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Quantifying Genetic Diversity and Designing Community-Based Breeding Program for Indigenous Sheep in Northwestern Ethiopia

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Animal Genetics and Breeding

Principal Advisor: Professor Kefyalew Alemayehu
Co-Advisors: Dr. Solomon Abegaz Kebede
Dr. Aynalem Haile
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May, 2023
BAHIR DAR

Declaration

This is to certify that the thesis entitled "Quantifying Genetic Diversity and Designing Community - Based Breeding Program for Indigenous Sheep in NorthWestern Ethiopia", submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy of College of Agriculture and Environmental Sciences, in Animal Genetics and Breeding of Department of Animal Science, Bahir Dar University, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

Name of the candidate Sisay Asmare Belachew Date 21/03/2023

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SCHOOL OF VETERNARY MEDICINE AND ANIMAL SCIENCES

DEPARTMENT OF ANIMAL SCIENCE

Approval of Dissertation/Thesis for Defense

I hereby certify that I have supervised, read, and evaluated this thesis/dissertation titled "Quantifying Genetic Diversity and Designing Community - Based Breeding Program for Indigenous Sheep in NorthWestern Ethiopia " by Sisay Asmare Belachew prepared under my guidance. I recommend the thesis/dissertation be submitted for oral defense.

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Approval of Dissertation/thesis for defense result

As members of the board of examiners, we examined this dissertation/thesis entitled "Quantifying Genetic Diversity and Designing Community - Based Breeding Program for Indigenous Sheep in NorthWestern Ethiopia" by Sisay Asmare Belachew. We hereby certify that the thesis/dissertation is accepted for fulfilling the requirements for the award of the degree of "Doctor of Philosophy (PhD)".

Board of Examiners

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Dedication

The PhD dissertation I am currently working on is a dedicated output after walking upside down and encountering various adverse circumstances. This piece of work was written in honor of my beloved wife, Sewareg Abraham, who morally supported me, as well as my beloved children, Tamirat Sisay, Nardos Sisay, Abraham Sisay, Robel Sisay, and my parents.

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Abstract

In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous. However, the productivity of local sheep under traditional production system is low with high mortality of lambs. Between sheep breed differences in performance do exist and have begun to attract some research attention in recent years. Yet, little selection has been undergone for improved meat production and true breed potentials are not known and not all breeds have been sufficiently well characterized. There is a need to better acknowledge the unique features of these breeds, their products, their socio-cultural and religious uses, and their production systems. Multiple-visit, multiple-subject survey was conducted to characterize sheep production system, growth and reproductive performance, phenotypic features and genetic diversity study and generate information' to design sheep breeding schemes. Purposive sampling method was employed to select study areas or districts and households engaged in sheep production. Pre-teested semi-structure questionnaire was administered for data collection. Data collection was carried out for two years from September, 2017 to October, 2019 G.C. Households under investigation have a small patch of land. Mean ±SD values of land holding per household of Burie, Mandura and Quara were 1.03±0.89 ha, 2.66±1.61 ha and 11.46±5.76 ha, respectively, resulting in insufficient pasture and feed shortages. Feed shortage, disease and parasites and lack of input were prioritized as major challenges of sheep production. The growth and reproductive performances traits of Washera and Gumuz sheep were comparable to other Ethiopian and African sheep. Breed type affected live weight significantly ($P<0.001$). Average age at first lambing and lambing interval were also affected by breed significantly. Body weight recorded for Washera, Gumuz and Rutana Sheep were 27.5, 26.89 and 38.71 kg, respectively. Chest girth and body length were best body weight predictors for Gumuz female sheep at $p<0.001$ level of significance. Tail length, ear length and body length were best body weight predictors for Gumuz male sheep at $p<0.001$ level of significance. For Washera female sheep, tail length, chest girth, height at withers and body length were best body weight predictors at $p<0.001$ level of significance. Tail length, chest girth and head length were best body weight predictors for Washera male sheep at p<0.001 level of significance. Higher mean values of morph metric traits were recorded canonical bone length. The variations in phenotypic features need to be supplemented by molecular diversity study. Clustering analysis using principal component (PC1) differentiates Rutana from Gumuz and Washera sheep supporting this variation. Polymorphic information content was 0.89, 0.90 and 0.88 for Gumuz, Rutana and Washera sheep, respectively. These values could be recognized as reasonably (moderately) informative to carry out genetic diversity study. Expected heterozygosity was found to be higher than observed heterozygosity attributed to the discrepancy to forces such as inbreeding. Observed heterozygosity ranged from 0.33 in Gumuz to 0.34 in Rutana and Washera sheep. Expected heterozygosity ranged from 0.37 in Rutana to 0.38 in Gumuz and Washera sheep. Higher inbreeding coefficient (0.12) was recorded for Gumuz sheep compared to 0.09 of Rutana and Washera sheep. Our whole-genome SNP analysis revealed high variation within populations. These within-breed variabilities were used as input for designing a selective breeding program. Phenotypically, two highly rated selection criteria (body size and litter size) were preferred for Gumuz and Washera ewe. Improving 25 kg sale weight (at yearling age) and the number of lambs qualifying for the market and home consumption were the proposed breeding objectives or goals. Genetic gain predicted for six- month weight of Gumuz and Washera sheep were 0.46 and 0.60 kg of live weight, respectively. Genetic gain predicted for yearling weight of Gumuz and Washera sheep were 0.58 and 0.66 kg of live weight, respectively. A sheep breeding program with 10% selection proportion and one year ram use for breeding was recommended giving special emphasis to yearling weight.

Key words: body weight; genetic gain; growth and reproductive performance traits; inbreeding; morphological variables

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Acronyms and abbreviations

AE	Acetate Ethylene
AEZ	Agro-Ecologic Zones
AFL	Age at First Lambing
AMOVA	Analysis of Molecular Variance
BHS	Black Head Somali
CADU	Chilalo Agricultural Development Unit
CBBP	Community Based Breeding Program
CSA	Central Statistical Agency
DNA	Deoxyribonucleic Acid
EDTA	Ethylene Diamine Tetraacetic Acid
EIAR	Ethiopian Institute of Agricultural Research
FAGR	Farm Animal Genetic Resources
FAO	Food and Agricultural Organization
F_{IS}	Inbreeding coefficient of an Individual relative to the Subpopulation
GLM	General Linear Model
HWE	Hardy Weinberg Equilibrium
IBC	Institute of Biodiversity Conservation
PA	Peasant Association
r_{pm}	revolution per minute
TAE	Tris Acetate Ethylene
TLU	Tropical Livestock Unit
µl	Micro liter

Chapter one: Introduction

Background of the study

Since domestication, sheep have become essential parts of farms across the world (Hirst, 2017) and comprises 16 percent of the total TLUs in sub-Saharan Africa (FAO, 2002). In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous breeds (CSA, 2020). These indigenous breeds have special adaptive features such as tolerance to a wide range of diseases, water scarcity tolerance and ability to better utilize the limited and poor-quality feed resources (Kosgey & Okeyo, 2007). However, the productivity of local sheep under traditional production system is low with high mortality of lambs (Tibbo, 2006). As a result, the increasing need for food of animal origin has largely been met with increasing number of sheep while productivity per sheep has remained low (FAO, 2015). One of the reasons for low productivity of sheep was lack of sustainable sheep breeding program (Haile et al., 2011; Zonabend, 2016; Karnuah et al., 2018). Hence, increasing the current level of productivity is essential to provide meat to the ever-increasing human population, to increase export earnings and household income thereby improving the living standard of smallholders (Tibbo, 2006).

Conservation of sheep genetic resources relies on demographic characterization, recording of production environments and effective data management is required (Groeneveld et al., 2010). In this regard, phenotypic and molecular characterizations of animal genetic resource are used to measure and describe genetic diversity in these resources as a basis for understanding them and utilizing them sustainably (FAO, 2007). There is a need to better acknowledge the unique features of these breeds, their products, their socio-cultural and religious uses, and their production systems (FAO, 2014). Understanding production systems and sustainable utilization of indigenous sheep requires on-farm monitoring and evaluation of productive and reproductive performance of a breed. On-farm performance evaluation gives a more representative performance level of the breed since it is undertaken under the natural production environment of the breed (Gizaw et al., 2011). Live weight and growth rate are economically critical features, requiring particular attention in any breeding program intended to improve overall productivity since lambs are mainly raised for mutton

(Tibbo, 2006). Besides, good reproductive performance is a prerequisite for any successful genetic improvement and it determines production efficiency which depends on various factors including age at first lambing, litter size, lambing interval and the life time productivity of the ewe (Abebe, 2008; Edea, 2008).

Higher mean values of morph metric traits were recorded canonical bone length. The variations in phenotypic features need to be supplemented by molecular diversity study. Clustering analysis using principal component (PC1) differentiates Rutana from Gumuz and Washera sheep supporting this variation. Polymorphic information content was 0.89, 0.90 and 0.88 for Gumuz, Rutana and Washera sheep, respectively. These values could be recognized as reasonably (moderately) informative to carry out genetic diversity study. Expected heterozygosity was found to be higher than observed heterozygosity attributed to the discrepancy to forces such as inbreeding. Observed heterozygosity ranged from 0.33 in Gumuz to 0.34 in Rutana and Washera sheep. Expected heterozygosity ranged from 0.37 in Rutana to 0.38 in Gumuz and Washera sheep. Higher inbreeding coefficient (0.12) was recorded for Gumuz sheep compared to 0.09 of Rutana and Washera sheep. Our whole-genome SNP analysis revealed high variation within populations. These within-breed variabilities were used as input for designing a selective breeding program. Phenotypically, two highly rated selection criteria (body size and litter size) were preferred for Gumuz and Washera ewe. Improving 25 kg sale weight (at yearling age) and the number of lambs qualifying for the market and home consumption were the proposed breeding objectives or goals. Genetic gain predicted for six- month weight of Gumuz and Washera sheep were 0.46 and 0.60 kg of live weight, respectively. Genetic gain predicted for yearling weight of Gumuz and Washera sheep were 0.58 and 0.66 kg of live weight, respectively. A sheep breeding program with 10% selection proportion and one year ram use for breeding was recommended giving special emphasis to yearling weight.

Statement of the problem

Studies on sheep production systems, production performance and phenotypic as well as genetic diversity of Washera ,Gumuz and Rutana sheep populations intended to design and implement appropriate sheep breeding schemes are rare. Visual estimation of body weight by farmers, sheep meat consumers and researchers might be far from hundred percent real measurement value of body weight and linear body measurements of sheep. Under such circumstances, smallholder farmers' and meat consumers may pay cash which is not proportional to the real market value of sheep. In addition, for research purposes, taking measurement of body weight was difficult due to lack of fixed weight scales as it was available for cattle in research centers and ranches. In which case biased research data on body weight may be collected. In earlier studies, genetic diversity of sheep has been reported (Nigussie, 2015, Gizaw et al.,2008) using microsatellite markers. Edea (2017), Amane (2020) and Deribe (2020) reported genetic diversity of sheep using low to medium density SNP dataset. However, despite the advancement of whole-genome sequencing technology, little research has been done on diversity studies of Gumuz, Rutana and Washera sheep populations based on whole-genome sequence data. Thus, this research was conducted to address such research gaps

Objectives of the study

The overall objective of this study was aimed at monitoring and evaluation of the husbandary practices, growth and reproductive performance, morphological features of sheep, quantifying genetic diversity and designing community - based breeding programs for indigenous sheep in northwestern Ethiopia. The specific objectives of this study are:

1. To characterize husbandary and breeding practices of indigenous sheep in north-western Ethiopia

2. To evaluate the growth and reproductive performances of Washera and Gumuz sheep

3. To study morphological features and generate body weight estimation formula for Washera and Gumuz sheep based on their liner body measurements

4. To study genetic diversity and within-breed variation between three indigenous Ethiopian sheep based on whole-genome sequence data analysis

5. To design selection schemes and predict genetic gains for traits of Washera and Gumuz indigeneous sheep

Significance of the study

Smallholder farmer' communities, sheep meat consumers and researchers will benefit from the out put of this study by using body weight prediction formula using a simple textile meter for saving time and energy. The out put of this study will also be used by policy makers, researchers and extension workers to intervene for improvement of sheep by designing breeding programs and proposing conservation priorities of these genetic resources which relies phenotypic and genetic diversity studies. The present dissertation is compiled based on the following papers/articles.

Article I. Husbandary and breeding practices of indigenous sheep

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Abstract

Multiple - visit, multiple-subject survey was employed to describe husbandary and breeding practices of sheep keepers of North Western Ethiopia. Pre-tested semi - structured questionnaire were used for data collection on agro-economic conditions (farm household characteristics, resource endowment and uses, livestock demography, purpose of sheep husbandary practice, breeding practices , feeds and feeding, housing facilities, and health service) and challenges and opportunities of sheep production. Data was collected from respondents during the period between November 2017 and November 2018. Descriptive statistic procedure of statistical Software for Social Science was employed to calculate mean values of land holding, flock size and flock composition. Chi-square tests were employed to test the independence between socio-economic features and district. Data on purpose of keeping sheep and challenges of sheep production were prioritized by index method. Households under investigation have a small patch of land. Mean ±SD values of land holding per household of Burie, Mandura and Quara were 1.03±0.89 ha, 2.66±1.61 ha and 11.46±5.76 ha, respectively, resulting in insufficient pasture land. Purpose of keeping sheep for income generation ranked first across the districts. Major challenges of sheep production in Burie, Mandura and Quara districts were multitude of technical, institutional and socio-economic problems. Feed shortage, disease and parasites, predator, lack of capital and labor shortage were the major challenges of sheep production. Using by-products of agr-inductries in Burie District could contribute to boost-up level of input in feed resources.

Key words: challenges; husbandary practice; sheep; selective breeding; sheep health; sheep productivity; sheep production

Introduction

Sheep and goats contribute a quarter of the domestic meat consumption, about half of the domestic wool requirements, about 40 % of fresh skins, and 92 % of the value of semi-processed skin and hide export trade. The increased domestic and international demand for Ethiopian sheep and goats has established them as important sources of inland revenue as well as foreign currency (Hirpa and Abebe, 2008). It has been reported (Hirpa and Abebe , 2008; Getachew et al.,2010) that small ruminants represent only 7 % of the average total capital invested in livestock in the mixed crop-livestock production system, but they account on average for 40% of the cash income and 19% of the total value of subsistence food derived from all livestock production. In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous (CSA, 2020). However, the production of local sheep under traditional production system is low with high mortality of lambs (Tibbo, 2006). The major reasons for low productivity of sheep were poor quality and quantity of feed supply, inadequate health care service, low producing African genotypes, and lack of sustainable sheep breeding programs (Tibbo, 2006; Zonabend, 2016).

According to (FAO, 2015) the increasing need for food of animal origin has largely been met with increasing number of sheep while productivity per sheep has remained low. Thus, increasing the current level of productivity of sheep is essential to meet the demands of the ever-increasing human population. Productivity can be improved in two ways. These are improving the production environment (feed, disease control/prevention) and improving genetic merit (Gizaw, 2009). Setting up sheep breeding programs starts with a description of sheep production system or the way we keep sheep and for which purpose (FAO, 2010; Haile et al., 2011). Besides, conservation and utilization of local breeds of sheep is part of animal husbandry and should, ideally, be based on complete information on distribution, structures, and trends, productive and adaptive performances of populations of the existing breeds (IBC, 2004). Indigenous sheep breeds are compatible genotypes for the low input traditional production system since indigenous sheep breeds have special adaptive features such as tolerance to a wide range of diseases, water scarcity tolerance and ability to better utilize the limited and poor-quality feed resources (Kosgey and Okeyo, 2007).

Washera sheep is a short fat tail, large body size, short-haired, predominantly brown, both males and females are polled reared by Amhara and Agew communities. Washera is a good meat producer under good environment (Gizaw, 2009). Gumuz sheep is long thin tail, somewhat dwarf, convex face profile, long pendulous ear, commonly plain brown or with patch coat color, polled and reared by Gumuz and Amhara communities (Gizaw et al., 2008). Gumuz sheep is adapted to heat and have unique genetic make-up (Gizaw, 2009). An earlier report (IBC, 2004) states that the prevailing sheep production systems were characterized by inadequate health care, smaller land holding often less than two hectares and small sheep flock size. Based on these criteria, (Gizaw et al., 2008) described the sheep production system as small scale, semi intensive, low input and traditionally managed. Rutana is long thin tailed sheep population found in Benishanguel Gumuz regional state and northwestern lowlands of Amhara Regional state of Ethiopia (Dagnawu et al., 2017). These sheep populations support the livelihood of sheep keepers in highlands and lowlands of northwestern Ethiopia. Thus, the overall objective of this study was to generate information on sheep husbandary and breeding practices of sheep.

Materials and methods

Description of the study area

This study was conducted in three districts of northwestern Ethiopia, Burie, Mandura and Quara. Washera, Gumuz and Rutana were predominant traditional sheep populations in Burie, Mandura and Quara districts, respectively. The prevailing sheep production systems of Burie and Mandura districts were highland cereal-livestock system and lowland crop-livestock system, respectively (Gizaw et al., 2008). As suggested by Abegaz et al.(2008), sheep production system of Quara district was agro–pastoral based on the criteria that, there is lesser integration between livestock and cereal crop production and due to the fact that the farming practice takes place in an agro-ecology below 1500 meters above sea level.

Sampling strategy and sample size determination

After preliminary survey, three districts Burie, Mandura and Quara were selected by purposive sampling method (ILCA, 1990) based on sheep production potential and the zonal administrative zones where the sheep populations are found. Similarly, three rural Peasant Associations (PAs i.e., smallest administrative units - Wanegedam, Daez Baguna and Dubaba) were selected from each district by purposive sampling method from their respective districts. The key informants including the development agents and peasant association administrators were given training for building their capability to enumerate smallholders engaged in sheep production and how to fill questionnaires. To keep the proportionality of households between districts, sampling frame suggested by FAO (2011) was used.

$$n = (z/m)^2 p(1-p)$$

where z is the z value (1.96 for 95 percent confidence level); m is the margin of error (0.05 = + or – 5 percent); and p is the estimated value for the proportion of the sample that will respond a given way to a survey question (0.50 for 50 percent). The finite population correction (FPC) factor were used in calculating sample sizes

S=n/(1+ (n/N))

where:

S=sample size

n is the sample size based on the calculations above and

N is the total number of households for each district before sampling using the above formula

Ultimately, from a total of 400 households in Burie district (Wanegedam PA) engaged in sheep production, 196 households were selected by random sampling method (ILCA, 1990). Likewise, from a total of 120 households of Mandura district (Daez Baguna PA) engaged in sheep production, 92 households were selected by random sampling method. Likewise, from a total of 40 households of Quara district (Dubaba PA) engaged in sheep production, 36 households were selected by random sampling method.

Data collection and management

Multiple-visit, multiple-subject surveys (ILCA, 1990) was employed to collect primary data of respondents during the period between November 2017 and November 2018. Pre-tested semi - structured questionnaire were used for data collection on agro-economic conditions (farm household characteristics, resource endowment and uses, livestock demography, purpose of sheep production , breeding practices , feeds and feeding, housing facilities, and health service) and challenges of sheep production. Data of livestock population were converted into tropical livestock unit (TLU) using conversion equivalents of sub-Saharan Africa livestock into TLU (FAO, 2002). Different formulas were used to calculate some parameters.

Data analysis

The collected data were coded and entered into excel spread sheet. The data were analyzed using descriptive statistics such as mean, standard deviation, frequency and percent using statistical package for social science, SPSS version 20.0 (SPSS, 2011). Analysis of variance (ANOVA) was employed to evaluate the effect of district on family size. Chi-square tests were employed to test the independence between socio-economic features (sex of household, educational background, source of income and farming activity) and district. Data on purpose of keeping sheep, dry and challenges and opportunities of sheep production were prioritized by index method (Kosgey, I. S., 2004). Index = sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] divided by sum [3 for rank 1 + 2 for rank 2 + 1 for rank 3] for all purposes of keeping sheep and challenges and opportunities of sheep production.

Results

Family size and land holding per household

Demographic features of Burie, Mandura and Quara districts were analyzed for a total of 324 households (Table 1). There is no significant difference in family size across the districts at $p<0.05$. Chi-square test result reveals that sex of household, educational background, source of income and farming activities of respondents were dependent on districts at high significant ($p<0.001$) level. Livelihood of families' of smallholders (Table 1) is supported by small land holding per households of Burie and Mandura districts believed to be densely populated areas. Mean ±SD values of land holding per household of Burie, Mandura and Quara were 1.03±0.89, 2.66±1.61 and 11.46±5.76 ha, respectively.

Table 1. Frequency of respondents recall regarding socio-economic characterstics Study

Particulars		Burie	Mand	Quara	Overall	F	Sig.
Family size(mean±SD)		5.7±1.6	5.6±1.	5.5±1.7	5.7±1.6	0.25	0.77
		Burie	Mandu	Quara	Total	X^2-	Sig.
Sex of household						31.6	.000
Male	Count	163	67	32	262		
	%	82.7%	74.4	86.5%	80.9%		
Female	Count	34	23	5	62		
	%	17.3%	25.6	13.5%	19.1%		
Total	Count	197	90	37	324		
	%	100.0%	100.0	100.0	100.0%		
Educational background						32.6	.000
Literate	Count	24	10	12	46		
	%	12.2%	11.1	32.4%	14.2%		
Illiterate	Count	45	22	19	86		
	%	22.8%	24.4	51.4%	26.5%		
Read and write	Count	128	58	6	192		
	%	65.0%	64.4	16.2%	59.3%		
Total	Count	197	90	37	324		
	%	100.0%	100.0	100.0	100.0%		
Source of income						56	.000
Agriculture	Count	193	88	30	311		
	%	98.0%	97.8	81.1%	96.0%		
GOV employee	Count	4	2	0	6		
	%	2.0%	2.2%	0.0%	1.9%		
Agriculture and trade	Count		0	7	7		
	%	0.0%	0.0%	18.9%	2.2%		
Total	Count	197	90	37	324		
	%	100.0%	100.0	100.0	100.0%		
Farming activity						67.9	.000
LS production only	Count	18	14	24	56		
	%	9.1%	15.6	64.9%	17.3%		
Both LS and Crop production	Count	179	76	13	268		
	%	90.9%	84.4	35.1%	82.7%		
Total	Count	197	90	37	324		
	%	100.0%	100.0	100.0	100.0%		

Purpose of keeping sheep

Communities in Burie, Mandura and Quara districts keep sheep for various purposes. They prioritize these purposes by giving ranks. Table 2 depicts details of purposes of keeping sheep.

Table 2. Purpose of keeping sheep and the ranking of these purposes by district

Purposes	Burie R 1	Burie R 2	Burie R 3	Burie Index 1	Burie R	Mandura R 1	Mandura R 2	Mandura R 3	Mandura Index 2	Mandura R	Quara R 1	Quara R 2	Quara R 3	Quara Index 3	Quara R	Over all index	R
Income	63	3	0	0.47	**1**	60	6	2	0.41	**1**	63	30	0	0.51	**1**	**0.46**	**1**
Meat for home consumption	2	35	21	0.23	**3**	14	25	13	0.22	**3**	45	18	12	0.35	**2**	**0.26**	**2**
Saving	4	29	28	0.24	**2**	9	41	11	0.25	**2**	0	24	24	0.14	**3**	**0.21**	**3**
Wealth Status	0	2	7	0.03		0	1	15	0.04		0	0	0	0		0.035	
Manure	0	0	10	0.02		0	1	18	0.04		0	0	0	0		0.03	
Skin	0	0	3	0.01		0	0	15	0.03		0	0	0	0		0.02	
Total	207	138	69	1		24	148	74	1		32	14	36	1		1	

Index = sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] divided by sum [3 for rank 1 + 2 for ran 2 + 1 for rank 3] for all purposes of keeping sheep for a district,R=Rank

Sheep flock size and composition

Sheep flock composition of Burie, Mandura and Quara districts was shown in Figure 1. Mean number of ewes at the age of one year and above were 2.5, 3 and 11 ewes for Mandura, Burie and Quara districts, respectively. This result indicates breeding female dominating flock structure in Quara district.

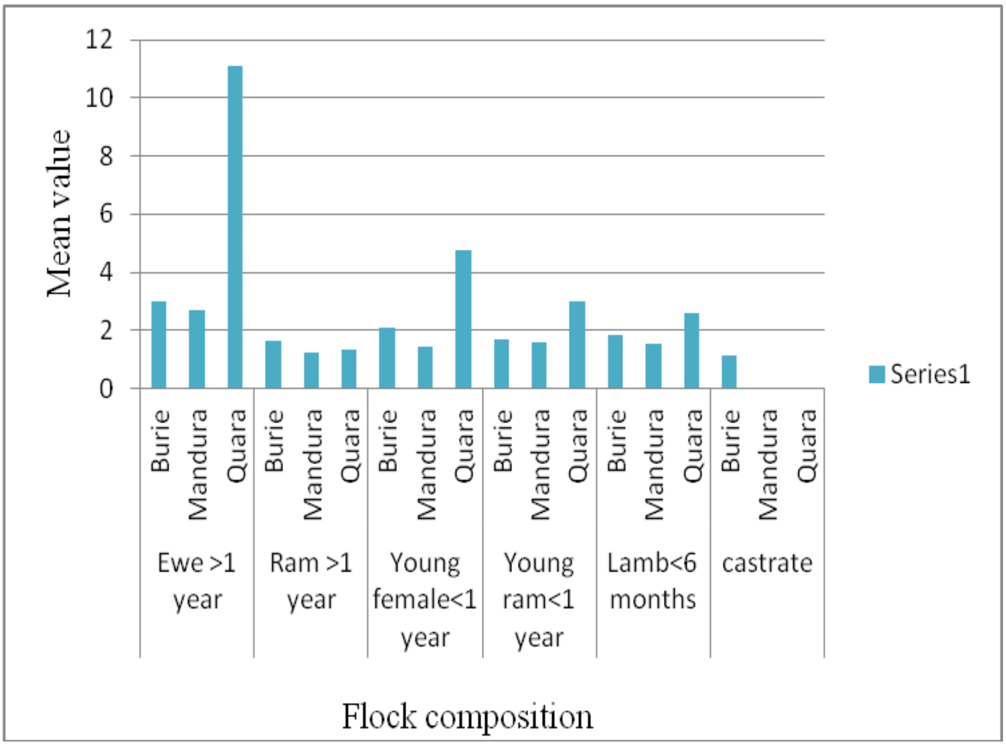

Figure 1. Sheep flock size , composion and flock structure

Sheep feed resources and grazing management

The results of the current study revealed that wet season grazing management of Burie district was free grazing according to 61% of respondents, 26 % herding (in a controlled herding practice), 7 % cut and carry and 6% tethering, according to the recall of respondents. Dry season grazing management was found to be free grazing according to 34 % of respondents, 20 % herding (in a controlled herding practice), 21 % cut and carry, and 25 % tethering. Wet season grazing management of Mandura district was free grazing according to 64 % of respondents, 31 % herded by herders , 5 % cut and carry, where as dry season grazing management was found to be 41.3 % free grazing, 54.6 % herding (in a controlled herding practice), 4.1 % cut and carry. Wet season grazing management of Quara district was free grazing according to 16.66 % of respondents, 50 % herded by herders, 33.33 % cut and carry. Dry season grazing management was found to be free grazing according to 75% of respondents, 23 % herded (in a controlled herding practice), and 2.0 % by cut and carry system.

Housing management

Sheep housing management practice in Burie district indicates that they used to have open barn according to 22 % of the respondents, shelter constructed in side main house as a small partition 59 %, and shelter constructed as extension of main house 19 %. On the other hand, housing practice in Mandura district for Gumuz sheep were found to be open barn according to 13% of respondents, separate house for sheep 12 %, shelter constructed in side main house 45.3 %, and shelter constructed as extension of main house were practiced by 29.7 % of respondents. Sheep housing practice of households in Quara district was separate shelter according to 50 % of respondents, inside residential house 8 %, and open barn according to 42 % of respondents. Housing practice of farmers in Burie district is characterized by extending sheep house to residential house according to 50 % of the respondents. The mere reason for higher rating of housing extended from main shelter of households was due to fear of theft and predators according to the recall of the respodents.

