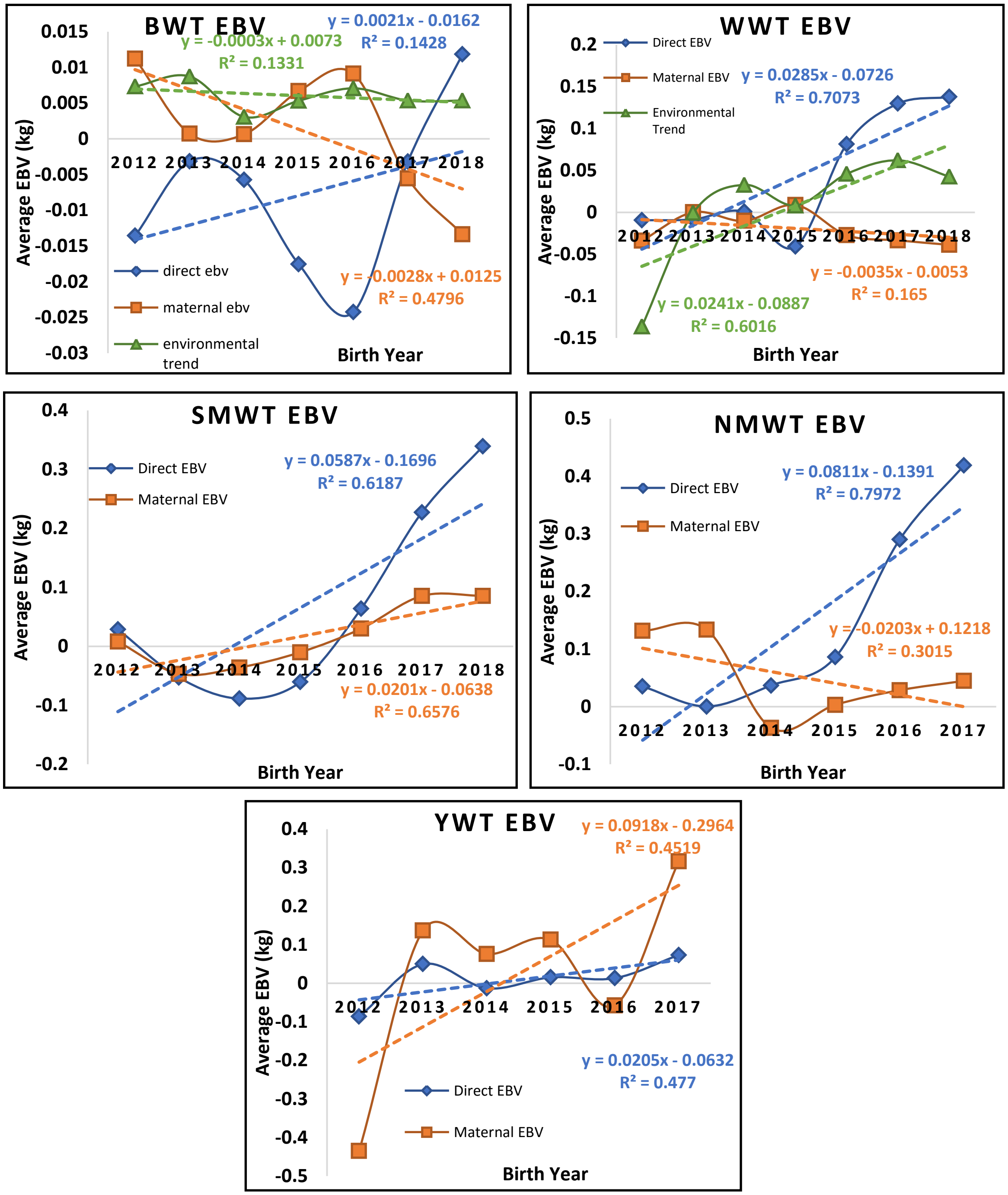



**Figure 2: Means of predicted breeding values (kg) over years for different body**

According to Gizaw *et al.* (2014) for Menz sheep genetic progresses per generation of the fourth-generation achieved in the WWT and SMWT from selection for SMWT in village flock's village lambs had a genetic superiority of 0.45kg and 1.30kg over the base generation lambs in WWT and SMWT which is higher than current result but lower by BWT which is 0.005. The annual genetic trend of current result was related with Horro sheep BWT from Partial regression coefficients (±S.E.) 0.0035±0.004 but higher result obtained for WWT -0.0063±0.023, SMWT -0.0308±0.032 and -0.1030±0.053 for YWT (Negussie *et al*., 2002). Current results of genetic gain for BWT was lower than on-station Sabi sheep of Zimbabwe 0.8kg but related for 0.14kg for WWT (Assan *et al*., 2002). A related genetic trend was estimated from Dorper sheep on-station improvement program in Kenya were 0.006, 0.096, 0.04, 0.096 and 0.163kg/year for BWT, WWT, SMWT, NMWT and YWT (Kariuki *et al*., 2010) and on-station Iranian native Ghezel sheep BWT, WWT, SMWT, NMWT and YWT 0.00234, 0.0462, 0.05511, 0.0334 and 0.02401kg/year respectively (Baneh and Ahmadpanah, 2018). The current result annual genetic trend was higher than BWT of South African Dormer and Ile de France sheep breed -0.002±0.001 and 0.001±0.0008kg respectively (Zishiri *et al*., 2010). There is a positive and better annual genetic trend ± SE of maternal genetic effect for Horro sheep of BWT 0.0012±0.005 and WWT 0.0036±0.025 but better trend was estimated from current result of SMWT -0.0330±0.033 and YWT -0.0329±0.054 (Negussia *et al*., 2002) and on-station Iranian native Ghezel sheep 0.00337, 0.01705, 0.01256 and 0.01630kg/year for BWT, WWT, SMWT, NMWT and YWT respectively (Baneh and Ahmadpanah, 2018).

### (i) Genetic and phenotypic gain and trend of six-month weight for each cooperative

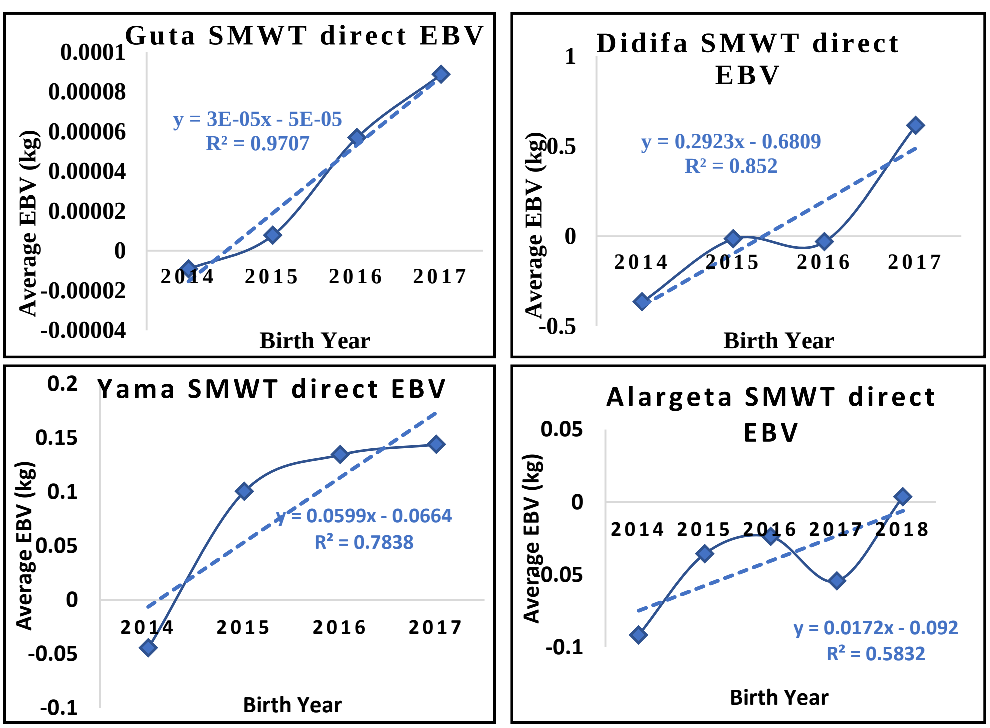
Even though 14 different CBBPs are found in similar environment and use same Bonga breed, looking them independently was considered mainly for two reasons. 1) Some of them were not genetically connected, 2) Looking the genetic progress in each CBBP will help to suggest optimization options for Bonga CBBP. Selection was based on six months weight so that results were presented for this trait only. Among the 14 CBBPs positive genetic trend was observed in 11 CBBPs while negative genetic trends were observed in the 3 of the CBBPs.

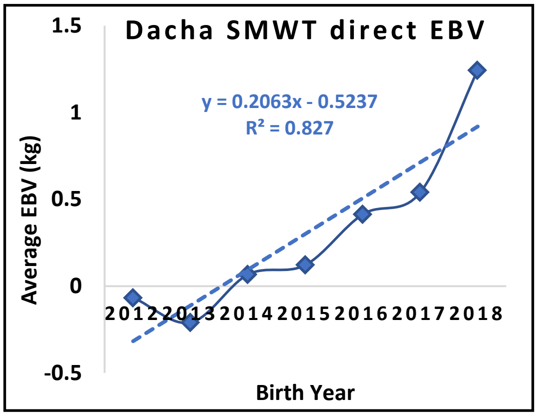
### (a) CBBPs Cooperatives Showing Positive Trend

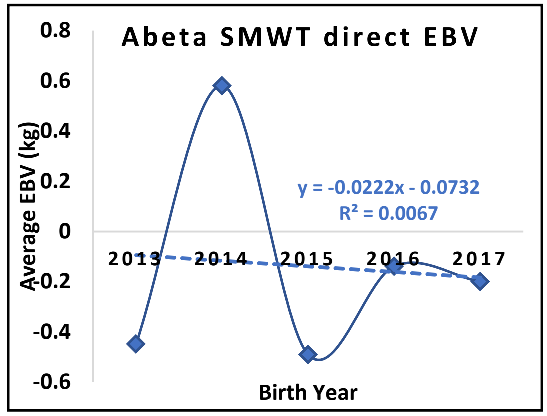
CBBP cooperatives observed positive trend were Alargeta, Angikolla, Omashonga, Wanabolla, Abeta, Didifa, Kicho, Dacha, Guta, Shosha and Yama. Perusal of Table 19 showed that estimates of direct genetic gain ranged between nearly 0.0 (Angiokola) and 1.451 (Omashonga) whereas estimates of phenotypic gain ranged between -7.98 (Omashonga) and 6.814 (Abeta) in the present study. The perusal of Figure 3 showed that direct genetic gain exhibited fluctuating behaviour with improvement over years. Results of CBBP cooperatives with positive genetic trends in this study have a number of implications. The major finding is that when participatorily implemented, CBBP recording systems can be highly reliable and effective. Secondly, appreciable genetic improvement could be achieved from selection using farmers' subjective criteria. Thirdly, the main reason for positive trends might be due to the fact that better top ram using system, better follow up of farmers for controlled matting, effectively data recording and follow up by enumerators and low rate of mixing flock with non-participants. Phenotypic performance is a combination of both genetic and environmental effects. The positive genetic trend of selection trait for Alargeta and Omashonga CBBP cooperatives is due to additive effect of the flock. For those CBBP cooperative phenotypic performance of body weight had negative change indicate that environmental management of flock is poor Table 19.

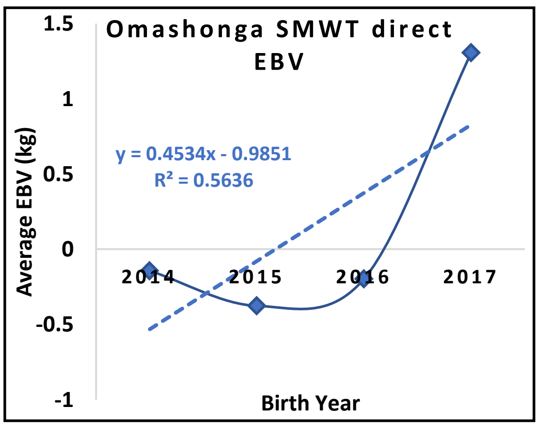
**Table 19: CBBP cooperatives having positive genetic and phenotypic gain of SMWT (Kg)**

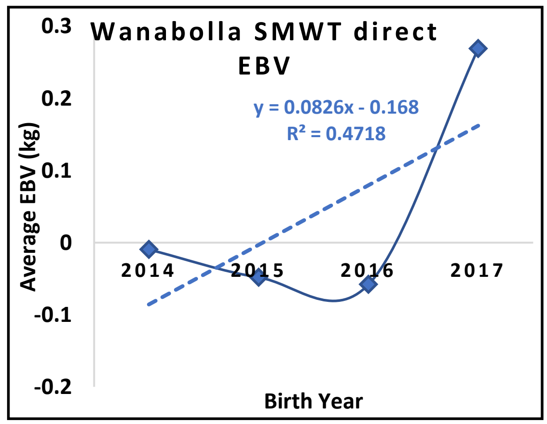
| Districts | CBBP Cooperative | Direct genetic gain | Phenotypic gain |
|---|---|---|---|
| Adiyo Kaka | Alargeta | 0.095 | -0.16 |
| | Angiokola | 3.26767E-06 | 2.586 |
| Chena | Omashonga | 1.451 | -7.98 |
| | Wanabola | 0.279 | 6.383 |
| Gesha | Abeta | 0.248 | 6.814 |
| | Didifa | 0.979 | 0.524 |
| | Kicho | 0.410 | 1.593 |
| Tello | Dacha | 1.310 | 7.333 |
| | Guta | 0.0001 | 4.470 |
| | Shosha | 0.413 | 1.412 |
| | Yama | 0.188 | 1.661 |

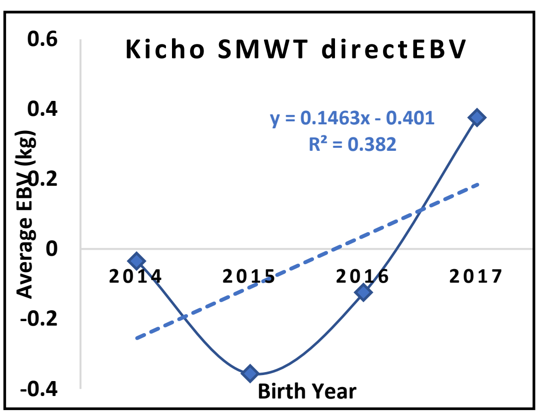


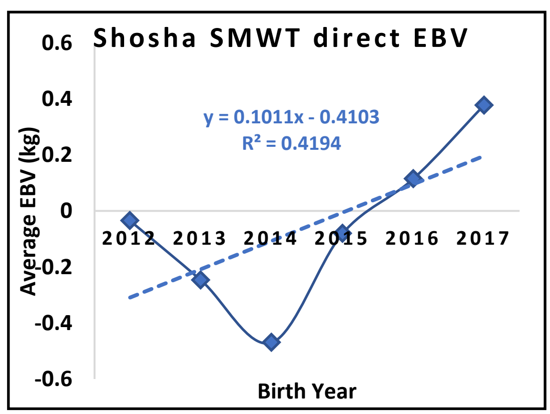

Dacha SMWT direct EBV
y = 0.2063x - 0.5237
R² = 0.827
Average EBV (kg)
1.5
1
0.5
0
-0.5
2012 2013 2014 2015 2016 2017 2018
Birth Year


Abeta SMWT direct EBV
y = -0.0222x - 0.0732
R² = 0.0067
Average EBV (kg)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
2013 2014 2015 2016 2017
Birth Year


Omashonga SMWT direct EBV
y = 0.4534x - 0.9851
R² = 0.5636
Average EBV (kg)
1.5
1
0.5
0
-0.5
-1
2014 2015 2016 2017
Birth Year


Wanabolla SMWT direct EBV
y = 0.0826x - 0.168
R² = 0.4718
Average EBV (kg)
0.3
0.2
0.1
0
-0.1
-0.2
2014 2015 2016 2017
Birth Year


Kicho SMWT directEBV
y = 0.1463x - 0.401
R² = 0.382
Average EBV (kg)
0.6
0.4
0.2
0
-0.2
-0.4
2014 2015 2016 2017
Birth Year


Shosha SMWT direct EBV
y = 0.1011x - 0.4103
R² = 0.4194
Average EBV (kg)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
2012 2013 2014 2015 2016 2017
Birth Year

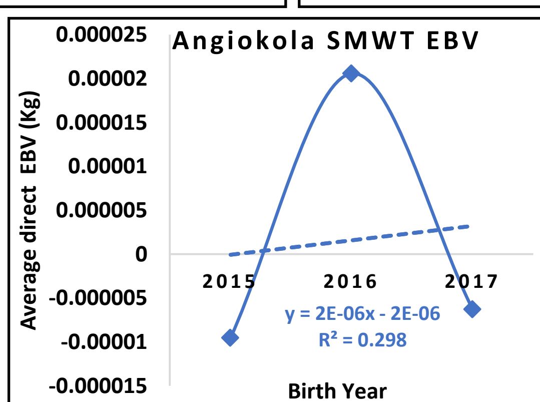

Angiokola SMWT EBV
Average direct EBV (Kg)
0.000025
0.00002
0.000015
0.00001
0.000005
0
-0.000005
-0.00001
-0.000015
2015 2016 2017
y = 2E-06x - 2E-06
R² = 0.298
Birth Year

**Figure 3: CBBP having positive genetic trend for six months weight breeding values**

**(b) CBBP Cooperatives Showing Negative Trend**

The estimates of direct genetic gain and phenotypic gain for each cooperative showing negative trends in SMWT are presented in Table 20. The EBV's plotted across years for each cooperative are plotted in Figure 4. In all three cooperatives (Buta, Meduta and Dirbedo) showed negative genetic and phenotypic trends in the SMWT. Perusal of Table 20 showed that estimates of direct genetic gain ranged between -0.3259 (Dirbedo) and -0.1750 (Meduta) whereas estimates of phenotypic gain ranged between -0.803 (Meduta) and -6.50 (Dirbedo) in the present study. The possible reason for negative trends may be due to the possibility of selection carried on phenotypic body weight (sometimes) which influenced highly by environment, the program is on-farm so sometimes enumerators may lack accuracy of data recording, mixing of flocks between participant and non-participant result poor controlled matting, and poor follow up of effectively used of selected top breeding rams. Besides, some participants practice fattening of un-castrated ram (purchased from market) which graze with flock, and regular purchase of new ewe/ ewe lamb.