Challenges and opportunities of sheep production

Table 3 shows details of ranking of the major challenges of sheep production. Feed shortage, disease and parasites, predator, lack of capital and labor shortage were major challenges of sheep production. However, by-products of Phi_Bela and Rich land agro-processing inductries are good opportunies for Noug cake supply contributing to upgrade inputs of sheep production through improvement of feed resources. Damot farmers' cooperatives flour milling industry is also source of wheat bran and wheat middlings improving inputs of feed resources.

Table 3. Challenges of sheep production and ranking of these challenges by district

Production factors	Burie R 1	Burie R 2	Burie R 3	Burie Index 1	Burie R	Mandura R 1	Mandura R 2	Mandura R 3	Mandura Index 2	Mandura R	Quara R 1	Quara R 2	Quara R 3	Quara Index 3	Quara R	Over all index	R
Disease and parasites	21	12	8	0.22	2	56	8	11	0.43	1	24	6	1	0.43	1	0.36	1
Feed shortage	25	15	7	0.26	1	3	18	20	0.14	2	3	6	0	0.12		0.17	2
Water Shortage	0	6	3	0.03		3	7	1	0.06		0	0	0	0		0.04	
Labor Shortage	14	16	11	0.21	3	3	12	5	0.07		3	2	2	0.15	3	0.14	3
Market Availability	0	2	3	0.03		4	8	12	0.08		0	0	3	0.04		0.06	
Predator	2	0	1	0.03		2	9	13	0.08		6	6	1	0.18	2	0.05	
Genotype	2	8	13	0.08		1	3	4	0.03		0	0	3	0.03		0.05	
Lack of input	7	9	23	0.15		2	10	14	0.09	3	0	4	2	0.05		0.1	
Total	71	68	69	1		74	75	80	1		36	2	12	1		1	

Index = sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] divided by sum [3 for rank 1 + 2 for rank 2 + 1 for rank 3] for all challenges of sheep production for a district, R=Rank

Health of indigenous sheep

Common diseases and parasites

Major challenges of sheep production in Burie, Mandura and Quara districts were multitude of technical, institutional and socio-economic problems of sheep productivity. The result of this study indicates that diseases and parasitic problems were ranked first by respondents in Mandura and Quara districts, and second in Burie district (Table 3). The first order ranking indicates how diseases and parasitic problems in the study areas are major challenges of sheep production. Common diseases and parasitic problems observed in Burie district were *chaquat* (local name for external parasite on the hoofs of sheep), liver fluke, sheep pox, foot and mouth disease and influenza according to 42 %, 28 %, 13 %, 10 % and 7 % of respondents, respectively. In Mandura district common diseases and parasitic infestations include *chaquat* (local name for external parasite on the hoofs of sheep), sheep pox and FMD according to 39 %, 44 % and 17 % respondents, respectively. Diarrhea with the respondents rating of 59.4 % and pasteurellosis according to 40.6 % of respondents were major sheep health limiting factors in Quara district. Sheep and Goat pox in Mandura district and *chaquat* (42 %) and liver fluke (28 %) in Burie were major contributors to high mortality of sheep as it was the case in other parts of the country. Sheep and goat pox (viral) disease is a common challenge of sheep production across the districts under investigation.

Sheep healthcare service

Vaccination service for sheep is delivered to 44.5 % of the respondents while 55.5 % of smallholders responded that they do not get vaccination service. The service is delivered before disease outbreak according to 46 % of target groups. Among the respondents 50 % of them recalled that vaccination service is delivered when disease outbreak occur. Smallholders with a rate of 4 % recalled that vaccination service is delivered any time in a year. Although it is insufficient, medicine and vaccination service is given by agricultural offices, according to 80 % of the respondents, by private veterinary vendors according to 18 % of the respondents and by none governmental organizations (NGOs) according to 2 % of the respondents.

Breeding practice of indigenous sheep keepers

Mating practice and sources of ram

Sheep mating system of smallholders is based on natural mating using local sheep as sole pure breeding animals with no artificial insemination in Burie, Mandura and Quara districts. The predominant mating system was uncontrolled performed by mixing ram with ewes in free grazing lands according to 87%, 92% and 95 % respondents of Burie, Mandura and Quara districts, respectively. On the other hand controlled natural mating was performed through ram introduction to ewes according to 13 %, 8% and 5% of respondents of Burie, Mandura and Quara districts, respectively. The result of this study indicates that acquisition of breeding rams and ewes was from own flock, neighbor and by purchase from market. The respondents recall indicates that average service age of a ram was 1.8 year, 2.5 year and 2.0 years for Burie, Mandura and Quara districts, respectively. Thus, subsequent ram replacement is crucial every 1.8 year, 2.5 year and 2.0 years for Burie, Mandura and Quara districts, respectively. For this purpose, mode of ram replacement or acquisition was from their own flock according to 75 % of respondents, 17 % from young lamb of neighbors and 8 % by purchase in Burie district. In Mandura district, 66.66 % of respondents use their own ram while 33.33 % of them use ram from neighbors. Mode of ram replacement in Quara district was from young lambs of own flock according to 70 % of respondents, 17 % young lamb of neighbors and 13 % by purchase. Sheep keepers practice special management for their rams according to 60, 12 and 30 percent of respondents of Burie, Mandura and Quara districts, respectively while 40, 88 and 70 percent of them do not practice special management.

Discussion

In order to efficiently utilize the special features of sheep and improve productivity, a need arises to generate information on sheep production and breeding practice. As an improvement program, for instance, setting up sheep breeding programs starts with a description of sheep production system or the way we keep sheep and for which purpose (Haile et al., 2011). Socio-economic features of the districts under study reveals that family size of the respondents was independent on district ($p>0.05$). The overall mean family size of the study areas was 5.7 persons per household. This average family size is greater than that of country average 5.23, 4.86 average household size of Amhara Region and 4.92 persons per household of West Gojjam Administrative region (CSA, 2008). Although house wives and children play a major role in managing sheep , the majority of households investigated were male-headed households compared to widows and unmarried female sheep keepers. Most of the respondents investigated were able to read and write indicating that communities with better educational status (in relative terms) have engaged in sheep production. Farming activity of these households practice mixed crop - livestock sheep production system with a rate of 90.9 % and 84.4 % of Burie and Mandura districts. The higher livestock holding per HH in Quara district shows their greater dependency on livestock for their livelihood. Both mixed crop - livestock (of Burie and Mandura districts) and agro-pastoral (of Quara district) farming systems were held by small land holding per HH due to shrinking land as a result of growing urbanization and population size. Land holding per household of smallholders in Burie district was small, less than 2.1 ha per household (Urgessa et al., 2012) but greater than that of 0.5 ha earlier report (Hirpa and Abebe, 2008) for densely populated areas of Ethiopia. Land holding per household of Mandura district was also less than 5.9 ha (Dagnawu et al., 2017) of Gumuz sheep producers in Metema area. Sheep flocks of smallholders of the districts under investigation were major components of livestock species. Sheep flock size per household of Quara district (23 sheep) concur with 23 sheep per household of Afar regional state (Getachew, 2008). The livestock herd composition of Burie district is more of sheep than goats and cattle. Primarily, this is due to the preference of sheep keepers for sheep. A stance is taken by (Tilahun and Schmidt, 2012) that sheep population is increasing compared to cattle in most areas of Ethiopia suggesting that while cattle production is important in the highlands for mixed-crop farming activities, sheep and goat production continues to increase throughout the country. Compared to cattle, the breeding life cycle of sheep is short. Compared with cattle, the initial capital requirements and the demand for arable land for sheep production is less. This increase in sheep population also may be due to the greater flexibility of grazing behavior of sheep and goats (Tilahun and Schmidt, 2012). Sheep becoming the dominant species, the flock structure in turn is dominated by ewes at the age of one year and above. Ewes at the age of one year and above of Quara were higher than breeding ewes of Burie and Mandura districts indicating breeding female dominating flock structure in Quara. The lesser proportion of yearlings' rams and castrates in all of the districts indicates higher off take rate for sale and meat for household consumption during major holidays such as Ethiopian New Year, Ethiopian Easter, and Christmas. This flock structure was in agreement with an earlier report (CSA, 2016) for West Gojjam, Metekel, and North Gondar Zonal administrative regions of Amhara region. The larger proportion of ewes was due to the fact that breeding ewes were reserved or acquired for reproduction and sustaining their flock the longer time possible by the smallholders. However, 3 ± 1.3 of breeding ewe per household for Burie district and 2.7 ± 1.0 ewes for Mandura district were less than to 4(four) breeding females per household earlier report (Clemens , 2015) for South Wollo and West Shoa zone of Amhara Regional State of Ethiopia. Mean value of breeding males per household (1.6 of Burie, 1.2 of Mandura, and 1.3 of Quara) recorded by this study were less than 2.0 (Clemens, 2015) breeding males per household of South Wollo and West Shoa zones of Ethiopia. This is due to the fact that young males in Burie, Mandura and Quara districts are sold to local markets which otherwise could be candidate breeding males for future generation (Gizaw et al., 2010). Sheep feeding management is based on major available feed resources. *Atella* (residue of local brewery), crop aftermath and communal grazing lands were major feed resources in decreasing order of ranking. Apart from being major feed resources, utilization of crop residues as a feed resource implies the presence of integration between crop production and the livestock sector. There is little or no concentrate supplementation even during the dry season when feed resources are scarce in all the study areas. As stated by Getachew (2008) such scarcities of feed were also challenges of sheep production of almost all farmers and pastoralists in Menz and Afar regions. Yami (2008) On the other hand reported that natural grazing land is the predominant feed source for sheep and goats in Ethiopia. Very little land is planted to introduced pastures or forage crops. Smallholders construct sheep house extended to residential house according to 43-50 % of respondents. A similar view is held by Getachew (2008) that during the rainy season 53.3% of the sheep owners used to house their sheep within the same roof of residential house. Sheep keepers of Quara district practice open barn sheep housing system according to 50 % of respondents. Such open barn sheep housing system in Quara district exposes sheep for predators. Because of this predator was ranked as the second challenge of sheep production of the area. Income generation is the first priority of keeping sheep. A similar result held by Hassen and Tesfaye (2014) and Fikru et al.(2015) concur with the current ranking. Keeping sheep for household meat consumption ranked third in Burie and Mandura districts and ranked second by respondents of Quara district. The third place ranking of keeping sheep for household meat consumption in Burie and Mandura districts is in line with FAO (2002) report regarding lower household per capita consumption of meat of households. It has been reported (FAO , 2002) that per capita consumption of meat was 11.0 kg per head/year of sub-Saharan Africa and 26.4 kg meat/per/head/year of the developing world.

Challenges of sheep production (feed shortage and disease and parasites) prioritized by the current study were in line with Hirpa and Abebe (2008) and Fikru et al. (2015) earlier reports. It is believed that animal feed shortage in Ethiopia began back in mid-sixties (EJAP, 2004). Disease and parasites ranked as the first challenge of sheep production in lowland crop-livestock and agro-pastoral sheep production systems of Mandura and Quara districts, respectively. Disease and parasites ranked as the second challenge of sheep production in Burie district. The first and second order ranking indicates how diseases and parasitic problems in the study areas are major challenges of sheep production. Sheep and goat pox disease is a common challenge of sheep production across the districts under investigation. It has also been reported (Hassen and Tesfaye ,2014; Getu, 2015) that sheep and goat pox disease was major challenge of sheep production in agro pastoral and pastoral production systems of Afar and other parts of Ethiopia. An earlier report (ILCA, 1990) indicated that up to half of all sheep deaths and morbidity on farms in the Ethiopian highlands are caused by pneumonia and endo-parasites. Vaccinations as disease preventive measure were delivered when disease outbreak occur according to 50 % of the respondents recall. Medicine and vaccination service is given by agricultural offices according to 80 % of the respondents, by private veterinary vendors according to 18 % of the respondents and by none governmental organizations (NGOs) according to 2 % of the respondents. Sheep disease and parasitic problems associated with insufficient veterinary services found by the current study were in line with the report (Urgessa, et al., 2012) for Bacho, Mettu and Darimu Districts of Ilu Abba Bora Zone of the Oromia regional State.

Conclusions

This study aims to describe the sheep production and healthcare practices of smallholders in northwestern Ethiopia. Disease and parasitic infestations and insufficient veterinary services are causes of healthcare problems ranked first challenge of sheep production. Little or no supplementary feed coupled with insufficient pasture land were causes of feed shortage. Smaller flock size makes the sheep populations to serve as both breeding and production units. In addition, small population size, uncontrolled mating (non-random mating) and absence of inclusion of new genetic resources (absence of immigration) were problems encountered in Gumuz sheep. Feed shortages and poor healthcare were major challenges of sheep production. Highly rated educational background (read and write) of respondents is a good opportunity for capacity building (training) of sheep keepers on improving sheep productivity by improving feed supply, preventive healthcare, capital supply and practicing selective breeding of sheep. Among the respondents nearly 50 % of them recalled that vaccination service is delivered when disease outbreak occurs. Thus, medicine, vaccination and drug supply services need to be addressed before disease outbreak since prevention is better than cure.

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Declarations

About the author

Sisay Asmare, is a PhD candidate, working research activities on areas of animal production and animal genetics and breeding. This study was carried out jointly with Professor Kefyalew Alemayehu who published more than 60 research articles in the field of animal genetics and breeding , Dr. Solomon Abegaz kebede who published more than 73 research articles currently works in Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia and Dr. Aynalem Haile , who published more than 181 research articles is a researcher/scientist in International Center for Agricultural Research in the Dry Areas(ICARDA), Addis Ababa, Ethiopia. The information obtained from this study can be used for further establishment of selective breeding, conservation and productivity improvement programs.

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Conflict of interest

We authors declare that we do not have conflict of interest.

Data Availability

The data that support the findings of this study are openly available in “figshare” at .https://figshare.com/s/2bc42d3c7998377bd24a

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Article II. On-farm evaluation of growth and reproductive performances

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Abstract

Growth and reproductive performance traits are traits of economic importance for sheep selection and productivity improvement interventions. This study aimed at on-farm evaluation of growth and reproductive performance of sheep in the highland and lowland agro-ecologies of northwestern Ethiopia. Data on growth performance traits were collected from 144 Washera (78 males and 66 females) lambs and 72 Gumuz (37 males and 35 females) lambs. Data on reproductive performance traits were collected from 260 Washera (130 rams and 130 ewes) sheep and 150 Gumuz (75 rams and 75 ewes) sheep. General linear model univariate procedure was employed to analyze the collected data. Breed(district by default) , the interaction effect between breed and season of birth as well as the interaction effect between breed and type of birth all exerted very high significant effect ($P<0.001$) on live weight at all age groups. Breed type affected pre-weaning average daily weight gain significantly ($P<0.01$). Pre-weaning average daily weight gain of Washera (70 g/day) was found much better performance than 60 g/day of Gumuz. Breed type exerts significant ($P<0.05$) effect on age at first lambing, lambing interval, annual reproductive rate and number of lambs born per ewe life time. Average age at first lambing and lambing interval of Washera sheep were 11.69 months and 9.27 months, respectively. The corresponding values for Gumuz sheep were 12.51 months and 10.43 months, respectively. Production and reproduction performance values of traits varied across the two breeds and sexes as well. These values can be used to set up breeding objectives or goals for selective breeding of sheep giving special emphasis to growth traits believed to have medium heritability values.

Key words: ewe; growth and reproductive performance; lamb; productivity; traits

Introduction

Since domestication, sheep have become essential parts of farms across the world [1] and comprises 16 percent of the total tropical livestock unit (TLU) in sub-Saharan Africa [2]. In part it is because of their ability to adapt to local environments [1]. Small ruminants represent only 7% of the average total capital invested in livestock in the mixed crop-livestock production system, but they account on average for 40 % of the cash income and 19 % of the total value of subsistence food derived from all livestock production [3-4]. Sheep and goats contribute a quarter of the domestic meat consumption; about half of the domestic wool requirements, about 40% of fresh skins and 92% of the value of semi-processed skin and hide export trade. The increased domestic and international demand for Ethiopian sheep and goats has established them as important sources of Inland Revenue as well as foreign currency

[3]. Therefore, integrated attempt with emphasis on prescribing and genetic enhancement is crucial for improving animal output by improving growth and fertility traits [5]. In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous [6]. However, the production of local sheep under traditional production system is low with high mortality of lambs [7]. Because of this the increasing need for food of animal origin has largely been met with increasing number of sheep while productivity per sheep has remained low [8]. Live weight and growth rate are economically critical features, requiring particular attention in any breeding program intended to improve overall productivity since lambs are mainly raised for mutton [7]. Besides, good reproductive performance is a prerequisite for any successful genetic improvement and it determines production efficiency which depends on various factors including age at first lambing, litter size, lambing interval and the life time productivity of the ewe [9-11]. Indigenous sheep breeds are compatible genotypes for the low input traditional production system since indigenous sheep breeds have special adaptive features such as tolerance to a wide range of diseases, water scarcity tolerance and ability to better utilize the limited and poor quality feed resources [12]. Conservation and utilization of these local breeds of sheep is part of animal husbandry and should, ideally, be based on complete information on distribution, structures, and trends, productive and adaptive performances of populations of the existing breeds [13].

Washera and Gumuz indigenous sheep were produced under highland cereal-livestock and lowland crop-livestock sheep production systems, respectively [14]. Morphologically, Washera is a short fat tail, large body size, short-haired, predominantly brown, both males and females are polled reared by Amhara and Agew communities. Washera is a good meat producer under good environment [15]. Gumuz sheep is long thin tail, somewhat dwarf, convex face profile, long pendulous ear, commonly plain brown or with patch coat color, polled and reared by Gumuz and Amhara communities [14]. Gumuz sheep is adapted to heat and have unique genetic make-up [15]. On-farm monitoring involves monitoring the productive and reproductive performance of a breed on selected representative village flocks or herds [16]. An earlier study was conducted on growth performance of Washera sheep in Quarit and Yelmandensa districts of Amhara region, Ethiopia [17]. Nevertheless, most Ethiopian sheep breed types are characterized by high within-population variability, have undergone little selection for improved meat production and true breed potentials are not known [18, 19].

In Ethiopia , researches regarding on-farm performance of indigenous sheep and their crosses with exotic breeds are not well grounded due to the reason that many researchers has tended to focus on-station performance evaluation rather than on-farm condition [20]. Yet, on-farm performance evaluation gives a more representative performance level of the breed since it is undertaken under the natural production environment of the breed [16]. Thus, the objective of this study was to evaluate growth and reproductive performance of Washera and Gumuz indigenous sheep and generate information for further establishment of selective breeding and productivity improvement programs under low input sheep production systems of highlands and lowlands of northwestern Ethiopia.

Materials and Methods

Ethics statement

Earlier to the study, data collection formats and procedures were reviewed and agreed by the research ethics review committee of Debre Markos University, Ethiopia (Ref. number DMU 10/2018 E.C). In addition, target group smallholder farmers provided their verbal informed consent to participate in this study. Besides, the data were analyzed namelessly; ethnicity and religious issues were not asked and recorded during data collection.

Descriptions of the study areas

This study was conducted in two districts, Burie and Mandura considered as potential areas for Washera and Gumuz sheep breed types in North Western Ethiopia. According to altitudinal location, rainfall and crop yields, the agro-ecological zone of Burie is highland and the agro-ecological zone of Mandura is lowland [21].

Sample size and sampling methods

After preliminary survey, two districts Burie and Mandura were selected by purposive sampling method [22] based on Washera and Gumuz sheep production potential. Similarly, two rural peasant associations (Wanegedam and Daez Baguna) were selected from their respective districts. The key informants including the development agents and peasant association administrators were given training to enumerate smallholders engaged in sheep production keeping three sheep or more and how to fill questionnaires.

In the mean time, from a total of 1103 households of Burie district engaged in sheep production, 260 households owning ram and ewe giving birth at commencement of data collection were selected by random sampling method. A total of 260 Washera (130 rams and 130 ewes) sheep were considered for the monitoring of reproductive performance. A total of 144 Washera (78 males and 66 females) lambs were considered for the monitoring of growth performance.

Similarly, from a total of 622 households of Mandura district engaged in sheep production, 150 households owning ewe giving birth at commencement of data collection were selected by random sampling method [22]. A total of 150 Gumuz (75 rams and 75 ewes) sheep were considered for the monitoring of reproductive performance. A total of 72 Gumuz (37 males and 35 females) lambs were considered for monitoring growth performance.

Data collection and animal management

The necessary data on growth and reproductive parameters were collected from sheep flocks managed under mixed - crop livestock farming system of Burie and Mandura districts. Data collection was carried out for two years from September, 2017 to October, 2019 G.C. Smallholders owning rams, ewes and lambs were asked for voluntarily for sparing their sheep and time while recording monitoring data on growth and reproductive performance traits. Live weight measurements were taken five times at the age of day 1, 90 days, 180 days, 270 days and 365 days. Live weight measurements were taken in the mornings, before the animals left the shelter to graze to avoid undesirable variations because of changes in rumen volumes [23, 24]. Lamb weight measurements were taken taking ethical and animal welfare into account. Suspended weighing scale, rope, tripod stick and soil fertilizer bags were purchased from Bahir Dar city general market and were used for measuring live weight of lambs. Concurrently, date of birth, birth weight, type of birth, sex of lamb, season of birth, lambing interval, age at first lambing, age at first mating, number of lambs born during life time of the ewe, reproductive age of the ewe, number of offspring produced, number of offspring weaned and ewe parity were recorded starting from 24 hours of the new born by the recruited enumerators in each respective study site. During the course of data collection, dams and lambs were managed to graze in communal grazing lands and crop aftermaths for an average of eight hour and supplemented with crop residues and *atella* (bi-product of local brewery). Different formulas were used to calculate some parameters.

Annual reproductive rate (ARR) of Washera and Gumuz ewes was calculated by formulae adopted from [27]:

Weight records at various ages were adjusted for actual age using different formulas used by [25, 26].

And average daily weight gain was calculated by the formulas:

Average daily weight gain from birth to weaning (g)

$$= (AWWT(kg) – BWT (kg))/ 90*1000……….(1)$$

Average daily weight gain from weaning to 6 month age (g)

$$= (A6MWT(kg) – AWWT(kg))/ 90*1000…….(2)$$

Average weight gain from 6 month age to 365 days yearling (g)

$$= (AYWT9(kg) – AWWT(kg))/ 275*1000…….(3)$$

Where :

BWT = Birth weight

AWWT = Adjusted weaning weight at 90 days

A6MWT = Adjusted 6 month weight at 180 days

AYWT = Adjusted yearling weight at 365 days

Annual reproductive rate (ARR)

= 365 * average litter size/average days of lambing interval…….(4)

Lamb survival rate was calculated by the formulae adopted from [28]:

Lamb survival rate (%)

= (Number of offspring weaned/ number of offspring produced) *100 ………(5)

Statistical analysis

The data collected on growth and reproductive performance traits were arranged in an excel spread sheet. Ultimately, the data were analyzed using General Linear Model(GLM) univariate procedure of Statistical Package for Social Science for window version 20.0, SPSS (2011) [29] fitting growth rate traits (birth weight, adjusted weaning weight, adjusted 6 month weight, adjusted yearling weight, pre weaning and post weaning average daily weight gain) and reproductive performance traits such as age at first lambing, lambing interval, annual reproductive rate, number of lambs born per ewe life time as dependent variable and non-genetic factors such as district (by default breed), sex of lamb, parity of the dam, season of birth and type of birth as fixed factor(s). Non significant effects of independent variables (non-genetic factors) were not reported. Data analysis of growth and reproductive performance traits were carried out using two different statistical models:

The statistical model for analyzing growth performance was written as follows:

$Y_{ijklmno} = \mu + B_i + S_j + P_k + S_l + T_m + (B_i x S_l)_n + (B_i x T_m)_o + e_{ijklmno}$ …….. .. (mode1 1)

Where :

$Y_{ijklmno}$ = the body weight and average daily weight gain of the *n*th lamb of growing lamb

μ=population mean

D_i= effect of ith District (Burie, Mandura)

S_j = effect of j^{th} sex of lamb (male or female)

P_k= effect of k^{th} parity of the dam (P=first, second, third and fourth)

S_l= effect of lth season of birth (B(*belg*)= short rainy season (March – May), S=cold dry season (September-November), DS = Dry Season (December-February), RS=Rainy Season (June-August)

T_m= effect of m^{th} type of birth (single, twin)

$D_i x S_l$= interaction effect of i^{th} breed and l^{th} season of birth

$D_i x T_m$= interaction effect of i^{th} breed and m^{th} type of birth

$E_{ijklmno}$= error/residual effect

The statistical model for analyzing reproductive performance was written as follows:

$Y_i = \mu + B_i + e_i$………………………………………….. (model 2)

Where:

Y_i= reproductive performance traits (age at first mating of males, age at first mating of females, age at first lambing of females, lambing interval of females, annual reproductive rate of females, number of lambs born per ewe life time of females etc)

U = population mean

B_i = the effect of i^{th} breed (Washera, Gumuz)

E_i= Error/residual effect

Results and Discussion

Growth performance of Washera and Gumuz sheep

Live weight of Washera and Gumuz sheep populations were analyzed for different age groups. Table 1 depicts live weight in kg at different age groups and the effect of factors associated with. Breed type affects pre-weaning average daily weight gain of lambs at very high significant level ($p<0.001$). Pre-weaning average daily weight gain were 70 g/day and 60 g/day for Washera and Gumuz lambs, respectively. There is no significant difference in pre-weaning average body weight gain of lambs across the two sexes. The overall post weaning average daily weight gain of lambs from 6 to 12 months of age was 50 g/day. Parity and season of birth all have very high significant (p<0.001) effect on post weaning average daily weight gain of Washera and Gumuz lambs.

Table 1. Least squares means of birth, weaning, six month, yearling weight and tests of between subject effects

Factors	N	BWT	WWT	6MW	YW
		Mean±SD	Mean± SD	Mean± SD	Mean± SD
District		***	***	***	***
Overall	216	1.98±0.60	8.22±0.11	13.35±1.16	21.33±2.00
Burie	144	2.16±0.54	8.59±0.79	13.94±1.2	21.8±1.91
Mandura	72	1.62±0.55	7.45±1.26	12.16±1.67	20.37±1.85
Sex of lamb		***	Ns	*	*
Male	115	2.19±0.52	8.41±1.09	13.87±1.47	22.08±1.78
Female	101	1.73±0.59	7.99±1.09	12.75±1.56	20.47±1.90
Parity		Ns	Ns	ns	***
1	74	1.78±0.66	7.75±1.14	12.34±1.46	19.67±1.12
2	67	2.15±0.54	8.63±0.79	14.24±1.23	22.9±1.33
3	40	2.08±0.53	8.49±1.13	14.09±1.24	22.98±1.35
4	35	1.94±0.53	8.08±1.16	12.9±1.56	19.9±1.03
Season of birth		Ns	*	**	***
Short rainy season(March – May)	54	2.12±0.53	8.88±0.63	14.07±0.86	21.68±0.93
Rainy Season(June-August)	74	2.08±0.57	8.42±1.10	14.23±1.37	23.36±1.13
Cold dry season (September-November)	32	1.85±0.57	7.75±1.14	12.6±1.62	20.44±0.79
Dry Season (December-February)	65	1.83±0.65	7.77±1.08	12.26±1.43	19.3±1.34
Type of birth		***	*	**	Ns
Single	92	2.48±0.60	8.57±1.15	13.95±1.49	21.74±2.00
Twin	124	1.6±0.60	7.95±1.08	12.89±1.70	21.02±2.00
D_ixS_l	216	***	***	***	***
D_ixT_m	216	***	**	***	***

SD = standard deviation, BWT =birth weight, WWT = weaning weight, 6MW = six month weight, YW = yearling weight, Bi=breed, SL=season of birth, Tm=type of birth, values, $B_i x S_l$= the interaction effect between breed and season of birth , $B_i x T_m$= the interaction effect between breed and type of birth, * =significant at p<0.05, **=significant at p<0.01, ***= very high significant at p<0.001, ns = non significant

Reproductive performance of Washera and Gumuz sheep

Measures of reproduction commonly used in sheep and goats include age at puberty, age at first lambing/kidding, post-partum interval, and parturition interval and fertility indices [10]. Table 2 depicts least squares mean values for some reproductive traits of Washera and Gumuz sheep and the effect of breed/ecotype.