**Table 20: CBBP cooperatives having negative genetic and phenotypic gain for SMWT (kg)**

| | District | | |
|---|---|---|---|
| | Adiyo Kaka | | Gesha |
| CBBP cooperative | Buta | Meduta | Dirbedo |
| Direct genetic gain (kg) | -0.2670 | -0.1750 | -0.3259 |
| Phenotypic gain (kg) | -0.734 | -0.803 | -6.50 |

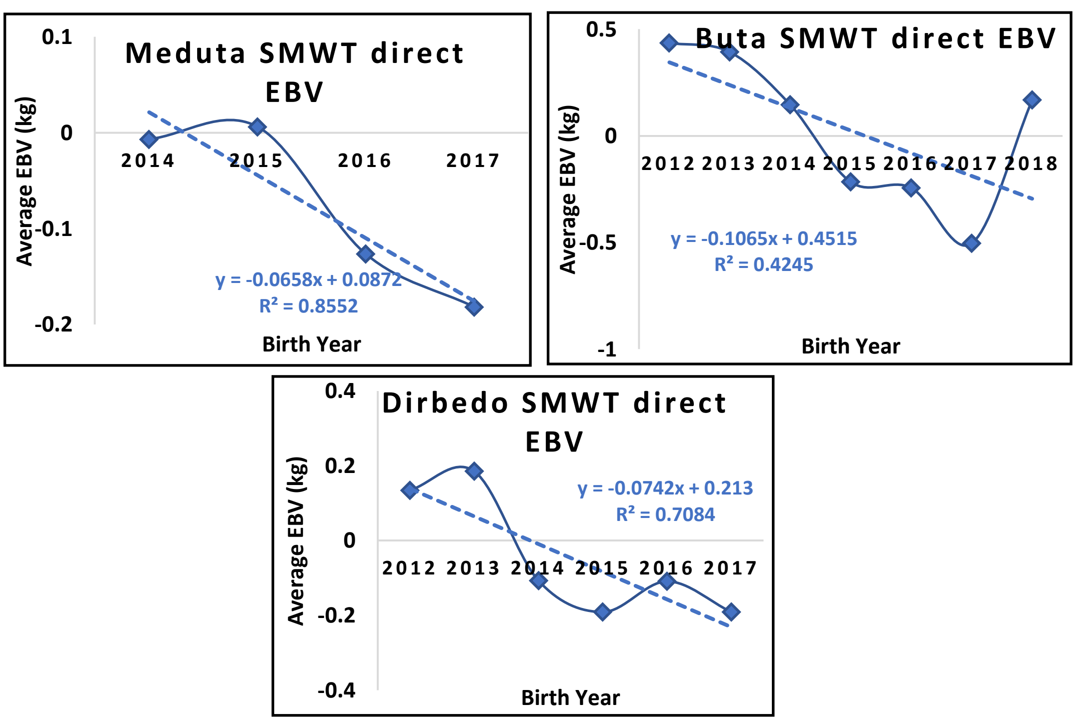



**Figure 4: CBBP having negative genetic trend for six months weight breeding value**

**(ii) Identified Sire and Dam Having**

### Higher Breeding Value

Identification of both breeding rams and dams having high breeding value may help to conserve and use their progenies to get better improvement across generation. Based on their breeding value of top 20 rams and dams having higher breeding value were indicated in Table 21. Dams breeding value was estimated based on the performance of progenies.

**Table 21: Breeding ram and dam having higher breeding value within flocks**

| S.No. | Best Ram | | | | Best Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | **Ram ID** | **Ram CBBP cooperative** | **Ram EBV** | **Accuracy** | **Dam ID** | **Dam CBBP Cooperative** | **Dam EBV** | **Accuracy** |
| 1 | 105913 | Dirbedo | 3.36506 | 68% | 1087513 | Dacha | 2.29488 | 49% |
| 2 | 10524313 | Dirbedo | 3.27334 | 62% | 10613914 | Kicho | 2.28251 | 50% |
| 3 | 11332417 | Guta | 3.15526 | 62% | 11012814 | Meduta | 2.16217 | 44% |
| 4 | 10516414 | Dirbedo | 2.74841 | 58% | 11342214 | Guta | 2.15773 | 30% |
| 5 | 11416314 | Omashonga | 2.73619 | 57% | 10843515 | Dacha | 2.13097 | 40% |
| 6 | 1136916 | Guta | 2.71602 | 66% | 1019017 | Alargeta | 2.12938 | 46% |
| 7 | 10211817 | Abeta | 2.69288 | 61% | 1066414 | Kicho | 2.10276 | 44% |
| 8 | 1159615 | Wanabolla | 2.65621 | 62% | 1062214 | Kicho | 2.07909 | 49% |
| 9 | 102917 | Abeta | 2.6101 | 58% | 1065614 | Kicho | 1.97305 | 41% |
| 10 | 10529313 | Dirbedo | 2.60187 | 59% | 11025014 | Meduta | 1.96414 | 44% |
| 11 | 10517314 | Dirbedo | 2.59714 | 59% | 10610214 | Kicho | 1.92001 | 39% |
| 12 | 1129813 | Shosha | 2.59259 | 58% | 11012914 | Meduta | 1.91782 | 29% |
| 13 | 1059112 | Dirbedo | 2.58244 | 57% | 10853514 | Dacha | 1.89704 | 42% |
| 14 | 10818117 | Dacha | 2.55188 | 64% | 10155814 | Alargeta | 1.88996 | 41% |
| 15 | 11335417 | Guta | 2.54374 | 62% | 10513613 | Dirbedo | 1.83226 | 29% |
| 16 | 10211517 | Abeta | 2.54279 | 61% | 11410514 | Omashonga | 1.82412 | 29% |
| 17 | 10816415 | Dacha | 2.53124 | 72% | 104314 | Didifa | 1.81096 | 34% |
| 18 | 1133315 | Guta | 2.48976 | 63% | 10550014 | Dirbedo | 1.80944 | 37% |
| 19 | 11346615 | Guta | 2.47332 | 72% | 1088215 | Dacha | 1.80213 | 41% |
| 20 | 106515 | Kicho | 2.45255 | 59% | 11037014 | Meduta | 1.79264 | 48% |

### (iii) Inbreeding Trend of Bonga Sheep Under CBBP

The number of animals in the pedigree file was 22352. The average inbreeding level of Bonga sheep in 2018 was 0.75% with annual rate of 0.13% (Figure 5). Statistically the annual rate of inbreeding was highly significance at ($P<0.0001$). Only 467 (2.09%) animals were inbred with an average inbreeding coefficient of 0.36%. The inbreeding coefficient amongst inbred animals was 17%. The average inbreeding values reflect the increased frequency of homozygous loci and loss of genetic variability (Vostry *et al*., 2018). As a rule of thumb, FAO (2010) recommends that the inbreeding rate should be maintained below the range of 0.5-1% per year to avoid risks of genetic disorders and inbreeding depression.

The overall inbreeding rate was comparable with Horro sheep 0.78% with annual trend 0.07±0.01% but higher inbreeding level than current result of inbred animals was 2.5% (Negussia *et al*., 2002) and Iranian Lori sheep inbreeding coefficients were 0.69% with annual 0.215% (Yeganehpur *et al*., 2016). Also, lower than Menz sheep inbreeding coefficient 1.7% (Gizaw *et al*., 2013) and 0.17% per generation and Romanov sheep in the Czech Republic the average inbreeding coefficients were 5.5% and the average inbreeding rate was 1% (Vostry *et al*., 2018). The inbreeding trend for each CBBP cooperatives was presented in APPENDIX Figure 1.

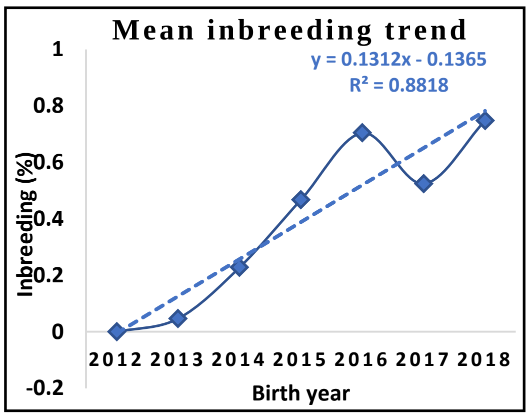



**Figure 5: Mean annual inbreeding trend of the breed**

**(B) Average Daily Gains (ADGs)**

The direct genetic gain (gm), maternal genetic gain (gm), and maternal permanent environment trend of daily gains (ADG1, ADG2, ADG3 and ADG4) traits is presented in Table 22. The means of breeding values for different years plotted against the year of birth, to show the genetic trend for body weight gains at different ages (ADG1, ADG2, ADG3 and ADG4) are shown in Figure 6. Perusal of results in Table 22 and Figure 6 showed that EBVs was positive for all direct genetic effect for ADG1, ADG2, ADG3 and ADG4. The direct genetic effect ranged between 1.4301 (ADG3) and 3.0414 (ADG2). The genetic gain with annual increasing value for each daily gain were 1.5325 with 0.3167, 3.0414 with 0.4848, 1.4301 with 0.2545 and 2.76 with 0.3714gm for ADG1, ADG2, ADG3 and ADG4, respectively. A highest genetic gain (3.0414 with 0.4848gm) due to direct genetic effect across birth year was obtained for ADG2. Statistically annual direct genetic trend for ADG1, ADG2, and ADG3 was highly significance at (P<0.0001) but non-significance for ADG4 (P>0.05).

**Table 22: Genetic gain for average daily gains (gm) of growth traits**

| Traits | Direct genetic gain | Maternal genetic gain | Maternal permanent environmental trend |
|---|---:|---:|---:|
| ADG1 | 1.5325 | 0.5438 | 1.3475 |
| ADG2 | 3.0414 | - | -1.6889 |
| ADG3 | 1.4301 | - | - |
| ADG4 | 2.76 | - | - |

The maternal genetic gain (Table 22 and Figure 6) was positive for ADG1 (0.5438) with annual trend of 0.0478 and non-significance at (P > 0.05). The graph (Figure 6) showed that there is a good change of EBV for direct genetic effect and maternal genetic effect for body weights gains

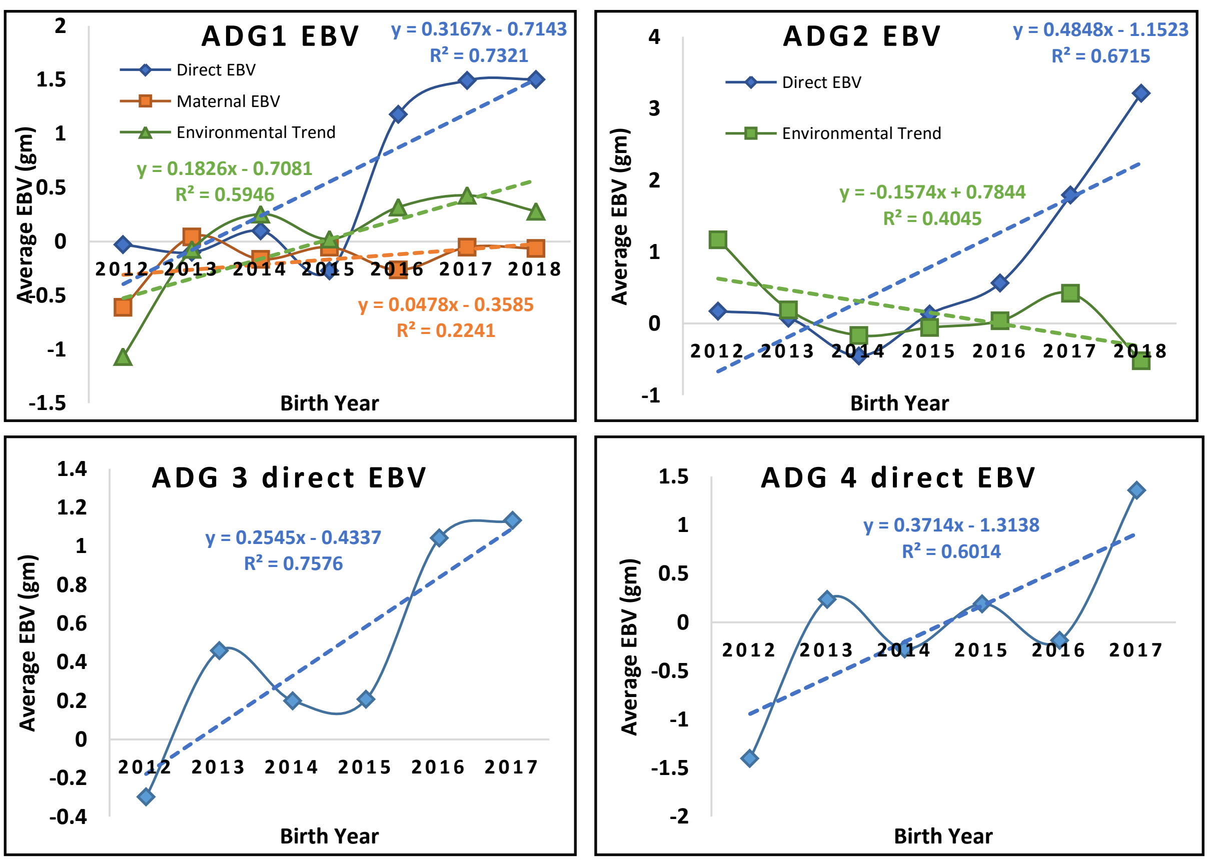



**Figure 6: Means of predicted breeding value (gm) over years for different average daily gains** (ADG1, ADG2, ADG3 and ADG4).

### 4.3.2. Reproductive traits

The direct genetic gain, maternal genetic gain and animal permanent environment trend for reproductive traits is presented in Table 23. The means of breeding values for different years plotted against the lambing year for LI and LS and against birth year for AFL, to show the genetic trends are shown in Figure 7. Perusal results in Table 23 and Figure 7 showed that direct genetic effect ranged between -0.2084 (AFL) and -0.0016 (LS). The genetic gain with annual decreasing value for each reproductive trait were -0.2084 with -0.0281 days, -0.1068 with -0.016 days and -0.0016 with -0.0002 lambs for AFL, LI and LS, respectively. The breeder aims to reduce both AFL and LI and negatively directed EBV for AFL and LI in the present study was reduced both these traits. However, for LS the breeder aims to increase twining rate but negative EBV for LS in the present study caused decrease in LS. The possible reason for this may be more emphasis for improving body weight and negatively correlated between body weight and LS. Statistically all reproductive traits annual genetic trend was not significance (P>0.05). Positive and better annual genetic trend for LS was estimated from Horro sheep 0.0009±0.004 from Partial regression coefficients (±S.E.) (Negussie *et al*., 2002). Related annual trend of AFL -0.012days/year and LS -0.0003lambs/year was recorded from on-station Brazilian Santa Ines sheep (Aguirre *et al*., 2017).

**Table 23: Genetic gain of reproductive traits**

| Traits | Direct genetic gain | Maternal genetic gain | Animal Permanent environment trend |
|---|---|---|---|
| AFL (days) | -0.2084 | - | - |
| LI (days) | -0.1068 | - | -7.2153E-06 |
| LS (lamb) | -0.0016 | -0.0002 | -0.0041 |

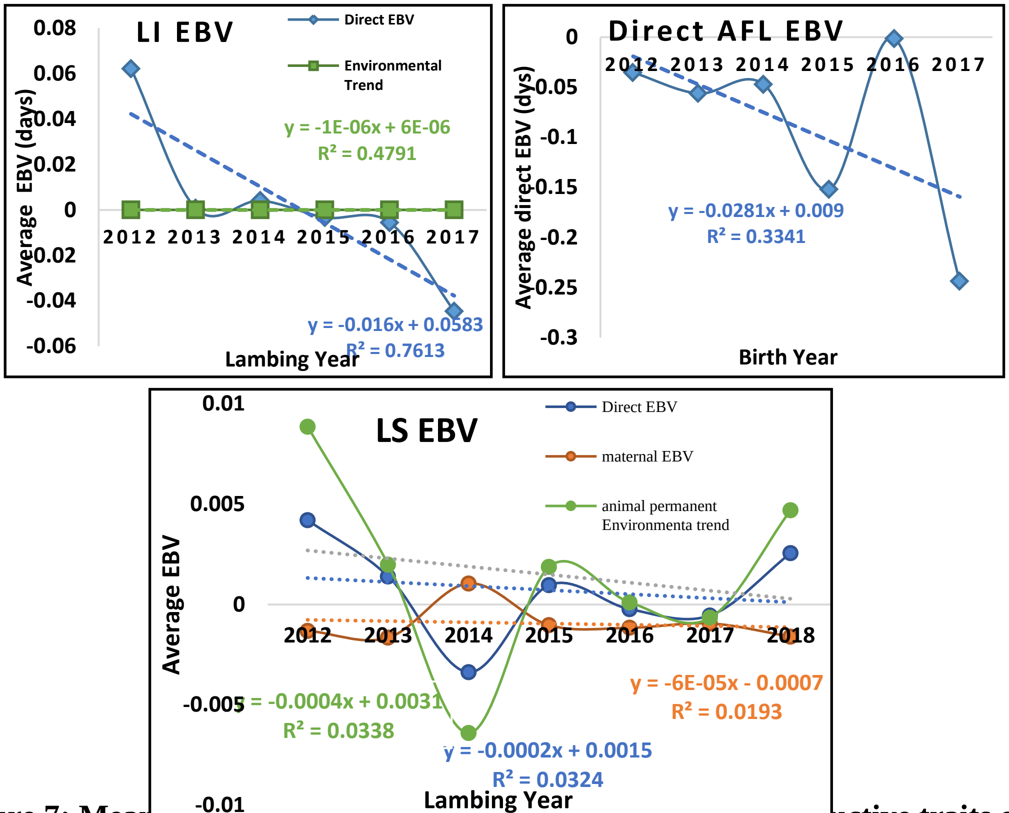



**Figure 7: Means of predicted breeding value for different reproductive traits over years**

The maternal genetic gain (Table 23 and Figure 7) was negative for LS (-0.0002). The graph (Figure 7) showed that there is a good change of EBV for direct genetic effect for reproductive (AFL, LI) traits whereas change was not in right direction for LS.