The impact of reproduction on sheep and goat productivity is best estimated by the annual reproductive rate [9]. Studies carried out over periods of several years have shown that the annual reproductive rate (number of young produced per breeding female per year) of African breeds varies from 1.5 to over two lambs [27]. This rate of reproduction results in part from the uncontrolled access of rams to ewes on a permanent basis and in part from the litter size , in that, annual reproductive rate (ARR) is a function of litter size and parturition interval (ARR=Liter size*365/ parturition interval. Annual reproductive rate was 2.12 and 1.71 lambs/ewe/year for Washera and Gumuz sheep, respectively. Annual reproductive rate of Washera (2.12 lambs/ewe/year) and Gumuz (1.71 lambs/ewe/year) was within the range of [27]. Lamb survival rate were 70.7% and 70.1% for Washera and Gumuz sheep, respectively.

Growth performance and the effect of factors

Mean±SD values of birth weight of Washera lamb was close to 2.2±0.04 kg of Wollo highland lambs [30] and 2.4±0.2 kg of Bonga sheep [31] under village management condition. Yearling weight values of Washera and Gumuz sheep were close to 23.7 ± 0.04 kg of Horro sheep [32].

Growth and reproductive performance of indigenous sheep could be improved through improvement of genetics and environment [5]. However, growth and reproductive performance of indigenous sheep was influenced by most of the non-genetic factors [35, 38] and it is thus appropriate to consider the factors affecting their outcome. The current study revealed similar result. For instance, breed, the interaction effect between breed and season of birth and the interaction effect between breed and type of birth all exerted significant effect (P<0.01) on live weight at all age groups. Sex affected live weight at all age groups significantly (P<0.05) except on weaning weight. Type of birth affects birth weight significantly (P<0.05). Larger birth weight was recorded for single born lambs than their twin contemporaries. This is due to the fact that single born lambs have got a better chance of getting good nourishment at the fetal stage. The effects of breed, sex and type of birth on birth weight were in agreement with the view of [7] for Horro and Menz sheep. Season of birth affects weaning weight significantly (P<0.05). Lambs born during rainy season (June-August) and short rainy season (March- May) of the year were found to be heavier than lambs born during cold dry season (September-November) and dry season (December-February). This could be due to feed availability during these seasons for the dam to meet its production requirement for lactation beyond maintenance requirement to suckle the lamb until weaning and to the lamb side to graze on green pasture from weaning onwards. Parity and season of birth were non-genetic factors exerting significant (P<0.001) effect on yearling weight. Larger yearling weight observed during 2nd and 3rd parities. Season of birth affects yearling weight significantly (P<0.001). Lambs born during rainy season (June-August) and short rainy season (March – May) of the year were found to be heavier than lambs born during cold dry season (September-November) and dry season (December-February). This could be due to feed availability during these seasons for the lamb to graze on green pasture. Breed type affected pre-weaning average daily weight gain significantly (P<0.01). The variations in pre-weaning average daily weight gain values of Washera and Gumuz sheep were in line with [19] report suggesting that wide variability exists among Ethiopian small ruminant breeds with respect to potential growth rates and mature weight. Type of birth affected pre-weaning average daily weight gain significantly (P<0.01). A similar view of this result was held by [7] for Horro and Menz sheep. The post-weaning growth rate of Washera sheep was comparable and even better than some other indigenous breeds indicating its potential for meat (mutton) production for the local and export markets [33]. For instance, post-weaning growth rate of Washera sheep found by this study was 60 g/day, which was close to 63.4±4.0 of Bonga sheep [32].

Reproductive performance and the effect of factors

The overall mean±SD value for average age of first mating for females was 6.93±1.54 months (207.9 days). These ewes were early maturing than Djallonké gimmers of Ghana mated when they are 8 months (240 days) old [34]. Litter sizes of Washera (1.62 lambs/birth) and Gumuz (1.43±0.49 lambs/birth) sheep were higher than 1.34 ± 0.01 lambs/birth of Horro sheep [33] in South Western Ethiopia. Litter size values of Washera and Gumuz sheep indicated that these sheep populations were prolific and comparable to other Ethiopian and most African breeds. The overall mean±SD value for lambing interval of this study was 9.69±2.96 months (290.7 days). This lambing interval was longer than 262 ±53.4 days of sheep in South Western part of Ethiopia [35]. However, improving the management practice will make shorter parturition intervals (below 9.69±2.96 months) enabling approximately three lamb crops to be obtained in two years. Annual reproductive rate of Washera ewe (2.12 lambs/ewe/year) was found to be greater than 1.88 ± 0.44 of sheep in South Western part of Ethiopia [35]. Annual reproductive rate (ARR) of Gumuz ewe (1.71lambs/ewe/year) looks closer to 1.88 ± 0.44 of sheep in South Western part of Ethiopia [35]. Annual reproductive rate of Washera and Gumuz sheep managed under smallholder mixed farming system of North Western Ethiopia found to be better performance compared to 1.20 and 1.05 [27] for pastoral and agro-pastoral areas of Ethiopia, respectively. The overall mean±SD value for number of lambs born per ewe life time (LBELT) of Washera and Gumuz sheep was 11.4±4.13 lambs per ewe life time. Lambs born per ewe life time of Washera and Gumuz sheep were less than 12.06 lambs per ewe life time of sheep in pastoral sheep production systems of Ethiopia [36]. Lamb survival rate were 70.7% and 70.1% for Washera and Gumuz sheep, respectively. This comparable value of lamb survival rate of Washera and Gumuz sheep was attributed to similar village management condition of sheep and similar mixed crop-livestock sheep production system to which these indigenous breeds are kept. Lamb survival rate of Washera and Gumuz were higher than 68% of Horro sheep but less than 83% of Menz sheep [37]. Thus, the tendency of pre weaning lamb loss will be higher for Washera, Gumuz and Horro than for Menz sheep. This variation in lamb survival rate between Washera, Gumuz and Menz could be attributed to sheep management system within which these indigenous breeds were kept (on-farm versus on-station). Moreover, the variation could be explained by varied sheep production systems (mixed crop-livestock of Washera and Gumuz versus sheep barley system of Menz sheep).

Tests between subject effects indicated that breed type exerted very high significant ($P<0.001$) effect on age at first mating of males , age at first mating of females and lambs born per ewe life time. The influence of breed type on age at first lambing, lambing interval, and type of birth was significant at $P<0.01$. However, the effect of breed type on average reproductive age of ewes is not significant. Age at first lambing, lambing interval, annual reproductive rate and number of lambs born per ewe life time all vary across the two breed types. The effect of breed type on most reproductive traits of Washera and Gumuz was in line with the earlier report [31] for Bonga sheep in Southern Ethiopia. The opposite view is expressed by [35, 38] report suggesting that district has no influence on age at first lambing, lambing interval, annual reproductive rate and number of lambs born per life time of ewe traditionally managed in the South Western part of Ethiopia and Begayt sheep of northwestern Zone of Tigray Region, in Humera district, Northern part of Ethiopia.

Table 2. Least squares means of reproductive traits and tests of between subject effects

Factors		AFMM	AFMF	AFLE	ALIE	TB	ARAE	LBELT
		Mean± SD	Mean± SD	Mean± SD	Mean± SD	Mean± SD	Mean± SD	Mean± SD
Breed	**N**	***	***	**	**	**	ns	***
Overall	410	11.0±0.2	6.9±1.5	11.9±1.9	9.6±2.9	2.1±1.3	6.6±1.7	11.4±4.1
Washera	260	12.2±0.2	6.5±1.3	11.6±1.9	9.2±3.5	2.4±1.5	6.6±1.8	12.2±4.5
Gumuz	150	9.8±0.5	7.6±1.6	12.5±1.9	10.4±1.2	1.7±0.6	6.7±1.4	9.8±2.7

SD=Standard deviation, AFMM= age at first mating of males, AFMF= age at first mating of females, AFLE= age at first lambing of ewes, ALIE=average lambing interval of ewes, TB=type of birth, ARAE=average reproductive age of ewes, LBELT= lambs born per ewe life time, * =significant at $p<0.05$, **=significant at $p<0.01$, ***= very high significant at $p<0.001$, ns = non significant

Conclusion

This study was aimed at evaluating growth and reproductive performance traits of indigenous sheep breeds under on-farm sheep management conditions of northwestern Ethiopia. Production and reproduction performance values for traits of Washera and Gumuz sheep were comparable to other Ethiopian and African breeds/ecotypes. The variations between minimum and maximum values of growth and reproductive performance traits indicated the presence of within breed variation. The observed variations in values of growth and reproductive performance were essential steps for setting up breeding objectives or goals of sheep breeding program for selection within and among indigenous sheep populations in the highlands and lowlands of northwestern Ethiopia by giving special consideration to growth rate traits believed to have medium heritability values. In the mean time, these values could be used as a valuable input for designing selective breeding or sheep genetic improvement programs.

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Competing interests

We authors declare that we do not have conflict of interest

Availability of data and material

All relevant data are within the manuscript and its Supporting Information files.

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Sisay Asmare. The first draft of the manuscript was written by Sisay Asmare. Kefyalew Alemayehu, Solomon Abegaz K.

and Aynalem Haile supervised the study and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Supporting information captions

S1 data. Data of growth performance
S2 data. Data of reproductive performance

Article III. Body Weight Estimation Formula for Washera and Gumuz Sheep

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Abstract

In Ethiopia, the growing want for foods of animal origin has largely been met with growing number of sheep whilst productivity per sheep has remained low. Genetic improvement of these sheep populations can be brought through selection. For selection to be efficient, the traits preferred must be measurable. Body weight, for instance, is a simple trait to assess because all that is required is a weighing scale. However, weighing scales are unavailable in most smallholder's community and local markets of Ethiopia. There is a need to look for other alternatives to estimate body weights of sheep. The objective of this research was to study the relationship between body weight and linear body measurements and generate body weight estimation formula for Washera and Gumuz sheep in Ethiopia from linear measurements. There is a need to look for other alternatives to estimate body weights of sheep. Data were collected by measuring body weight and taking linear body measurements during the period between January and June of 2018 from full-mouth sheep selected by purposive sampling method. The mean values of morphological features were calculated using descriptive statistics. Average body weights recorded for Washera and Gumuz sheep were 27.5 and 26.89 kg, respectively. Chest girth and body length together were best body weight predictors for Gumuz female sheep at $p<0.001$ level of significance. Tail length, ear length and body length together were best body weight predictors for Gumuz male sheep at $p<0.001$ level of significance. For Washera female sheep, tail length, chest girth, height at withers and body length together were best body weight predictors at $p<0.001$ level of significance. Tail length, chest girth and head length together were best body weight predictors for Washera male sheep at $p<0.001$ level of significance. Body weight of Gumuz and Washera sheep (27.5 kg vs 26.89 kg) were found comparable. Linear body measurements were retained as predictor variables of body weight at $p<0.001$ level of significance for the two sexes of Gumuz and Washera sheep.

Key words: Body weight; Chest girth; Height at withers; Gumuz sheep;Mathematical formula; Tail length;Washera sheep

1. Introduction

Farm animals are regarded as a major means of reducing poverty in the developing world (Joost et al., 2016). Sheep are an extremely vital domestic animals for food security due to their high reproductive capacity and low initial investment, making them ideal for resource-limited farmers such as landless youth and womens' (Abebe et al., 2015; Li et al., 2020). With Ethiopia's growing human population, urbanization, economic development, and domestic and export markets, there is a huge opportunity to increase sheep production using diverse indigenous sheep (Abebe et al., 2015). Among the indigenous sheep populations of Ethiopia, Washera and Gumuz are predominant in Burie and Mandura districts of Amhara Regional State of Ethiopia, respectively (Gizaw et al., 2008). Washera is primarily brown, has a short fat tail, a huge body, and short hair. Both males and females are polled (have no horns) and often reared by both Amhara and Agew communities. Washera is a good meat producer in a favorable environment (Gizaw, 2009). Gumuz sheep are thin-tailed, somewhat dwarf, with a convex face profile and a long pendulous ear, and are polled and reared by Gumuz and Amhara communities (Gizaw et al., 2008). Gumuz sheep are bred for meat and skin production in the lowland and hotter areas of northwestern Ethiopia.

In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous (CSA, 2020). Nevertheless, Tibbo (2006) reported that, the productivity of local sheep is low with high mortality of lambs. Because of this problem the increasing need for food of animal origin has largely been met with a growing number of sheep while productivity per sheep has remained low (FAO, 2015). Gizaw (2009) suggested two ways of improving the performance of sheep and goats. These are improving the environment and/or their genetic potential or genotype. Conventionally three main pathways have been considered for genetic improvement of sheep: selection between breeds, cross breeding and selection within breeds (FAO, 2010). For selection to be effective, the selected traits must be: heritable, variable and measurable. Body weight, for instance, is an easy trait to be measured because all that is needed is a weighing scale (Awgichew and Abegaz, 2008; Mueller et al., 2015). However, weighing scales are unavailable in most smallholder farmers' communities and local markets of Ethiopia. Most sheep producers select breeding animals and sheep for meat consumption based on visual appearance, also known as phenotype (Awgichew, 2007). Visual estimation of body weight by farmers and researchers (for research purpose) might be far from being hundred percent real measurement value of body weight and linear body measurements of sheep. Under such circumstances, smallholder farmers' may pay cash which is not proportional to the real market value of sheep. In addition, for research purposes, taking measurement of body weight was diificult due to lack of fixed weight scales as it was available for cattle in research centers and ranches. In which case biased research data on body weight may be collected. Getachew (2008) reported body weight prediction formulas for Afar and Menz sheep of Ethiopia. Similar works from West Africa and Europe were reported by Birteeb and Ozoje (2012), Sabbioni et al.(2020) and Thys and Hardouin(1991) for

West African Long-Legged and West African Dwarf Sheep, Cornigliese and Poulfouli sheep, respectively. However, such studies were not touched to address Washera and Gumuz sheep in border areas of northwestern Ethiopia. The information obtained by this research will be used as a tool for prediction of body weight for smallholder farmers' communities. Furthermore; the output of this research will be used as an input for further studies and to intervene productivity improvement strategies by policy makers. "Which linear body measurements are best predictor variables of body weight of Gumuz and Washera sheep" is the research question to be addressed. This study, therefore, was carried out to predict body weight of Gumuz and Washera sheep and use it for selection, exchange of sheep in smallholder farmers' communities and local markets in northwestern Ethiopia and to use the research output for further studies.

2. Materials and methods

2.1 Ethics statement

Before conducting the study, data collection formats and procedures were reviewed and agreed by the Research Ethics Review Committee of Debre Markos University, Ethiopia (Ref. number DMU 10/2019). The committee confirmed that this study was to be conducted according to established animal welfare guidelines. In addition, target group smallholder farmers provided their verbal informed consent to participate in this study. Besides, the data were analyzed namelessly; ethnicity and religious issues were not asked and recorded during data collection.

2.2 Description of study area and sheep production environments

This study was conducted in three districts, Mandura, Quara and Burie of Northwestern Ethiopia. Gumuz, Rutana and Washera sheep (Figure 1) are predominant indigenous sheep populations found in Mandura, Quara and Burie districts, respectively. The coordinates of each sheep population were recorded using the Global Positioning System (GPS). Burie is located at 10^0 12' 7.8'' latitude and 37^0 03' 58'' longitudes and at altitude ranging from 1600 to 2000 meters above sea level (Table 1). The rainy season in Burie is from May to September with a monomial pattern and annual rainfall ranging between 1386 – 1757 mm. The long term annual temperature of Burie ranges between 14 ºC to 24 ºC. Mandura is one of the 20 districts in the Benishangul-Gumuz Region of Ethiopia. Geographical coordinates of Mandura district is 10^0 50’ 6’’ latitude and 35^0 33’ 36’’ longitudes and it is located at an altitude of less than 1000 meters above sea level. The minimum average temperature of Mandura district is 28 ^{0}C and it receives annual average rainfall ranging from 900 to 1400 mm. Similarly, the geographical coordinates of Quara district is 12^0 37’ 5’’ latitude and 37^0 28’23’’ longitudes. The district lies at an altitudes ranging between 528 and 654 meters above sea level. The minimum and maximum temperature of Quara district ranges between 26 to 42 ^{o}C and the area receives annual rainfall ranging between 400 and 1200 mm.

The prevailing sheep production systems of Burie and Mandura districts are highland cereal-livestock system and lowland crop-livestock system, respectively (Gizaw et al., 2008a). These systems are also characterized by inadequate health care, smaller land holding often less than two hectares and small sheep flock size. Based on these criteria, Gizaw et al. (2008) described sheep production system of the area as small scale, semi intensive, low input and traditional type. Rutana sheep are found in Benishanguel Gumuz Regional State and the northwestern lowlands of Amhara Regional State of Ethiopia, where they are primarily reared for meat and skin products under arid agro-pastoral production systems (Dagnew et al., 2017; Deribe et al., 2021).

2.3 Sampling strategy and sample size

After enumerating all smallholder farmers engaged in sheep production by key informants, from the three districts, households keeping three or more sheep were selected by purposive sampling method (ILCA, 1990). As suggested by FAO (2012), most quantitative traits are dependent on the age of the animal and the type of production environment in which they are kept. Consequently, it is imperative to sample only adult animals maintained in their typical production environments (FAO, 2012). A total of 200 adult sheep (180 male and 120 female) with a dentition of three pairs of permanent incisors were used for this study.

2.4 Data collection and management

Data were collected through a formal survey during the period spanning between January and June, 2018. The data were generated by measuring the live weights and linear measurements of sheep in the mornings, before the animals left the shelter to graze to avoid undesirable variations because of changes in rumen volumes (FAO, 2012). On the basis of the definitions suggested by FAO (2012) (Table 1), measurements of nine quantitative traits including body weight (BW), tail length (TL), ear length (EL), body length (BL), chest girth (CG), height of withers (HW), rump height (RH), canonical bone length (CBL), and head length (HL) were measured for female sheep. And measurements of ten quantitative traits including body weight (BW), tail length (TL), ear length (EL), body length (BL), chest girth (CG), height at wither (HW), rump height (RH), canonical bone length (CBL), scrotal circumference, and head length (HL) were measured for male sheep with records taken to the nearest centimeters after restraining and holding the animal in an unforced position. Weighing balance of 50 kg and a textile measuring tape were used for collecting data of actual body weight and other linear measurements.

Table 1. Quantitative variables for body measurements

Quantitative variables	Descriptions
Body weight:	The fasted live body weight (in kilograms).
Ear length:	Length (in centimeters) of the external ear from its root on the poll to the tip.
Horn length:	Length of the horn (in centimeters) on its exterior side from its root at the poll to the tip.
Height at withers:	The (vertical) height (in centimeters) from the bottom of the front foot to the highest point of the shoulder between the withers. Measurement
Chest girth:	The circumference of the body (in centimeters) immediately behind the shoulder blades in a vertical plane, perpendicular to the long axis
Body length:	The horizontal distance (in centimeters) from the point of shoulder to the pin bone.
Pelvis width:	The horizontal distance (in centimeters) between the extreme lateral points of the hook bone (tuber coxae) of the pelvis.
Tail length (TL)	It was taken as the distance from the base to the tip of the tail on the outer side of the tail
Rump height (RH)	Height from ground to the spina illiaca (cm).

Source: FAO, 2012; Deribe, 2020

2.5 Data analysis

Descriptive statistics of data obtained from measurement of body weight and linear body measurements were analyzed using SPSS version 24.0(SPSS, 2016) to describe phenotypic characteristics of Washera and Gumuz sheep populations. Similarly, the relationships between morphological features were analyzed following the procedure of bi-variate Pearson correlation and multiple regressions. Regression analysis was conducted separately for the two sexes of full-mouth Washera and Gumuz sheep to select model fits to predict body weight. Best fitted models were selected based on coefficient of determination (R^2). General linear model and stepwise procedure of multiple linear regressions of SPSS version 24.0(SPSS, 2016) was employed. Basic assumptions of regression analysis were checked before final analysis.

The statistical model for linear multiple regression was adopted from Sabbioni et al.(2020) and it is written as follows:

$$Yi = b_0 + b_i x_{i1} + b_2 x_{i2} + \ldots + b_n x_{in} + e$$

Where:

y_i = the dependent variable (body weight in kg)

b_0= the intercept

Xi = are the independent variables; tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length , respectively(cm)

b_n = is regression coefficient of the variable Xi

e_j = the residual random error

3. Results

3.1 Morphological features study for Gumuz and Washera sheep

Table 2 depicts mean values of morphological features and the significance level among the indigenous sheep types or populations. Except for CBL, there was a significant difference in morphological traits between the two sheep types at p< 0.05.

Table 2. Number of observations, overall mean, CV, significant level and least square means (±SE) of body weight and linear body measurement of short Washera and Gumuz sheep breeds/types

Morpho metric traits	Overall			Sheep populations				P-value
				Washera		Gumuz		
	N	LSM±SE	CV	N	LSM±S	N	LSM±SE SE	
BW	200	28.44±0.	18.2	100	27.5±0.	100	26.89±0.25	P<0.01
TL	200	26.17±0.	37.0	100	21.86±0	100	25.72±0.24	P<0.001
EL	200	11.55±0.	16.6	100	11.91±0	100	10.22±0.06	P<0.01
BL	200	55.42±0.	9.45	100	53.8±0.	100	57.58±0.32	P<0.001
CG	200	72.04±0.	10.4	100	71.48±0	100	70.04±0.47	P<0.01
HW	200	64.73±0.	7.84	100	65.79±0	100	61.85±0.27	P<0.001
RH	200	67.97±0.	6.31	100	67.46±0	100	66.8±0.18	P<0.01
CBL	200	14.63±0.	7.22	100	14.55±0	100	14.74±0.04	P<0.05
HL	200	19.42±0.	6.89	100	19.67±0	100	18.72±0.05	P<0.01

LSM= Least Square Mean, SE=standard error, CV=coefficient of variation, BW=body weight, TL=tail length, EL=ear length, BL=body length, CG=chest girth, HW=height at wither, RH=rump height, CBL= canonical bone length, HL=head length

3.2 The relationship between morphological features of Gumuz female sheep

Bivariate Pearson correlation between morphological features and regression coefficient of Gumuz female sheep was presented in Table 3 and Table 4. A multiple linear regression was fitted to explain body weight based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length. Model two explains 55.0% variation (R^2 = 0.55) of body weight, and it is significantly useful in explaining body weight, p < 0.001. All two variables added statistically significantly to the prediction, p <0.05. With one-unit increase in chest girth, the body weight increases by 0.26, which was found to be a significant change, p < 0.001. With one- unit increase in body length, the body weight increases by 0.27, which was found to be a significant change, p < 0.001.

Table 3. Bivariate Pearson correlation between morphological markers of Gumuz female sheep

	BW	TL	EL	BL	CG	HW	RH	CBL	HL
BW	1.000	.158	.159	.454	.580	.321	.239	.105	.029
TL	.158	1.000	.134	.080	.157	.003	.118	.015	.094
EL	.159	.134	1.000	.289	.210	.065	.297	.112	.149
BL	.454	.080	.289	1.000	.368	.276	.011	-.102	.064
CG	.580	.157	.210	.368	1.000	.440	-.069	-.036	.001
HW	.321	.003	.065	.276	.440	1.000	-.211	.020	-.123
RH	.239	.118	.297	.011	-.069	-.211	1.000	.124	.560
CBL	.105	.015	.112	-.102	-.036	.020	.124	1.000	-.033
HL	.029	.094	.149	.064	.001	-.123	.560	-.033	1.000

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length, HL=Head Length,*= P<0.05, **= P<0.001

Table 4. Regression coefficient for adult Gumuz female sheep

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta	T	Sig.	Lower Bound	Upper bound	Tolerance	VIF
1	(Constant)	3.876	2.335		1.66	0.099	-0.728	8.481		
	CG	0.325	0.032	0.58	10.16	0.000	0.262	0.388	1	1
2	(Constant)	-7.664	3.281		-2.336	0.02	-14.134	-1.194		
	CG	0.268	0.033	0.477	8.181	0.000	0.203	0.332	0.865	1.15
	BL	0.276	0.058	0.279	4.775	0.000	0.162	0.389	0.865	1.15

a. Dependent Variable: BW

BW=Body Weight, BL=Body Length, CG=Chest Girth, VIF= Variant Inflation Factor*= P<0.05, **= P<0.001

3.3 The relationship between morphological features of Gumuz male sheep

Bivariate Pearson correlation between morphological features and regression coefficient of Gumuz male sheep was presented in Table 5 and Table 6. A multiple linear regression was fitted to explain body weight based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , head length and scrotal circumference. Model three explains 62.0% variation (R^2 = =0.62) of body weight, and it is significantly useful in explaining body weight, p < 0.001. All three variables added statistically significantly to the prediction, p<0.05. With one- unit increase in tail length, the body weight increases by 0.57, which was found to be a significant change, p < 0.001. With one-unit increase in ear length, the body weight increases by 1.03, which was found to be a significant change, p < 0.001. With one- unit increase in body length, the body weight increases by 0.17, which was found to be a significant change, p < 0.01.

Table 5. Pearson correlations coefficient between body weight and linear measurements of adult Gumuz male sheep

	BW	TL	EL	BL	CG	RH	CBL	SC	HL
BW	1	0.703	0.52	0.535	0.554	0.203	0.203	0.15	0.096
TL	0.703	1	0.293	0.398	0.52	0.206	0.206	0.037	0.079
EL	0.52	0.293	1	0.483	0.362	-0.031	-0.031	-0.017	0.027
BL	0.535	0.398	0.483	1	0.554	0.163	0.163	0.05	0.137
CG	0.554	0.52	0.362	0.554	1	0.182	0.182	0.001	0.085
RH	0.203	0.206	-0.031	0.163	0.182	1	1	-0.059	-0.068
CBL	0.203	0.206	-0.031	0.163	0.182	1	1	-0.059	-0.068
SC	0.15	0.037	-0.017	0.05	0.001	-0.059	-0.059	1	-0.097
HL	0.096	0.079	0.027	0.137	0.085	-0.068	-0.068	-0.097	1

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length, Scrotal Circumference, HL=Head Length,*= P<0.05, **= P<0.001

Table 6. Regression coefficient for adult Gumuz male sheep

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	T	Sig.	Tolerance	VIF
1	(Constant)	7.352	1.541		4.772	0.000		
	TL	0.738	0.059	0.703	12.415	0.000	1	1
2	(Constant)	-3.479	2.151		-1.617	0.108		
	TL	0.632	0.055	0.602	11.431	0.000	0.914	1.094
	EL	1.323	0.203	0.344	6.531	0.000	0.914	1.094
3	(Constant)	-8.632	2.655		-3.251	0.001		
	TL	0.577	0.057	0.55	10.217	0.000	0.828	1.208
	EL	1.038	0.217	0.27	4.786	0.000	0.755	1.325
	BL	0.168	0.053	0.185	3.152	0.002	0.695	1.44
4	(Constant)	-16.475	3.978		-4.142	0.000		
	TL	0.574	0.056	0.547	10.338	0.000	0.828	1.208
	EL	1.065	0.213	0.277	4.997	0.000	0.753	1.328
	BL	0.16	0.052	0.177	3.061	0.003	0.693	1.444
	SC	0.287	0.11	0.126	2.611	0.01	0.995	1.005
a. Dependent Variable: BW								

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length, Scrotal Circumference, HL=Head Length, VIF=Variant Inflation Factor*= P<0.05, **= P<0.001

3.4 The relationship between morphological features of Washera female sheep

Bivariate Pearson correlation between morphological features and regression coefficient of Washera female sheep was presented in Table 7 and Table 8. A multiple linear regression was fitted to explain body weight based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length. Model four explains 54% variation ($R^2 = 0.54$) of body weight, and it is significantly useful in explaining body weight, $p < 0.001$. All four variables added statistically significantly to the prediction, $p < 0.05$. With one-unit increase in tail length, the body weight increases by 0.31, which was found to be a significant change, $p < 0.001$. With one-unit increase in height at wither, the body weight increases by 0.20, which was found to be a significant change, $p < 0.001$. With one-unit increase in body length, the body weight increases by 0.11, which was found to be a significant change, $p < 0.01$. With one- unit increase in chest girth, the body weight increases by 0.10, which was found to be a significant change, $p < 0.01$.