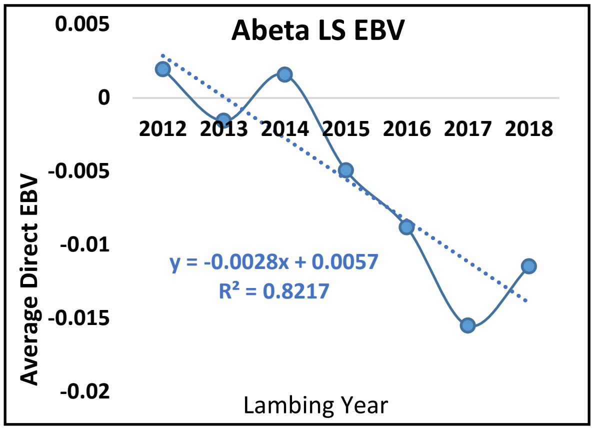
## (I) Genetic and Phenotypic gain and Trend for LI and LS Traits of Each CBBP Cooperatives

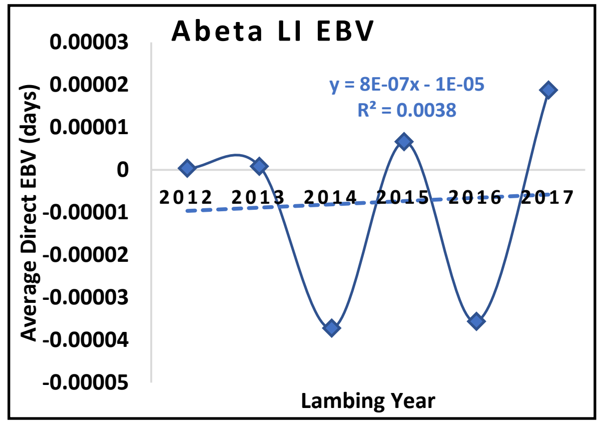
The estimates of direct genetic gain and phenotypic gain for each cooperative for LS and LI are presented in Table 24. While for AFL the recorded data was insufficient to analysis each CBBP cooperatives. The EBV's plotted across lambing years for each cooperative are plotted shown in Figure 8. Perusal of Table 24 and Figure 8 showed that there was no uniform trend across the cooperatives in both genetic and phenotypic gain for LS and LI. Both traits showed positive as well as negative genetic and phenotypic gain/trend across cooperatives. CBBP cooperatives which estimated positive genetic gain of LS by additive genetic effect are 7 out of 14 which are Alrgeta, Angikolla, Buta, Dacha, Didifa, Shosha, and Wanabolla but others have negatively changed Table 24. Among positively changed cooperatives Buta 0.0618 have highest LS gain. Buta CBBP cooperative was negatively trended for selected traits of six-month weight (Figure 4) but better positive change for litter size. It indicates that negative effect of litter size on body weight. The genetic and phenotypic gains of LS were in the same direction (Positive/ negative) for most cooperatives except Abeta, Dacha, Didifa, Meduta, Omashonga and Wanabolla cooperatives. In Dacha, Didifa and Wanabolla cooperatives the genetic gain was positively directed with its corresponding phenotypic gain negatively directed whereas reverse (negatively directed genetic gain but positively directed phenotypic gain) was true for Abeta, Meduta and Omashonga cooperatives. Similarly, the genetic and phenotypic gains of LI were in the same direction (Positive/ negative) for all cooperatives except Abeta, Omashonga and Yama cooperatives. In Abeta and Omashonga cooperatives the genetic gain was positively directed with its corresponding phenotypic gain negatively directed whereas reverse (negatively directed genetic gain but positively directed phenotypic gain) was true for Yama cooperative. The heritability of LI (Table 16) was low in present study there by indicating that generally this trait was influenced by rearing management particularly ability of farmers for timely detection of heat (Estrus) signs, feeding system, introduction of new ewe to the program and top ram using mechanism highly influence its progress.

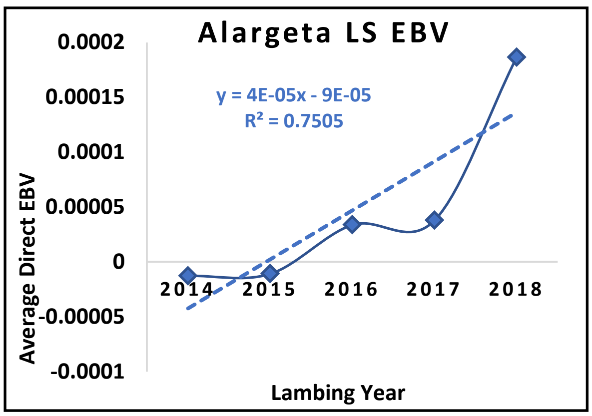
**Table 24: Genetic and phenotypic gain for LS and LI of each cooperative**

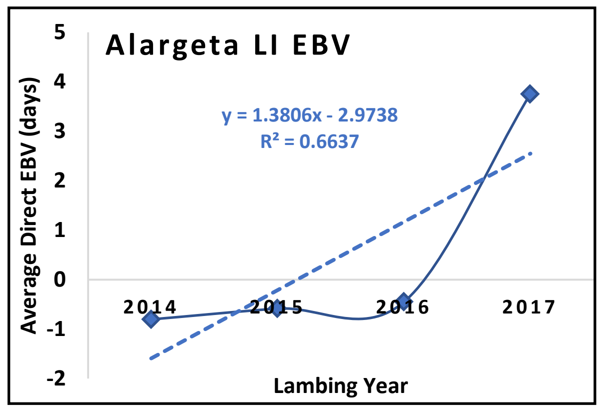
| Cooperative | Genetic gain of traits | | Phenotypic gain | |
|---|---|---|---|---|
| | Litter size (LS) | Lambing interval (LI) | Litter size (LS) | Lambing interval (LI) |
| Abeta | -0.0134 | 0.0000 | 0.1686 | -16.6251 |
| Alrgeta | 0.0001 | 4.5566 | 0.1406 | 4.9399 |
| Angikolla | 0.0010 | -1.9729 | 0.0974 | -2.4500 |
| Buta | 0.0618 | -1.7209 | 0.0333 | -90.5152 |
| Dacha | 0.0011 | 0.0000 | -0.1358 | 21.0000 |
| Didifa | 0.0013 | -0.0193 | -0.0644 | -76.5000 |
| Dirbedo | -0.0237 | -21.7747 | -0.0907 | -42.9571 |
| Guta | -0.0122 | -0.0004 | -0.0269 | -11.1212 |
| Kicho | -0.0223 | 5.5906 | -0.0472 | 16.2333 |
| Meduta | -0.0001 | 8.0299 | 0.0172 | 10.1186 |
| Omashonga | -0.0014 | 0.0010 | 0.0478 | -91.6436 |
| Shosha | 0.0055 | -0.0009 | 0.0098 | -62.8040 |
| Wanabolla | 0.0000 | -0.0004 | -0.0276 | -17.5000 |

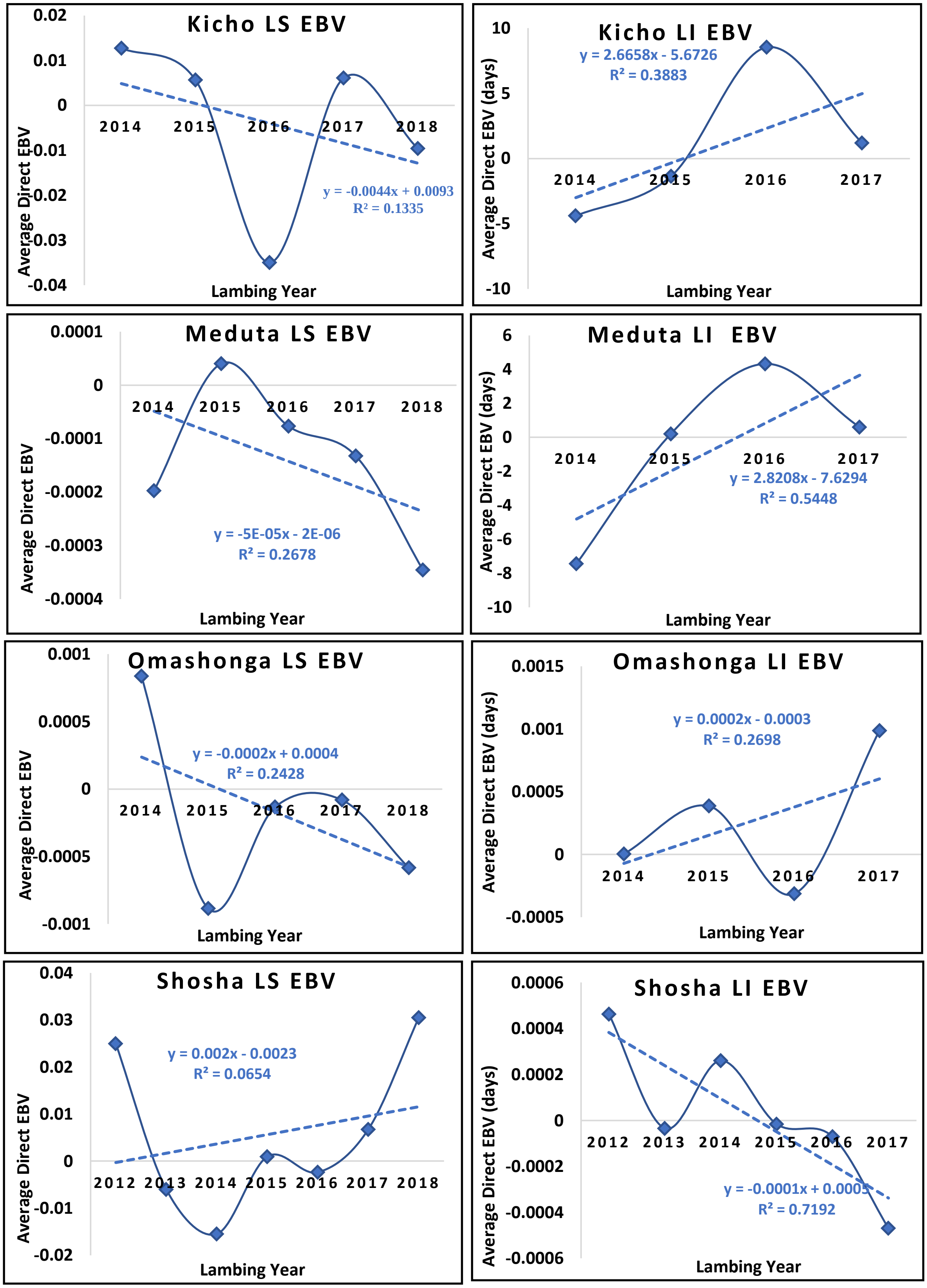
| | | | | |
|---|---|---|---|---|
| Yama | -0.0002 | -0.0068 | -0.0697 | 31.2400 |



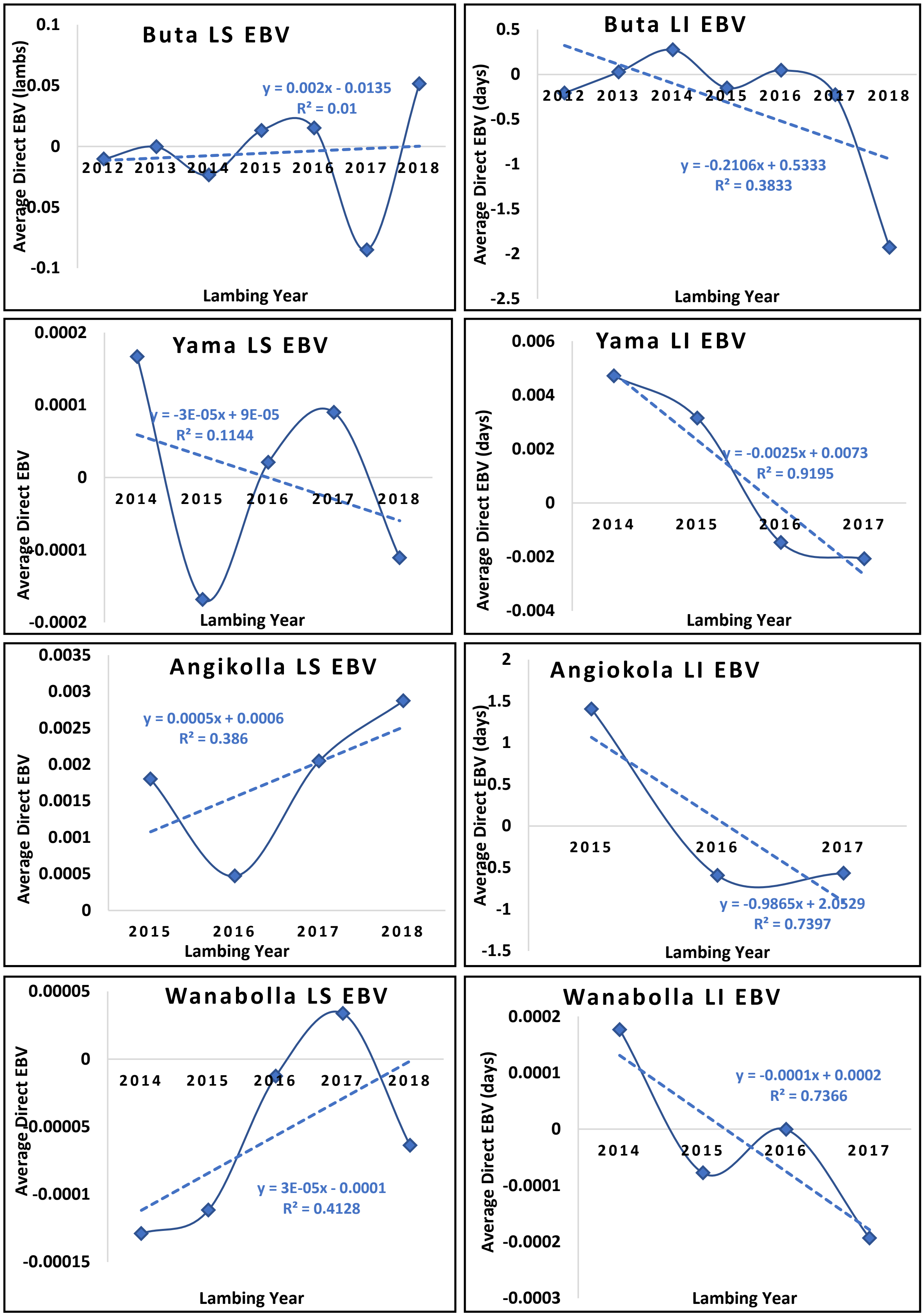





Kicho LS EBV
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
2014
2015
2016
2017
2018
y = -0.0044x + 0.0093
R² = 0.1335
Average Direct EBV
Lambing Year
Kicho LI EBV
10
5
0
-5
-10
y = 2.6658x - 5.6726
R² = 0.3883
2014
2015
2016
2017
Average Direct EBV (days)
Lambing Year
Meduta LS EBV
0.0001
0
-0.0001
-0.0002
-0.0003
-0.0004
2014
2015
2016
2017
2018
y = -5E-05x - 2E-06
R² = 0.2678
Average Direct EBV
Lambing Year
Meduta LI EBV
6
4
2
0
-2
-4
-6
-8
-10
2014
2015
2016
2017
y = 2.8208x - 7.6294
R² = 0.5448
Average Direct EBV (days)
Lambing Year
Omashonga LS EBV
0.001
0.0005
0
-0.0005
-0.001
2014
2015
2016
2017
2018
y = -0.0002x + 0.0004
R² = 0.2428
Average Direct EBV
Lambing Year
Omashonga LI EBV
0.0015
0.001
0.0005
0
-0.0005
y = 0.0002x - 0.0003
R² = 0.2698
2014
2015
2016
2017
Average Direct EBV (days)
Lambing Year
Shosha LS EBV
0.04
0.03
0.02
0.01
0
-0.01
-0.02
y = 0.002x - 0.0023
R² = 0.0654
2012
2013
2014
2015
2016
2017
2018
Average Direct EBV
Lambing Year
Shosha LI EBV
0.0006
0.0004
0.0002
0
-0.0002
-0.0004
-0.0006
2012
2013
2014
2015
2016
2017
y = -0.0001x + 0.0005
R² = 0.7192
Average Direct EBV (days)
Lambing Year


Buta LS EBV
y = 0.002x - 0.0135
R² = 0.01
Average Direct EBV (lambs)
Lambing Year
Buta LI EBV
y = -0.2106x + 0.5333
R² = 0.3833
Average Direct EBV (days)
Lambing Year
Yama LS EBV
y = -3E-05x + 9E-05
R² = 0.1144
Average Direct EBV
Lambing Year
Yama LI EBV
y = -0.0025x + 0.0073
R² = 0.9195
Average Direct EBV (days)
Lambing Year
Angikolla LS EBV
y = 0.0005x + 0.0006
R² = 0.386
Average Direct EBV
Lambing Year
Angiokola LI EBV
y = -0.9865x + 2.0529
R² = 0.7397
Average Direct EBV (days)
Lambing Year
Wanabolla LS EBV
y = 3E-05x - 0.0001
R² = 0.4128
Average Direct EBV
Lambing Year
Wanabolla LI EBV
y = -0.0001x + 0.0002
R² = 0.7366
Average Direct EBV (days)
Lambing Year

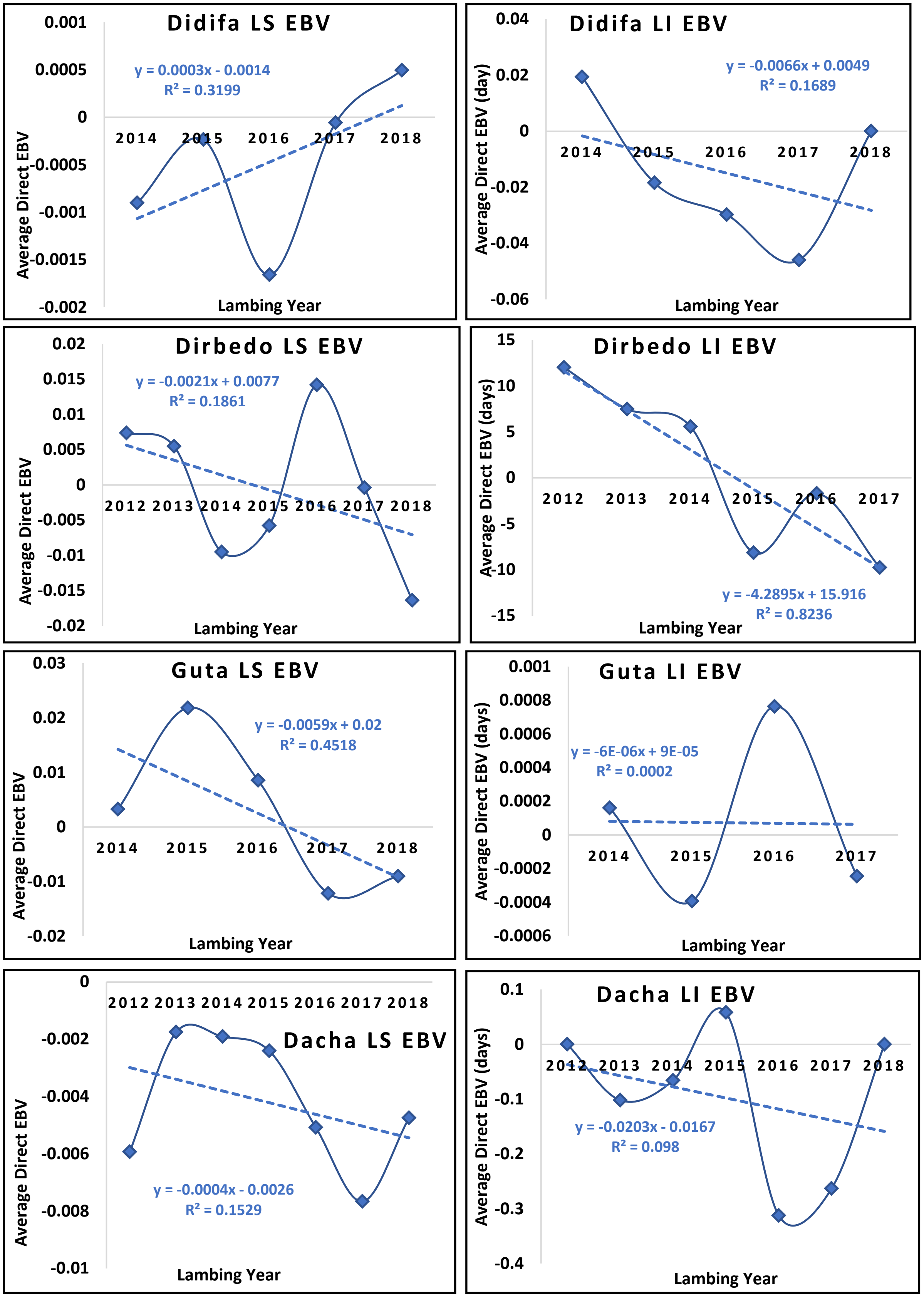



**Figure 8:Estimated direct breeding value for LS and LI traits of each cooperatives**

### 4.4. Farmers Perception in Community Based Breeding Programs

Based on focus group discussion in single smallest administrative; kebele; on average 800 households were available and on average 95 households were participated in CBBPs when calculated with all participants community members of 1331within 14 cooperatives. This indicated that only 11.9% of kebele members were included by CBBP. The reason of less participants as reported by them was due to fees to join the CBBP cooperatives, no sheep flock, and residence at remote. Interview and discussion with participants revealed that participant farmers reported that they were developed different type of skills which includes using top ram, importance of selection, keeping elite flock, avoid negative selection, system and importance of record keeping, culling system, selection mechanism and effect of inbreeding.