Table 7. Pearson correlations coefficient between body weight and linear measurements of adult Washera female sheep

	BW	TL	EL	BL	CG	HW	RH	CBL	HL
BW	1	0.596	-0.003	0.388	0.323	0.33	0.215	0.263	0.086
TL	0.596	1	0.003	0.439	0.194	0.193	0.115	0.19	-0.085
EL	-0.003	0.003	1	0.234	-0.057	-0.131	0.028	0.197	0.029
BL	0.388	0.439	0.234	1	0.137	0.011	0.009	0.328	-0.071
CG	0.323	0.194	-0.057	0.137	1	0.363	0.354	0.203	-0.075
HW	0.33	0.193	-0.131	0.011	0.363	1	0.504	0.127	-0.144
RH	0.215	0.115	0.028	0.009	0.354	0.504	1	0.287	0.056
CBL	0.263	0.19	0.197	0.328	0.203	0.127	0.287	1	-0.047
HL	-0.086	-0.085	0.029	-0.071	-0.075	-0.144	0.056	-0.047	1

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length, HL=Head Length,*= P<0.05, **= P<0.001

3.5 The relationship between morphological features of Washera male sheep

Bivariate Pearson correlation between morphological features and regression coefficient of Gumuz male sheep was presented in Table 9 and Table 10. A multiple linear regression was fitted to explain body weight based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , head length and scrotal circumference. Model three explains 86.8% variation of body weight, and it is significantly useful in explaining body weight, $p < 0.001$. All three variables added statistically significantly to the prediction, $p < 0.05$. With one- unit increase in tail length, the body weight increases by 0.82, which was found to be a significant change, $p < 0.001$. With one- unit increase in chest girth, the body weight increases by 0.92, which was found to be a significant change, $p < 0.001$. With one- unit increase in head length, the body weight increases by 0.38, which was found to be a significant change, $p < 0.001$.

Table 8. Regression coefficient for adult Washera female sheep

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	17.637	0.817		21.6	0.000		
	TL	0.406	0.032	0.596	12.509	0.000	1	1
2	(Constant)	2.302	3.301		0.697	0.486		
	TL	0.376	0.032	0.553	11.818	0.000	0.963	1.039
	HW	0.241	0.05	0.224	4.783	0.000	0.963	1.039
3	(Constant)	-4.515	3.766		-1.199	0.232		
	TL	0.321	0.035	0.472	9.216	0.000	0.772	1.296
	HW	0.256	0.05	0.237	5.157	0.000	0.956	1.046
	BL	0.127	0.036	0.178	3.537	0.000	0.801	1.248
4	(Constant)	-7.522	3.851		-1.953	0.052		
	TL	0.313	0.035	0.46	9.069	0.000	0.766	1.305
	HW	0.202	0.052	0.188	3.884	0.000	0.843	1.187
	BL	0.118	0.036	0.164	3.297	0.001	0.794	1.259
	CG	0.1	0.034	0.144	2.972	0.003	0.845	1.183
a. Dependent Variable: BW								

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length,*= P<0.05, **= P<0.001

3.6 Regression formulas to predict body weights of sheep

A multiple regression was run to predict live weight of Gumuz sheep from tail length, ear length, body length, chest girth, height at wither, rump height, canonical bone length, scrotal circumference (for males) and head length. Chest girth and body length were found to be best predictor variables of body weight for Gumuz female sheep. Tail length, ear length and body length were found to be best predictor variables of body weight for Gumuz male sheep.

Similarily, a multiple regression was run to predict live weight of Washera sheep from tail length, ear length, body length, chest girth, height at wither, rump height, canonical bone length, scrotal circumference (for males) and head length. Tail length, body length, chest girth and height at wither were found to be best predictor variables of body weight for Washera female sheep. Tail length, head length, and chest girth were found to be best predictor variables of body weight for Washera male sheep.

Table 9. Pearson correlations coefficient between body weight and linear measurements of adult Washera male sheep

	BW	TL	EL	BL	CG	HW	RH	CBL	SC	HL
BW	1	0.834	0.578	0.786	0.525	0.815	0.821	0.831	0.244	0.711
TL	0.834	1	0.584	-0.629	0.157	0.616	0.605	0.662	0.317	0.513
EL	0.578	0.584	1	-0.601	0.377	0.593	0.578	0.633	0.164	0.554
BL	0.786	-0.629	-0.601	1	-0.716	-0.853	-0.865	-0.95	-0.113	-0.736
CG	0.525	0.157	0.377	-0.716	1	0.843	0.88	0.757	-0.056	0.586
HW	0.815	0.616	0.593	-0.853	0.843	1	0.974	0.901	0.115	0.698
RH	0.821	0.605	0.578	-0.865	0.88	0.974	1	0.913	0.109	0.707
CBL	0.831	0.662	0.633	-0.95	0.757	0.901	0.913	1	0.119	0.775
SC	0.244	0.317	0.164	-0.113	-0.056	0.115	0.109	0.119	1	0.168
HL	0.711	0.513	0.554	-0.736	0.586	0.698	0.707	0.775	0.168	1

BW=Body Weight, TL=Tail Length, EL=Ear Length, BL=Body Length, CG=Chest Girth, HW=Height at Wither, RH=Rump Height, CBL= Canonical Bone Length, Scrotal Circumference, HL=Head Length,*= P<0.05, **= P<0.001

Table 10. Regression coefficient for adult Washera male sheep

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	T	Sig.	Tolerance	VIF
1	(Constant)	8.935	0.848		10.539	0.000		
	TL	0.986	0.046	0.834	21.661	0.000	1	1
2	(Constant)	-66.413	5.052		-13.146	0.000		
	TL	0.911	0.032	0.77	28.576	0.000	0.975	1.025
	CG	1.175	0.078	0.405	15.016	0.000	0.975	1.025
3	(Constant)	-56.042	5.363		-10.45	0.000		
	TL	0.827	0.036	0.699	23.043	0.000	0.705	1.418
	CG	0.927	0.093	0.319	9.929	0.000	0.628	1.592
	HL	0.381	0.085	0.165	4.464	0.000	0.474	2.108
4	(Constant)	-58.455	5.416		-10.793	0.000		
	TL	0.867	0.04	0.733	21.826	0.000	0.564	1.773
	CG	0.966	0.094	0.333	10.274	0.000	0.606	1.649
	HL	0.42	0.086	0.182	4.872	0.000	0.455	2.198
	EL	-0.146	0.065	-0.077	-2.261	0.025	0.551	1.814
a. Dependent Variable: BW								

BW=Body Weight, TL=tail length, EL=Ear Length, CG=chest girth, HL=head length, VIF=Variant Inflation FActor*$_=$ P<0.05, **$_=$ P<0.001

Accordingly, the following formulas were proposed for body weight prediction:

BW = -7.66+ 0.26*CG + 0.27* BL ----- formula 1 (for Gumuz female sheep)

BW = -8.63 + 0.57*TL + 1.03* EL + 0.16*BL----- formula 2 (for Gumuz male sheep)

BW = -7.52 + 0.31*TL + 0.3*HW +0.11* BL+0.1*CG ----- formula 3 (for Washera female sheep)

BW = -56+ 0.82 *TL +0.92 *CG +0.38*HL ----- formula 4(for Washera male sheep)

4. Discussion

Because of their strong correlations with production traits such as meat and milk production, traits such as body weight, chest girth, body length and height at withers are used as proxy indicators of the production traits (FAO, 2012. Live weight and growth rate are economically critical features, requiring particular attention in any breeding program intended to improve overall productivity since lambs are mainly raised for mutton (Abegaz, 2014). Body weights recorded for Washera and Gumuz sheep by the current study were far below 40 to 50 kg (Awgchew and Abegaz, 2008) of the average, traditionally maintained mature Awassi ewe. However, according to Ayele and Urge (2019), even slaughter body weight of Washera can be improved up to 52 kg by various types of supplementation.

Mature body weights of Washera and Gumuz sheep obtained by the current study were less than from 32.8 kg and 31.0 kg, respectively reported earlier by Gizaw *et al*.(2007) for the same breeds. The decrease in body weight of the current study could be attributed to lower intake of feed due to shrinking pasture land for grazing as a result of increasing urbanization and population growth. Tail length recoreded by the current study were 39.46 cm and 39.92 cm for females and males of Gumuz sheep, respectively. These mean values were comparable to 38.7 cm (Deribe et al., 2021) for the same sheep breed. A variation in phenotypic measurements was also observed in body weight of Gumuz sheep. In that, body weight of Washera and Gumuz sheep populations recorded by the current study were less than 35.9 kg (Deribe et al., 2021) in northwestern low lands of Amhara Regional State of Ethiopia. This variation in phenotypic performance could be attributed to the effect of environmental factors among which feeding and feed resource availability is the most important varying between Mandura district and Metema districts. Sesame and sesame by-products were available in and around Metema districts of northwestern lowlands while not available in Mandura district of Benishanguel Gumuz Regional State of Ethiopia.

When selecting the ideal slaughter time for a breed of sheep raised for meat, body weight estimation is crucial. (Sabbioni et al., 2020). Mathematical formula generated by the current study to predict body weight was performed by using the highest number of linear body measurements ranging from two to four. This is in accord to Sabbioni et al.(2020). According to Sabbioni et al.(2020), the best model fits were obtained when the highest number of body measurements of Cornigliese sheep breed was included in the model. The retention of heart girth as predictor variable of body weight for Gumuz female, Washera male and female sheep by this study was in accord to Getachew (2008), selecting chest girth as a predictor variable of body weight for Afar and Menz sheep in Ethiopia. Similarly, Thys and Hardouin (1991) reported heart girth as prediction variable of body weight for Poulfouli sheep. Selection of chest girth as a predictor variable of body weight by the current study was also in agreement to Birteeb and Ozoje (2012). Birteeb and Ozoje (2012) compared both linear and quadratic models for predicting body weight and they stated that among the linear body measurement traits, heart girth was the best predictor of live weight irrespective of the breed or age of the West African long-legged and West African Dwarf sheep in northern Ghana.

5. Conclusion

Body weight of Gumuz and Washera sheep were found comparable. However, in rural communities and local markets of Ethiopia most sheep producers select breeding animals and sheep for meat consumption based on visual appraisal. In addition, body weight measurement for research purposes is difficult due to lack of fixed weighing scale. The visual estimation of live body weight of sheep might be far from real body weight. To address this constraint, we generate a formula to predict body weight of both Washera and Gumuz sheep for the two sexes independently. Linear body measurements were retained as predictor variables of body weight at $p<0.001$ level of significance for the two sexes of Gumuz and Washera sheep. Regression formula generated by linear multiple regression analysis of this study could be used to predict body weight of Gumuz and Washera sheep using a simple textile meter where weighing scales are unavailable in rural communities , local markets and research communities of Ethiopia.

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Article IV. Genetic diversity and within-breed variation in sheep

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Abstract

The objective of this work was to study genetic diversity based on whole genome sequence data of Rutana, Gumuz and Washera sheep found in Amhara and Benishanguel gumuz regional states of Ethiopia. We employed variant calling format tools version 0.1.15 to calculate some genetic diversity indices such as observed heterozygosity, expected heterozygosity, inbreeding coefficient, and nucleotide diversity. The results revealed that, observed heterozygosity ranged from 0.33 in Gumuz to 0.34 in Rutana and Washera sheep. Expected heterozygosity ranged from 0.37 in Rutana to 0.38 in Gumuz and Washera sheep. Expected heterozygosity was found to be higher than observed heterozygosity. Higher inbreeding coefficient (0.12) was recorded for Gumuz sheep compared to 0.09 of Rutana and Washera sheep. This higher inbreeding coefficient in gumuz sheep could be attributed to non-random mating due to small population size, closed population (no immigration) and uncontrolled mating. Mean nucleotide diversity values were 0.0029, 0.0030 and 0.0028 for Gumuz, Rutana and Washera sheep, respectively. Higher values of nucleotide diversity were recorded for Rutana sheep. Population structure analysis using principal component analysis revealed no clear separation between Gumuz, Rutana and Washera sheep populations with possibility of gene flow attributed to geographical location proximity. The smaller population size, closed breeding system, genetic drift and uncontrolled (non-random) mating might lead to higher rate of inbreeding in Gumuz, Rutana and Washera sheep, requiring timely intervention. This intervention helps to prevent inbreeding depression and extinction of these valuable breeds of sheep, which helps in sustaining the livelihood of sheep keepers in lowlands and highlands. Nevertheless, the whole- genome analysis revealed high within- breed variation. Uncovered areas of studies like mapping quantitative trait loci, identifying genes underpinning productivity traits such as carcass quantity and meat quality could be carried out on diversified sheep resources identified by the current study. Identifying the genomic regions and biological pathways that contribute to explaining variability in these traits is of great importance for selection purposes. The information obtained will be used as an input for designing sheep selective breeding programs for breeds with high rate of inbreeding and for managing the genetic diversity.

Key words: conservation; inbreeding; selection; sheep; whole - genome genotyping

1. Introduction

Farm animals are regarded as a major means of avoiding poverty in the developing world [1]. Sheep are an extremely important livestock species for food security due to their high reproductive capacity and low initial investment, making them ideal for resource-limited farmers such as landless youth and women [2-3]. With Ethiopia's growing human population, urbanization, economic development, and domestic and export markets, there is a huge opportunity to increase sheep production using diverse indigenous sheep [2]. The first step in conserving and exploiting these diverse sheep populations is obtaining a thorough understanding of the genetic diversity that exists [4-5]. The ability to select superior animals for breeding is enabled by the presence of genetic diversity. If there is no genetic diversity, i.e. if all animals are genetically related, selection will not result in an improvement in the next generation [6].

Among the indigenous sheep populations of Ethiopia, Washera and Gumuz were predominant in Burie and Mandura districts of Amhara regional state of Ethiopia, respectively [7]. Washera has a short fat tail, a large body size, short hair, and is predominantly brown. Both males and females are polled and are kept by Amhara and Agew communities. Washera is a good meat producer in a favorable environment [8]. Gumuz sheep are thin-tailed, somewhat dwarf, with a convex face profile and a long pendulous ear, and are polled and reared by Gumuz and Amhara communities [7]. Gumuz sheep were bred for meat and skin production in lowland and hotter areas of northwestern Ethiopia. The prolific and large-sized Rutana sheep were found in Benishanguel Gumuz regional state and the northwestern lowlands of Amhara regional state of Ethiopia, where they were primarily reared for meat and skin under arid agro-pastoral production systems [9-10].

Genetic diversity among organisms is measured as a result of changes in DNA sequences and environmental factors [11]. Basic genetic diversity analysis deals with different types of variables or parameters. Some of them are intra-population genetic diversity, inter-population genetic diversity, and diversity and differentiation at the nucleotide level. Molecular markers found to be suitable for marking such variability. A molecular marker, also known as a DNA marker, is a segment of DNA that indicates mutations or variations and can be used to detect polymorphism (base deletion, insertion, and substitution) between different genotypes or alleles of a gene in a specific population or gene pool [12-13]. Single nucleotide polymorphism (SNPs) is becoming especially important as markers. Because they are very stable, i.e. have very low mutation rates and they can be amplified with PCR for testing. SNP studies have recently been proposed in population genetics to investigate for adaptive evolution imprints. A single nucleotide polymorphism is a difference in DNA sequence caused by a nucleotide substitution at a specific site in the genome [14]. Because of their prevalence in any organism's genome (coding and non-coding regions), and capacity to uncover hidden polymorphism that is not typically identified by other genetic markers and methodologies, these types of markers are becoming increasingly appealing in molecular marker development [15]. SNPs account for more than 90% of all differences between people, making them a valuable genetic variation resource for population studies and genome mapping [16]. Other genomics technologies applied to diversified sheep populations include candidate gene approach. According to [17], the candidate gene approach investigates the association between phenotypes and known genes that may be involved in the physiological pathways that underpin the trait. In other words, this approach assumes that a gene involved in the physiology of the trait could harbor a mutation causing variation in the trait. SNPs and whole-genome sequence data are among the cutting-edge molecular and genomic technologies used to study genetic variability of sheep. This broadens the options for determining breed ancestry, variability, and genetic value of specific markers and candidate genes for adaptation, genomic selection, and production enhancement [18]. [19] reported that the use of 22 microsatellite data to characterize eastern Ethiopia sheep revealed significant genetic variation within ten subpopulations, which was linked to their inherent breeding practice. Genomic data of some of Ethiopian sheep groups (Gumuz and Rutana sheep not included in the study) were analyzed using medium density SNP bead chips. The genetic variation between these sheep groups was attributed to variations within and among populations [20-22]. Despite the advancement of whole-genome sequencing technology, little research has been done on diversity studies of Gumuz, Rutana and Washera sheep populations based on whole-genome sequence data. To this end, whole-genome sequencing and genotyping enable the identification of a large number of single-nucleotide polymorphisms (SNP). The large number of SNPs allows for unprecedented accuracy in describing individual and breeds relationships and has the potential to supplement or substitute pedigree data when there are no pedigree records or are insufficient [23]. Whole-genome sequence data allows us to obtain comprehensive dataset to investigate the phenotypic and genetic variability, recommending conservation priority and proposing appropriate selective breeding strategies. This study, therefore, was carried out to investigate genetic diversity of three sheep populations in Ethiopia using whole-genome analysis.

2. Materials and methods

2.1 Ethics statement

Earlier to the study, data collection formats and procedures were reviewed and agreed by the research ethics review committee of Debre Markos University, Ethiopia (Ref. number DMU 10/2019). The committee confirmed that these experiments were conducted according to established animal welfare guidelines. In addition, target group small holder farmers provided their verbal informed consent to participate in this study. Besides, the data were analyzed anonymously; ethnicity and religious issues were not asked or recorded during data collection.

2.2 Description of study area and sheep production environments

This study was conducted in three districts, Mandura, Quara and Burie of North Western Ethiopia. Gumuz, Rutana and Washera sheep (Figure 1) were predominant indigenous sheep populations found in Mandura, Quara and Burie districts, respectively. The coordinates of each sheep population were recorded using the Global Positioning System (GPS). Burie is located at 10^0 12’ 7.8’’ latitude and 37^0 03’ 58’’ longitudes and at an altitude of 1600-2000 meter above sea level (Table 1). The rainy season in Burie is from May to September with a monomial pattern and annual rainfall of 1386 – 1757 mm. The long term annual temperature of Burie ranges from 14 ºC to 24 ºC. Mandura is one of the 20 districts in the Benishangul-Gumuz Region of Ethiopia. Geographical coordinates of Mandura district is 10^0 50’ 6’’ latitude and 35^0 33’ 36’’ longitudes and it is located at an altitude of less than 1000 meter above sea level. The minimum temperature of Mandura district was 28 ^{0}C and it receives 900-1400 mm annual rainfall. Similarly, geographical coordinates of Quara district is 12^{0} 37’ 5’’ latitude and 37^{0} 28’23’’ longitudes and is located at an altitude of 528 to 654 meter above sea level. The minimum and maximum temperature of Quara district was 26-42 ^{o}C and it receives 400-1200 mm annual rainfall.

Washera is a short fat tail, large body size, short-haired sheep, predominantly brown coat color, both males and females are polled reared by Amhara and Agew communities. Washera is a good meat producer under good environment [8]. Gumuz sheep is long thin tail, somewhat dwarf, convex face profile, long pendulous ear, commonly plain brown or with patch, polled and reared by Gumuz and Amhara communities [7]. Gumuz sheep are heat-adapted and have a unique genetic make-up to thrive in lowland and hotter areas reared for meat and skin production[8]. The prevailing sheep production systems of Burie and Mandura districts were highland cereal-livestock system and lowland crop-livestock system, respectively [7]. These systems are also characterized by inadequate health care, smaller land holding often less than two hectares and small sheep flock size. Based on these criteria, [7] described the scale of sheep production system as small scale, semi intensive, low input and traditional type. Rutana sheep were found in Benishanguel Gumuz regional state and the northwestern lowlands of Amhara regional state of Ethiopia, where they were primarily reared for meat and skin products under arid agro-pastoral production systems [9-10].

2.3 Sampling

Average flock size of 310 Gumuz, 180 Rutana and 550 Washera sheep were considered for this study in three districts selected purposively. A total of 45 Ethiopian indigenous sheep from three diverse indigenous breeds were selected by purposive sampling method. Whole blood samples were collected from Gumuz and Rutana sheep distributed in moist lowlands and Washera in wet, warmer mid-highland environments of northwestern Ethiopia. Table 1 depicts the phenotypic characteristics and ecology of sheep populations under study. The samples were collected from different households with each sheep were as unrelated as possible considering the pedigree relationships information obtained from sheep owners according to the recommendations of [23]. From each sheep, 5 ml whole blood was collected from jugular vein and stored in a tube that contained 1 ml preservative and anti-coagulant ethylene diamine tetraacetic acid (EDTA k+). The sample tube was identified with a permanent marker and the sampling form was filled at the time of sampling. The collected whole blood was refrigerated at -20 ^{o}c immediately after collection until DNA isolation. DNA was extracted from blood using the Quick-start protocol QIAGEN kit user manual QIAGEN-DNeasy QIAGEN Group, 2011, according to the manufacturer's instructions. The quality and quantity of DNA were evaluated using Nano Drop spectrophotometer and agarose gel electrophoresis. A total of 30 DNA samples were selected with greater DNA integrity for sequencing.

Washera sheep Gumuz sheep Rutana sheep

Figure 1. Indigenous sheep populations under study

Table 1. Agro-ecological distribution of sheep and their phenotypic features

Sheep populations	Agro-ecology	Geographic distribution	Phenotypic feature	Production system	Purpose of keeping sheep	Reference
Gumuz	Moist lowlands (< 1 000 m.a.s.l)	Benishangul-gumuz regional state; lowlands of Amhara regional state	Long thin tail; dwarf; convex face profile; commonly plain brown or with patch coat pattern	Lowland crop-livestock system	Meat; Skin, manure	Gizaw et al., 2008
Rutana	528 to 654 m.a.s.l	Lowlands of Metema and Quara districts of Amhara regional state	Long thin tailed; long legged	arid pastoral system	Meat; Skin, manure	Gizaw 2009; Dagnew et al.,2017
Washera	Wet, warmer mid-highlands (1600-2000 m.a.s.l)	West and East Gojam and Agew Awi zones of Amhara regional state; Dangur, madura and Alefa Takusa districts	Short fat tail; large body size; short-haired; predominantly brown;	Highland cereal-livestock system	Meat; Skin, manure	Gizaw et al.,2008

2.4 SNP genotyping , read mapping and variant calling

After evaluating the quality of our FASTQ data and quality filtration of the raw FASTQ files (http://www.bioinformatics.babraham.ac.uk/projects/fastqc/), low-quality reads were trimmed using trimmomatic software version 0.36 [24]. The Burrows–Wheeler Aligner (BWA) [25] alignment tool was applied for alignment of RAW reads to the Oar_v3.1 reference genome (Ensemble AssemblyaccessionnumberGCA_000298735.1)http://www.ensembl.org/Ovis_aries_rambouillet/Info/Strains?db=core). Only paired-end reads were used in the alignment step. Picard-tools, Version 2.22.8 (http://broadinstitute.github.io/picard/) was employed for sorting the aligned reads to the Binary Alignment MAP (BAM) files.

Polymerase chain reaction (PCR) duplicates are marked with a certain tag using an algorithm (Mark Duplicates) available in the Picard-tools version 2.22.8. Picard-tools, v 2.22.8 (http://broadinstitute.github.io/picard/) was also employed for indexing the BAM file and for performing Add or Replace Read Groups step to the BAM files (https://github.com/broadinstitute/picard). The sequencing machine's raw scores are prone to technical errors, resulting in over- or under-estimated base quality scores. To address this issue, base quality score recalibration (BQSR) empirically models these errors and re-adjusts the base quality scores accordingly [26]. Base quality scores were generated and readjusted by performing the recalibration table and printing the recalibrated reads using GATK-Base Recalibrator, v 4.1.7.0. We then applied the Best Practices of Genome Analysis Toolkit (GATK) v 4.1.7.0 workflow from the Broad Institute to perform variant discovery (https://software.broadinstitute.org/gatk/best-practices) using GATK- Haplotype Caller (GATK v 4.1.7.0 and comparing the aligned reads to reference genome. GATK-Genotype GVCFs, Version 4.1.7.0 was used for joint- genotyping the variants. Variant quality score recalibration (VQSR) was performed using gatk Variant Recalibrator v 4.1.7.0.

2.5 Quality control, joint – genotyping and selecting variants

Three-stage quality control strategies including quality control of the raw data using FastQC, alignment quality control involving trimming of low quality reads using trimmomatic and quality control on variant calling were performed as implemented by [27]. SNPs associated with all individuals were identified and filtered using PLINK v.1.9 [28] following the specified standards [29]. Accordingly, quality control of SNP data applied the following criteria: (1) Minor allele frequency (MAF) > 0.01 within the breeds; (2) SNPs with a call rate > 0.90; (3) Missing genotyping frequency < 0.02; (4) p-value for Hardy-Weinberg equilibrium > 0.000001; and (5) only autosomal SNPs with known positions were used. The GATK v 4.1.7.0 Combine GVCFs and Joint-Genotype GVCFs commands were employed to combine and genotype raw variants, respectively. The command select variants were used to select SNP and INDEL in autosome using GATK v 4.1.7.0. The final dataset after QC filtering comprises of 29,103,927 autosomal SNPs and 15 animals.

2.6 Calculating mean values of genetic diversity parameters

Within breed genomic diversity including observed heterozygosity (H_O), expected heterozygosity (H_E), inbreeding coefficient, polymorphic SNP (polymorphic information content) and nucleotide diversity (π) were analyzed by employing vcftools v 0.1.15 software. For each parameter, different bioinformatics scripts or commands were used. Similarly, mean and standard deviations of the observed heterozygosity (H_O), expected heterozygosity (H_E), inbreeding coefficient and nucleotide diversity (π) were calculated using R v.4.0.3 software and bioinformatics scripts or commands. PLINK v 1.9 [28] was also employed to investigate the population differentiation between Gumuz, Rutana and Washera sheep using principal component analysis. A schematic diagram of the first two principal components (PC1 and PC2) was generated using the prcomp function in the R package [30].

3. Results

3.1 Mapping output of three sheep populations

In total, 29,103,927 SNPs (single nucleotide polymorphisms) were discovered in all individuals out of which 22,946,362 were already reported SNPs in dbSNP (disabled single nucleotide polymorphisms) and 6,157,565 are novel SNPs obtained by this study (Table 2). The mean sequence depth was 7.48 per sample ranging from 6.86 to 7.93 (Table 3) in all individuals across the three sheep populations.