#### *i.* Record Keeping Mechanism

Record keeping is the main component for sustainability of CBBPs. It was done at three levels to keep the data as safe as possible (Figure 9). Each participant farmers have own recording book which is recorded by enumerator and keep it in their home. Secondly each enumerator had three types of recording book which are lamb data recording book, ewe data recording book, and inventory recording book for each CBBP cooperative. Lastly the data used to be compiled and kept in computer excel spread sheet at BARC as soft copy.

Computer excel spread sheet    Enumerator recording notebook    Farmers recording book

**Figure 9: Method of recorded data keeping system**

Additionally, for Boka-Shuta CBBP cooperative the data routinely collected by the enumerators is periodically compiled entered in to Data Recording and Management Systems (DREMS). However, Haile *et al*. (2019) has explained that one of the major challenges in use of DREMS is the need for reliable internet connection, which is difficult to get in most African rural villages. To tackle this challenge, an offline application “AniCloud” is being developed in collaboration with by AbacusBio limited from New Zealand. This application is being tested and will be made available when it is ready. The overall survey result of frequency of data recording in farmers level is indicated in the Table 25. Perusal of Table 25 showed that 85.7% respondent farmers replied that enumerators always record of biological data of their flocks. These farmers always inform to the enumerators for every birth of lamb. Enumerators calculated recording date of body weights after birth weight and taking record without waiting farmers calling. The number of flocks having recorded data was decreasing when age increasing due to mortality, sold, missing of record and become pregnant for females (Table 11).

**Table 25: percentage of respondents keeping record for their flock**

| Record data | Frequency | Percent |
|---|---|---|
| Always | 138 | 85.7 |
| Most of the time | 22 | 13.7 |
| Rarely | 1 | 0.6 |
| Total | 161 | 100.0 |

### *ii.* Using and Management of Top Ram

Top ram refers to the first top 10% of selected breeding rams retained for breeding in mating of participant flocks (Figure 10 showing top ram and ewe). The CBBP breeding scheme encourage to use only best selected rams to obtain improvement over generations.

**Figure 10: Sample of Bonga top breeding ram and ewe**

Frequency of using top ram was indicated in Table 26 which shows that 88.5% of participants were always using it. The remaining percentage of respondents (11.5%) were either using top rams either most of times or sometimes. The possible reason may be that the sheep owners fail to observe heat (estrus) signs in their ewes.

**Table 26: percentage frequency of top ram user**

| Using top ram | Frequency | Percent |
|---|---|---|
| Always | 108 | 88.5 |
| Most of the times | 4 | 3.3 |
| Sometimes | 10 | 8.2 |
| Total | 122 | 100.0 |

Even if all participants have interest to use top ram and most of them using it frequently; however, they show less interest to keep and manage rams. The main reason for poor interest of managing the ram was fear of thieves, difficult to handle by women and children, due to its size difficult to control by rope and due its large size buyers was not interested to take it as a breeding ram. As indicate in Table 27 that 19.9% were managing top ram currently among participant of interviewee and focus group discussion. Normally breeding rams was not expected to keep in every household because they use it as a group.

**Table 27: percentage of respondents involved in managing top ram**

| Keeping top ram | Frequency | Percent |
|---|---|---|
| No | 129 | 80.1 |
| Yes | 32 | 19.9 |
| Total | 161 | 100.0 |

Most of the respondent and discussant agreed that the selected top rams were best of candidates. This is due to participation of the community during selection and every participant know the criteria of selection. From randomly selected sample of interviewee and discussant up to 98.13% like their top ram that full fill their trait preference but the remaining 1.88% have complain. The main reason of complain was lower body size and coat color when compared with other top rams. According to respondents there were different criteria to say the ram is best. Among these criteria convex facial profile, progeny resemblance, long and fat tail, coat color especially (red, light red, and red with white spot), pedigree information, growth performance, libido performance, having toggle, temperament, and polled character were mentioned.

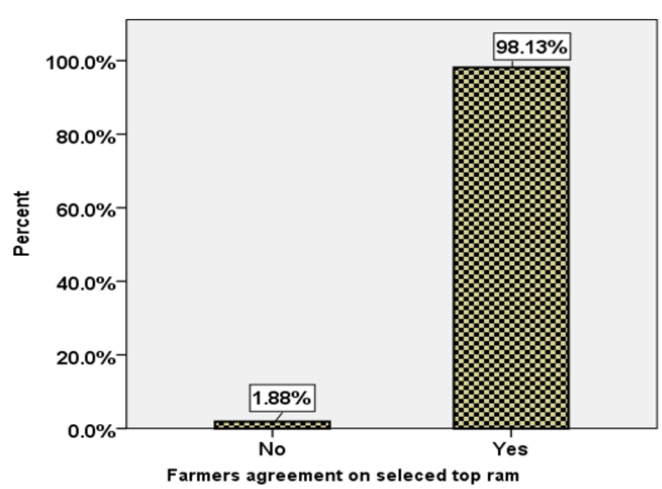


**Figure 11: Perception on selected top rams**

Age is directly related with breeding efficiency like ability to mate as a result top rams were used in age bounded manner. As a rule, in the guideline of CBBP, discussion was made with the community during startup of the program which suggest a single top ram is assigned as breeding purpose for 2 years. During interview and group discussion, the respondent wanted to use only for one year after assigned as top ram. As mentioned earlier top ram was used as mutton production or as breeding sire for other communities and selling is based on its body weight after 2 years' service. Most of these top rams had high kg which make sire buyer were not interested to take it because it consumes high money. So, this low interest of buyer makes participant members to use these rams only for one year.

Almost all respondents aware about inbreeding and its negative consequence. The main effect of inbreeding what they metioned was poor growth, tendency to malformation, poor reproductive performance and delay puberty. The problem is sometimes happened as observed in field observation. Negative selection is a problem of non-participants as they used to sell fast growing animals in better price compared to the inferior ones. This is also reported by Gizaw *et al*. (2014) that farmers usually sell off fast growing rams that are potentially best breeding ram and this resulted in negative selection. Most of the non-participant respondents (60%) had shortage of breeding rams. To alleviate this problem non-participant community members wanted to participate in the program. Up to 33.1% the respondents sometimes use selected breeding rams from participant members. The remaining 67% of respondent were not used top ram because CBBP members are not allowed to share sires outside of their group. The main reason for non-participants to didn't maintain best animal was lack of proper attention. According to discussants report uncontrolled breeding was common and result inbreeding problem, poor reproductive and productive performance of their flock.

### 4.4.1. Perception on the change of improvement

The change of improvement was verified by respondents during interviwee and focus group disscusions. Figure 12 shows that 96.89% of participant for this study were agreed that there was a change of improvement by productive and reproductive traits across years.

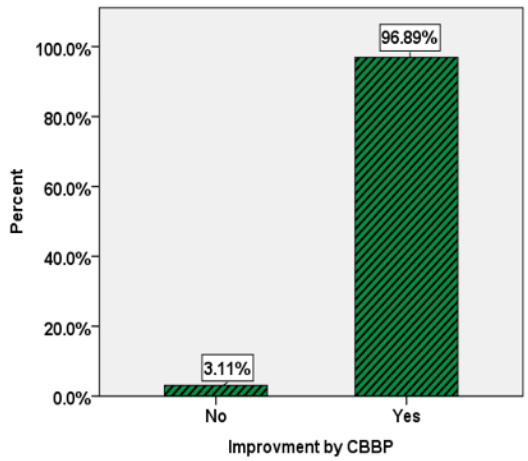



**Figure 12: Percentage of respondents observed improvement**

From the Figure 12, about 3.11% of respondents didn't agree the presence of improvement due to the CBBP intervention. They debated that no change of improvement but the only change was market access and selling price. They strengthen their idea that there was no selection on ewes and follow similar management as before. Similarly, Gutu *et al.* (2015) stated that 95.8% and 4.2% of interviwed participant showed improvement and showed no change, respectively. The farmers' ranked the traits improved from the time of starting of the out scaled breeding program under CBBP and the results are presented in Table 28.

**Table 28: Types of improved traits**

| Traits | 1st | 2nd | 3rd | Sum | Index | Rank |
|---|---|---|---|---|---|---|
| Age at first lambing | 2 | 11 | 29 | 42 | 0.08 | 4 |
| Coat color | 1 | 2 | 0 | 3 | 0.01 | 6 |
| Growth performance | 114 | 16 | 7 | 137 | 0.56 | 1 |
| Lamb survival | 9 | 17 | 15 | 41 | 0.11 | 3 |
| Lambing interval | 13 | 1 | 16 | 30 | 0.08 | 4 |
| Twining rate | 15 | 25 | 8 | 48 | 0.15 | 2 |

| | | | | |
|---|---|---|---|---|
| **Sum** | **154** | **72** | **75** | **1** |

Perusal of results (Table 28) indicated that as ranking of farmers' growth performance, twining rate, lamb survival, AFL / lambing interval and coat colour improved in the order of I, II, III, IV/IV and VI, respectively. Thus growth performance was the first improved traits when compared with the others. The second and third improved traits was twining rate and lamb survival. Selection was based on six-month weight ram lamb but consider other effects like birth type and color. So, improvement of growth performance traits was expected and due to intervention of health activity survivability of lamb also show improvement. The farmers' ranking that growth improved at first was in agreement with the present results showing improvement in growth (Table 11, 18 and 22).

The respondent farmers, who participated in the survey, agreed that there was difference between degree of improvement between the sheep of participant and non-participant farmers. The output of the result is indicated in Table 29.

**Table 29: participants perception on improvement difference between participant and non-participant**

| Improvement difference | Frequency | Percent |
|---|---|---|
| Missing | 5 | 3.1 |
| No | 10 | 6.2 |
| Unknown | 1 | 0.6 |
| Yes | 145 | 90.1 |
| Total | 161 | 100.0 |

Similarly, according to focus group discussion and interview participants 75.6% non-participant interviewee agreed that there was a difference genetic improvement between participant and non-participant members. They believed that the type of traits that made difference were physical appearance, reproductive performance, growth rate, and lamb survival. Oppositely, those who replied as no difference from both participant and non-participant which account 6.2% and 21.3% respectively gave their reason that they follow similar management of flock between participants and non-participant but the only difference was their selling price due to market access and participation by CBBP.

### 4.4.2. Income difference between participant and non-participant

The sale price of different categories (Ram lambs, Ewe lambs, Rams, and Ewes) of Bonga sheep of both participant and non-participant farmers is presented in Table 30. Perusal of results showed that average sale price of ram lambs, ewe lambs, rams and ewes for participant respondents was greater whereas for non-participant farmer it was smaller than the mean sale price of all these four categories of sheep. There is a significant difference of sale price of sheep, between participant and non-participant farmers, based on Mann-Whitney U test of non-parametric test of independent samples. The present result was in agreement with finding of Gutu *et al*. (2015) who reported that even unselected rams from the cooperatives fetch better sale price compared with other rams in the market. The rams of participant farmers were sold to other community within SNNPR or out of the region based on body weight as 1kg/100 ETB. However, rams of non-participants farmers were sold in local market as usual based on the agreement of buyer and seller.

**Table 30: Selling price difference between participant and non-participants**

| Category | | Ram lamb | Ewe lamb | Ram | Ewe | p-value for Mann-Whitney U test |
|---|---|---|---|---|---|---|
| Participant | N | 147 | 74 | 147 | 104 | |
| | Mean | 1476.19 (194.82) | 1293.92 (222.37) | 3483.67 (564.36) | 1890.38 (163.41) | 0.000 |
| Non-participant | N | 138 | 72 | 138 | 106 | |
| | Mean | 1120.29 (147.07) | 972.22 (226.56) | 2267.39 (540.01) | 1406.60 (228.98) | 0.000 |
| Total | N | 285 | 146 | 285 | 210 | |
| | Mean | 1303.86 (248.38) | 1135.27 (275.82) | 2894.74 (821.72) | 1646.19 (313.51) | 0.000 |

Though ewe and ewe lamb selling were not common by the cooperatives and main reason of selling female stock were when no other choice, increasing of age, poor mothering ability, long lambing interval and physical defects. The buyers bought ewe and ewe lamb by adding some premium than local market due to their origin from improved flock.

### 4.4.3. Farmers flock trend

The population trend of Bonga sheep among participant and non-participant respondents is presented in Figure 13. The Bonga flock showed increasing trend as stated by 78.88% from 161 participant respondents whereas 55% of non-participant respondents reported that their flock size is decreasing. This decreasing trend of flock size was related with shrinking of grazing land and paucity of labor. In a study by Haile *et al.* (2013) free grazing land is not common in Kaffa zone and each farmer used private grazing land by tethering for both cattle and small ruminants. This situation warrants intervention to overcome decreasing rate of the flock and main strategy could be conserving best flock either on farm or on-station.

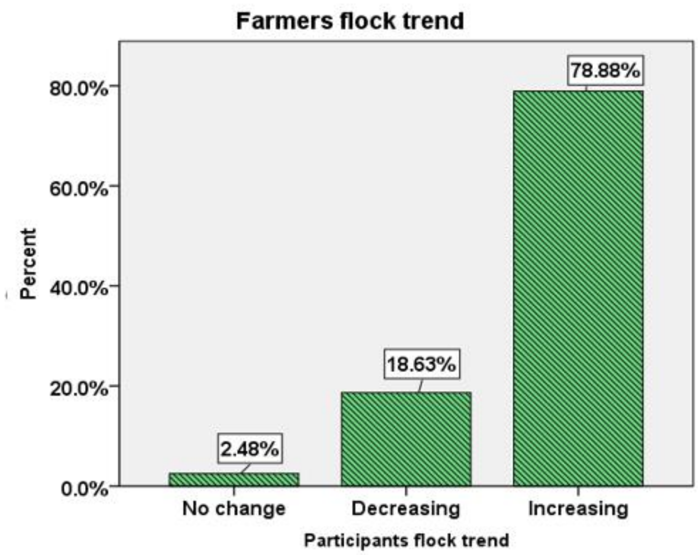



**Figure 13: Status assessment of Bonga breed farmers flock trend**

### 4.4.4. Major constraints of CBBP in the study area

Among respondent of farmers almost all had a positive attitude change because all participants wanted to continue as a member and most of non-participants community have great interest to become a member but faced different constraints. An indicator for attitude change is the degree of satisfaction i.e. how happy farmers feel the program has impacted their lives and changes in individual mentalities over time (Bohner and Dickel, 2011). The constraints were financial, ineffective working of CBBP cooperative committee, and limitations which were raised for enumerator and breeders. Shortage of training for community members of participants in the program, poor interest of ram buyers to take high body weight ram and shortage of health experts are the first three constraints. Table 31 indicated that type and rank of constraints of CBBP participants.

**Table 31: Major constraints of CBBP participants**

| Constraint | 1st | 2nd | 3rd | Sum | Index | Rank |
|---|---|---|---|---|---|---|
| Delay selection | 0 | 2 | 5 | 7 | 0.010 | 14 |
| Few numbers of ewe | 7 | 0 | 2 | 9 | 0.026 | 11 |
| Shortage of training for participants | 23 | 13 | 18 | 54 | 0.128 | 1 |
| Low selling price of ram | 27 | 3 | 15 | 45 | 0.116 | 4 |
| Shortage health expert | 13 | 25 | 16 | 54 | 0.119 | 3 |
| Delay market (ram distribution) | 16 | 21 | 8 | 45 | 0.111 | 5 |
| No maternal selection | 9 | 12 | 3 | 24 | 0.061 | 8 |
| Poor initiation for increasing member | 0 | 1 | 0 | 1 | 0.002 | 16 |
| Not working management bodies effectively | 13 | 19 | 7 | 39 | 0.095 | 6 |
| Delay replacing top ram | 0 | 2 | 5 | 7 | 0.010 | 14 |
| Poor supervision | 6 | 4 | 9 | 19 | 0.040 | 9 |
| Delay auditing and profit sharing | 17 | 6 | 18 | 41 | 0.092 | 7 |
| Not interested buyer to take high weight ram | 11 | 37 | 1 | 49 | 0.123 | 2 |
| Travelling long distance to sell rams | 0 | 5 | 0 | 5 | 0.011 | 13 |
| Poor interest to keep top ram | 0 | 0 | 1 | 1 | 0.001 | 17 |
| No labour | 2 | 3 | 12 | 17 | 0.027 | 10 |
| Poor linkage with district and zone administration | 0 | 4 | 14 | 18 | 0.025 | 12 |
| **Sum** | **144** | **157** | **134** | | **1** | |

## 4.5. Implication of the Result to Future Bonga Sheep Breeding Programme

The current study has provided important information on the extent of additive genetic variation in the existing flocks. This variation indicates that opportunities of genetic improvement for growth and litter size traits. Bonga sheep breed improvement and multiplication is managed by small-scale farmers, and used as nucleus flock for new established CBBP, small-scale farmers, private farms, governmental and non-governmental institutions. It would be, therefore, expected that further selection to improve performance of growth and litter size traits of such nucleus flocks is put in place to guarantee animals of good genetic merit for dissemination. There is negative association between selection traits of body weights (WWT and SMWT) with LS. The next step should be focus on increasing body weights and protecting loss of prolificacy by using estimated breeding value that estimated by BLUP.

The program is focused on paternal line selection but also maternal line selection also had own contribution to facilitate genetic improvement of flock. So, it is better to incorporate for the future to get better result and consider maternal effect for selection.

Environmental effects are the main determining effect for age at first lambing and lambing interval so critical follow up for feeding and heat detection is needed for the future.

Even if more than 78% of CBBP members replied that their flock was increasing trend but the actual recorded lamb across year for each CBBP cooperative become decreasing and some participants and majority of non-participants agreed their flock was in decreasing trend. Even though CBBP breeding strategy serve both the breed improvement and conservation purpose; it needs special attention for either on- farm or on-station conservation program for prolific flocks due to negative correlation between growth traits and litter size.

This program is the most preferred breed improvement program when genetic variation was available within population. So, expanding the CBBP may help to improve the breed uniformly which alleviate problem of slow progress on genetic gain like Buta, Meduta and Dirbedo due to mixing with flocks of non-participant community members and joining of new flock which are purchased from local markets.

The study also provides useful information on farmers perception and expectation. Participants highly depend on selling breeding rams that is the base for sustaining CBBP in the study area. Sometimes they are not interested to bring their lambs for selection if selling of sire was delayed. Oppositely continuous breeding sire buyers in the region and/or national level may be a problem for the future. The estimates indicate that higher rates of genetic gain in the breeding objective traits, and translate to higher economic returns. So, selection of animals for both breeding purpose and commercial mutton production for domestic and export market may help to sustain the breeding program. Also, forming union cooperatives will have power to determine markets and in the long run establishing Bonga sheep breed breeding society. Additionally, ministry of agriculture should think about breeding sire buyers from international level with considering of genotype by environment interaction, establishing abattoir plant in the area after assessment of exact population number of the breed with in geographical distribution of the breed, and encourage CBBP participant members will have better income for small-scale farmers. Periodically evaluation of the program by using adjusted body weights to avoid biasness and considering each random effect to solve influence of non-genetic factors will help for decision making.

# 5. CONCLUSION AND RECOMMENDATION

## 5.1. Conclusion

The present study provided very useful information for the progress of phenotypic performance of productive and reproductive traits across year, data structure of Bonga sheep, estimated genetic parameter and inbreeding level of CBBPs. Non-genetic factors like birth year, sex, dam parity, birth type, and CBBP cooperatives had a significance influence on the performance of the animal for growth trait and needs to consider during estimation of breeding values. Similarly, for reproductive traits like LI, LS, and ARR lambing year, lambing season, dam parity and CBBP cooperative were important factors but only birth year was significant for AFL. Based on comparison between current result with literature Bonga sheep had better growth and reproductive performances than other Ethiopian and some exotic sheep breeds due to intervention of breed improvement mechanism.

The difference in heritability estimates obtained from the different models, suggest that model choice is an important aspect for obtaining reliable parameter estimates to be used in prediction of breeding values. The direct additive, maternal genetic and maternal permanent environmental effects were very important parameters to be and considered during selection for breeding. While for second round selection at six-month weight direct additive genetic effect and maternal genetic effects should be consider (model 3). Similarly model 3 was appropriate best fit model for evaluation of NMWT and YWT of growth traits. For reproductive traits model 1, 2, and 6 was best fit model for AFL, LI, and LS traits respectively. The genetic parameters estimated indicate that there is genetic variation between animals that could be utilized for genetic improvements in growth and litter size traits. But for reproductive traits like AFL and LI heritability was low indicating difficult to improve by direct selection because female reproductive traits are highly influenced by environment. So, it could be more improved through manipulation of production management to reduce environmental influence.

The moderate to high estimates of heritability for most of the growth traits and positive genetic trends indicated scope for further improvement of these traits. As a response to selection of genetic gain for productive traits showed attractive gain across breeding years. Generally, the greater the superiority of the individuals selected for breeding purposes and the higher the heritability of the trait, the more progress will be made in selection. Positive genetic trend of each CBBPs provide information to continue as usual.

On the other hand, for those having negative trend need immediate action focus on capacity building for both enumerators and participant members, immediately castrate rams bought by farmers from local market for fattening purpose in addition of culled ram and critically follow up top ram using mechanism. Selection of animals with higher phenotypic values doesn't mean that animals with higher breeding values. So never select animals without estimating breeding value.

There is positive and medium to high genetic correlation among body weights but BWT with YWT have low correlation. From this correlated response to selection for other body weights traits was expected. The high negative estimates of direct-maternal correlations for growth traits suggest that it would be difficult to jointly improve direct and maternal effect for Bonga sheep but it needs deep pedigree, more than 4 progeny per dam and more than 40% of dam should have records to know correlation between direct and maternal effects.

Current strategy of two stage selection was preferred mechanism that selecting larger number of lambs at weaning age and final approval at six months. The result of positive and medium correlation between WWT and SMWT also supported that WWT is good indicator for SMWT performance. This helps to protect selling of ram lambs before selection age. Also, WWT and SMWT heritability values and importance of these traits approved the best option for selection age.

The evaluation of CBBP based on farmers perception revealed that CBBPs resulted in improvement of animal management, visible genetic improvement, decreased mortality rate, positive changes in income through breeding ram selling and benefit sharing of CBBP cooperative, develop better knowledge and skills and positive attitudes about breed improvement but selected ram distribution as participants income is the basis for sustainable of the program.

Also, proportion of farmers participated in CBBP was increasing and good breeding CBBP cooperative was established as a community level. Generally, from output of the studies, it can be concluded that Bonga sheep CBBPs have huge opportunity to improve growth trait and LS through selection and improved management.

## 5.2. Recommendations

The following recommendation may help for further genetic improvement of the breed.

- Selection should be based on estimated breeding value for traits of WWT and SMWT.
- Establish a good linkage between BARC and other stakeholders of Kaffa zone (Administration, Agriculture and Livestock Office and Cooperative Office).
- Improve credit service to protect selling of candidate lambs before screening selection.
- Top rams are the basis for breeding program which consider as half of the flock. So, further awareness creation of using and managing of top rams is very crucial especially for 3 (Buta, Dirbedo and Meduta) negatively trend CBBP cooperatives.
- Participants have mainly focused on selling of rams than breed improvement. This is one of the reasons that when selected ram selling was delayed the number of candidate lambs for selection was decreased. Further awareness creation is needed to alleviate this awareness gap in addition of thinking of market linkage.
- Collection of baseline data specifically the area of the community before out-scaled help for comparisons of achievements (improvement) during evaluation.
- Strengthen ram rotation between and within CBBP cooperatives result genetic link that make genetic evaluation easier, can make uniform genetic improvement progress among CBBP cooperatives, have common selection breeding value and protect inbreeding.
- The number of females' record is lower than males indicate that missing of records for female lambs which affect evaluation of reproductive traits. So maternal line selection and maternal effect consider during selection may help better improvement and reduce loss of female's data.
- Pedigree and performance data becoming big and it would be advisable to use electronic data base system to facilitate data storage and utilizations.

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# 7. APPENDIX

**Appendix A**: Analysis of variance for body weight traits

**APPENDIX A TABLE 1: Analysis of variance for BWT**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 58.9554558 | 9.8259093 | 29.08 | <.0001 |
| CBBP cooperative | 12 | 679.3784130 | 56.6148678 | 167.54 | <.0001 |
| Birth type | 2 | 608.8035252 | 304.4017626 | 900.84 | <.0001 |
| Sex | 1 | 126.1369167 | 126.1369167 | 373.29 | <.0001 |
| Dam parity | 6 | 140.9434366 | 23.4905728 | 69.52 | <.0001 |
| Birth season | 1 | 0.2116080 | 0.2116080 | 0.63 | 0.4288 |
| Error | 16087 | 5435.938066 | 0.337909 | | |

**APPENDIX A TABLE 2: Analysis of variance for WWT**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 398.92240 | 66.48707 | 9.37 | <.0001 |
| CBBP cooperative | 12 | 20258.68413 | 1688.22368 | 237.91 | <.0001 |
| Birth type | 2 | 8528.86160 | 4264.43080 | 600.96 | <.0001 |
| Sex | 1 | 3837.71651 | 3837.71651 | 540.83 | <.0001 |
| Dam parity | 6 | 178.96566 | 29.82761 | 4.20 | 0.0003 |
| Birth season | 1 | 35.72420 | 35.72420 | 5.03 | 0.0249 |
| Error | 11441 | 81185.3504 | 7.0960 | | |

**APPENDIX A TABLE 3: Analysis of variance for SMWT**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 265.165329 | 44.194221 | 3.11 | 0.0049 |
| CBBP cooperative | 12 | 8466.891502 | 705.574292 | 49.62 | <.0001 |
| Birth type | 2 | 1876.127244 | 938.063622 | 65.97 | <.0001 |
| Sex | 1 | 9416.359590 | 9416.359590 | 662.18 | <.0001 |
| Dam parity | 6 | 37.479613 | 6.246602 | 0.44 | 0.8529 |
| Birth season | 1 | 39.218624 | 39.218624 | 2.76 | 0.0968 |
| Error | 4209 | 59852.82219 | 14.22020 | | |

**APPENDIX A TABLE 4: Analysis of variance for NMWT**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 5 | 698.412992 | 139.682598 | 9.37 | <.0001 |
| CBBP cooperative | 9 | 1645.277994 | 182.808666 | 12.26 | <.0001 |
| Birth type | 2 | 286.836588 | 143.418294 | 9.62 | <.0001 |
| Sex | 1 | 6771.922899 | 6771.922899 | 454.14 | <.0001 |
| Dam parity | 6 | 76.685344 | 12.780891 | 0.86 | 0.5259 |
| Birth season | 1 | 43.669024 | 43.669024 | 2.93 | 0.0873 |
| Error | 1326 | 19772.69076 | 14.91153 | | |

**APPENDIX A TABLE 5: Analysis of variance for YWT**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 5 | 650.422789 | 130.084558 | 4.34 | 0.0007 |
| CBBP cooperative | 11 | 2126.550127 | 193.322739 | 6.45 | <.0001 |
| Birth type | 2 | 272.413284 | 136.206642 | 4.54 | 0.0111 |
| Sex | 1 | 3933.077572 | 3933.077572 | 131.16 | <.0001 |
| Dam parity | 6 | 106.118968 | 17.686495 | 0.59 | 0.7386 |
| Birth season | 1 | 11.892550 | 11.892550 | 0.40 | 0.5291 |
| Error | 536 | 16073.07032 | 29.98707 | | |

**Appendix B**: Analysis of Variance for Average daily gains (ADGs)

**APPENDIX B TABLE 6: Analysis of variance for ADG1**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 29042.570 | 4840.428 | 5.74 | <.0001 |
| CBBP cooperative | 12 | 2541897.916 | 211824.826 | 251.23 | <.0001 |
| Birth type | 2 | 648946.313 | 324473.156 | 384.83 | <.0001 |
| Sex | 1 | 334466.970 | 334466.970 | 396.68 | <.0001 |
| Dam parity | 6 | 6706.501 | 1117.750 | 1.33 | 0.2416 |
| Birth season | 1 | 3604.119 | 3604.119 | 4.27 | 0.0387 |
| Error | 11441 | 9646680.03 | 843.17 | | |

**APPENDIX B TABLE 7: Analysis of variance for ADG2**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 77882.6931 | 12980.4488 | 9.66 | <.0001 |
| CBBP cooperative | 12 | 575925.0470 | 47993.7539 | 35.71 | <.0001 |
| Birth type | 2 | 12326.8836 | 6163.4418 | 4.59 | 0.0102 |
| Sex | 1 | 250030.3363 | 250030.3363 | 186.06 | <.0001 |
| Dam parity | 6 | 31863.7163 | 5310.6194 | 3.95 | 0.0006 |
| Birth season | 1 | 73.1898 | 73.1898 | 0.05 | 0.8155 |
| Error | 4185 | 5624016.539 | 1343.851 | | |

**APPENDIX B TABLE 8: Analysis of variance for ADG3**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 5 | 128284.3691 | 25656.8738 | 19.69 | <.0001 |
| CBBP cooperative | 9 | 224225.0856 | 24913.8984 | 19.12 | <.0001 |
| Birth type | 2 | 9468.9625 | 4734.4813 | 3.63 | 0.0267 |
| Sex | 1 | 54148.2056 | 54148.2056 | 41.55 | <.0001 |
| Dam parity | 6 | 11588.2436 | 1931.3739 | 1.48 | 0.1807 |
| Birth season | 1 | 131.7925 | 131.7925 | 0.10 | 0.7505 |
| Error | 1297 | 1690361.741 | 1303.286 | | |

**APPENDIX B TABLE 9: Analysis of variance for ADG4**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 4 | 8174.571035 | 2043.642759 | 1.55 | 0.1919 |
| CBBP cooperative | 7 | 4322.008376 | 617.429768 | 0.47 | 0.8570 |
| Birth type | 2 | 334.100197 | 167.050099 | 0.13 | 0.8814 |
| Sex | 1 | 8060.583818 | 8060.583818 | 6.10 | 0.0147 |
| Dam parity | 6 | 5487.104493 | 914.517416 | 0.69 | 0.6565 |
| Birth season | 1 | 255.434670 | 255.434670 | 0.19 | 0.6609 |
| Error | 146 | 192965.3739 | 1321.6806 | | |

**Appendix C**: Analysis of variance for Reproductive traits

**APPENDIX C TABLE 10: Analysis of variance for AFL**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Birth year | 6 | 82351.64017 | 13725.27336 | 2.28 | 0.0354 |
| CBBP cooperative | 12 | 74870.41092 | 6239.20091 | 1.04 | 0.4130 |
| Birth type | 2 | 13459.55862 | 6729.77931 | 1.12 | 0.3275 |
| Dam parity | 6 | 6835.35300 | 1139.22550 | 0.19 | 0.9797 |
| Birth season | 1 | 3053.21429 | 3053.21429 | 0.51 | 0.4765 |
| Error | 384 | 2308531.016 | 6011.800 | | |

**APPENDIX C TABLE 11: Analysis of variance for LI**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Lambing year | 6 | 119182.1163 | 19863.6860 | 2.69 | 0.0133 |
| CBBP cooperative | 12 | 184170.7234 | 15347.5603 | 2.08 | 0.0155 |
| Lambing type | 2 | 20136.7899 | 10068.3950 | 1.36 | 0.2564 |
| Dam parity | 6 | 99849.4820 | 16641.5803 | 2.25 | 0.0359 |
| Lambing season | 1 | 114643.1364 | 114643.1364 | 15.50 | <.0001 |
| Error | 3813 | 28194052.62 | 7394.19 | | |

**APPENDIX C TABLE 12: Analysis of variance for LS**

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Lambing year | 6 | 1.10817886 | 0.18469648 | 0.69 | 0.6594 |
| CBBP cooperative | 12 | 19.91762009 | 1.65980167 | 6.18 | <.0001 |
| Dam parity | 6 | 6.13863974 | 1.02310662 | 3.81 | 0.0008 |
| Lambing season | 1 | 0.47777776 | 0.47777776 | 1.78 | 0.1822 |
| Error | 11603 | 3115.099489 | 0.268474 | | |

## APPENDIX C TABLE 13: Analysis of variance for ARR

| Source of variation | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| CBBP cooperative | 12 | 31.7300369 | 2.6441697 | 4.59 | <.0001 |
| Lambing year | 6 | 16.6311019 | 2.7718503 | 4.81 | <.0001 |
| Dam parity | 6 | 504.0778761 | 84.0129793 | 145.86 | <.0001 |
| Lambing season | 1 | 5.3864131 | 5.3864131 | 9.35 | 0.0022 |
| Error | 3814 | 2196.858491 | 0.575999 | | |

**Appendix D**: Phenotypic performance of growth and reproductive traits for each CBBP cooperative

For LI, LS and ARR effect non-genetic factors on lambing of ewe was considered instead of lamb birth effect. NA= Not Applicable

## APPENDIX D TABLE 14: Phenotypic performance of growth and reproductive traits for Abeta CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.16** | **15.33** | **23.73** | **28.27** | **30.68** | **348.42** | **262.00** | **1.41** | **2.12** |
| | CV | 20.02 | 17.31 | 14.69 | 13.86 | 13.79 | 18.77 | 28.45 | 36.14 | 40. 71 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | 0.0368 | NS | NS | NS | NS | NA | NA |
| | Single | 3.55$^{a}$ | 16.85$^{a}$ | 25.00$^{a}$ | 28.59 | 31.20 | 411.45 | 277.53 | | |
| | Twin | 3.18$^{b}$ | 14.71$^{b}$ | 23.41$^{b}$ | 27.96 | 30.16 | 397.34 | 272.52 | | |
| | Triple | 2.77$^{c}$ | 14.43$^{b}$ | 22.79$^{b}$ | - | - | 236.49 | 246.85 | | |
| Sex/ lambing sex | P-value | 0.0011 | <.0001 | NS | NS | NS | NA | NA | NA | NA |
| | Male | 3.22 | 16.05 | 24.91 | 30.61 | 33.51 | | | | |
| | Female | 3.11 | 14.62 | 22.55 | 25.94 | 33.51 | | | | |
| Birth/ lambing Parity | P-value | <.0001 | NS | NS | NS | NS | NS | NS | NS | <.0001 |
| | 1 | 2.87$^{c}$ | 15.10 | 24.05 | 28.41 | 32.01 | 339.85 | 267.10 | 1.35 | 1.49c |
| | 2 | 3.04$^{b}$ | 15.18 | 24.97 | 28.18 | 34.54 | 349.71 | 272.62 | 1.37 | 2.23$^{ab}$ |
| | 3 | 3.04$^{b}$ | 15.00 | 24.06 | 27.87 | 33.27 | 349.64 | 261.59 | 1.40 | 2.09$^{ab}$ |
| | 4 | 3.17$^{ab}$ | 15.63 | 25.21 | 31.72 | 33.71 | 364.84 | 269..09 | 1.37 | 1.89$^{b}$ |
| | 5 | 3.38$^{a}$ | 15.31 | 22.48 | 29.03 | 31.32 | 335.15 | 243..80 | 1.49 | 2.27$^{ab}$ |
| | 6 | 3.30$^{ab}$ | 15.45 | 21.36 | 23.89 | 24.77 | 352.10 | 261.70 | 1.44 | 2.50$^{a}$ |
| | 7 | 3.35$^{ab}$ | 15.66 | 24.01 | 28.81 | 25.16 | 347.68 | 284.12 | 1.45 | 2.35$^{ab}$ |
| Birth/ lambing Season | p-value | NS | NS | 0.0302 | NS | NS | NS | 0.0046 | NS | 0.0415 |
| | Dry | 3.18 | 15.21 | 23.01 | 27.62 | 29.95 | 350.59 | 275.31 | 1.40 | 2.05 |
| | Wet | 3.14 | 15.46 | 24.46 | 28.93 | 31.41 | 346.26 | 255.70 | 1.42 | 2.19 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | <.0001 | NS | NS | NS | NS | NS | NS |
| | 2012 | 2.64$^{d}$ | 16.73$^{a}$ | - | 28.61 | 30.50 | 374.65 | 275.43 | 1.29 | 2.16 |
| | 2013 | 2.92$^{c}$ | 14.55$^{c}$ | 20.25$^{c}$ | 26.50 | 29.94 | 347.75 | 267.14 | 1.49 | 2.24 |
| | 2014 | 3.51$^{a}$ | 14.75$^{c}$ | 22.63$^{b}$ | 28.12 | 30.02 | 336.54 | 253.30 | 1.44 | 2.22 |
| | 2015 | 3.36$^{b}$ | 15.56$^{b}$ | 22.51$^{bc}$ | 27.38 | 32.58 | 378.55 | 247.79 | 1.41 | 2.10 |
| | 2016 | 3.04$^{c}$ | 15.30$^{b}$ | 26.16$^{a}$ | 30.07 | 30.36 | 381.52 | 271.54 | 1.38 | 1.99 |
| | 2017 | 3.30$^{b}$ | 15.71$^{b}$ | 27.11$^{a}$ | 28.96 | - | - | 256.81 | 1.38 | 2.00 |
| | 2018 | 3.38$^{ab}$ | 14.73$^{bc}$ | - | - | - | - | - | 1.48 | - |