Table 2. Number of biallelic SNPs and INDELS

Particulars	Sheep populations			
	Washera	Gumuz	Rutana	Combined(All samples)
Number of Biallelic SNP in the Autosomes	21,226,832	21,812,392	22,695,900	29,103,927
Number of INDELS in the Autosomes	2,949,919	3,012,770	3,095,901	3,758,552
Already Reported SNP in dbSNP	17,492,652	17,991,477	18,791,133	22,946,362
Number of Novel SNP obtained	3,734,180	3,820,915	3,904,767	6,157,565

Table 3. Mean sequencing depth of individual sheep

Individuals	N_sites	Mean site_depth
G1	29081378	7.56
G10	29081436	7.63
G14	29081824	7.71
G4	29081714	7.48
G9	29081056	7.63
R14	29081286	7.61
R16	29082087	7.93
R4	29081827	7.66
R5	29081499	7.76
R8	29081850	7.57
W13	29081815	7.31
W14	29081467	7.23
W15	29081679	7.15
W17	29080506	6.86
W9	29081493	7.20

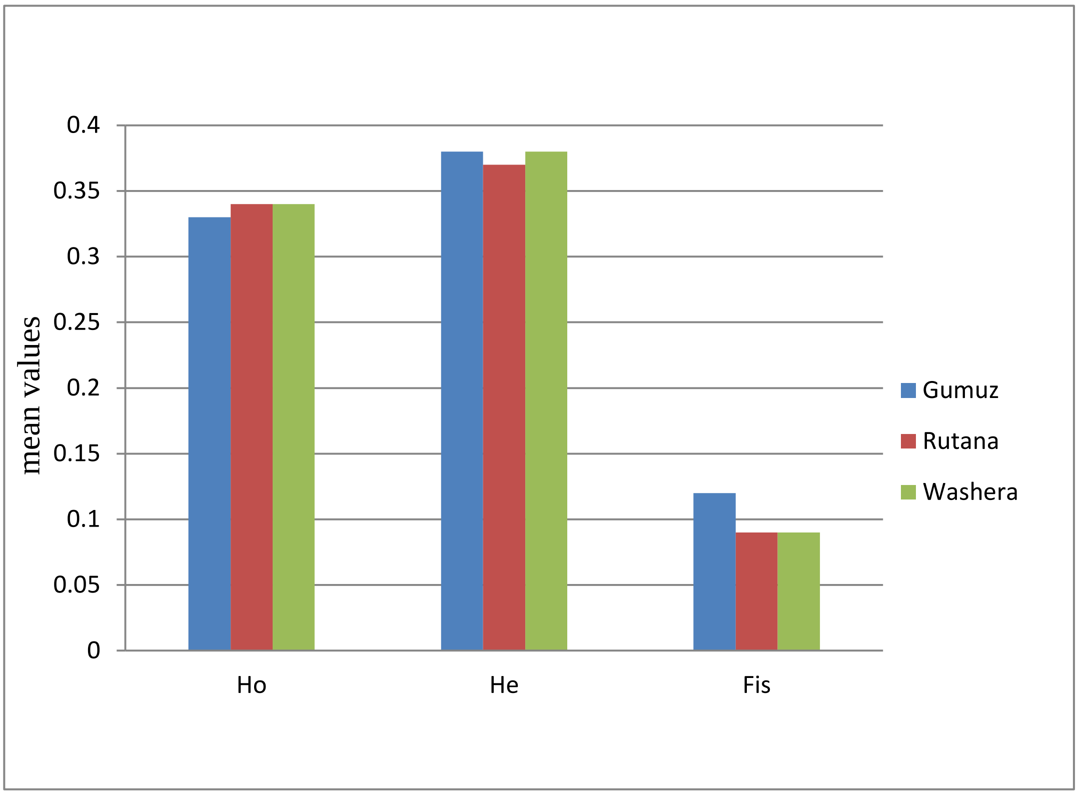
3.2 Genetic diversity

To estimate the genetic diversity across the three sheep populations (Gumuz, Rutana and Washera), we calculated polymorphic SNP, observed heterozygosity (H_O) , expected heterozygosity (H_E), inbreeding coefficient (F_{IS}), and nucleotide diversity using vcftools v 0.1.15. Expected heterozygosity (gene diversity) ranged from 0.37 in

Rutana to 0.38 in Gumuz and Washera sheep. Mean nucleotide diversity values were 0.0029, 0.0030 and 0.0028 for Gumuz, Rutana and Washera sheep, respectively (Table 4, Figure 2).

Table 4. Mean values of genetic diversity indices

Sheep population	Polymorphic SNP(PN)	Observed heterozygosity (H_O)	Expected heterozygosity (H_E)	Inbreeding coefficient (F_{IS})	Nucleotide diversity(π)
		mean±SD	mean±SD	mean±SD	mean±SD
Gumuz	0.89	0.33±0.01	0.38±5.34	0.12±0.01	0.0029±0.00
Rutana	0.90	0.34±0.01	0.37±3.79	0.09±0.01	0.0030±0.0
Washera	0.88	0.34±0.01	0.38±8.28	0.09±0.02	0.0028±0.00



Ho=observed heterozygosity, He=Expected heterozygosity, F_{IS}=inbreeding cofficient

Figure 2. Heterozygosity estimates for the three sheep populations based on analysis of whole genome data

3.3 Population structure using principal component analysis

Principal component analysis (PCA) was used to elucidate relationships between the three sheep populations (Gumuz, Rutana and Washera) with 27,600,963 SNPs passing filtering and quality control (QC). Principal component one (PC_1) and Principal Component two (PC_2) accounted for 11.16 %, and 9.08 % of the total variation, respectively. Individuals in the three sheep populations were not clearly clustered to separate the sheep populations although, PC1 looks better in segregating long-thin tailed Rutana sheep from the short fat-tailed Washera and thin-tailed Gumuz sheep (Figure 3). PC_2 partitioned short fat-tailed Washera from thin-tailed Gumuz sheep although one individual from Washera found to be an outlier.

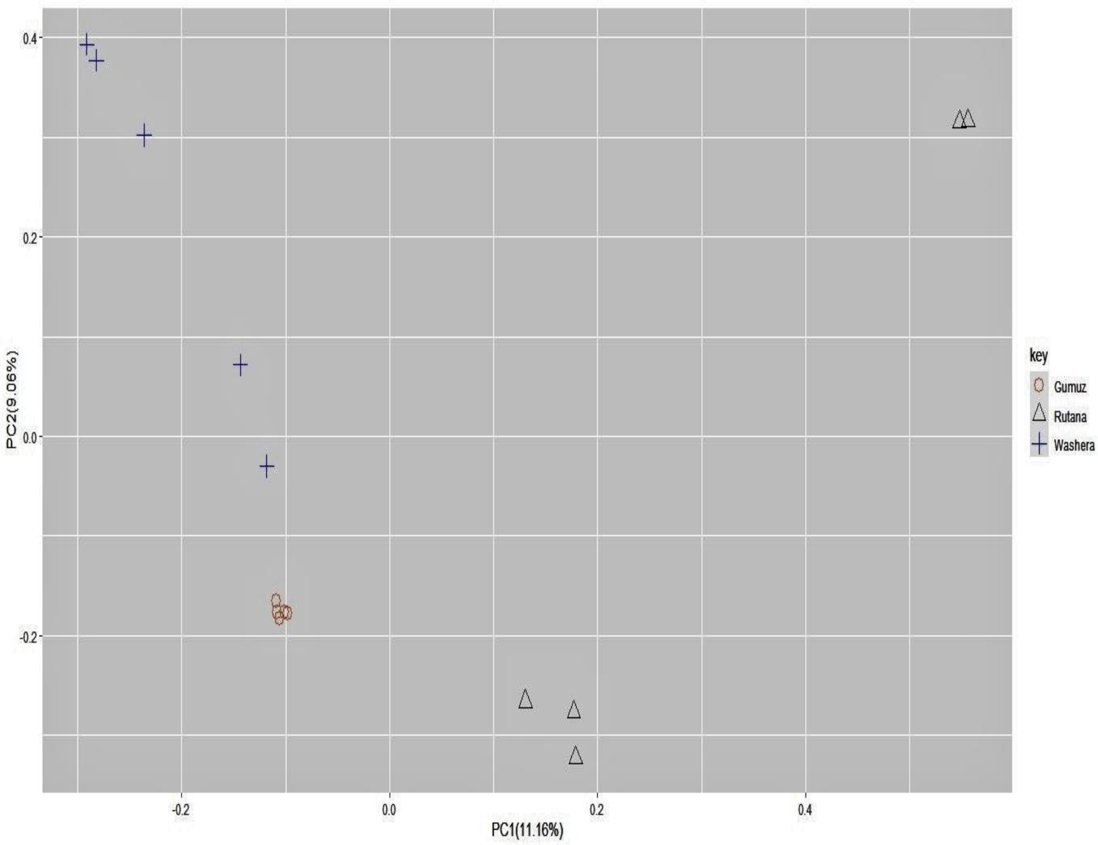


Figure 3. Animals clustered on the basis of principal component analysis using individual genotypes

4. Discussion

The genetic diversity of an animal population is a measure of its genetic differences (i.e. genetic variation). It is vital to monitor and maintain genetic diversity in order for a conventional breeding to remain viable in the future [6]. Recently studies [20-22] were conducted to assess the relationships among Ethiopian sheep breeds using phylogeny tree, principal component analysis, and Bayesian model based population structure. According to these researches, the ancestral relationship between Ethiopian sheep populations, including the breeds under investigation, follows a distinct pattern of tail morphology, phylo-geography, and environmental adaptation (altitude or temperature). Nonetheless, genetic diversity and population structure in Gumuz, Rutana, and Washera sheep have not been adequately addressed in previous studies using whole-genome data. Stratification of the sheep populations using principal component analysis was not clear especially that explained by $PC_{2.}$ However, between-breeds phenotypic variation in body weight was reported by different scholars, which was attributed to their genetic make-up. In this regard, large sized Rutana sheep weighing 43.1 kg [10] differs phenotypically with both Washera sheep weighing 32.8 kg and Gumuz sheep weighing 31.0 kg [31]. High within-breed variability is a feature of large traditional populations that have not been subjected to intense selection [32]. Meanwhile, we focused on evaluating within- breed genetic variability of Gumuz, Rutana and Washera sheep populations using genetic diversity indices such as polymorphic SNP (PN) , observed heterozygosity (H_O), expected heterozygosity (H_E), inbreeding coefficient (F_{IS}), and nucleotide diversity (π).

Polymorphic SNP (PN) contents of the current study were lower than Asian breeds such as 0.93 of Changthangi, 0.92 of Tibetan sheep, and 0.96 of Australian Merino, European breeds such as 0.95 of Finnsheep and 0.95 of German Texel, African breed such as 0.93 of Red Maasai but, were close to 0.91 of African Dorper, and were comparable to 0.88 of Cyprus Fat Tail sheep [29].

The average observed and expected heterozygosity values of the current study were in line with [33]. According to [33], the heterozygosity value ranges from zero to one. Values of expected heterozygosity were higher than observed heterozygosity for the three sheep populations. The genetic diversity across all loci of sheep populations under study were in accord with 0.35 - 0.38 [22] reported for Horro, Wollo, and Farta breeds studied using 50 kilo base (kb) SNP markers. Mean genetic diversity values of the current study were higher than 0.29 - 0.32 [20] reported for Adilo, Arsi-Bale, Blackhead Somali and Horro sheep studied using 60 kb SNP markers. The likelihood of sheep being heterozygous at a marker site is determined by the number of alleles and their frequency in the population. The mean heterozygosity values of Gumuz, Rutana, and Washera sheep (0.37 to 0.38) were less than 0.5, the value appropriate to study genetic diversity as suggested by [34]. However, these results are considered moderately heterozygous although they were on the low side. These mean heterozygosity values were far below heterozygosity values 0.65 to 0.74 [5] reported for fourteen traditional sheep populations of Ethiopia studied using 17 microsatellite markers. This difference in values of heterozygosity could be due to decreasing genetic diversity of Gumuz, Rutana and Washera sheep attributed to small base population, inbreeding, and genetic drift. Comparing these values from global point of view, mean expected heterozygosity (gene diversity) of the current study were higher than Asian breeds such as 0.35 of Changthangi, 0.34 of Tibetan sheep,0.33 of African Dorper, and 0.32 of Red Maasai [29]. Expected heterozygosity of the current study were comparable to 0.37 of Australian Merino but, higher than 0.36 of Finnsheep, 0.35 of German Texel , and 0.31 of Cyprus Fat Tail sheep [29].

Mean inbreeding coefficient ranged from 0.09 of Rutana and Washera to 0.12 of Gumuz sheep. A high positive F_{IS} value shows a high level of homozygosity, while a low negative value indicates a low level of inbreeding [34]. This study showed that inbreeding rates were higher than the tolerable value of 0.0625 [35] for the three sheep populations. These higher levels of inbreeding might result from non-random mating between closely related individuals. These higher levels of inbreeding might in turn cause inbreeding depression. F_{IS} values of the current study were in accord with 0.09–0.16 [36] reported for some Turkish sheep breeds but lower than 0.23 [19] reported for three sheep breeds of Ethiopia studied using 22 microsatellite markers. Higher positive F_{IS} (0.12) is recorded for Gumuz sheep. In that, an inbred Gumuz sheep is expected to have 12 percent more homozygous gene pairs than a non-inbred individual from the same Gumuz breed. The higher rate of inbreeding in Gumuz sheep might be because of the small population size [7], uncontrolled mating and genetic drift. In this regard, an earlier report by [5] indicated that Gumuz sheep was considered to be endangered and ranked second next to semien sheep for conservation priority. Higher nucleotide diversity estimates were recorded for Rutana sheep than its counterparts. In addition, [37] reported that Rutana sheep are relatively more suitable than Gumuz and Washera sheep for production of better carcass yield. Thus, selecting individuals having higher nucleotide diversity from breeds like Rutana will lead to better yield from productivity traits such as carcass yield.

Mean nucleotide diversity (π) values ranged from 0.0028 in Washera to 0.0030 in Rutana. These sheep populations have moderate nucleotide diversity, nearly 0.3% as implemented by [38]. These values were considered to be indicators of the presence of moderate genetic diversity in Gumuz, Rutana and Washera sheep. However, the π value of Gumuz, Rutana and Washera sheep were lower than that of 0.0082, 0.0106, 0.0146 and 0.0150 [39] of Abergelle, Elle, Begait and Highland sheep, respectively studied in Tigray regional state of Ethiopia using Mitochondrial DNA.

5. Conclusion

We analyzed population structure of Gumuz, Rutana and Washera sheep populations using principal component analysis. However, individuals in Rutana and Washera sheep populations were not clearly stratified to separate the sheep populations some of the individuals being outliers. Meanwhile, we focused on evaluating within-population genetic variability of Gumuz, Rutana and Washera sheep populations using some parameters of genetic diversity such as observed heterozygosity, expected heterozygosity, rates of inbreeding, and nucleotide diversity. We found higher expected heterozygosity (gene diversity) values than the observed heterozygosity for sheep populations under investigation. In addition, we found higher values of nucleotide diversity. The smaller population size, closed breeding system, genetic drift and uncontrolled (non-random) mating might lead to higher rate of inbreeding in Gumuz, Rutana and Washera sheep, requiring timely intervention to prevent inbreeding depression and extinction of these valuable breeds of sheep, which helps in sustaining the livelihood of sheep keepers in lowlands and highlands. Nevertheless, our whole-genome analysis revealed higher within-population genetic variability. Uncovered areas of studies like mapping quantitative trait loci, identifying genes underpinning productivity traits such as carcass quantity and meat quality could be carried out on diversified sheep resource identified by the current study. Identifying the genomic regions and biological pathways that contribute to explaining variability in these traits is of great importance for selection purposes. The information obtained will be used as an input for designing sheep selective breeding programs for breeds with high rate of inbreeding and for managing the genetic diversity.

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Article V. Designing sheep breeding program and predicting genetic gains

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Submitted

Abstract

The objective of this study was to prioritize selection criteria for sheep by estimating genetic and economic responses of traits of Gumuz and Washera sheep. To address this objective, deterministic approach of ZPLAN software is used for modeling input parameters. Population, production, biological and cost parameters were used as input parameters. Live weight gain estimated for six month weights were 0.46 and 0.60 kg in Gumuz and Washera sheep, respectively. Live weight gain estimated for yearling weights were 0.58 and 0.66 kg per year in Gumuz and Washera sheep, respectively. Estimated Return for economic traits were 0.17, 0.74 and 0.94 Ethiopian birr for litter size, six month weight, and yearling weight, respectively. Estimated values were 0.27 and 1.71 Ethiopian birr for monetary genetic gain per year and, discounted profit, respectively. The corresponding values for Washera sheep were the following. Estimated genetic gains for were 0.60 kg and 0.66 kg per year for six month weight, and yearling weight, respectively. Estimated Return for economic traits were 0.22, 0.96 and 12.1 Ethiopian birr for litter size, six month weight and yearling weight, respectively. Estimated values were 0.33 and 2.30 Ethiopian birr for monetary genetic gain per year and discounted profit, respectively. Accuracy of breeding value estimation was 0.54 and 0.55 in Gumuz and Washera sheep, respectively. Yearling weight could be prioritized as selection criterion in sheep selective breeding program which is significantly outperforming six-month weight and litter size.

Key words: genetic improvement; traits; selection criteria; sheep

Introduction

In the developing world, farm animals are considered to be a major pathway out of poverty (Joost et al., 2016). In Ethiopia, there are 32.85 million sheep, more than 99% of which are indigenous (CSA, 2020). However, the productivity of local sheep under traditional production system is low (Tibbo, 2006; FAO, 2015). Because of this the increasing need for food of animal origin has largely been met with increasing number of sheep while productivity per sheep has remained low (FAO, 2015). Indeed, there are two ways of improving the performance of sheep and goats. These are improving the environment and/or their genetic potential or genotype (Gizaw, 2009). Conventionally three main pathways have been considered for genetic improvement of sheep. These are selection between breeds, cross breeding and selection within breeds (FAO, 2010). Breed substitution and cross breeding programs involving exotic breeds are rarely successful due to incompatibility of the genotypes with the farmers breeding objectives and the production systems (Haile et al., 2019). On the other hand, selective breeding of the adapted indigenous breeds is the best possible option for genetic improvement of small ruminants in tropical countries (Mueller et al., 2015; Haile et al., 2019).

Indigenous sheep breeds are compatible genotypes for the low input traditional production system since, indigenous sheep breeds have special adaptive features such as: tolerance to a wide range of diseases, water scarcity tolerance and ability to better utilize the limited and poor quality feed resources (Kosgey and Okeyo, 2007). Washera is a populous indigenous breed in Ethiopia with wide area coverage. Washera is a good meat producer under good environment (Gizaw, 2009). Gumuz sheep is considered as one of the most diversified indigenous breed type of Ethiopia. Gumuz sheep are heat-adapted and can thrive in lowland and hotter areas reared mainly for their meat and skin products (Gizaw, 2009). Awgichew and Abegaz (2008) noted that meat is the most important product of small ruminants in Ethiopia. The quantity of meat produced depends on the number and weight of surplus animals at age of sale. The importance of reproduction rate must be stressed in relation to the number of meat animals for sale. Live weight and growth rate are economically critical features, requiring particular attention in any breeding program intended to improve overall productivity since lambs are mainly raised for mutton (Tibbo, 2006). Besides, good reproductive performance is a prerequisite for any successful genetic improvement and it determines production efficiency which depends on various factors including age at first lambing, litter size, lambing interval and the life time productivity of the ewe (Edea, 2008). Based on this background information, six month weight, yearling weight and prolificacy (litter size) were candidate traits of interest for increasing meat production. Where small ruminants are kept primarily for meat production, selection will be on the number and weight of offspring weaned per female per year (Awgichew and Abegaz, 2008). However, accurate pedigree records are unavailable or incomplete especially under on-farm sheep production environments (FAO, 2011). In addition, absence of pre-evaluation of genetic and bio-economic feasibility of sheep breeding programs are some gaps discovered recently (Gizaw et al., 2018). Under such circumstances, simulation studies could be carried out to evaluate and prioritize selection criteria of sheep by estimating genetic and economic responses of traits. This study, therefore, was carried out to predict genetic gains and economic responses for breeding objective traits of Gumuz and Washera sheep populations and use the information as an input for establishment of sheep selective breeding program in the region.

Materials and methods

Description of production environment and sheep populations

This study was conducted in two districts (Burie and Mandura) of northwestern Ethiopia. According to altitudinal location, rainfall and crop yields, the agro-ecological zone of Burie is highland while the agro-ecological zone of Mandura is lowland. Burie is located at 10^0 12’ 07’’ latitude and 37^0 03’ 58’’ longitudes and at an altitude of 2067 meters above sea level. The rainy season in Burie is from May to September with a monomodal pattern and annual rainfall of 1386 – 1757 mm. Mandura district is located at 10^0 50’ 06’’ latitude and 35^0 33’ 36’’ longitudes and its altitude is 1146 meters above sea level. It receives 900-1400 mm annual rainfall. Setting up sheep breeding programs starts with a description of sheep production system or the way how sheep are kept in the region and for a certain purpose (Tibbo, 2006; FAO, 2010). Washera and Gumuz were predominant traditional sheep populations in Burie and Mandura districts, respectively. Washera is a short fat tail, large body size, short-haired, predominantly brown, both males and females are polled reared by Amhara and Agew communities. Washera is a good meat producer under good environment (Gizaw, 2009). Gumuz sheep is long thin tail, somewhat dwarf, convex face profile, long pendulous ear, commonly plain brown or with patch, polled and reared by Gumuz and Amhara communities (Gizaw et al., 2008). Gumuz sheep are heat-adapted and have a unique genetic make-up that allows them to thrive in lowland and hotter areas for their meat and skin products (Gizaw, 2009). The prevailing sheep production systems of Burie and Mandura districts were highland cereal-livestock system and lowland crop-livestock system, respectively (Gizaw et al., 2008). These systems are also characterized by inadequate health care, smaller land holding often less than two hectares and small sheep flock size. Based on these criteria, Gizaw et al. (2008) described the scale of sheep production system as small scale, semi intensive, low input and traditionally type.

Breeding objective traits or selection criteria

Identifying sheep breeding objective traits and their relative importance is a prerequisite in the design of village breeding program (Oldenbroek & van der Waaij L, 2014; Woldu, 2016). The objective has to be comprehensive and incorporate the needs and interests of the target group, farmers mostly at subsistence level, as well as ecological conditions (Sölkner *et al*., 1998; Haile *et al*., 2013). A clear idea should be developed about the merits of individual traits to be successful in genetic selection (Awgichew and Abegaz, 2008). In that, for selection to be effective, the selected traits must be heritable, variable and measurable (Awgichew and Abegaz, 2008; FAO, 2010; Mueller *et al*., 2015). Weight, for example, is an easy trait to measure because all that is needed is a weighing scale. Based on these background information's, we compared live weight traits(six month and yearling weight) in which animals will be at marketable size and litter size (number of lambs born alive per lambing) to look at the correlated response between live weight traits and prolificacy (litter size). Table 1, Table 2 and Table 3 illustrate short listed breeding objective traits for rams and ewes of Gumuz and Washera sheep

Table 1. List of traits of Gumuz and Washera rams prioritized by respondents

Traits	Gumuz		Washera	
	Freq	%	Freq	%
Coat color type	64	23.02	112	19.92
Body size	120	43.16	208	37.01
Libido	80	28.77	88	15.65
Tail size	14	5.03	154	27.40
Sum	278	100	562	100

Table 2. List of candidate breeding objective traits of Gumuz and Washera ewes

Traits	Gumuz		Washera	
	Freq	%	Freq	%
Coat color type	60	7.02	44	4.57
Body size	116	13.58	176	18.29
Body length	72	8.43	52	5.40
Chest girth	64	7.49	44	4.57
Height at wither	80	9.36	68	7.06
Litter size(lambs/birth)	88	10.3	128	13.3
Lamb growth	32	3.74	34	3.53
Lambing interval	48	5.62	56	5.82
No of lambing /life time of the ewe	48	5.62	50	5.19
No of lambs born /ewe / year	20	2.34	46	4.78
No of lambs weaned/ ewe joined	74	8.66	90	9.35
Tail size	32	3.74	32	3.32
Age(PPI)	120	14.05	142	14.76
Sum	854	100	962	100

Table 3. Selection criteria for ewes and their ranking by breed type

Selection	Washera						Gumuz						Overall index	Overall R
	Ranks				Index	R	Ranks				Index	R		
	1 (4)	2 (3)	3 (2)	Inferior (1)			1 (4)	2 (3)	3 (2)	Inferior (1)				
body weight	45	9	7	5	0.26	1	41	8	5	5	0.25	1	0.255	1
Coat color	8	10	7	5	0.09		2	2	1	3	0.02		0.055	
Litter size (lambs/bir	5	13	21	23	0.14	2	10	19	23	23	0.21	2	0.18	2
Lamb survival	0	5	2	7	0.03		0	1	3	6	0.02		0.025	
Lamb	2	16	11	9	0.10		1	4	7	7	0.05		0.075	
Lambing interval	10	16	6	10	0.13	3	4	28	16	16	0.18	3	0.155	3
Mothering ability	1	3	9	5	0.04		10	6	11	8	0.11		0.075	
Age at maturity	1	0	9	6	0.03		0	0	2	2	0.008		0.019	
No of lambs born /ewe	8	5	11	13	0.09		9	5	10	0	0.08		0.085	
No of lambs weaned/	5	3	13	6	0.07		4	3	12	1	0.06		0.065	
Total					1						1			

Variance components and goal trait values

Larger across-generation data sets are lacking under low input production systems. According to FAO (2010) recommendation literature averages could be used as an input in optimization of alternative breeding schemes (Table 4). Economic weights of breeding objective traits were adopted from Gizaw (2021, unpublished)

Table 4. Weighted mean phenotypic correlations (above diagonal), genotypic correlations (below diagonal) and heritability (along the diagonal)

Breed/ecotype	Traits	SMW	YW	LS
Washera	SMW	0.22	0.74	0.01
	YW	0.93	0.29	-0.02
	LS	0.17	0.27	0.10
Gumuz	SMW	0.22	0.70	0.01
	YW	0.93	0.29	-0.02
	LS	0.17	0.27	0.10

SMW = six month weight,   YW = yearling weight,   LS = litter size
Source: Safari et al.(2005)

Population structure and selection pathways

A survey data consisting of population, production, biological and cost parameters were collected and used as input parameters (Table 5). Reproduction parameters and the survival rate of the lambs were biological parameters used to predict the number of confirmed (candidate) sheep per time unit (year). For modeling input parameters of indigenous sheep breeds, ZPLAN software (William et al., 2008) is employed. As used by Gizaw et al.(2014) six selection groups in one-tier cooperative scheme were used for simulation purpose using gene flow and selection index method. Rams selected produce rams (RM>RM), ewes selected produce rams (EW>RM), Rams selected produce ewes (RM>EW), ewes selected produce ewes (EW>EW), rams selected produce ewes in the production unit (RM>EP) and ewes selected to produce ewes in the production unit (EW>EP). Genetic dissemination was predicted to be through ram exchange among members of cooperatives (villages) and between villages. Two villages consisting of 99 (50 and 49) households of Washera and two villages consisting of 90 (45 and 45) households of Gumuz sheep keepers each household owning a flock size of five ewes and above were considered. In this study, only the cost of routine activities and fixed costs of housing were regarded as a cost parameter. The average population size of breeding ewes were based on flock inventory taken from each community member households during the own-flock ranking experiment. Information on reproductive performance were mainly obtained from the national literatures (Gizaw et al., 2007; Gizaw, 2009; Taye et al., 2011; Mekuriaw et al., 2013).

Selection proportion and time unit of ram use

Four alternative selection scheme scenarios were used using selection index and gene flow method with varying selection proportion and time unit of ram use as implemented by Mirkena et al.(2012). We plan two scenarios of ram use for breeding (for one year versus for two years). The number of rams chosen was determined by the amount of ewes available for mating, with a male: female allocation ratio of 1: 30 (Haile et al., 2020). The proportion of selection commonly used is 10% (10%* candidate rams). Thus, we plan optimization of the schemes by increasing proportion of selection to 15 % (15%* candidate rams).

Scheme 1. 10% selection proportion and 2 years of ram use for breeding
Scheme 2. 10% selection proportion and 1 year of ram use for breeding
Scheme 3. 15% selection proportion and 2 years of ram use for breeding
Scheme 4. 15% selection proportion and 1 year of ram use for breeding

Cost estimation of economic parameters

Cost estimation of economic parameters was based on current price of items obtained by discussion with target sheep keepers (Table 6).