**APPENDIX D TABLE 15: Phenotypic performance of growth and reproductive traits for Dirbedo CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.03** | **18.66** | **27.18** | **33.17** | **38.46** | **355.81** | **299.09** | **1.41** | **2.24** |
| | CV | 14.84 | 12.43 | 11.04 | 8.49 | 14.46 | 19.60 | 30.77 | 37.05 | 38.23 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | 0.0008 | 0.0002 | NS | NS | NS | NA | NA |
| | Single | $3.43^{a}$ | $19.43^{a}$ | $27.77^{a}$ | $34.70^{a}$ | 40.88 | 323.32 | 279.01 | | |
| | Twin | $3.17^{b}$ | $18.55^{b}$ | $26.66^{ab}$ | $33.73^{b}$ | 37.75 | 420.67 | 285.55 | | |
| | Triple | $2.49^{c}$ | $18.00^{b}$ | $27.12^{b}$ | $31.09^{c}$ | 36.75 | 323.44 | 332.69 | | |
| Sex/ lambing sex | P-value | <.0001 | NS | NS | NS | - | NA | NA | NA | NA |
| | Male | 3.15 | 18.81 | 27.25 | 32.38 | 38.46 | | | | |
| | Female | 2.91 | 18.52 | 27.12 | 33.97 | - | | | | |
| Birth/ lambing Parity | P-value | NS | 0.0020 | 0.0188 | NS | NS | NS | NS | 0.0491 | <.0001 |
| | 1 | 3.00 | $18.14^{b}$ | $26.45^{bc}$ | 33.02 | 35.72 | 380.01 | 306.53 | $1.30^{c}$ | $1.48^{b}$ |
| | 2 | 2.98 | $18.13^{b}$ | $26.89^{bc}$ | 33.22 | 39.21 | 350.48 | 294.79 | $1.38^{c}$ | $2.26^{ab}$ |
| | 3 | 3.00 | $18.64^{a}$ | $27.04^{abc}$ | 34.08 | 39.88 | 343.90 | 318.68 | $1.40^{c}$ | $2.18^{ab}$ |
| | 4 | 3.06 | $18.86^{a}$ | $28.24^{ab}$ | 34.42 | 31.61 | 378.26 | 301.28 | $1.45^{b}$ | $2.32^{ab}$ |
| | 5 | 3.03 | $18.86^{a}$ | $25.94^{bc}$ | 31.10 | 39.15 | 295.83 | 330.77 | $1.45^{b}$ | $1.89^{ab}$ |
| | 6 | 3.06 | $19.02^{a}$ | $28.21^{ab}$ | 33.50 | 42.15 | 367.21 | 287.84 | $1.43^{b}$ | $2.65^{a}$ |
| | 7 | 3.10 | $18.99^{a}$ | $27.52^{abc}$ | 32.87 | 41.49 | 374.98 | 253.70 | $1.47^{a}$ | $2.90^{a}$ |
| Birth/ lambing Season | P-value | <.0001 | NS | NS | 0.0350 | NS | NS | NS | NS | NS |
| | Dry | 2.97 | 18.78 | 27.41 | 33.67 | 39.35 | 340.24 | 308.54 | 1.43 | 2.18 |
| | Wet | 3.09 | 18.55 | 26.96 | 32.67 | 37.57 | 371.38 | 289.63 | 1.39 | 2.30 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | <.0001 | <.0001 | NS | NS | NS | NS | NS |
| | 2012 | $2.74^{bc}$ | $21.08^{a}$ | $31.73^{a}$ | $38.82^{a}$ | 36.83 | - | 326.39 | 1.44 | 2.21 |
| | 2013 | $2.66^{c}$ | $19.54^{b}$ | $27.89^{b}$ | $36.70^{a}$ | 42.69 | 345.55 | 311.81 | 1.45 | 2.28 |
| | 2014 | $2.91^{b}$ | $19.74^{b}$ | $28.39^{b}$ | $33.69^{b}$ | 35.85 | 350.71 | 306.52 | 1.38 | 2.20 |
| | 2015 | $3.24^{a}$ | $17.58^{c}$ | $25.02^{c}$ | $29.27^{c}$ | - | 418.74 | 276.69 | 1.40 | 2.32 |
| | 2016 | $3.19^{a}$ | $17.73^{c}$ | $24.99^{c}$ | $30.19^{c}$ | - | 336.50 | 293.29 | 1.47 | 2.26 |
| | 2017 | $3.18^{a}$ | $17.86^{c}$ | $25.09^{c}$ | $30.36^{c}$ | - | 327.55 | 279.81 | 1.41 | 2.18 |
| | 2018 | $3.31^{a}$ | $17.11^{c}$ | - | - | - | - | - | 1.34 | - |

**APPENDIX D TABLE 16: Phenotypic performance of growth and reproductive traits for Buta CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.78** | **16.65** | **24.81** | **31.36** | **39.78** | **396.11** | **262.87** | **1.45** | 2.51 |
| | CV | 9.93 | 12.05 | 12.51 | 9.77 | 9.24 | 19.2 | 32.60 | 36.44 | 35.21 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | <.0001 | NS | 0.0461 | NS | NS | NA | NA |
| | Single | 4.12[a] | 17.85[a] | 26.35[a] | 29.84 | 40.26[a] | 400.76 | 265.91 | | |
| | Twin | 3.87[b] | 16.68[b] | 24.96[b] | 31.00 | 38.85[ab] | 405.79 | 266.61 | | |
| | Triple | 3.35[c] | 15.42[c] | 23.13[c] | 33.23 | 40.23[b] | 381.78 | 256.08 | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | <.0001 | 0.0418 | NS | NA | NA | NA | NA |
| | Male | 3.84 | 17.22 | 26.94 | 33.86 | 39.31 | | | | |
| | Female | 3.71 | 16.09 | 22.69 | 28.85 | 40.25 | | | | |
| Birth /lambing Parity | P-value | <.0001 | <.0001 | NS | NS | NS | NS | 0.0347 | 0.0025 | NS |
| | 1 | 3.64[d] | 16.31[b] | 24.57 | 30.60 | 39.81 | 393.90 | 255.36[a] | 1.50[a] | 1.41 |
| | 2 | 3.74[c] | 16.57[a] | 24.94 | 31.56 | 40.09 | 380.88 | 264.81[ab] | 1.45[b] | 2.09 |
| | 3 | 3.77[bc] | 16.70[a] | 24.51 | 31.00 | 39.48 | 399.44 | 253.19[a] | 1.40[bc] | 2.30 |
| | 4 | 3.80[ab] | 16.69[a] | 24.83 | 30.93 | 39.33 | 410.36 | 259.15[ab] | 1.43[b] | 2.03 |
| | 5 | 3.84[a] | 16.73[a] | 24.82 | 30.31 | 38.84 | 407.88 | 276.73[ab] | 1.34[c] | 2.20 |
| | 6 | 3.83[ab] | 16.74[a] | 25.43 | - | 41.59 | 394.89 | 281.34[b] | 1.42[bc] | 2.11 |
| | 7 | 3.83[ab] | 16.81[a] | 24.61 | 33.75 | 39.34 | 385.42 | 249.48[a] | 1.41[bc] | 2.43 |
| Birth /lambing Season | P-value | NS | 0.0242 | 0.0063 | 0.0169 | 0.0042 | NS | NS | NS | 0.0126 |
| | Dry | 3.77 | 16.72 | 25.05 | 32.43 | 38.81 | 389.97 | 265.63 | 1.49 | 2.15 |
| | Wet | 3.79 | 16.58 | 24.58 | 30.29 | 40.76 | 402.25 | 260.10 | 1.47 | 2.44 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | <.0001 | NS | <.0001 | NS | 0.0005 | NS | NS |
| | 2012 | 3.83[b] | 16.00[d] | 24.79[cd] | - | 41.53[a] | 431.88 | 279.68[a] | 1.41 | 2.85 |
| | 2013 | 4.11[a] | 17.08[b] | 26.52[ab] | - | 41.43[a] | 398.03 | 261.85[a] | 1.41 | 2.01 |
| | 2014 | 4.08[a] | 18.61[a] | 26.82[a] | - | 40.26[a] | 399.56 | 270.03[a] | 1.40 | 2.98 |
| | 2015 | 3.78[b] | 17.35[b] | 25.71[bc] | 31.46 | 38.18[ab] | 396.53 | 263.30[a] | 1.43 | 2.00 |
| | 2016 | 3.70[c] | 16.47[c] | 24.13[d] | 31.25 | 37.53[b] | 394.16 | 265.37[a] | 1.44 | 2.99 |
| | 2017 | 3.48[d] | 15.66[de] | 23.05[d] | - | - | 356.50 | 307.26[b] | 1.31 | 2.76 |
| | 2018 | 3.46[d] | 15.39[e] | 22.68[d] | - | - | - | 192.57[a] | 1.45 | 2.64 |

## APPENDIX D TABLE 17: Phenotypic performance of growth and reproductive traits for Shosha CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.37** | **16.53** | **24.85** | **29.34** | **35.44** | **404.20** | **290.15** | **1.50** | **2.33** |
| | CV | 15.90 | 16.67 | 14.75 | 13.81 | 16.44 | 17.67 | 32.20 | 36.12 | 37.88 |
| Birth/ Lambing Type | P-value | <.0001 | <.0001 | <.0001 | NS | NS | NS | NS | NA | NA |
| | Single | $3.74^{a}$ | $18.59^{a}$ | $26.27^{a}$ | 30.47 | 35.73 | 413.56 | 280.97 | | |
| | Twin | $3.42^{b}$ | $16.14^{b}$ | $24.51^{b}$ | 29.51 | 34.44 | 375.45 | 278.02 | | |
| | Triple | $2.96^{c}$ | $14.86^{c}$ | $23.76^{b}$ | 28.04 | 36.16 | 423.6 | 311.44 | | |
| Sex/ lambing sex | P-value | 0.0003 | <.0001 | <.0001 | 0.0025 | 0.0151 | NA | NA | NA | NA |
| | Male | 3.43 | 16.99 | 26.09 | 30.97 | 37.45 | | | | |
| | Female | 3.32 | 16.07 | 23.61 | 27.71 | 33.43 | | | | |
| Birth/ lambing Parity | P-value | <.0001 | 0.0225 | NS | NS | NS | NS | NS | NS | <.0001 |
| | 1 | $3.19^{c}$ | $16.44^{ab}$ | 25.08 | 30.17 | 35.57 | 451.99 | 297.86 | 1.46 | $1.55^{d}$ |
| | 2 | $3.33^{b}$ | $16.50^{ab}$ | 24.89 | 30.72 | 35.75 | 352.97 | 303.84 | 1.45 | $2.30^{bc}$ |
| | 3 | $3.18^{c}$ | $16.23^{ab}$ | 25.09 | 30.20 | 35.14 | 433.03 | 298.89 | 1.43 | $2.07^{c}$ |
| | 4 | $3.36^{ab}$ | $16.81^{ab}$ | 24.26 | 26.39 | 34.05 | - | 295.22 | 1.52 | $2.48^{b}$ |
| | 5 | $3.48^{ab}$ | $15.54^{b}$ | 23.67 | 27.52 | 37.04 | 452.82 | 302.89 | 1.43 | $2.69^{a}$ |
| | 6 | $3.55^{a}$ | $17.42^{a}$ | 25.25 | 29.01 | 35.71 | 343.82 | 277.86 | 1.61 | $2.42^{b}$ |
| | 7 | $3.53^{ab}$ | $16.76^{ab}$ | 25.70 | 31.36 | 34.86 | 390.60 | 254.46 | 1.59 | $2.80^{a}$ |
| Birth/ lambing Season | P-value | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | Dry | 3.39 | 16.58 | 25.10 | 28.78 | 35.05 | 401.94 | 294.37 | 1.51 | 2.32 |
| | Wet | 3.36 | 16.48 | 24.60 | 29.90 | 35.84 | 406.47 | 285.92 | 1.49 | 2.34 |
| Birth/ lambing year | P-value | 0.0010 | <.0001 | 0.0005 | 0.0198 | 0.0346 | NS | NS | NS | NS |
| | 2012 | $3.35^{ab}$ | $13.99^{c}$ | $23.59^{b}$ | - | $34.23^{b}$ | 456.09 | 316.30 | 1.59 | 2.26 |
| | 2013 | $3.38^{ab}$ | $15.12^{c}$ | $23.66^{b}$ | - | $31.55^{b}$ | 380.33 | 283.74 | 1.44 | 2.43 |
| | 2014 | $3.27^{b}$ | $16.71^{b}$ | $25.27^{ab}$ | $31.53^{a}$ | $35.76^{ab}$ | 383.66 | 308.13 | 1.42 | 2.20 |
| | 2015 | $3.39^{ab}$ | $17.19^{ab}$ | $26.25^{a}$ | $31.22^{a}$ | $35.61^{ab}$ | 455.17 | 290.50 | 1.47 | 2.26 |
| | 2016 | $3.48^{a}$ | $16.72^{b}$ | $25.45^{ab}$ | $28.81^{b}$ | $40.07^{b}$ | 441.99 | 285.96 | 1.46 | 2.88 |
| | 2017 | $3.39^{ab}$ | $17.59^{a}$ | $24.87^{b}$ | $25.79^{b}$ | - | 307.98 | 256.24 | 1.51 | 2.54 |
| | 2018 | $3.37^{ab}$ | $18.39^{a}$ | - | - | - | - | - | 1.60 | - |

## APPENDIX D TABLE 18: Phenotypic performance of growth and reproductive traits for Dacha CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.30** | **15.10** | **22.47** | **28.87** | **29.25** | **423.85** | **333.19** | **1.47** | **2.16** |
| | CV | 15.82 | 16.77 | 13.67 | 11.77 | 12.09 | 19.42 | 28.33 | 36.30 | 38.13 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | <.0001 | NS | NS | NS | 0.0015 | NA | NA |
| | Single | $3.62^{a}$ | $16.10^{a}$ | 23.45 | 29.35 | 30.58 | 414.25 | $291.39^{a}$ | | |
| | Twin | $3.34^{b}$ | $14.74^{b}$ | 22.28 | 28.87 | 29.55 | 433.44 | $293.22^{a}$ | | |
| | Triple | $2.93^{c}$ | $14.47^{b}$ | 21.68 | 28.40 | 27.63 | - | $462.25^{b}$ | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | NA | NA | NA | NA |
| | Male | 3.40 | 15.84 | 25.09 | 32.81 | 34.92 | | | | |
| | Female | 3.20 | 14.37 | 19.85 | 24.93 | 23.58 | | | | |
| Birth/ lambing Parity | P-value | <.0001 | NS | NS | 0.0255 | NS | NS | NS | NS | <.0001 |
| | 1 | $3.14^{d}$ | 15.02 | 22.40 | $28.65^{ab}$ | 28.77 | 392.47 | 359.75 | 1.35 | $1.51^{c}$ |
| | 2 | $3.30^{bc}$ | 14.99 | 22.43 | $29.46^{ab}$ | 29.96 | 405.93 | 356.91 | 1.32 | $2.12^{b}$ |
| | 3 | $3.23^{c}$ | 14.97 | 22.06 | $28.11^{a}$ | 28.92 | 455.02 | 357.99 | 1.37 | $1.95^{b}$ |
| | 4 | $3.38^{ab}$ | 15.58 | 23.44 | $30.04^{a}$ | 32.42 | 416.22 | 338.98 | 1.43 | $2.22^{ab}$ |
| | 5 | $3.53^{ab}$ | 14.87 | 22.61 | $30.59^{a}$ | 29.04 | 540.32 | 340.27 | 1.48 | $2.54^{ab}$ |
| | 6 | $3.44^{ab}$ | 15.18 | 22.11 | $27.20^{b}$ | 26.58 | 333.13 | 335.46 | 1.73 | $2.46^{ab}$ |
| | 7 | $3.05^{cd}$ | 15.11 | 22.21 | $28.06^{ab}$ | 29.07 | - | 353.31 | 1.64 | $2.29^{ab}$ |
| Birth/ lambing Season | P-value | NS | <.0001 | NS | NS | NS | NS | 0.0086 | NS | 0.0247 |
| | Dry | 3.29 | 15.39 | 22.44 | 28.92 | 29.54 | 424.92 | 358.85 | 1.46 | 2.08 |
| | Wet | 3.30 | 14.82 | 22.49 | 28.83 | 28.96 | 422.77 | 339.06 | 1.49 | 2.23 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | <.0001 | NS | <.0001 | NS | 0.0421 | NS | NS |
| | 2012 | $3.77^{a}$ | $17.53^{a}$ | $18.48^{d}$ | - | $16.81^{b}$ | 477.92 | $393.91^{b}$ | 1.58 | 1.79 |
| | 2013 | $3.51^{b}$ | $15.39^{ab}$ | $22.28^{c}$ | - | - | 396.49 | $323.80^{b}$ | 1.45 | 2.18 |
| | 2014 | $3.19^{c}$ | $14.62^{bc}$ | $22.11^{c}$ | 28.73 | $32.81^{a}$ | 436.35 | $324.40^{b}$ | 1.42 | 2.12 |
| | 2015 | $3.19^{c}$ | $14.59^{c}$ | $23.62^{b}$ | 28.63 | $33.25^{a}$ | 387.62 | $332.10^{b}$ | 1.42 | 2.03 |
| | 2016 | $3.05^{d}$ | $14.32^{c}$ | $23.46^{b}$ | 28.95 | $31.53^{a}$ | 418.04 | $348.76^{b}$ | 1.50 | 1.95 |
| | 2017 | $3.17^{c}$ | $14.22^{c}$ | $22.87^{bc}$ | 29.19 | $31.86^{a}$ | 426.66 | $306.86^{a}$ | 1.50 | 2.31 |
| | 2018 | $3.20^{c}$ | $15.06^{bc}$ | $24.46^{a}$ | - | - | - | $412.84^{b}$ | 1.45 | 2.70 |

## APPENDIX D TABLE 19: Phenotypic performance of growth and reproductive traits for Meduta CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.03** | **14.20** | **21.34** | **28.71** | **382.36** | **266.14** | **1.41** | **2.21** |
| | CV | 19.57 | 19.71 | 18.69 | 12.75 | 21.83 | 29.86 | 37.59 | 38.49 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | <.0001 | 0.0299 | NS | NS | NA | NA |
| | Single | 3.50[a] | 16.84[a] | 23.66 | 30.27 | 381.68 | 259.09 | | |
| | Twin | 3.04[b] | 13.89[b] | 20.63 | 28.93 | 397.44 | 278.40 | | |
| | Triple | 2.55[c] | 11.87[c] | 19.72 | 26.95 | 367.95 | 260.93 | | |
| Sex/ lambing sex | P-value | 0.0476 | <.0001 | <.0001 | <.0001 | NA | NA | NA | NA |
| | Male | 3.06 | 15.10 | 23.36 | 30.71 | | | | |
| | Female | 2.99 | 13.30 | 19.32 | 26.71 | | | | |
| Birth/ lambing parity | P-value | 0.0010 | NS | NS | NS | NS | NS | NS | <.0001 |
| | 1 | 2.92 | 13.95 | 22.00 | 27.74 | 397.25 | 290.58 | 1.37 | 1.44[c] |
| | 2 | 2.97 | 13.99 | 21.29 | 29.31 | 362.42 | 278.72 | 1.43 | 2.07[bc] |
| | 3 | 3.01 | 14.09 | 22.00 | 27.68 | 396.38 | 262.49 | 1.34 | 2.30[b] |
| | 4 | 3.14 | 14.09 | 20.95 | 27.24 | 394.15 | 270.78 | 1.44 | 2.45[b] |
| | 5 | 3.17 | 14.46 | 21.22 | 26.71 | 452.37 | 242.83 | 1.40 | 2.74[a] |
| | 6 | 3.11 | 15.02 | 21.38 | 35.22 | 343.26 | 233.96 | 1.40 | 2.29[bc] |
| | 7 | 2.89 | 13.80 | 20.53 | 27.10 | 330.68 | 283.61 | 1.50 | 2.21[bc] |
| Birth/ lambing season | P-value | NS | 0.0003 | NS | NS | NS | NS | NS | NS |
| | Dry | 3.03 | 14.57 | 21.44 | 29.35 | 386.24 | 264.62 | 1.44 | 2.23 |
| | Wet | 3.02 | 13.83 | 21.23 | 28.08 | 378.48 | 267.66 | 1.39 | 2.18 |
| Birth /lambing year | P-value | <.0001 | <.0001 | NS | NS | NS | NS | NS | 0.0047 |
| | 2014 | 2.97[c] | 14.69[a] | 22.17 | 30.72 | 363.12 | 252.89 | 1.39 | 2.46[a] |
| | 2015 | 2.79[d] | 13.95[a] | 22.03 | 29.98 | 396.82 | 265.06 | 1.43 | 2.28[ab] |
| | 2016 | 3.01[bc] | 13.30[b] | 20.98 | 29.23 | 382.38 | 272.81 | 1.45 | 2.15[ab] |
| | 2017 | 3.15[ab] | 14.32[a] | 20.16 | 24.92 | 387.13 | 273.79 | 1.39 | 1.96[b] |
| | 2018 | 3.22[a] | 14.74[a] | - | - | - | - | 1.40 | - |

**APPENDIX D TABLE 20: Phenotypic performance of growth and reproductive traits for Alargeta CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | YWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.42** | **17.34** | **24.37** | **31.17** | **36.72** | **359.13** | **283.77** | **1.42** | **2.25** |
| | CV | 14.11 | 10.98 | 12.02 | 11.33 | 10.34 | 23.73 | 33.75 | 36.59 | 40.71 |
| Birth /lambing type | P-value | <.0001 | <.0001 | 0.0009 | NS | NS | NS | NS | NA | NA |
| | Single | $3.73^{a}$ | $18.61^{a}$ | $25.12^{a}$ | 32.14 | 36.08 | 382.10 | 290.01 | | |
| | Twin | $3.41^{b}$ | $17.48^{b}$ | $24.25^{b}$ | 31.35 | 36.93 | 363.55 | 290.23 | | |
| | Triple | $3.11^{c}$ | $15.94^{c}$ | $23.75^{b}$ | 30.01 | 37.15 | 331.75 | 270.97 | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | NA | NA | NA | NA |
| | Male | 3.54 | 18.09 | 25.91 | 33.19 | 39.77 | | | | |
| | Female | 3.29 | 16.60 | 22.84 | 29.15 | 33.68 | | | | |
| Birth /lambing parity | P-value | <.0001 | 0.0199 | NS | NS | NS | NS | NS | NS | <.0001 |
| | 1 | $3.26^{cd}$ | $17.08^{b}$ | 24.17 | 30.48 | 34.28 | 359.12 | 276.17 | 1.40 | $1.57^{c}$ |
| | 2 | $3.36^{c}$ | $17.47^{a}$ | 24.43 | 30.92 | 35.82 | 374.12 | 279.77 | 1.48 | $2.34^{ab}$ |
| | 3 | $3.38^{c}$ | $16.88^{b}$ | 24.13 | 30.41 | 34.81 | 329.62 | 293.19 | 1.45 | $2.15^{ab}$ |
| | 4 | $3.50^{b}$ | $17.18^{a}$ | 24.11 | 30.25 | 34.73 | 430.72 | 286.99 | 1.46 | $2.39^{ab}$ |
| | 5 | $3.41^{bc}$ | $17.37^{a}$ | 24.93 | 31.66 | 39.41 | 302.09 | 253.00 | 1.30 | $2.43^{ab}$ |
| | 6 | $3.77^{a}$ | $17.76^{a}$ | 24.97 | 33.56 | 39.92 | - | 232.67 | - | - |
| | 7 | $3.23^{cd}$ | $17.66^{a}$ | 23.86 | 30.91 | 38.10 | - | 364.59 | - | - |
| Birth /lambing season | P-value | NS | NS | NS | NS | 0.0177 | NS | NS | NS | NS |
| | Dry | 3.42 | 17.40 | 24.40 | 31.45 | 35.19 | 364.95 | 288.20 | 1.39 | 2.17 |
| | Wet | 3.41 | 17.28 | 24.34 | 30.89 | 38.26 | 353.31 | 279.33 | 1.44 | 2.33 |
| Birth /laming year | P-value | <.0001 | <.0001 | <.0001 | <.0001 | NS | NS | NS | 0.0223 | NS |
| | 2014 | $3.36^{bc}$ | $17.59^{ab}$ | $23.43^{b}$ | $34.92^{a}$ | - | 405.89 | 277.25 | $1.33^{b}$ | 2.30 |
| | 2015 | $3.35^{c}$ | $17.19^{bc}$ | $23.94^{b}$ | $29.59^{b}$ | 36.69 | 461.39 | 294.02 | $1.44^{a}$ | 2.16 |
| | 2016 | $3.46^{b}$ | $16.94^{c}$ | $24.03^{b}$ | $29.73^{b}$ | 36.75 | 321.22 | 278.52 | $1.38^{a}$ | 2.25 |
| | 2017 | $3.29^{c}$ | $17.72^{a}$ | $25.63^{a}$ | $30.43^{b}$ | - | 343.71 | 285.28 | $1.48^{a}$ | 2.30 |
| | 2018 | $3.62^{a}$ | $17.28^{abc}$ | $24.84^{ab}$ | - | - | - | - | $1.46^{a}$ | - |

**APPENDIX D TABLE 21: Phenotypic performance of growth and reproductive traits for Angiokolla CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|
| | **Over all** | **3.64** | **17.05** | **27.56** | **232.70** | **1.45** | **2.25** |
| | CV | 13.57 | 18.71 | 12.77 | 28.48 | 36.14 | 35.55 |
| Birth /lambing Type | P-value | <.0001 | <.0001 | NS | NS | NA | NA |
| | Single | 3.93 | $19.59^{a}$ | 26.96 | 237.38 | | |
| | Twin | 3.69 | $17.39^{b}$ | 26.69 | 260.64 | | |
| | Triple | 3.30 | $14.17^{c}$ | 29.02 | 200.07 | | |
| Sex/ lambing sex | P-value | 0.0001 | <.0001 | 0.0452 | NA | NA | NA |
| | Male | 3.73 | 18.22 | 28.62 | | | |
| | Female | 3.55 | 15.89 | 26.49 | | | |
| Birth/ lambing parity | P-value | <.0001 | NS | NS | NS | NS | <.0001 |
| | 1 | $3.31^{c}$ | 16.65 | 26.93 | 272.29 | 1.42 | $1.49^{c}$ |
| | 2 | $3.58^{ab}$ | 16.99 | 28.04 | 268.99 | 1.42 | $2.41^{ab}$ |
| | 3 | $3.51^{b}$ | 17.59 | 28.92 | 232.07 | 1.46 | $2.14^{b}$ |
| | 4 | $3.69^{ab}$ | 17.86 | 29.36 | 207.18 | 1.55 | $3.03^{a}$ |
| | 5 | $3.70^{ab}$ | 16.59 | 26.50 | 187.51 | 1.38 | $2.03^{bc}$ |
| | 6 | $3.74^{ab}$ | 16.59 | 26.60 | 228.13 | - | $2.44^{bc}$ |
| | 7 | $3.94^{a}$ | 17.08 | 26.54 | - | - | - |
| Birth /lambing season | P-value | <.0001 | 0.0010 | NS | NS | NS | NS |
| | Dry | 3.79 | 16.46 | 27.88 | 238.39 | 1.44 | 2.19 |
| | Wet | 3.49 | 17.64 | 27.23 | 227.01 | 1.45 | 2.32 |
| Birth /lambing year | P-value | <.0001 | <.0001 | <.0001 | NS | NS | NS |
| | 2015 | $3.60^{b}$ | $14.43^{b}$ | $25.25^{b}$ | 237.01 | 1.41 | 2.41 |
| | 2016 | $3.87^{a}$ | $16.69^{a}$ | $30.39^{a}$ | 232.43 | 1.44 | 2.37 |
| | 2017 | $3.75^{a}$ | $18.38^{a}$ | $27.03^{ab}$ | 228.65 | 1.41 | 1.98 |
| | 2018 | $3.34^{c}$ | $18.70^{a}$ | - | - | 1.52 | - |

**APPENDIX D TABLE 22: Phenotypic performance of growth and reproductive traits for Guta CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|---|
| | **Over all** | **2.88** | **16.61** | **25.56** | **30.99** | **453.02** | **277.96** | **1.34** | **2.12** |
| | CV | 13.99 | 19.17 | 17.5 | 12.56 | 23.44 | 32.07 | 35.34 | 37.78 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | NS | NS | NS | NS | | |
| | Single | 3.56$^{a}$ | 17.26 | 25.95 | 30.63 | 432.35 | 276.21 | NA | NA |
| | Twin | 2.82$^{b}$ | 15.96 | 25.16 | 31.35 | 473.69 | 279.70 | | |
| | Triple | 2.25$^{b}$ | - | - | - | | - | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | 0.0032 | NS | | | | |
| | Male | 3.07 | 17.67 | 27.73 | 33.64 | NA | NA | NA | NA |
| | Female | 2.68 | 15.54 | 23.38 | 28.33 | | | | |
| Birth/ lambing parity | P-value | <.0001 | NS | NS | NS | NS | NS | NS | <.0001 |
| | 1 | 2.71$^{c}$ | 16.40 | 26.55 | 31.72 | 402.15 | 306.08 | 1.38 | 1.43$^{c}$ |
| | 2 | 2.75$^{c}$ | 16.45 | 24.98 | 30.89 | 421.83 | 296.61 | 1.38 | 2.16$^{ab}$ |
| | 3 | 2.80$^{bc}$ | 16.86 | 26.93 | 32.19 | 473.55 | 274.35 | 1.32 | 2.33$^{a}$ |
| | 4 | 2.94$^{ab}$ | 16.45 | 25.31 | 29.94 | 545.39 | 276.22 | 1.40 | 1.93$^{bc}$ |
| | 5 | 3.10$^{a}$ | 16.80 | 24.73 | 31.61 | 422.17 | 277.91 | 1.34 | 2.12$^{b}$ |
| | 6 | 3.03$^{ab}$ | 17.26 | 26.21 | 30.70 | - | 268.06 | 1.26 | 2.03$^{bc}$ |
| | 7 | 2.81$^{abc}$ | 16.05 | 24.19 | 29.86 | - | 246.46 | 1.31 | 2.88$^{a}$ |
| Birth /lambing season | P-value | NS | NS | NS | NS | NS | NS | 0.0037 | NS |
| | Dry | 2.85 | 16.44 | 25.51 | 31.59 | 405.14 | 277.85 | 1.39 | 2.20 |
| | Wet | 2.90 | 16.78 | 25.61 | 30.39 | 500.89 | 278.06 | 1.29 | 2.05 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | 0.0087 | NS | NS | NS | NS | NS |
| | 2014 | 2.97$^{a}$ | 17.84$^{a}$ | 24.57$^{b}$ | 32.48 | 427.50 | 274.87 | 1.35 | 2.27 |
| | 2015 | 2.69$^{c}$ | 15.33$^{b}$ | 25.92$^{ab}$ | 31.43 | 422.64 | 269.24 | 1.41 | 2.09 |
| | 2016 | 2.95$^{a}$ | 15.65$^{b}$ | 23.94$^{b}$ | 30.73 | 474.51 | 293.30 | 1.35 | 2.03 |
| | 2017 | 2.85$^{b}$ | 17.00$^{a}$ | 27.80$^{a}$ | 29.32 | 487.41 | 274.41 | 1.30 | 2.11 |
| | 2018 | 2.92$^{ab}$ | 17.22$^{a}$ | - | - | - | - | 1.29 | - |

**APPENDIX D TABLE 23: Phenotypic performance of growth and reproductive traits for Yama CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | NMWT (kg) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|
| | **Over all** | **2.77** | **17.39** | **28.09** | **34.52** | **270.87** | **1.39** | **2.29** |
| | CV | 16.86 | 13.55 | 11.37 | 9.16 | 30.58 | 33.03 | 36.68 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | NS | NS | NS | NA | NA |
| | Single | 3.15 | 18.93[a] | 28.83 | 35.22 | 253.85 | | |
| | Twin | 2.87 | 17.56[b] | 27.95 | 33.83 | 286.98 | | |
| | Triple | 2.28 | 15.66[c] | 27.49 | - | 271.78 | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | <.0001 | NS | NA | NA | NA |
| | Male | 2.84 | 18.02 | 29.80 | 34.88 | | | |
| | Female | 2.70 | 16.75 | 26.38 | 34.17 | | | |
| Birth /lambing Parity | P-value | <.0001 | NS | NS | NS | NS | NS | <.0001 |
| | 1 | 2.58[c] | 17.15 | 27.87 | 35.44 | 311.81 | 1.42 | 1.52[d] |
| | 2 | 2.73[b] | 17.35 | 29.47 | 35.47 | 286.22 | 1.35 | 2.19[bc] |
| | 3 | 2.71[b] | 17.33 | 28.86 | 35.84 | 274.85 | 1.47 | 2.05[c] |
| | 4 | 2.78[ab] | 17.78 | 28.37 | 33.34 | 254.25 | 1.46 | 2.54[b] |
| | 5 | 2.81[ab] | 17.62 | 29.06 | 32.53 | 305.58 | 1.43 | 1.92[cd] |
| | 6 | 2.96[a] | 17.80 | 27.02 | - | 305.58 | 1.27 | 3.28[a] |
| | 7 | 2.81[ab] | 16.66 | 25.98 | - | 242.04 | 1.31 | 2.52[b] |
| Birth /lambing season | P-value | <.0001 | NS | NS | NS | NS | 0.0219 | NS |
| | Dry | 2.86 | 17.27 | 27.88 | 34.15 | 264.76 | 1.43 | 2.36 |
| | Wet | 2.68 | 17.50 | 28.31 | 34.89 | 276.99 | 1.34 | 2.22 |
| Birth /lambing year | P-value | <.0001 | NS | NS | NS | NS | NS | NS |
| | 2014 | 3.61[a] | 17.38 | 27.46 | 36.58 | 257.49 | 1.44 | 2.53 |
| | 2015 | 3.12[b] | 17.83 | 28.44 | 34.30 | 261.11 | 1.34 | 2.25 |
| | 2016 | 2.16[e] | 17.54 | 28.00 | 34.38 | 259.83 | 1.41 | 2.33 |
| | 2017 | 2.38[d] | 17.09 | 28.46 | 32.84 | 305.07 | 1.41 | 2.04 |
| | 2018 | 2.57[c] | 17.09 | - | - | - | 1.33 | - |

**APPENDIX D TABLE 24: Phenotypic performance of growth and reproductive traits for Didifa CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|
| | **Over all** | **2.80** | **17.26** | **25.82** | **269.98** | **1.45** | **1.96** |
| | CV | 19.49 | 14.16 | 14.48 | 31.02 | 37.39 | 39.52 |
| Birth /lambing type | P-value | <.0001 | <.0001 | NS | NS | NA | NA |
| | Single | 3.23[a] | 18.59[a] | 26.42 | 268.75 | | |
| | Twin | 2.75[b] | 17.23[b] | 26.06 | 280.57 | | |
| | Triple | 2.41[c] | 15.97[b] | 24.99 | 260.60 | | |
| Sex/ lambing sex | P-value | <.0001 | NS | 0.0141 | NA | NA | NA |
| | Male | 2.90 | 17.45 | 27.54 | | | |
| | Female | 2.69 | 17.07 | 24.11 | | | |
| Birth /lambing parity | P-value | <.0001 | NS | NS | NS | 0.0471 | <.0001 |
| | 1 | 2.92[a] | 17.47 | 26.33 | 276.15 | 1.39[bc] | 1.39[b] |
| | 2 | 2.86[a] | 16.99 | 26.29 | 259.38 | 1.40[c] | 2.20[a] |
| | 3 | 2.66[b] | 16.94 | 25.50 | 271.25 | 1.38[c] | 1.99[a] |
| | 4 | 2.88[a] | 17.09 | 25.73 | 281.04 | 1.60[a] | 2.19[a] |
| | 5 | 2.90[a] | 17.83 | 25.91 | 260.05 | 1.42[b] | 2.07[a] |
| | 6 | 2.76[ab] | 16.71 | 23.00 | 263 | 1.64[a] | 1.99[a] |
| | 7 | 2.59[b] | 17.80 | 28.00 | 278.95 | 1.34[c] | 1.87[a] |
| Birth /lambing season | P-value | NS | NS | NS | NS | NS | NS |
| | Dry | 2.79 | 17.14 | 25.26 | 271.18 | 1.46 | 1.99 |
| | Wet | 2.80 | 17.38 | 26.38 | 268.78 | 1.45 | 1.94 |
| Birth/ lambing year | P-value | <.0001 | <.0001 | 0.0147 | 0.0370 | NS | 0.0018 |
| | 2014 | 3.16[a] | 18.41[a] | 26.43[a] | 272[a] | 1.53 | 2.34[a] |
| | 2015 | 2.82[b] | 17.27[b] | 24.00[b] | 289.28[a] | 1.44 | 1.97[b] |
| | 2016 | 2.61[c] | 16.37[c] | 25.99[ab] | 315.10[b] | 1.43 | 1.72[c] |
| | 2017 | 2.58[c] | 16.43[bc] | 26.87[a] | 264.56[a] | 1.40 | 1.97[b] |
| | 2018 | 2.80[b] | 17.82[ab] | - | 208.94[a] | 1.46 | 1.79[bc] |