Table 6. Economic parameters and their cost estimation

Economic Parameters	Sheep populations		Explanations for cost estimation
	Washera	Gumuz	
Payment for Enumerator	24 ETB /ewe	26.66 ETB /ewe	for data collection payment=annual payment divided by number of ewes/female breeding sheep
Veterinary service and drug supply	69.5 ETB/ewe /year	69.5 ETB/ewe /year	25 ETB/ewe /year; 2.78(an ewe+1.78 per Time Unit(TU)=3 lambing in two years,1.5 lambing per TU)*1.19 Litter size(LS)* 25 ETB
Vaccination	10 ETB/ewe/ year	10 ETB/ewe/ year	5 ETB/ewe/ vaccination*2 vaccinations /year

ETB is approximately equal to 0.025 $ exchange rate in 2021

Flock projection

Flock projection for each breed was done considering the population and biological parameters. The formula used by Nitter et al.(1994) and Mirkena et al.,(2012) was employed. Accordingly, in Burie for example, given a population of breeding ewes of 495 with 90% fertility, 85% lambing rate, 1.06 twinning rate, 1.5 lambing per year (3 lambing per 2 year)*LS, 67 % lamb survival to yearling and a sex ratio of 50%, the projection yields 240 yearling candidate rams (i.e., number of proven males/year = population size (ewes) * fertility rate* lambing rate* twinning rate* 1.5 lambing (3 lambing per 2 year*LS)* lamb survival to yearling *sex ratio = 495*0.9*0.85*1.06*1.5*1.19*0.67*0.5 = 240).

As a quality measure of sheep breeding scheme, maintenance of genetic diversity measured by the rate of inbreeding is given a due attention. Based on population parameters obtained from the survey data, the effective population size with different numbers of males and females was calculated following the formula used by Groeneveld (2009).

Ne = 4Nm*Nf / (Nm+Nf)

Where:

Ne – Effective population size

Nm_ Number of males

Nf _ Number of females

The rate of inbreeding per generation was calculated following the formula used by Groeneveld (2009).

$\Delta F=1/(2Ne)$

Where:

Ne – effective population size

ΔF – rate of inbreeding

Table 7. Input parameters for Zplan modeling

Parameters	Unit	Washera	Gumuz	Source
Population Parameters				
Population size (ewes)	No	495	450	
Number of proven males/year	No	240	218	
Proportion of rams selected	%	10 % ;15%	10 % ; 15 %	
Biological Parameters				
Breeding ewes in use	year	5	5	
Breeding rams in use	year	1; 2	1; 2	
Mean age of rams at birth of first offspring	year	1.27 (464 days)	1.14	Gizaw et al.,2007 ;Taye et al.,2011
Mean age of ewes at birth of first offspring	year	1.27 (464 days)	1.14	Gizaw et al.,2007 ;Taye et al.,2011
Lambing interval	year	0.83 (303 days)	0.55	Gizaw et al.,2007; Mekuriaw et al.,2013
Fertility (conception rate)	%	0.90	0.90	Mirkena et al., 2012
Lambing rate	%	0.85	0.85	Mirkena et al., 2012
Twining rate	%	1.06	1.06	Mirkena et al., 2012
Mean number of lambs per birth (litter size)	No	1.19	1.31	Gizaw ,2009; Taye et al.,2011
Mean number of lambs/ewe/year	No	1.8	1.9	3 lambing per 2 year=1.5 lambing / year*Litter size
Lambing survival to yearling	%	67	88	Gizaw , 2009; Mekuriaw et al.,2013
Sex ratio	%	50	50	
Estimated production costs				
Sources of costs				
Feed				
Hay	ETB	20	20	
Noug cake	ETB	29	20	
Veterinary and management cost				
De-worming	ETB	3.5	3.5	
Vaccinations	ETB	10	10	
Veterinary treatment	ETB	69.5	74	
Marketing	ETB	1.0	1.55	
Enumerator payment for performance recording	ETB	24	26.66	
Interest rate costs (%)	%	0.08	0.08	
Fixed costs(Housing)	ETB	1.2	0.5	
Investment period	year	15	15	

Results

Estimated genetic responses

Table 7 illustrates the estimated response to selection of breeding objective traits. Selection responses found to be higher in alternative selection scheme two when 10% of the candidate rams selected and used for one year breeding taking into account that ram replacement takes place through ram exchange between villages every year. For Gumuz sheep, estimated live weight gains were 0.46 kg and 0.58 kg per year for six month weight, and yearling weight, respectively. Estimated Return for economic traits were 0.17, 0.74 and 0.94 Ethiopian birr for litter size, six month weight, and yearling weight, respectively. Estimated values were 0.27 and 1.71 Ethiopian birr for monetary genetic gain per year and, discounted profit, respectively. The corresponding values for Washera sheep were the following. Estimated genetic gains for were 0.60 kg and 0.66 kg per year for six month weight, and yearling weight, respectively. Estimated Return for economic traits were 0.22, 0.96 and 12.1 Ethiopian birr for litter size, six month weight and yearling weight, respectively. Estimated values were 0.33 and 2.30 Ethiopian birr for monetary genetic gain per year and discounted profit, respectively.

Table 7. Estimated responses to selection

Sheep Population		Alternative selection Schemes	Traits	Outputs: Live weight and litter size per year for the single traits	Return for economic traits (ETB)	Monetary genetic gain Per year (ETB)	Dis counted profit (ETB)
Gumuz	1	10 % selection proportion; 2 years of ram use	SMW	0.43 kg	0.68	0.25	1.56
			YW	0.55 kg	0.87		
			LS	0.08 la/birth	0.16		
	2	10 % selection proportion; 1 year of ram use	SMW	0.46 kg	0.74	0.27	1.71
			YW	0.58 kg	0.94		
			LS	0.09 la/birth	0.17		
	3	15 % selection proportion; 2 years of ram use	SMW	0.43 kg	0.67	0.25	1.54
			YW	0.54 kg	0.86		
			LS	0.08 la/birth	0.16		
	4	15 % selection proportion; 1 year of ram use	SMW	0.46 kg	0.73	0.26	1.68
			YW	0.57 kg	0.93		
			LS	0.08 la/birth	0.17		
Washera	1	10 % selection proportion; 2 years of ram use	SMW	0.55 kg	0.87	0.31	2.1
			YW	0.62 kg	11.0		
			LS	0.09 la/birth	0.22		
	2	10 % selection proportion; 1 year of ram use	SMW	0.60 kg	0.96	0.33	2.3
			YW	0.66 kg	12.1		
			LS	0.09 la/birth	0.22		
	3	15 % selection proportion; 2 years of ram use	SMW	0.55 kg	0.86	0.30	2.1
			YW	0.60 kg	10.9		
			LS	0.09 la/birth	0.2		
	4	15 % selection proportion; 1 year of ram use	SMW	0.56 kg	0.92	0.32	2.3
			YW	0.64 kg	11.1		
			LS	0.09 la/birth	0.22		

SMW = six month weight, YW = yearling weight, LS = litter size, la/bir=lambs per birth

Table 8. Criteria for choosing the best sheep breeding schemes

Sheep populations		Alternative selection schemes	Criteria: Monetary Genetic Gain for aggregate genotype (ETB)	Return to investment (ETB)	Profit/ewe/year (ETB)	Rate of inbreeding (%)
Gumuz	1	10 % selection proportion and 2 years of ram use	0.25	1.71	1.56	0.6
	2	10 % selection proportion and 1 year of ram use	0.27	1.86	1.71	0.6
	3	15% selection proportion and 2 years of ram use	0.25	1.69	1.54	0.4
	4	15% selection proportion and 1 year of ram use	0.26	1.83	1.68	0.4
Washera	1	10 % selection proportion and 2 years of ram use	0.31	1.86	1.66	0.6
	2	10 % selection proportion and 1 year of ram use	0.33	1.91	1.54	0.6
	3	15% selection proportion and 2 years of ram use	0.30	1.84	1.44	0.4
	4	15% selection proportion and 1 year of ram use	0.32	1.88	1.48	0.4

ETB=Ethiopian Birr, SMW = six month weight, YW = yearling weight, LS = litter size, la/bir=lambs per birth

Discussion

We compared responses to selection of six-month weight, yearling weight and litter size in four simulated one-tier cooperative village breeding schemes. In a one-tier cooperative village breeding scheme, genetic gain per year for single traits was estimated and higher values were recorded for yearling weight. In this regard, live weight gain estimated for six month weights were 0.46 and 0.60 kg in Gumuz and Washera sheep, respectively. Live weight gain estimated for yearling weights were

0.59 and 0.66 kg per year in Gumuz and Washera sheep, respectively. The corresponding predicted six month weight gain were 0.44 kg, 0.89 kg, 0.94 kg and 0.69 kg in Afar, Horro, Bonga, and Menz sheep, respectively with 10 % selection intensity and 2 years of ram use for breeding (Mirkena et al., 2012). Mirkena et al.(2012) reported that predicted live weight gains at yearling age were 0.41 kg, 0.87 kg, 0.88 kg and 0.63 kg in Afar, Horro, Bonga, and Menz sheep, respectively with 15% selection intensity and 2 years of ram use for breeding. The predicted yearling weight of Washera and Gumuz sheep of the current study were higher than that of Afar and Menz sheep but lower than that of Horro and Bonga sheep. Recently Haile et al .(2020) reported that pedigree data recorded for nine consecutive years were used and found lower but more reliable values (0.21 kg/year in Bonga sheep, and 0.18 kg/year in Horro sheep and 0.11 kg/year in Menz sheep) of genetic gain. Much more values of genetic gains were also reported in other species of livestock. For instance, live weight gain for six month weight was 0.87-0.87 kg per year (Abegaz et al., 2014) for Western Lowland goat when all the traits selected all together. With the same time unit of ram use for breeding (one and two years), values of live weight gain, return for economic traits, monitory genetic gain per year and discounted profit decreased with increasing proportion of ram selection. The decrement in genetic gain with increasing proportion of ram selection is in accord with Fitzmaurice et al.(2022) for sheep within and across UK and Ireland when selection of sires is top 10 and top 20.

The estimated live weight gain per year for yearling weight of Gumuz and Washera sheep were greater than that predicted for six month weight because selection for six month weight enabled substantial genetic improvement on yearling weight. In addition, the greater live weight gain per year predicted for six month weight and yearling weight than for litter size were attributed to the higher heritability values of six month weight and yearling weight(Safari et al.,2005) and due to correlated response. The lower estimated genetic response for litter size of this study was in accord with Mirkina et al. (2012) report for Afar, Horro, Bonga, and Menz sheep. This lower estimated genetic response for litter size is attributed to low heritability value and low genetic correlations with growth rate traits (Safari et al., 2005).

In a simulated village-based selection program, genetic gains predicted for litter size of were 0.08 and 0.09 lambs/birth for Gumuz and Washera sheep, respectively. These values were greater than 0.0013 lambs/birth (Gizaw et al., 2014) of Menz sheep. Estimated monetary genetic gains per year were 0.24 ETB and 1.05 ETB for Gumuz and Washera sheep, respectively. Predicted monetary genetic gain for Gumuz sheep was less than 5.66 ETB (Gizaw et al., 2014) of Menz sheep. Washera sheep had a higher predicted monetary genetic gain than 5.66 ETB (Gizaw et al., 2014) of Menz sheep.

The higher monetary genetic for aggregate genotype (0.27 ETB), return to investment (1.86 ETB), profit/ewe/year (1.71 ETB) were estimated in selection scheme two with 10% selection proportion and one year ram use for Gumuz sheep. Similarily, the higher monetary genetic for aggregate genotype (0.33 ETB), return to investment (1.91 ETB), profit/ewe/year (1.54 ETB) were estimated in selection scheme two with 10% selection proportion and one year ram use for Washera sheep. Among the two sheep populations higher selection responses were estimated for Washera sheep which could be attributed to higher movement of breeding sheep, rendering to frequent ram replacement by small holders in Burie district. Mean inbreeding coefficient ranged from 0.04 to 0.06 for both Washera and Gumuz sheep. A high positive F_{IS} indicates a high degree of homozygosity and vice versa while negative values indicate low level of inbreeding (Dorji et al., 2012). Based on this background knowledge, the inbreeding coefficient values of sheep recorded by this study were below critical level of 6.25% (Li et al., 2009)

Conclusion

With the same time unit of ram use for breeding, values of live weight gain, return for economic traits, monitory genetic gain per year and discounted profit decreased with increasing proportion of ram selection. Selection responses found to be higher in alternative selection scheme two when 10% of the candidate rams selected and used for one year breeding taking into account that ram replacement takes place through ram exchange between villages every year. Meanwhile, yearling weight gain was found to be greater than six month weight gain for both sheep populations. Thus, yearling weight could be prioritized as a selection criterion in selective breeding programs for Gumuz and Washera sheep. The correlated response between yearling weight and six month weight may also be given second priority in order to produce lamb crops with reasonable live weight at yearling age.

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Chapter two: Literature review

Domestication and distribution route of domestic Sheep to Ethiopia

Some evidence suggests that overhunting of wild sheep may have contributed to the domestication process. There are signs that the number of wild sheep in western Asia dramatically declined around 10,000 years ago, while others have suggested a commensal relationship in which farmers took in orphaned mouflon (Ovis gmelini) lambs. The management of a diminishing resource may have been a more probable route, according to Carr and Hirst (2017). Sheep (Ovis Aries), along with goats, cattle, pigs, and cats, were among the first domesticated "meat" animals. They made their way to Cyprus around 10,000 years ago. Additionally, according to Hirst (2017), domestic sheep likely arrived in Africa in waves through the Horn of Africa and northern Africa, with the first wave arriving around 7000 B.P. Today, there are four different kinds of sheep found in Africa: thin-tailed with hair, thin-tailed with wool, fat-tailed, and fat-rumped (Hirst, 2017). These sheep are arrived to Ethiopia from Asia via the Strait of Bab El Mandeb (Kassahun and Solomon, 2008). The wide distribution of sheep is a reflection of their adaptability to different environments and this has resulted in enormous morphological variation among populations (Kijas *et al.*, 2009; Hirst, 2017). Since their domestication, sheep have been selected for meat, wool and milk production (Kijas *et al.*, 2009; Hirst, 2017) and become essential parts of farms across the world (Hirst, 2017). Sheep comprises 16 percent of the total TLUs in sub-Saharan Africa (FAO, 2002). Meanwhile, in Ethiopia*;* there are 32.85 million sheep, more than 99% of which are indigenous (CSA, 2020).

Contribution of **S**heep to livelihoods

Sheep are the highest number of recorded breeds contributing 25% to the total mammalian breeds (Boettcher et al., 2010) and are mostly kept by smallholders and the rural poor, including women-headed households (Tibbo, 2006). They contribute substantially to the livelihoods of Ethiopian smallholder households as a source of income, food (meat and milk), and non-food products like manure, skins and wool.

They also serve as a means of risk mitigation during crop failures, property security, monetary saving and investment in addition to many other socio-economic and cultural functions (Tibbo, 2006; Getachew et al., 2010). At the farm level, sheep contribute up to 63% to the net cash income derived from livestock production in the crop–livestock production system (Negassa &Jabbar, 2008).

Sheep production systems in Ethiopia

Traditional small ruminant production systems can be classified into four subsystems: small ruminant in annual crop-based system located in northern, northwestern, and central highlands; small ruminant in perennial crop-based, mostly found in southern and southwestern highlands; small ruminants in cattle based systems, these systems usually exist in agropastoral and semi-arid areas; small ruminant dominated systems found in pastoral and arid areas of eastern and northeastern Ethiopia, where sheep and goats are the dominant livestock species(Getahun,2008). Gizaw (2008) also classified sheep production systems in Ethiopia into five subsystems based on Environment, geographic regions, main products and scale of production and management. These are: subalpine sheep–cereal system, highland cereal–livestock system, highland perennial crop system, lowland crop–livestock system (agropastoral) and pastoral system

Mixed crop-livestock system

According to Getahun (2008), this sheep production system is a small ruminant in annual crop-based system located in northern, northwestern, and central highlands.This system is generally found in highland areas where the altitude ranges between 1500 and 3000 meters .above sea level (IBC, 2004; Tibbo, 2006; Gizaw et al., 2008; Abegaz et al., 2008) and the system is mainly categorized based on the integration between crop and livestock productions. Crop production and livestock production complement to each other. In that, crop residues from crop production are major feed resources for sheep and oxen are mainly used for traction for crop production from the livestock side. However, Livestock production is a secondary enterprise in the highland mixed crop–livestock systems, although livestock assumes a major importance in areas (e.g. subalpine areas) where crop production is unreliable (Gizaw et al., 2010). The average land size per household is often less than two hectares. Consequently, farming is mainly subsistence in nature (IBC, 2004). Small flocks are herded together with other livestock species and kept mainly as a source of cash income, meat, manure and skins (Tibbo, 2006; Gizaw et al., 2008; Taye et al., 2009; Dagnaw et al., 2017). The sheep production system is characterized by small scale production, semi-intensive and low-input (Gizaw et al., 2008).

Pastoral and agro-pastoral

These are sheep production systems practiced by the pastoral communities in arid and semi arid areas located below 1500 meters .above sea level (Tibbo, 2006; Abegaz et al., 2008). This system is also known as small ruminants in cattle based systems. These systems usually exist in agropastoral and semi-arid areas (Getahun, 2008) .The pastoral extensive livestock production is mostly the sole source of livelihood with little or no cropping. In the submoist/moist lowlands, agropastoralism is the main mode of production. Crop and livestock production are both important activities. The system is either transhumant or sedentary. The pastoral production system in some areas has been evolving into agropastoral system (Gizaw et al., 2010). Household landholding is often greater than in the mixed farming system (IBC, 2004). The production system is characterized by rangeland-based large-scale sheep production, extensive and low-input (Gizaw et al., 2008). These systems are also characterized by little or no integration between sheep production and crop agriculture and high mobility in search of grazing and water. Livestock are maintained as a principal activity (Abegaz et al., 2008).

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Urban and peri-urban Sheep production system

These systems cover only small proportion of sheep production systems in Ethiopia. Urban and peri-urban system involves the production of sheep within and at the periphery of cities with small flock sizes (Abegaz et al., 2008). In recent years, peri-urban and urban small-scale sheep fattening is increasing in and around cities and major towns (IBC, 2004; Gizaw et al., 2010). Feed resources are usually household wastes, market area wastes, mill leftovers, by-products and roadside grazing (particularly in the peri-urban system).

Ranching

Sheep ranches although they are not common in Ethiopia, there are two government ranches managed either intensively or semi-intensively (Tibbo, 2006). According to Tibbo (2006), two ranches (namely, Debre Berhan and Amed Guya) have been established by government. Their objective being crossbreeding and distributing crossbred rams to farmers on cost-recovery basis until banned in 2001 when maedi-visna disease was confirmed in crossbreds and associated sheep flocks.

Growth and reproductive performance of indigenous sheep

Growth performance of indigenous Sheep

Growth in animals can be measured by the increase in live weight (Tibbo, 2006). Wide variability exists among Ethiopian small ruminant breeds with respect to potential growth rates and mature weight. Further, most Ethiopian breeds have undergone little selection for improved meat production and true breed potentials are not known (Sebsibie, 2008). Growth performance traits are the most important traits for meat production. In order to increase economic return from sheep production it requires improvements in market weight of lambs and mature sheep (Abegaz, 2014). Growth performance may be separated into pre-weaning (birth weight, weaning weight and pre weaning growth rate) and post weaning (six months weight, yearling weight and mature weight).

Table 2.2 Growth performance of some indigenous Sheep populations of Ethiopia

Indigenous sheep	Body weight in kg	Post weaning growth rate	Management Type	Source
Horro	45-50 (MW)	150	traditional	Sebsibie, 2008
	25–33.5 (W12)		traditional	Awgichew and Abegaz,2008
	19.0 (W12)	31	on-station	Tibbo,2006
Afar	40 (MW)	100	traditional	Sebsibie,2008
	25.8 (W12)		traditional	Awgichew and Abegaz,2008
Menz	26–30 (W12)		traditional	Awgichew and Abegaz,2008
	17.1(W12)	29.1	on-station	Tibbo,2006
		<100	on-station	Sebsibie,2008
Washera	32.8 (MW)		traditional	Gizaw et al.,2007
	23.47 (W12)	60.1	traditional	Taye et al.,2009
Gumuz	31.0 (MW)		traditional	Gizaw et al.,2007
Bonga	34.2 (MW)		traditional	Gizaw et al.,2007

MW=mature weight, W12=weight at 12 months of age

Reproductive performance of indigenous Sheep

Reproduction determines several aspects of sheep production and an understanding of reproduction is crucial in reproductive management. A high rate of reproductive efficiency is important for perpetuation of the species, production of meat, milk, skin and fiber, and replacement of breeding stock. Measures of reproduction commonly used in sheep and goats include age at puberty, age at first lambing/kidding, post-partum interval, parturition interval and fertility indices, fertility, litter size and annual reproductive rate (Abebe, 2008). Thus, good reproductive performance of sheep is a prerequisite for any successful genetic improvement (Abebe, 2008; Edea, 2008; Getachew, 2008).

Table 2.1 Reproductive performance of some indigenous Sheep populations

Sheep population	Reproductive performance traits			Management type	Sources
	Age at first lambing (AFL) in months	Lambing interval in months	Litter size in number of lambs		
Horro	13.3	7.8	1.36	Traditional	Edea, 2008
			1.14	On-station	Tibbo et al., 2004
Afar	13.5 (405.6 days)	9.0 (270.5 days)		Traditional	Getachew,2008
Menz	15.2	7.6-9.1	1.11	Traditional	Mekoya,1999
			1.13	On-station	Tibbo et al., 2004
Washera	15.5 (464.2 days)	8.95(268.5 days)	1.19	Traditional	Taye et al.,2011
Gumuz	13.7	6.6	1.17	Traditional	Gizaw et al.,2007
			1.28	Traditional	Gizaw et al.,2008
Bonga	14.9	8.9	1.40	Traditional	Edea, 2008
BHS	23.6	10.5		Traditional	Firew,2008
Abera	9.6	12.9	1.50	On-station	Marufa et al.,2017

BHS=Black Head Somalia

Characterization of indigenous **S**heep populations of Ethiopia

Genetic resources can be characterized with respect to genotypes, phenotypes, morphological traits, measures of genetic diversity, genetic distance, population size and structure, geographical distribution and degree of endangerment. Biotechnology applications for characterization include molecular markers and the so-called ―omic technologies (Boettcher et al., 2010). Results from fragmented studies indicate that there are 18 indigenous sheep populations in Ethiopia (Tibbo, 2006). Based on their performance and unique attributes, the indigenous sheep breeds of Ethiopia could be clustered into five main groups including large breeds (e.g. Horro, Bonga, Dangila/Washera/Agew) adapted to per-humid to sub-humid and moist agro-ecological zones, medium-sized breeds (e.g. Wello, Arsi-Bale) adapted to moist and sub moist high altitude regions, small breeds (e.g. Tukur, Menz) adapted to moist and sub-moist precipitous high altitude regions where feed (grazing) is scarce, unique breeds (e.g. Abergelle, Afar, Black Head Somali, Gumuz, Rutana, Sekota-Agew) adapted to semi-arid to arid harsh climate (water and feed scarce areas) with low to high growth potential and others for which information is limited (Akale Guzai, Barka, Farta) (Tibbo, 2006). Similarly , Abegaz and Awgichew(2008) suggested a modification of descriptor lists or master record of FAO (1986) and FAO (2012) of quantitative and qualitative traits to classify tropical sheep and goats considering height at withers and live weight (body size) as a criteria. Sheep and goat breeds are said to be large sized when height at withers is >65 cm and weight 37–50 kg; small breed if height at withers is 51-65 cm and weight 26–36 kg; dwarf sheep, if height at withers is<50 cm and weight 18–25 kg. Gizaw et al.(2008) stated that Ethiopia is a home of most populous and diversified indigenous sheep breeds; classified into fourteen traditionally recognized sheep populations. These indigenous sheep populations of Ethiopia were categorized into four groups (sub-alpine short-fat-tailed, highland long-fat-tailed, lowland fat-rumped, lowland thin-tailed) based on their ecological distribution, geographic proximity, tail types and tail form/shape (short vs long). Further, they were classified into nine genetically distinct breeds and six breed groups which have adapted to a range of environments from the cool alpine climate of the mountains to the hot and arid pastoral areas of the lowlands.

Overview of genetic diversity study in Sheep

Sheep genetic diversity is commonly recognized as not only the observation of different forms and functions *between* species but also one may define the total genetic diversity in a trait *within* species as the variance of the phenotypes between breeds and between individuals within breed (Zonabend, 2016). It also comprises not only variation in production and functional traits, but also the variation in the ability to adapt to different environments, including food and water availability, climate, pests and diseases (FAO, 2007). A wide variety of factors has contributed to the loss, replacement or genetic dilution of many local breeds. Genetic variability within the more common commercial breeds has been greatly decreased by intense selective breeding program (Boettcher et al., 2010).

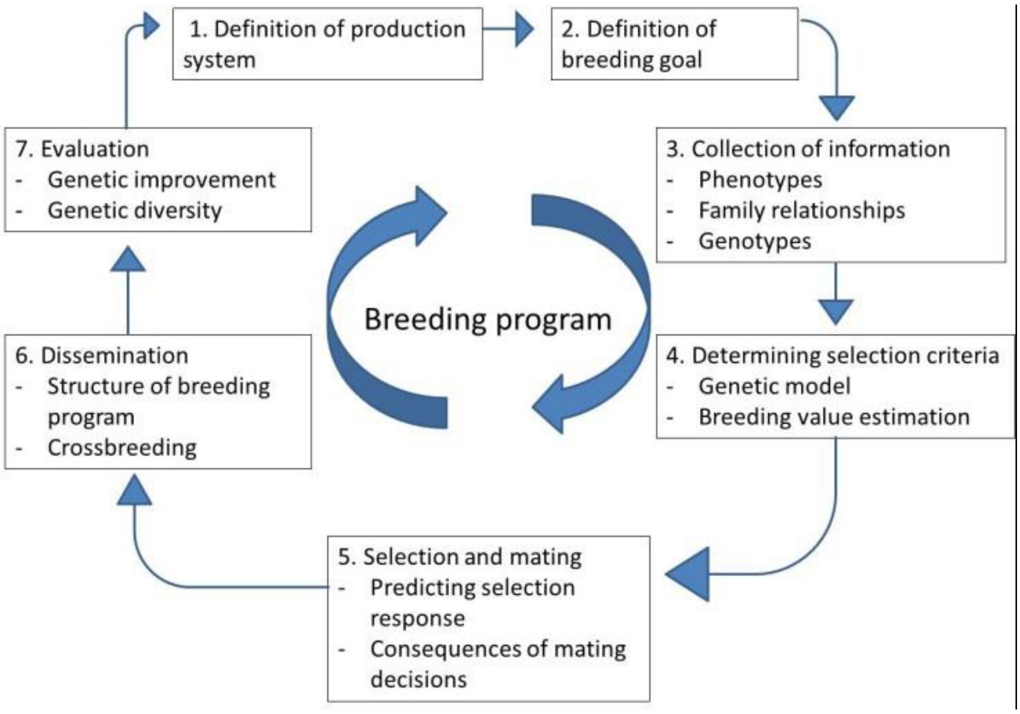
According to FAO (2011b), expected heterozygosity or allelic richness within breeds indicates the influence of drift on breed diversity, where decreased heterozygosity is associated with increased drift. Differences between expected and observed heterozygosity, as well as departure from Hardy-Weinberg Equilibrium (HWE), indicate non-random mating or the existence of population substructures. The presence of inbreeding can be tested by F statistics (Weir & Cockerham, 1984), in particular by testing if the within-breed fixation index *(FIS)* parameter is significantly larger than zero. Genetic subdivision may be explored further by model-based clustering (Pritchard et al., 2000). Depending on the results, it may be decided to exclude from further analysis markers that do not satisfy the expectation of neutrality or outlier individuals (e.g. unrecorded cross-breeds)

Breed formation has led to a partitioning of the total diversity into a within-breed and among-breed component. These components and others, e.g. the component due to the geographic location of breeds, can be quantified by analysis of molecular variance (AMOVA) (Excoffier et al., 1992) and reflect history and breeding practices. Typically, 50 to 90 percent of the total diversity corresponds to the within-breed component, depending upon the group of breeds sampled and the sources of variability considered (FAO, 2011b). The genetic diversity of indigenous sheep of Ethiopia were studied using microsatellite markers and reported by Gizaw (2008) and Nigussie (2015). Similar studies were reported using low density SNP markers (Deribe, 2020) , using 50k and 60k SNP markers by Edea(2017) and Amane(2020).