**APPENDIX D TABLE 25: Phenotypic performance of growth and reproductive traits for Kicho CBBP cooperative**

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.08** | **14.85** | **22.82** | **361.29** | **265.25** | **1.46** | **2.49** |
| | CV | 11.05 | 15.04 | 17.23 | 19.06 | 29.72 | 36.79 | 38.89 |
| Birth /lambing type | P-value | <.0001 | <.0001 | 0.0006 | NS | NS | NA | NA |
| | Single | $3.38^{a}$ | $16.28^{a}$ | $24.34^{a}$ | 351.24 | 259.01 | | |
| | Twin | $3.15^{b}$ | $14.84^{b}$ | $23.42^{b}$ | 371.34 | 262.30 | | |
| | Triple | $2.71^{c}$ | $13.43^{c}$ | $20.71^{c}$ | - | 274.45 | | |
| Sex/ lambing sex | P-value | 0.0007 | 0.0069 | <.0001 | NA | NA | NA | NA |
| | Male | 3.12 | 15.07 | 23.90 | | | | |
| | Female | 3.04 | 14.63 | 21.74 | | | | |
| Birth /lambing Parity | P-value | <.0001 | 0.0260 | NS | NS | NS | NS | <.0001 |
| | 1 | $3.03^{b}$ | $14.67^{b}$ | 23.06 | 316.97 | 293.83 | 1.40 | $1.45^{c}$ |
| | 2 | $2.99^{b}$ | $14.41^{b}$ | 22.87 | 373.37 | 267.61 | 1.41 | $2.39^{b}$ |
| | 3 | $3.01^{b}$ | $14.37^{b}$ | 22.23 | 341.25 | 273.68 | 1.39 | $2.49^{b}$ |
| | 4 | $3.11^{ab}$ | $15.05^{ab}$ | 23.19 | 304.66 | 271.54 | 1.49 | $2.50^{ab}$ |
| | 5 | $3.30^{a}$ | $15.62^{a}$ | 23.95 | 342.19 | 258.35 | 1.56 | $2.56^{ab}$ |
| | 6 | $3.14^{ab}$ | $15.52^{ab}$ | 23.62 | 459.72 | 246.53 | 1.50 | $2.72^{a}$ |
| | 7 | $2.97^{b}$ | $14.31^{b}$ | 20.84 | 390.88 | 245.22 | 1.46 | $3.38^{a}$ |
| Birth /lambing season | P-value | 0.0109 | NS | NS | NS | 0.0010 | NS | 0.0005 |
| | Dry | 3.05 | 14.73 | 22.77 | 355.93 | 281.008 | 1.64 | 2.32 |
| | Wet | 3.11 | 14.97 | 22.88 | 366.65 | 249.50 | 1.67 | 2.66 |
| Birth /lambing year | P-value | <.0001 | NS | NS | NS | NS | NS | 0.0059 |
| | 2014 | $3.21^{a}$ | 15.16 | 22.47 | 414.57 | 251.52 | 1.48 | $2.77^{a}$ |
| | 2015 | $3.15^{a}$ | 14.85 | 22.35 | 360.96 | 262.62 | 1.47 | $2.39^{b}$ |
| | 2016 | $3.06^{b}$ | 14.57 | 22.56 | 343.70 | 278.06 | 1.40 | $2.30^{b}$ |
| | 2017 | $3.03^{bc}$ | 14.82 | 23.91 | 325.94 | 268.81 | 1.49 | $2.50^{b}$ |
| | 2018 | $2.94^{c}$ | - | - | - | - | 1.46 | - |

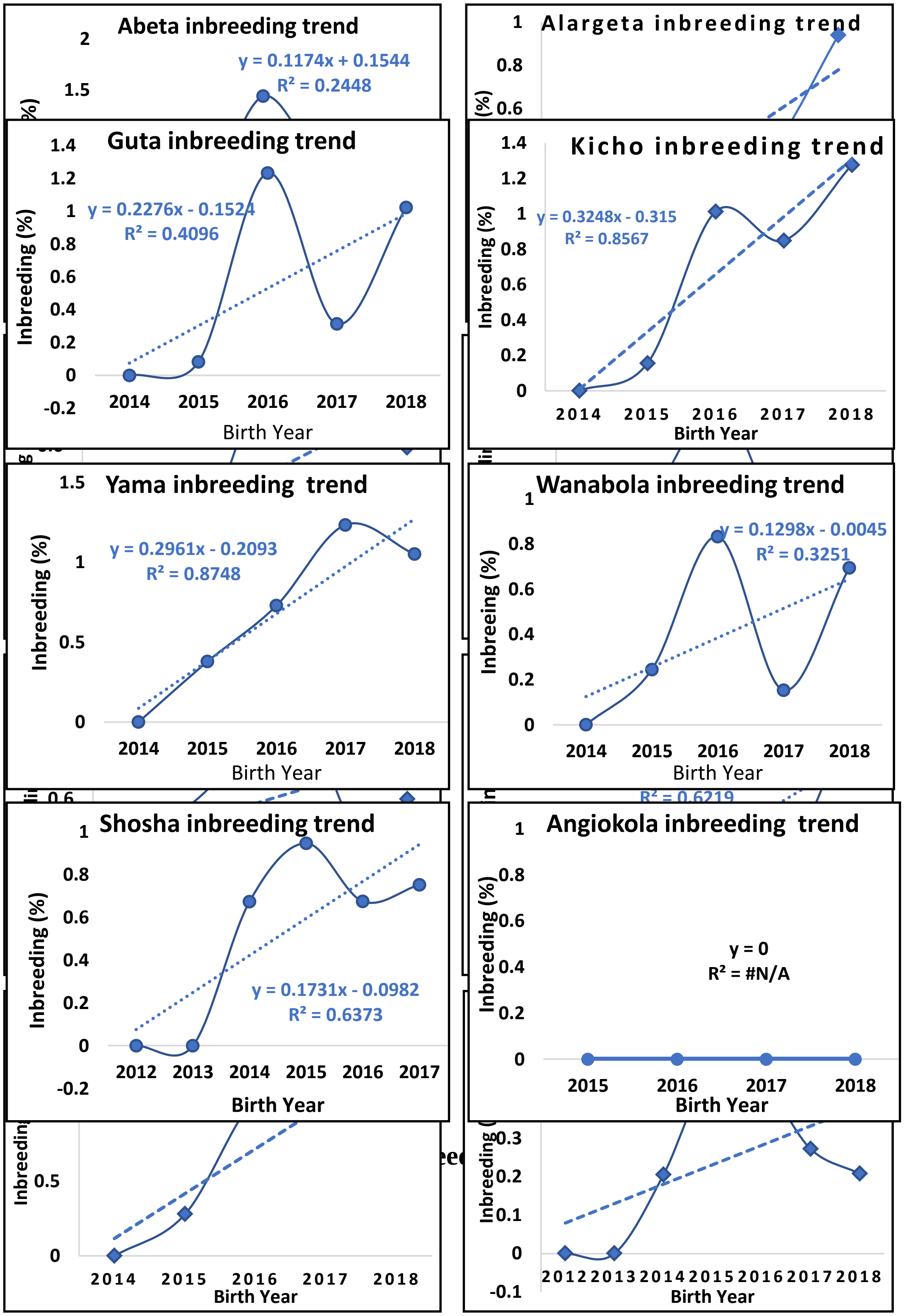
## APPENDIX D TABLE 26: Phenotypic performance of growth and reproductive traits for Omashonga CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|
| | **Over all** | **3.39** | **14.45** | **24.26** | **292.15** | **1.56** | **2.42** |
| | CV | 15.72 | 11.26 | 16.49 | 31.44 | 35.60 | 35.84 |
| Birth /lambing type | P-value | <.0001 | <.0001 | NS | NS | NA | NA |
| | Single | 3.62[a] | 15.46[a] | 24.22 | 270.68 | | |
| | Twin | 3.43[b] | 14.77[b] | 24.50 | 289.75 | | |
| | Triple | 3.10[c] | 13.12[c] | 24.06 | 316.02 | | |
| Sex/ lambing sex | P-value | <.0001 | <.0001 | 0.0004 | NA | NA | NA |
| | Male | 3.65 | 15.34 | 26.31 | | | |
| | Female | 3.13 | 13.57 | 22.21 | | | |
| Birth /lambing parity | P-value | 0.0001 | NS | NS | NS | NS | <.0001 |
| | 1 | 3.20[b] | 14.45 | 23.42 | 324.46 | 1.56 | 1.56[d] |
| | 2 | 3.25[b] | 14.40 | 23.66 | 306.59 | 1.67 | 2.24[bc] |
| | 3 | 3.27[b] | 14.52 | 23.28 | 268.29 | 1.54 | 2.39[b] |
| | 4 | 3.42[ab] | 14.43 | 24.69 | 282.58 | 1.56 | 2.61[a] |
| | 5 | 3.56[a] | 14.87 | 24.93 | 293.43 | 1.56 | 2.72[a] |
| | 6 | 3.55[ab] | 14.48 | 26.39 | 267.18 | 1.43 | 3.32[b] |
| | 7 | 3.45[ab] | 14.03 | 23.43 | 302.51 | 1.59 | 2.11[c] |
| Birth /lambing season | P-value | 0.0318 | 0.0042 | NS | NS | NS | NS |
| | Dry | 3.43 | 14.66 | 24.39 | 283.71 | 1.55 | 2.47 |
| | Wet | 3.35 | 14.25 | 24.12 | 300.59 | 1.56 | 2.37 |
| Birth /lambing year | P-value | 0.0046 | <.0001 | 0.0495 | 0.0227 | 0.0192 | NS |
| | 2014 | 3.37[b] | 11.85[c] | 26.58[b] | 331.12[b] | 1.62[a] | 2.42 |
| | 2015 | 3.39[ab] | 15.32[a] | 28.21[a] | 303.39[b] | 1.57[a] | 2.41 |
| | 2016 | 3.27[ab] | 15.57[a] | 25.45[c] | 279.15[ab] | 1.42[b] | 2.28 |
| | 2017 | 3.44[a] | 14.79[b] | 22.81[d] | 254.93[a] | 1.53[b] | 2.57 |
| | 2018 | 3.47[a] | 14.75[b] | 18.23[e] | - | 1.66[a] | |

### APPENDIX D TABLE 27: Phenotypic performance of growth and reproductive traits for Wanabolla CBBP cooperative

| Fixed effect | | BWT (kg) | WWT (kg) | SMWT (kg) | AFL (days) | LI (days) | LS (lamb) | ARR (lamb) |
|---|---|---|---|---|---|---|---|---|
| | **Over all** | **3.72** | **14.34** | **22.59** | **429.51** | **264.79** | **1.37** | **2.41** |
| | CV | 16.77 | 20.05 | 15.05 | 17.66 | 28.60 | 37.21 | 37.03 |
| Birth/ lambing type | P-value | <.0001 | <.0001 | 0.0045 | NS | NS | NA | NA |
| | Single | $3.89^{a}$ | $15.86^{a}$ | $25.17^{a}$ | 357.87 | 271.48 | | |
| | Twin | $3.65^{b}$ | $13.69^{b}$ | $22.42^{b}$ | 420.01 | 288.94 | | |
| | Triple | $3.61^{b}$ | $13.48^{b}$ | $20.18^{b}$ | 510.66 | 233.96 | | |
| Sex/ lambing sex | P-value | <.0001 | 0.0035 | 0.0009 | NA | NA | NA | NA |
| | Male | 3.81 | 14.72 | 24.13 | | | | |
| | Female | 3.63 | 13.96 | 21.05 | | | | |
| Birth/ lambing parity | P-value | <.0001 | NS | NS | NS | NS | NS | <.0001 |
| | 1 | $3.20^{d}$ | 13.73 | 21.38 | 437.78 | 295.59 | 1.42 | $1.39^{d}$ |
| | 2 | $3.52^{c}$ | 14.18 | 23.42 | 438.89 | 270.99 | 1.40 | $2.14^{c}$ |
| | 3 | $3.63^{bc}$ | 14.30 | 22.50 | 446.23 | 266.99 | 1.45 | $2.03^{bc}$ |
| | 4 | $3.88^{ab}$ | 14.71 | 22.87 | 397.10 | 298.31 | 1.31 | $2.24^{b}$ |
| | 5 | $3.95^{ab}$ | 15.26 | 21.44 | 438.18 | 276.37 | 1.32 | $2.23^{bc}$ |
| | 6 | $4.12^{a}$ | 14.55 | 21.73 | 418.91 | 207.54 | 1.42 | $2.64^{b}$ |
| | 7 | $3.72^{abc}$ | 13.67 | 24.81 | - | 237.76 | 1.28 | $4.21^{a}$ |
| Birth /lambing season | P-value | 0.0379 | NS | NS | NS | 0.0179 | NS | NS |
| | Dry | 3.76 | 14.56 | 22.26 | 437.27 | 281.72 | 1.38 | 2.30 |
| | Wet | 3.67 | 14.12 | 22.92 | 421.76 | 247.86 | 1.37 | 2.52 |
| Birth /lambing year | P-value | <.0001 | NS | <.0001 | NS | NS | 0.0001 | 0.0114 |
| | 2014 | $3.99^{a}$ | 14.04 | $19.03^{b}$ | 419.27 | 276.32 | $1.35^{b}$ | $2.50^{a}$ |
| | 2015 | $3.53^{b}$ | 14.62 | $24.78^{a}$ | 437.82 | 258.83 | $1.50^{a}$ | $2.59^{a}$ |
| | 2016 | $3.57^{b}$ | 14.47 | $23.66^{a}$ | 400.35 | 261.75 | $1.46^{a}$ | $2.47^{a}$ |
| | 2017 | $3.88^{a}$ | 14.52 | $22.90^{ab}$ | 460.61 | 262.27 | $1.22^{c}$ | $2.09^{b}$ |
| | 2018 | $3.62^{b}$ | 14.06 | - | - | - | $1.33^{b}$ | - |

**Appendix E:** Mean annual inbreeding percentage trend for each CBBP cooperative



**Appendix F** : Questionnaires and checklist for participant and non-participant for Farmers perception evaluation ;

**A : Questionnaires for participants**

1. CBBP cooperative name …………………...
2. Name of respondent ……………………………
3. Sex of respondent A. Male B. Female
4. Skill development from CBBP
   I. How often would you keep record performance of sheep born in the flock (characteristics and pedigree)? A. Always B. Most of the time C. Rarely D. Not at all
   II. Do you know inbreeding? A. Yes B. No
   III. If yes what are the sign?
      A. High mortality C. Poor reproduction performance E. delay in puberty
      B. Poor growth D. delay in testicular development F. Tendency of malformation
5. Ram using
   I. Which ram you used? A. Any selected ram B. Top ram only C. Both of them
   II. Are you involved in managing top ram? A. Yes B. No
   III. Where your top ram sells at the end of the service? A. Other community B. Local market C. Village consumption
6. Improvement
   I. Do you observe increasing of productive and reproductive change of your flock overtime? A. Yes B. No
   II. If yes for I, which traits? Rank them. Rank
      A. Growth D. Lamb survival
      B. Lambing interval E. Age at first lambing
      C. Twining rate
   III. Is there any genetic improvement difference for participant and non-participant of the program? A. Yes B. No
   IV. If yes for III, what is the difference?
      A. Growth rate difference C. Survival of lamb difference
      B. Reproductive performance difference D. Physical appearance difference
7. Economic difference between participant and non-participant
   I. Do you observe price difference between you and other non-participants animal in the market?
      A. Yes B. No
   II. If yes for I, explain difference in birr respective with age and sex?
      A. ram lamb _____ birr B. ram ______ birr C. ewe lamb _____birr D. ewe_____ birr
   III. Explain the program in the point of economic development.
      A. Increase income B. Decrease income C. No change
8. Is there any constrained which hinder effectiveness of the program? Mention.

**B: Questionnaires for non-participants**

1. Community of respondent …………………….
2. Name of respondent ………………...
3. Sex of respondent A. Male B. Female
4. Genetic improvement difference between participant and non-participant
   I. Do you think improving local sheep through best ram selection? A. Yes B. No
   II. Do you use selected best rams from participant? A. Yes B. No
   III. If yes for II, how often? A, Always B, Sometimes C, Rarely
   IV. If no for III why?
   A, Members are not allowed to share C, I'm not give attention E. No sheep
   B, I'm not interested to use D. My sire is better than selected sire
   V. Is there any genetic improvement difference for participant and non-participant of the program? A. Yes B. No
   VI. If yes for V, what is the difference?
   A. Growth difference C. Survival difference
   B. Reproductive performance difference D. Physical appearance difference
   VII. If no for V, why?
5. Experience development from participant
   I. Do you get any experience from participant? A. Yes B. No
   II. If yes for I, what type of experience? Mention them.
   III. Do you know inbreeding? A, yes B, no
   IV. If yes for III, what is the sign? A. High mortality B. Poor growth C. Poor reproduction performance D. delay in testicular development E. delay in puberty F. Tendency of malformation
   V. Do you have a habit of castration? A. Yes B. No
   VI. If yes for V, what is the criteria for castration? A. Old age B. For fattening C. Poor performance D. no criteria
   VII. Have you an interest to participate in the CBBP? A, Yes B, No
   VIII. If yes for VII, why? A. To get improved lamb C. Just to become a member
   B. To increase income D. Other specify…
   VIII. If no for VII, why?
   A. No change of improvement C. Not happy by rule of CBBP cooperative
   E. No labor
   B. No sheep flock D. I have better flock than participants
6. Economic difference between participant and non-participant
   I. Do you observe price difference between you and other participants sheep in the market? A. Yes B. No C. unknown
   II. If yes for I, explain difference in birr respective with age and sex?
   A. ram lamb ______birr C. ewe lamb_____birr
   B. ram ____ birr D. ewe____ birr