Overview of indigenous **S**heep breeding programs in Ethiopia

Sheep genetic improvement program in Ethiopia is at its infantile stage. The sheep population is huge, but off-take very low, with an average lamb carcass weight of 10 kg (Tibbo, 2006). Sheep genetic improvement in Ethiopia started in 1944 with the introduction of the Merino breed from Italy to improve the performance of the local Arsi-Bale breed at CADU and later sheep research and development have been practiced for decades dating back to the early 1960s to improve the productivity of the local flocks, increase off take rates, and increase their contribution to the livelihoods of farmers and pastoralists and to the national economy (Gizaw et al., 2013a). After ten years breeding programs in Ethiopia started in the 1970s by the EIAR. The programs utilized closed-nucleus breeding flocks maintained exclusively in research centers. Therefore; the design of selective breeding schemes is the major determinant factors for the success of breeding programs, i.e bringing genetic improvement and improving income and in the meantime improving the livelihood of smallholder farmers. Designing a suitable breeding scheme for smallholder livestock production systems has remained a challenge. Until recently, livestock breeding programs in Ethiopia had adopted exclusively the conventional hierarchical breeding schemes. All the cross-breeding programs and the earlier Afar and Horro sheep breeding programs were hierarchically structured (Gizaw et al., 2013a).

According to Haile et al. (2013), community-based management of animal genetic resources should take into account the peculiar nature of each production circumstances and the community. Thus, understanding traditional knowledge on selection of sheep, ram sharing and management, and community views on some genetic parameters (heritability and correlation) is determinant for design of breed improvement program at the community level. In the community-based breeding programs, relatively small groups of smallholder farmers are the primary target groups (Gizaw et al., 2013a) and they are involved in planning and implementation process of the breeding program (Figure 1). Moreover, improvement plans for indigenous sheep should also consider socio cultural believes, ethnical interests of the country (Kunene, 2010) and need to incorporate existing traditional herding, breeding practices, trait preferences and the multiple roles of sheep (Getachew et al., 2010) and finally, design of genetic improvement programs is focused on a range of decisions in a logical order: planning and optimization.



Source: Oldenbroek & van der Waaij L (2014)

Figure 2.1 Components of a breeding program

Optimization of alternative Sheep selection scheme

As a primary step, identifying breeding objective traits and their relative importance is a prerequisite (Woldu, 2016). The breeding objectives and the selection criteria or traits, on which the livestock keepers wish to improve and base their selection, have to be understood. In this regard the homogeneity and heterogeneity of breeding objectives and selection criteria among community members, as well as between neighboring communities, should be assessed. Uniform and consistent views of farmers facilitate the creation of a common understanding and working towards a clear formulation of common objectives (Haile et al.; 2011). Optimization means that using resources needed for animal breeding most effectively in such a way those optimal gains would be secured both in terms of genetic gains and monetary genetic gains (Jembere, 2016). In optimized breeding strategies; maximizing of genetic gain while restricting rate of inbreeding needs to be considered (Gizaw et al., 2009; Gizaw et al., 2013b). Modeling using ZPLAN and Fortran 90 computer program (William et al., 2008) is used for optimization purpose. A simulation models were developed to optimize alternative sheep breeding scheme (Gizaw et al., 2010; Mirkina et al., 2012; Gizaw et al., 2014a). The program is based on a pure deterministic approach. Its advantage is multi-trait modeling including return and costs over a given time horizon and the program is fast.

Indigenous Sheep conservation practices in Ethiopia

In developing countries, animal genetic resources are being eroded through rapid transformation of agricultural systems. One of the major causes to the loss of indigenous breeds of farm AnGR is indiscriminate use of exotic genetic resources (IBC, 2004). In order to cope up with this problem, conservation measures could be taken as a genetic improvement intervention. Conservation can be viewed as the rational utilization and protection of existing genotypes from genetic erosion. Unfortunately, in Ethiopia, no conservation activities of farm AnGR have so far been practiced in the country, except for limited activities that are meant to maintain pure stocks of cattle and sheep breeds (IBC, 2004). In this regard, from the 1950s to 1970s, conservation programs were established in the form of ranches and multiplications centers for the conservation of Fogera, Boran, Horro and Arsi cattle breeds and Menz sheep (Workeneh, 2004; FAO , 2007) . These include Bako sheep ranch and Menz sheep ranch. However, most of them, including sheep ranches (Horro sheep ranch at Bako, Menz sheep ranch at Sheno and Amed-Guya Menz sheep multiplication centre) are closed with a disappearance of thousands of animals. Because, developing countries do not put conservation of animal genetic resources as a priority, mainly because their main goals are increased production and competitiveness in the global market in the short term (Kebede et al., 2016).

Chapter three: Materials and methods/research methods

Design of the Study

This dissertation was produced through a collection of inter related articles. Data collection was carried out for two years from September, 2017 to October, 2019 G.C. Different data collection techniques were used. Multiple-visit, multiple-subject survey with semi-structured questionnaire, body weight measurement of sheep at different age groups, body weight and linear measurements, blood sample collection from jugular vein of sheep, personal interview of sheep keepers and own flock sheep ranking experiments were used for data collection. Weighing scale(spring),,rope, textile meter,fertilizer bag,scissors,syringe,EDTA+ coated tube were tools used for data collection.

Description of study area

This study was conducted in three districts of northwestern Ethiopia: Burie, Mandura and Quara. Burie is in West Gojjam Zone and Quara is found in central Gondar administrative Zone of Amhara regional state of Ethiopia. Mandura is one of the seven districts of Metekel Zone in Benishanguel Gumuz regional state of Ethiopia (Figure 3.1).

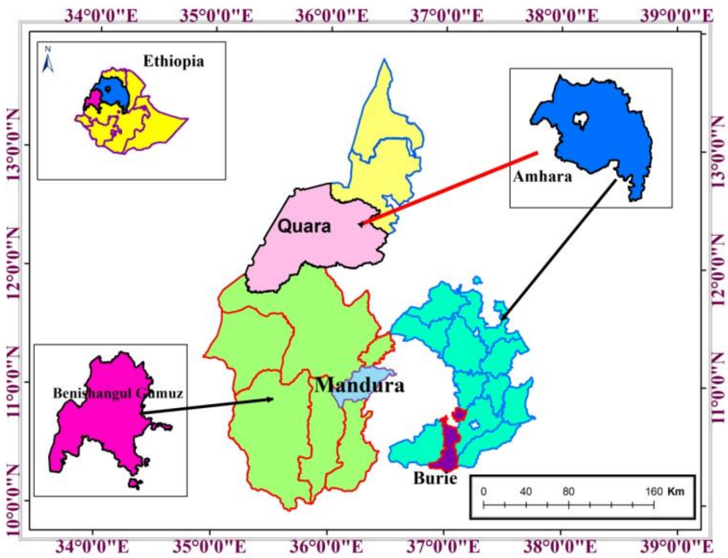


Figure 3.1 Map of the study areas

These districts were selected purposively targeting potential areas where sheep populations under study are found. Based on preliminary survey data on size of sheep populations collected by development agents (key informants), Washera, Gumuz and Rutana were predominant traditional sheep populations in Burie, Mandura and Quara districts, respectively. Burie district of West Gojjam Zone and Mandura district of Metekel Zone were used for studies compiled into **Articles I, II, III, IV and V**. Quara district in central Gondar administrative Zone of Amhara regional state where Rutana sheep is predominant, is used for studies compiled into **Articles I and IV.** Rutana sheep was not part of the study proposal and Rutana was included for comparison purpose or as an out-group for genetic diversity studies with Washera and Gumuz sheep and including information on production environment of Rutana sheep in paper I is belived to be important for the genetic diversity study. Moreover; ethinic conflict problem between kimant and Amhara was not enabling environment to include Rutana sheep in other chapters of the study.

Data collection tools/methods

Data collection was carried out for two years from September, 2017 to October, 2019 G.C. Different data collection techniques were used. Multiple-visit, multiple-subject survey (ILCA, 1990; FAO, 2012) with semi-structured questionnaire was used for collecting data for production system study. Body weight measurement of sheep at different age groups for growth performance study of sheep along with production and reproduction data collected from the recall of respondents for the reproductive performance study. body weight and linear measurements were taken from full-mouth sheep to study morphological feature studt and to generate body weight prediction formula for Gumuz and Washera sheep. Genetic diversity study was conducte by collecting blood samples from jugular vein of unrelated sheep. Personal interview of sheep keepers and own flock sheep ranking experiments were data collection techniques used for the study regarding designing sheep breeding proram.

Data collection method

After preliminary survey, three districts Burie, Mandura and Quara were selected by purposive sampling method based on sheep production potential. Similarly, three rural Peasant Associations (PAs i.e., smallest administrative units - Wanegedam, Daez Baguna and Dubaba) were selected by purposive sampling method from their respective districts. The key informants including the development agents and peasant association administrators were given training for building their capability to enumerate smallholders engaged in sheep production and how to fill questionnaires. To keep the proportionality of households between districts under study, the sampling frame proposed by FAO (2011) was used for sample size determination for all monitoring studies. However, sample size of individual sheep varies for each study based the availability of type of sheep required for each monitoring studies. For instance, for growth performance study, for measureing birth weight at the age of day one, the number of ewes giving birth at the commencement of the study is the determining factor to use the households size determined by the sampling frame partially or totally. For own flock sheep ranking experiment,out of the househods size determined by the sampling frame those having four ewes and above were considered for ranking first, second , third and inferior.

For the genome analysis, samples were collected from three districts of North Western Ethiopia namely; Buri, Mandura and Quara purposively representing Washera, Gumez and Rutana sheep populations, respectively. A total of forty five blood samples were collected from Washera, Gumez and Rutana sheep populations. To avoid sampling of closely related animals, the samples were collected from sheep of different households as unrelated as possible (**Article IV).** Own flock animal ranking method and personal interview were found to be the preferred methods to identify breeding objectives of Washera and Gumuz sheep. To collect the necessary data from target group sheep keepers, open ended questionnaire was administered. Trait preference of sheep keepers for Washera and Gumuz rams were conducted by home to home personal interview of 72 smallholders keeping Washera ram and 35 smallholders keeping Gumuz ram. For the own-flock ranking experiment , 72 households keeping Washera sheep and 44 households keeping Gumuz sheep owning four or more ewes were visited at their homesteads and were asked to select with reasons, the first best, second best, third best, and the most inferior ewes from their own flock (**Article V).**

Multiple-visit, multiple-subject survey was employed to collect primary data of respondents. Multiple visits of respondents were undertaken to collect data using questionaires for production system study, to measure body weight and linear body measures, to collect data on production and reproduction based on respondents recall , and to measure live body weight at different age groups (**Article I to III).**

Pre-tested semi - structured questionnaire were used for data collection on agro-economic conditions (farm household characteristics, resource endowment and uses, livestock demography, purpose of sheep production , breeding practices ,feeds and feeding, housing facilities, and health service) and challenges of sheep production. Data of livestock population were converted into tropical livestock unit (TLU) using conversion equivalents of sub-Saharan Africa livestock into TLU (**Article I).**

Live weight measurements were taken five times at the age of day 1, 90 days, 180 days, 270 days and 365 days. Live weight measurements were taken in the mornings, before the animals left the shelter to graze to avoid undesirable variations because of changes in rumen volumes. Lamb weight measurements were taken taking ethical and animal welfare into account. Suspended weighing scale, rope, tripod stick and soil fertilizer bags were used for measuring live weight of lambs. Concurrently, date of birth, birth weight, type of birth, sex of lamb, season of birth, lambing interval, age at first lambing, age at first mating, number of lambs born during life time of the ewe, reproductive age of the ewe, number of offspring produced, number of offspring weaned and ewe parity were calculated with different formula based on raw data collected from respondents recall. During the course of data collection, dams and lambs were managed to graze in communal grazing lands and crop aftermaths for an average of eight hour and supplemented with crop residues and *atella* (bi-product of local brewery) (**Article II).** Formal survey data was collected during the period between January and June, 2018. Data was collected by measuring live weight and linear measurements of 200 sheep in the mornings, before the animals left the shelter to graze to avoid undesirable variations because of changes in rumen volumes (FAO, 2012). On the basis of definitions suggested by FAO (2012) (Table 1), measurements of nine quantitative traits including body weight (BW), tail length (TL), ear length (EL), body length (BL), chest girth (CG), height at wither (HW), rump height (RH), canonical bone length (CBL), and head length (HL) were measured for both sexes with records taken to the nearest centimeters after restraining and holding the animal in an unforced position. Weighing balance of 50 kg and a textile measuring tape was used for collecting data of actual body weight and other linear measurements (**Article III)**.

Ewe traits of interest short listed by sheep keepers were coat color type, litter size, lamb growth, body size (conformation), lambing interval, number of weaned lambs and tail size. Following the shortlisting of traits, producers are enquired or encouraged to independently rank or assign scores to each trait or trait category without influencing the respondents in a predetermined format. Age, previous reproduction, and production information of the identified animals were inquired; live body weight and some linear body measurements were taken to assess the correlation between the farmers' rankings and the actual quantitative measurements taken on the animals. Traits of interest short listed by sheep keepers for rams were coat color type, conformation and libido and tail size for both traditional sheep populations. A total of 288 Washera ewes and 140 Gumuz ewes were ranked by their respective owner's and household members for preferring breeding objective traits. The methodological approach by live sheep ranking experiment and was calculated by index method. As used by Gizaw et al.(2014) six selection groups in one-tier cooperative scheme were used for simulation purpose using gene flow and selection index method. Rams selected produce rams (RM>RM), ewes selected produce rams (EW>RM), Rams selected produce ewes (RM>EW), ewes selected produce ewes (EW>EW), rams selected produce ewes in the production unit (RM>EP) and ewes selected to produce ewes in the production unit (EW>EP). Genetic dissemination was predicted to be through ram exchange among members of cooperatives (villages) and between villages. Two villages consisting of 99 (50 and 49) households of Washera and two villages consisting of 90 (45 and 45) households of Gumuz sheep keepers each household owning a flock size of five ewes and above were considered. In this study, only the cost of routine activities and fixed costs of housing were regarded as a cost parameter. The average population size of breeding ewes were based on flock inventory taken from each community member households during the own-flock ranking experiment. Information on reproductive performance was mainly obtained from the national literatures (Gizaw et al., 2007; Gizaw, 2009; Taye et al., 2011; Mekuriaw et al., 2013).

Four alternative selection scheme scenarios were used using selection index and gene flow method with varying selection proportion and time unit of ram use as implemented by Mirkena et al.(2012). We plan two scenarios of ram use for breeding (for one year versus for two years). The number of rams chosen was determined by the amount of ewes available for mating, with a male: female allocation ratio of 1: 30 (Haile et al., 2020). The proportion of selection commonly used is 10% (10%* candidate rams). Thus, we plan optimization of the schemes by increasing proportion of selection to 15 % (15%* candidate rams). Scheme 1. 10% selection proportion and 2 years of ram use for breeding, scheme 2. 10% selection proportion and 1 year of ram use for breeding, scheme 3. 15% selection proportion and 2 years of ram use for breeding, and scheme 4. 15% selection proportion and 1 year of ram use for breeding (**Article V).**

Blood samples were collected from three districts of North Western Ethiopia namely; Burie , Mandura and Quara purposively representing Washera , Gumez and Rutana sheep populations. A total of forty five blood samples, fifteen per sheep populations were collected. To avoid sampling of closely related animals, the samples were collected from sheep of different households. The selection of individual animals was done in such a way that each sheep are as unrelated as possible. Whole blood samples of individual animals were taken from the jugular vein and stored in a tube that contains the preservative and anticoagulant ethylene diamine tetraacetic acid (EDTA k+). The sample tube was identified with a permanent marker and the sampling form was filled at the time of sampling. The collected whole blood was refrigerated at -20 degrees centigrade's immediately after collection until DNA isolation. Genomic DNA were isolated from white blood cells of 15 samples from each populations (a total of

30 blood samples from three sheep populations) using the protocol of QIAGEN DNeasy kit with the higher DNA integrity. In a 2 milliliter micro centrifuge tube 20 µl proteinase K , 200 µl whole blood and 200 µl AL buffer were mixed together and vortexed for 20 seconds. After incubating the solution in a hot water bath of 56 ^{o}c for 10 minutes, 200 µl of ethanol alcohol of molecular grade were added. The solution was pipette into a DNeasy spin column and centrifuge for 1 minute at 10,000 rpm. After discarding the flow through and the tube, the spin columns were placed into a new 2 milliliter micro centrifuge tube. Then 500 µl AW1 buffer were added into each tubes and centrifuge for 1 minute at 10,000 rpm. Again, after discarding the flow through and the tube, the spin column were placed into a new 2 milliliter micro centrifuge tube and 500 µl AW2 buffer were added into the tubes and centrifuge for 3 minute at 15,000 rpm. The flow through and the tubes were discarded and the spin columns were transferred into a new 1.5 milliliter micro centrifuge tubes. The DNA was eluted by adding 200 µl AE buffer. After 5 minutes of elusion at room temperature, the eluted solutions of each sample were centrifuge for 1 minute and 30 seconds at 12,000 rpm. After discarding the spin columns, the 1.5 milliliter micro centrifuge tubes containing the DNA were put into ice for 30 minutes before measuring the concentration, quality at 260/280 and quality at 260/230 by adding 1 µl eluted DNA into NENOVIX Nano drop**.**

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Gel electrophoresis was conducted to check the integrity of the extracted DNA. We prepared agarose gel solution by mixing 1 gram agarose powder with 100 milliliter of 1 % TAE. The solution were heated for 2 minutes and 30 seconds and cooled down. One drop of gold view was added. The agarose TAE solution is poured into a casting tray that, once the gel solution has cooled down and solidified, creates a gel slab with a row of wells at the top by inserting and removing comb. The solid gel is placed into a chamber filled with TAE buffer. The gel is positioned so that the chamber wells are closest to the negative electrode of the chamber. A loading dye of 1 drop is used for every 2 µl DNA of samples and loaded to the gel chamber wells before the gel photographed by gel doc (**Article IV).**

Data analysis

The collected monitoring data on sheep husbandary practices and breeding practices were coded and entered into excel spread sheet. The data were analyzed using descriptive statistics such as mean, standard deviation, frequency and percent of statistical package for social science, SPSS version 20.0 (SPSS, 2011). Analysis of variance (ANOVA) was employed to evaluate the effect of district on family size. Chi-square tests were employed to test the independence between socio-economic features (sex of household, educational background, source of income and farming activity) and district. Data on purpose of keeping sheep, dry and wet season feed resources, selection criteria of breeding rams and ewes, challenges and opportunities of sheep production were prioritized by index method(Kosgey, 2004). Index = sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] divided by sum [3 for rank 1 + 2 for rank 2 + 1 for rank 3] for each purposes of keeping sheep and challenges and opportunities of sheep production (**Article I).**

Data on birth weight, weaning weight, six month and yearling weight at different age groups were collected and later converted to birth weight, adjusted weaning weight , adjusted 6 month weight , adjusted yearling weight, pre weaning and post weaning average daily weight gain . The data collected on growth and reproductive performance traits were arranged in an excel spread sheet. Ultimately, the data were analyzed using General Linear Model(GLM) univariate procedure of Statistical Package for Social Science for window version 20.0(2011) fitting non-genetic factors such as district (by default breed), sex of lamb, parity of the dam, season of birth and type of birth as fixed factor(s)(**Article II).** Descriptive statistics of data obtained from measurement of body weight and linear body measurements were analyzed using SPSS version 24.0(SPSS, 2016) to describe physical characteristics of Washera and Gumuz sheep populations. Similarly, the relationship between morphological features were analyzed following the procedure of bi-variate Pearson correlation and multiple regression. Regression analysis was conducted for Washera and Gumuz sheep separately for the two sexes and best fitted models with higher coefficient of determination(R) were considered for generating formala for body weight estimation.

The statistical model for linear multiple regression was written as follows:

$$Yi = b_0 + b_1x_{i1} + b_2x_{i2}+\ldots+ b_nx_{in}+e$$

Where:

y_i = the dependent variable (body weight in kg)

b_0= the intercept

Xi = are the independent variables; tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length , respectively(cm)

b_n = is regression coefficient of the variable *Xi*

e_j = the residual random error

(**Article III)**. Sheep population pattern within breeds related to genomic diversity such as observed (HO), expected (HE) heterozygosity and inbreeding coefficient were calculated using vcftools v 0.1.15. Principal component analysis was employed for population structure analysis (**Article IV).** Traits of interest for rams preferred by sheep keepers were analyzed using frequency procedure of Statistical Package for Social Science for windows, release 20.0 (SPSS, 2011). Based on short listed traits of sheep keepers, ewe trait preference was calculated by index method (Kosgey, 2004). Input parameters of two indigenous sheep breeds (Washera and Gumuz) were used for modeling ZPLAN and Fortran 90 computer program (William et al., 2008). For predicting genetic gains the following procedure was used : preparing (filling) the parameter file, preparing the NBILD-number subroutine, opening the z10.for , copying what is written in the NBILD and pasting it at the end of the z10.for.Then, going to build menu in the already opened FORTRAN : Compile z10.for , : Build z10.exe and Execute z10.EXE (**Article V).**

Validity and reliability test/ data trustworthiness

The primary data from sheep keepers and key informants were valid and were reliabile for the qualitative, quantitative and experimental study procedures of these studies and all data used for analysis work of this dissertation were collected and used honestly.

Research protocol with human/animal participants

Data collection formats and procedures were reviewed and agreed by the research ethics review committee of Debre Markos University, Ethiopia (Ref. number DMU 10/2019). The committee confirmed that these experiments were conducted according to established animal welfare guidelines. In addition, target group small holder farmers provided their verbal informed consent to participate in this study. Besides, the data were analyzed anonymously; ethnicity and religious issues were not asked or recorded during data collection.

Chapter four: Results/findings

Demographic features of Burie, Mandura and Quara districts were analyzed for a total of 324 households. There is no significant difference in family size across the districts at ($p<0.05$) level of significance. The majority of households investigated were male-headed households compared to widows and unmarried youths. Most of the respondents investigated were able to read and write. The ability of sheep keepers to read and write enables them to participate actively, in training and record keeping in the process of designing sheep breeding program. Chi-square test result reveals that the sex of the household, educational background, source of income and farming activities of respondents vary across the districts at high level of significance ($p<0.001$). This could be attributed to difference in educational facilities, health care facilities, market access, infrastructure , credit services and etc across the districts. Livelihood of families' of smallholders is supported by small land holding per households of Burie and Mandura districts. Mean ±SD values of land holding per household of Burie, Mandura and Quara were 1.03±0.89 ha, 2.66±1.61 ha and 11.46±5.76 ha, respectively. Purpose of keeping sheep for income generation ranked first across the districts. Major challenges of sheep production in Burie, Mandura and Quara districts were multitude of technical, institutional and socio-economic problems of sheep productivity. Feed shortage, disease and parasites, predator, lack of capital and labor shortage were the major challenges of sheep production. However, in Burie district, the establishment of Phi Bela and Rich land oil producing Agro-processing industries are good opportunies for the supply of Noug cake used as a supplement for sheep producers in and around the district. Flour milling agro-processing plant of Burie Damot cooperatives becomes also a good opportunity for Furiska and wheat middlings for sheep feeding. These agroindustries are belived to solve feed shortage partially which in the long run could be a good opportunity for the establishment of high input sheep production system.

Under such low input sheep production system, birth, weaning, six month and yearling weights of Washera sheep were 2.16±0.54 kg, 8.59±0.79 kg, 13.94±1.2 kg and 21.8±1.91 kg, respectively. Birth, weaning, six month and yearling weights of Gumuz sheep were 1.62±0.55 kg, 7.45±1.26 kg, 12.16±1.67 kg and 20.37±1.85 kg, respectively. Pre-weaning average daily weight gain of Washera (70 g/day) was found much better than 60 g/day of Gumuz. Breed , the interaction effect between breed and season of birth as well as the interaction effect between breed and type of birth all exerted very high significant effect (P<0.001) on live weight at all age groups. Breed type affected pre-weaning average daily weight gain significantly (P<0.01). Breed type also exerted significant (P<0.05) effect on age at first lambing, lambing interval, annual reproductive rate and number of lambs born per ewe life time. Average age at first lambing and lambing interval of Washera sheep were 11.69 months and 9.27 months, respectively. The corresponding values for Gumuz sheep were 12.51 months and 10.43 months, respectively. Production and reproduction performance values of traits varied across the two breeds and sexes. These values can be used as an essential step for setting up breeding goals for designing selective breeding program of sheep giving special emphasis to growth traits which are believed to have medium heritability values and a recorded higher genetic gain.

Mature body weight recorded for Washera and Gumuz sheep were 27.5, 26.89 and 38.71 kg, respectively. A multiple linear regression model fit was selected to explain body weight of full-mouth Gumuz female sheep based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length. Model two explains 55.0% variation ($R^2 = 0.55$) of body weight, and it is significantly useful in explaining body weight, $p < 0.001$. The two variables added statistically significantly to the prediction, $p < 0.05$. With one-unit increase in chest girth, the body weight increases by 0.26, which was found to be a significant change, $p < 0.001$. With one- unit increase in body length, the body weight increases by 0.27, which was found to be a significant change, $p < 0.001$. A multiple linear regression model fit was selected to explain body weight of full-mouth Gumuz male sheep based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , head length and scrotal circumference. Model three explains 62.0% variation ($R^2 = =0.62$) of body weight, and it is significantly useful in explaining body weight, $p < 0.001$. All three variables added statistically significantly to the prediction, $p<0.05$. With one- unit increase in tail length, the body weight increases by 0.57, which was found to be a significant change, $p < 0.001$. With one-unit increase in ear length, the body weight increases by 1.03, which was found to be a significant change, $p < 0.001$. With one- unit increase in body length, the body weight increases by 0.17, which was found to be a significant change, $p < 0.01$.

A multiple linear regression model fit was selected to explain body weight of full-mouth Washera female based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , and head length. Model four explains 54% variation ($R^2 = 0.54$) of body weight and it is significantly useful in explaining body weight, $p < 0.001$. All four variables added statistically significantly to the prediction, $p < 0.05$. With one-unit increase in tail length, the body weight increases by 0.31, which was found to be a significant change, $p < 0.001$. With one-unit increase in height at wither, the body weight increases by 0.20, which was found to be a significant change, $p < 0.001$. With one- unit increase in body length, the body weight increases by 0.11, which was found to be a significant change, $p < 0.01$. With one- unit increase in chest girth, the body weight increases by 0.10, which was found to be a significant change, $p < 0.01$. Similarly, regression model fit was selected to explain body weight of full-mouth Washera male based on tail length , ear length , body length , chest girth , height at wither , rump height , canonical bone length , head length and scrotal circumference. Model three explains 86.8 %($R^2 = 0.86$) variation of body weight, and it is significantly useful in explaining body weight, $p < 0.001$. All three variables added statistically significantly to the prediction, $p < 0.05$. With one-unit increase in tail length, the body weight increases by 0.82, which was found to be a significant change, $p < 0.001$. With one- unit increase in chest girth, the body weight increases by 0.92, which was found to be a significant change, $p < 0.001$. With one- unit increase in head length, the body weight increases by 0.38, which was found to be a significant change, $p < 0.001$.

As that of live weight, mean values of morphometric traits varied between sheep populations vary across sheep populations at very high significant level ($p<0.001$)

except for canonical bone length. These variations in phenotypic features between sheep populations need to be supplemented by molecular diversity study. The results from genomic diversity study elucidiates that polymorphic information content was 0.89, 0.90 and 0.88 for Gumuz, Rutana and Washera sheep, respectively. These values could be recognized as reasonably informative to carry out genetic diversity study. Expected heterozygosity was found to be higher than observed heterozygosity. Observed heterozygosity ranged from 0.33 in Gumuz to 0.34 in Rutana and Washera sheep. Expected heterozygosity (gene diversity) ranged from 0.37 in Rutana to 0.38 in Gumuz and Washera sheep. Higher inbreeding coefficient (0.12) was recorded for Gumuz sheep compared to 0.09 of Rutana and Washera sheep. This could be attributed to smaller population size and closed population (no immigration) was highly pronounced in Gumuz sheep compared to its counterparts.

As it is well known, community based sheep breeding program is belived to be genetic improvement interevention under low input sheep production system. For designing appropriate community based sheep breeding program, defining breeding objectives and identification of breeding objective traits need to be done first. Reasons for setting up priority were small, medium and large for body size. Low, moderate and high were reasons for prioritizing libido (sexual activeness). Brown, white, red, black, mixed black and white and mixed red and white were reasons for prioritizing coat color. Tail size was prioritized based on subjective judgment of its size as small, medium and large. Accordingly, smallholder's traits preference for Gumuz ram was calculated based on the frequency of respodent's vote for the traits of their interest giving reasons for their preference. Body size and libido were highly rated traits ranked first and second, respectively. Smallholder's traits preference for Washera ram was calculated based on the frequency of respodent's vote for the traits of their interest. Body size and tail size were highly rated traits ranked first and second, respectively. Body size (weight) and litter size were first and second best breeding objective traits of Washera ewe ranked by index method. Same breeding objective traits for Gumuz ewe were preferred with similar rank. Body size and litter size were first and second best traits. The result of this study indicates that average service age of a ram was 1.8 year and 2.5 year for Burie and Mandura districts, respectively. Thus, subsequent ram replacement is required every 1.8 year and 2.5 year for Burie and Mandura districts, respectively. Mode of ram replacement was from their own flock according to 75% of respondents, 17% from young lamb of neighbors and 8% by purchase from market in Burie district. In Mandura district, 66.66 % of respondents use their own ram while, 33.33% of them use ram from neighbors. Body size (conformation), libido and coat color were similar criteria for selecting breeding male (ram) of both Washera and Gumuz sheep. Increasing sale weight and the number of lambs qualifying for the market and homestead consumption were the suggested breeding objectives of Washera and Gumuz sheep keepers. Genetic gain per year for the single traits in one-tier cooperative village breeding scheme was predicted. Genetic gain predicted for six month weight of Gumuz and Washera sheep were 0.46 and 0.60 kg, respectively. Genetic gain predicted for yearling weight of Gumuz and Washera sheep were 0.58 and 0.66 kg, respectively. The predicted genetic gains per year for yearling weight of Gumuz and Washera sheep were greater than that predicted for six month weight and litter size because selection for six month weight enabled substantial genetic improvement on yearling weight. The highest percentage returns on investment from trait groups of Gumuz sheep was contributed by six month weight (SMW) accounting 39.89. The remaining percentage return from trait groups was contributed by yearling weight (YW) and litter size (LS) accounting to 60.11. The highest percentage return from trait groups of Washera sheep was contributed by six month weight accounting 40. The remaining percentage return from trait groups was contributed by yearling weight and litter size accounting to 60. In this study, for Gumuz sheep scheme 2 with higher monetary genetic gain for aggregate genotype of 0.27 ETB, return to investment of 1.86 ETB and profit/ewe/year of 1.71 ETB was preferred. Similarly, for Washera sheep scheme 2 with higher monetary genetic gain for aggregate genotype of 0.33 ETB, return to investment of 1.91 ETB and profit/ewe/year of 1.54 ETB was preferred.

Chapter five: Discussion and implications

In sub-Saharan Africa, traditional livestock production has been an important source of income for the rural poor. The most important contribution of AnGR diversity to current food production and food security – both at household and national level – probably lies in its role in enabling livestock to be raised in a wide range of production environments and in enabling production systems to better withstand shocks such as droughts and disease outbreaks. It also contributes to the production of more nutritionally diverse food products. This diversity is mainly at species level. However, breed-level differences do exist and have begun to attract some research attention (FAO, 2015). Phenotypic and molecular characterizations of sheep genetic resources are used to measure and describe genetic diversity in these resources as a basis for understanding them and utilizing them sustainably (FAO, 2012; Asefa et al., 2017). There is need to better acknowledge the unique features of these breeds and, their products, socio-cultural and, religious uses, and their production systems (FAO, 2014). Description of the production system is particularly relevant in developing regions where farm animals are kept under diverse production systems and for multiple uses (Gizaw et al., 2011). Purpose of keeping sheep for income generation ranked first across the districts and provides social security in the bad crop years (IBC, 2004; Getachew et al., 2010).The purpose of keeping sheep for income generation prioritized in the current study was in line with Kosgey et al. (2008) and Fikru and Gebeyew (2015) report. Earlier reports (IBC, 2004; Getachew et al., 2010) also stated that income generation was ranked first by smallholders keeping sheep in different districts of Ethiopia. In Burie and Mandura districts keeping sheep for saving was ranked second due to the fact that sheep together with other livestock species are considered as the living banks of the smallholders. Keeping sheep for household meat consumption ranked third in Burie and Mandura districts and ranked second in Quara district. This household meat consumption was supposed to meet major part of the average annual per capita meat consumption of 8 kg/year (Sebsibie, 2008). Frequency of male-headed households were 162(82.6), 68(73.9) and 32(88.8) for Burie, Mandura and Quara districts, respectively. Although womens and children play greater role in managing sheep, the majority of households investigated were male-headed households compared to widows and single (unmarried females) engaged in sheep production. Most of the respondents investigated were able to read and write with higher frequency. Mean ±SD values of land holding per household of Burie and Mandura were 1.03±0.89 ha and 2.66±1.61 ha, respectively. Land holding per household of smallholders in Burie district was less than 1.31 ha of Amhara region and 1.44 ha of West Gojjam Zone of Amhara regional state of Ethiopia. But, it is comparable to 1.18 ha of the country average (CSA, 2008). Land holding per household of sheep keepers in Burie district and Mandura district was also less than 5.9 hectare (Dagnawu et al., 2017) per household of Gumuz sheep producers in Metema district. This small land holding leads to pasture land scarcity aggravating feed shortage. This supports the result of this study. In that, feed shortage becomes the major challenges of sheep production followed by diseases and parasites. The first and second order ranking of feed shortage, disease and parasites indicates the need for improvement of non-genetic factors affecting sheep production prior to improving the genotype. This helps to get the opportunity of making use of adaptive and compatibility advantage of indigenous sheep to feed shortage, disease and parasites problems. Improving these challenges of sheep production (feed shortage, disease and parasites) than genotype could help to be beneficiary from the socio-economic advantage of indigenous sheep which was found feasible for goats (Ayalew et al., 2003). Ayalew et al.(2003) stated that the non-genetic improvement strategies – better feeding practices and greater attention to basic healthcare were more successful than genetic strategies alone to bring productivity and genetic improvement of goats faster than the genetic factor. Considering amount of land tenure as level of inputs, sheep husbandary practices of Burie and Mandura districts can be classified as low input (IBC, 2004). Labor shortage in Burie and lack of capital in Mandura districts were also criteria to classify sheep husbandary practice as low input. In all the districts under investigation, according to respondents' frequency, sheep house was constructed by extending to residential house. This traditional housing system coupled with little utilization of supplementary feed, contribute to classification of sheep husbandary practice to be low input and traditional type.

Under such low input and traditional sheep husbandary practice, the growth and reproductive performance values for traits of Washera and Gumuz sheep were comparable to other Ethiopian and African breeds/ecotypes. The variations between minimum and maximum values of growth and reproductive performance traits indicated the presence of within breed variation. The observed variations in values of growth and reproductive performance were essential steps for setting up breeding schemes of sheep. For selection within and among indigenous sheep populations, it is recommended to give special consideration to growth rate traits which are believed to have medium heritability values. Because of their strong correlations with production traits such as meat and milk production, traits such as body weight, chest girth, body length and height at withers are used as proxy indicators of the production traits (FAO, 2012). Live weight and growth rate are economically critical features, requiring particular attention in any breeding program intended to improve overall productivity since lambs are mainly raised for mutton (Tibbo, 2006; Abegaz, 2014). Body weights of Washera and Gumuz recorded by the current study were less than 32.8 kg and 31.0 kg of earlier report by Gizaw et al.(2007). The decrease in body weight could be attributed to shrinking pasture land for grazing as a result of urbanization and population growth and it could be due to genetic erosion. Body weights recorded for Washera and Gumuz by the current study were far below 40 to 50 kg (Awgchew & Abegaz, 2008) of traditionally maintained mature Awassi ewe. However, according to Ayele and Urge (2019), even slaughter body weight of Washera can be improved up to 52 kg by various types of supplementation.

When selecting the ideal slaughter time for a breed of sheep raised for meat, body weight estimation is crucial (Sabbioni et al., 2020). Regression formula generated by the current study to predict body weight was performed by using the highest number of linear body measurements ranging from two to four. This is in accord to Sabbioni et al.(2020). According to Sabbioni et al.(2020), the best model fits were obtained when the highest number of body measurements of Cornigliese sheep breed was included in the model. The retention of heart girth as predictor variable of body weight for Gumuz female, Washera male and female sheep by this study was in accord to Tesfaye Getachew (2008), selecting chest girth as a predictor variable of body weight for Afar and Menz sheep in Ethiopia. Similarly, Thys and Hardouin

(1991) reported heart girth as prediction variable of body weight for Poulfouli sheep. Selection of chest girth as a predictor variable of body weight by the current study was also in agreement to Birteeb and Ozoje (2012). Birteeb and Ozoje (2012) compared both linear and quadratic models for predicting body weight and they stated that among the linear body measurement traits, heart girth was the best predictor of live weight irrespective of the breed or age of the West African long-legged and West African Dwarf sheep in northern Ghana.

Phenotypic characterization of sheep needs to be supplemented by genetic diversity study. Genetic diversity is a measure of genetic differences between animals in a population (i.e. genetic variation). To make sure that a breeding program remains viable in the future it is essential to monitor and maintain genetic diversity (Oldenbroek & van der Waaij, 2014). We evaluated the genetic diversity of Gumuz, Rutana and Washera sheep populations using observed heterozygosity (H_O), expected heterozygosity (H_E), and inbreeding coefficient (F_{IS}). The mean values of observed and expected heterozygosity across all loci on studied sheep populations were in line with studies carried out on Horro, Wollo, and Farta breeds (Amane et al., 2020). Mean observed and expected heterozygosity values of the current study were higher than that of the values reported by Edea (2017) for Adilo, Arsi-Bale, Blackhead Somali and Horro sheep. The variation in mean values of observed and expected heterozygosity might be attributed to the difference in the number of SNP data sets used (50k versus whole genome). In that, higher number of SNP data sets could be obtained by whole genome sequence data than low and medium density SNP markers. Mean inbreeding coefficient ranged from 0.09 of Rutana and Washera to 0.12 of Gumuz. The higher inbreeding coefficient of Gumuz sheep coupled with smaller population size, nearly 50,000 (Gizaw et al., 2008) makes the breed endangered. As genetic improvement intervention, Gizaw et al.(2008) ranked Gumuz sheep (considered to be endangered) second next to simien sheep for conservation priority .Recent studies (Edea et al., 2017; Amane et al., 2020; Ahbara et al., 2021) were conducted to assess the ancestral relationships among Ethiopian and global sheep breeds using phylogeny tree, principal component analysis (PCA), and Bayesian model based population structure analysis. These scholars reported that the population structure of Ethiopian sheep populations, including the breeds of the current study here follows a clear pattern of tail morphology, phylo-geography, and environmental adaptation (altitude or temperature).

Our whole-genome SNP analysis revealed moderate within breed variationas or heterozygosity as implemented by canon et al.(2006). Within breed variation found by the current study was in line with Deribe(2020) report stating that there was genetic variation between and within fat and thin tailed populations in the Amhara region of North Gonder (Metema and AbraJira woredas) and Western Administrative zones (Kafta Humera Woreda) of the Tigray regional state of Ethiopia. There was high variation within individuals across all populations of Begayit, Gumz Rutana, Afar, SSFT, and Tumele sheep populations based on low density SNP analysis. Hence, conservation based selective breeding can be carried out using economically important traits of each breed. Designing the appropriate sheep selection scheme requires identification of breeding objective traits. The decisive step in the designing of village breeding programmes is the identification of breeding objective traits and their relative importance (Woldu, 2016). The minimum effective population size of these study districts were 87-125 for Washera and 79-114 for Gumuz. Effective population size of both breeds/ecotypes was greater than 50, and concurs with Rai (2003) suggesting that for persistence of a population, the minimum effective population size should not be smaller than 50 breeding individuals. In order to keep a breed vigorous and sustainable it is necessary that the population is not too small or too inbred (Zonabend, 2016). As it is well known, selective breeding is believed to be genetic improvement intervention for sheep with small population size like Gumuz (Gizaw, 2008). Desighing sheep breeding program is an intervention for managing genetic diversity in which definition of breeding objectives and breeding objectives traits are crucial. Breeding objectives can be defined through personal interview , participatory own flock live animal ranking experiment and by developing bio-economic models as implemented by Gizaw et al. (2010) , Mirkena(2012), Haile et al.(2011) and Edea et al.(2012). Meat production trait (body size or body weight) and litter size (reproductive trait) were prioritized traits of sheep keepers which are positively correlated, although the correlation is weak to moderate. Awgichew and Abegaz (2008) suggest that where small ruminants are kept primarily for meat production, selection will be on the number and weight of offspring weaned per female per year. The selected breeding objective traits of Washera and Gumuz sheep concur with breeding objective traits of eastern Ethiopia indigenous sheep populations (Nigussie, 2015). Body weight or body size was heritable with medium heritability value of 0.29 (Safari et al., 2005). Litter size was selection criteria with low heritability value of 0.10 (Safari et al., 2005). These traits were prioritized as selection criteria for Gumuz ewe with weak genetic correlation coefficient value, r =0.25 (Safari et al., 2005; Lobo et al., 2009). Similarly , body weight or body size and litter size were traits prioritized for selecting Washera ewe with moderate correlation coefficient value, r = 0.25 (Safari et al., 2005; Lobo et al.,2009) . Phenotypic correlations were found to be positive for selective breeding using the two defined breeding objective traits at once. The positive correlation between the prioritized traits indicates that selection for one trait improves the other trait through correlated response. Breeding objectives or goals of smallholders identified by the current study were improving sale weight (24 kg at yearling age) and the number of lambs qualifying for the market and homestead consumption under low input crop-livestock mixed farming systems of highlands and lowlands of northwestern Ethiopia.

One - tier structure of village or community based breeding program was proposed since setting up and maintaining a nucleus flock under village sheep breeding management condition was difficult (Haile et al., 2011; Gizaw et al., 2014). From sheep selection schemes perspective, we planned and evaluated four alternative sheep selection schemes and the best possible option was chosen. The selection of appropriate sheep selection scheme was undertaken by evaluating the selection response out put of each scheme obtained from running ZPLAN computer program (William et al., 2008). Genetic gain per year for the single traits in one-tier cooperative village breeding scheme was predicted. Genetic gain predicted for six month weight of Gumuz and Washera sheep were 0.46 and 0.60 kg, respectively. These genetic gains were greater than to 0.12 kg of Menz sheep flock (Gizaw et al., 2014) organized by similar one-tier cooperative village breeding scheme. Genetic gain predicted for yearling weight of Gumuz and Washera sheep were 0.58 and 0.66 kg, respectively. The corresponding predicted values were 0.44 kg, 0.89 kg, 0.94 kg and 0.69 kg for Afar, Horro, Bonga and Menz sheep, respectively with 10 % selection intensity and 2 years of ram use for breeding (Mirkena et al., 2012). Genetic gain predicted by Mirkena et al.(2012) for yearling weight were 0.41 kg, 0.87 kg, 0.88 kg and 0.63 kg for Afar, Horro, Bonga and Menz sheep, respectively with 15 %

selection intensity and 2 years of ram use for breeding. The predicted response for yearling weight of Washera and Gumuz sheep by this study were greater than that predicted for Afar sheep but less than from Horro, Bonga and Menz sheep (Mirkena et al., 2012). This might be attributed to difference in genetic improvement interventions and extention service delivered is less than for Afar area. The predicted genetic gains per year for yearling weight of Gumuz and Washera sheep were greater than that predicted for six month weight and litter size because selection for six month weight enabled substantial genetic improvement on yearling weight. In addition, the greater genetic gain per year predicted for six month weight and yearling weight than litter size was attributed to the higher heritability values of six month weight and yearling weight (Safari et al., 2005). The slow genetic progress in litter size of this study for Gumuz and Washera sheep is in line with earlier report (Safari et al., 2005; Mirkena et al., 2012) for Afar, Horro, Bonga and Menz sheep. The slow genetic progress in litter size is attributed to low heritability and low genetic correlations with growth rate traits (Safari et al., 2005). Genetic gain predicted for litter size of Gumuz and Washera sheep was 0.08 and 0.09 lambs, respectively. This predicted genetic gain is greater than to response to selection of 0.0013 lambs of Menz sheep in a simulated village-based selection program (Gizaw et al., 2014). The predicted monetary genetic gain per year for aggregate genotype predicted for Gumuz and Washera sheep was 0.24 ETB and 1.05 ETB, respectively. The predicted monetary genetic gain of Gumuz sheep was less than 5.66 ETB for Menz sheep (Gizaw et al., 2014). The predicted monetary genetic gain of Washera sheep was greater than 5.66 ETB for Menz sheep (Gizaw et al., 2014). The highest percentage returns on investment from trait groups of Gumuz sheep was contributed by six month weight (SMW) accounting 39.89. The remaining percentage return from trait groups was contributed by yearling weight (YW) and litter size (LS) accounting to 60.11. The highest percentage return from trait groups of Washera sheep was contributed by six month weight accounting 40. The remaining percentage return from trait groups was contributed by yearling weight and litter size accounting to 60. The returns on investment from trait groups of Washera and Gumuz sheep contributed by six month weight was in agreement with Gizaw et al.(2014).

Designing between village selection schemes two involving two villages with the highest selection proportion (P=10 %) and ram use for one year was found appropriate. Selection proportion (P=15 %) and ram use for one year breeding has been proposed by Mirkena et al.(2012). Mirkena et al.(2012) suggested that rams should be used only for a single year in a given ram-group flocks and then exchanged with a distant ram-group. This will serve at least two major purposes. It minimizes inbreeding and creates genetic links across different flocks.

Chapter six: Conclusions, and future directions /recommendations

General conclusions

A comprehensive evaluation of productive and reproductive performance, morphological features, genomic diversity and designing sheep breeding scheme as demonstrated in a series of studies in this dissertation revealed the tremendous potential of indigenous Ethiopian sheep breeds for improved productivity considering the following conclusions:

Purpose of keeping sheep for income generation ranked first across the districts. Keeping sheep for saving ranked second in Burie and Mandura, due to the fact that, sheep together with other livestock species are considered as the living banks of the smallholders. Keeping sheep for household meat consumption ranked third in Burie and Mandura districts and ranked second by respondents of Quara district. Feed shortage, disease and parasites and lack of input were prioritized as major challenges of sheep production. Although it is tedious and time consuming, the body weight of sheep measured using hanging/spring weighing scale indicates that body weight of Gumuz and Washera sheep were found comparable. Two to four linear body measurements were retained as predictor variables of body weight for the two sexes of Gumuz and Washera sheep. For body weight prediction formula, two for each breeds were generated where chest girth were included in the model fit for Gumuz female, Washera female and Washera male.

There exists variation in growth and reproductive performance traits between Washera and Gumuz sheep populations. The average daily weight gain of Washera is greatre than that of Gumuz sheep

Our whole-genome sequence data analysis revealed that the SNP datasets were moderately or reasonably informative to study genetic diversity. The result of genetic diversity study revealed moderate within breed gene diversity and higher rate of inbreeding. In addition, smaller proportion of breeding rams coupled with small flock size found to be the major problems leading to smaller effective population size and a higher rate of inbreeding. Maintainng the gentic diversity and increasing the population size might be interventions to protect loss of genetic diversity and bring genetic improvement by designing appropriate sheep breeding program. Designing appropriate sheep breeding program requires identification of breeding objective traits. Smallholder farmers prioritized highly rated and positively correlated traits. Body size/weight and litter size were prioritized breeding objective traits where by default meat production was supposed to be breeding objective of Washera and Gumuz sheep Keepers. The predicted genetic gains per year for yearling weight of Gumuz and Washera sheep was promising. In that, the predicted genetic gains per year for yearling weight of Gumuz and Washera sheep were greater than that predicted for six month weight and litter size. After comparing the genetic responses of alternative selection schemes, selection scheme 2 with 10% selection proportion and one year ram use for breeding found to be the best alternative. Two-tier selection schemes where found appropriate by which ram sharing among farmers is found to be the means for genetic dissemination.

Limitations

Further population differentiation (between breed genetic variability) was not well addressed by this study due to time constraint and this study was planned to be revised by including other indigenous sheep populations(outgroups).

Future directions/recommendations

Based on the results of the present study, uncovered areas of studies could be addressed based on the following proposed recommendations:-

- It is recommended that sheep producers need to utilize by-products from Phi-Bela and Rich Land agro-processing inductries as a supplement feed resources in Burie district. As one type of inputs for sheep production, this contributes for smallholders to exercise a high-input, high-output and modern type of sheep production.

- Selective breeding within the adapted indigenous breeds is the best possible option for genetic improvement using positively correlated traits (body weight and litter size).

- The information obtained will be used as an input for designing sheep selective breeding programs for breeds with high rate of inbreeding and for managing the recorded moderate genetic diversity.

- Sheep breeding schemes need to be optimized to maintain the existing high rate of inbreeding at minimum risk. Two tier breeding schemes were recommended where the selected villages being breeding units and the adjacent villages and PAs being production units. A sheep breeding program with 10% selection proportion and one year ram use for breeding was recommended to be designed giving special emphasis to yearling weight with higher predicted genetic response.

Chapter seven: References

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Chapter eight: Appendices

Appendix A: Tables

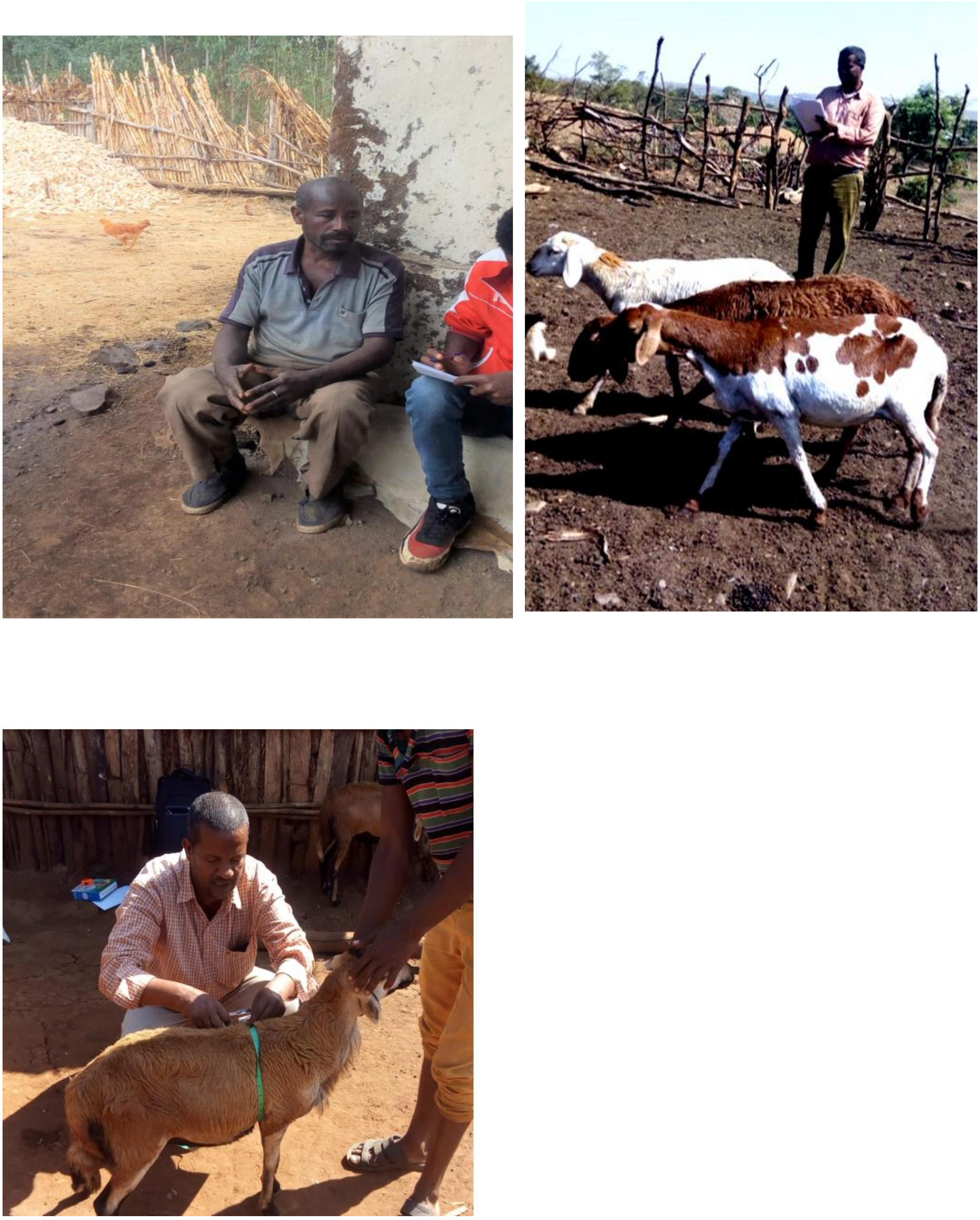
Appendix A: table 1. Estimates of age of sheep and goats from dentition

Stage	Age (year)	Characteristic change on teeth
Lamb	under 1 year	8 sharp milk incisors
Yearling	1–2 years	central pair of permanent incisors
Young	adult 2–3 years	2 pairs of permanent incisors
Adult	3–4 years	3 pairs of permanent incisors
Mature	4–5 years	4 pairs of permanent incisors
Old	over 5 years	without teeth and some missing

Source : FAO,2012

Appendix B: Figures

Appendix B: figure 1. Survey data collection

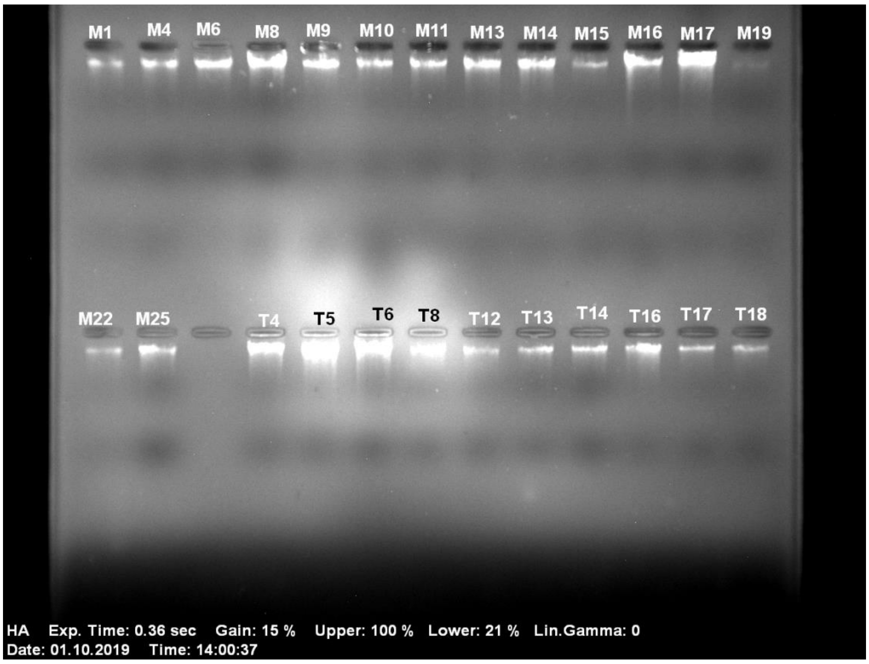


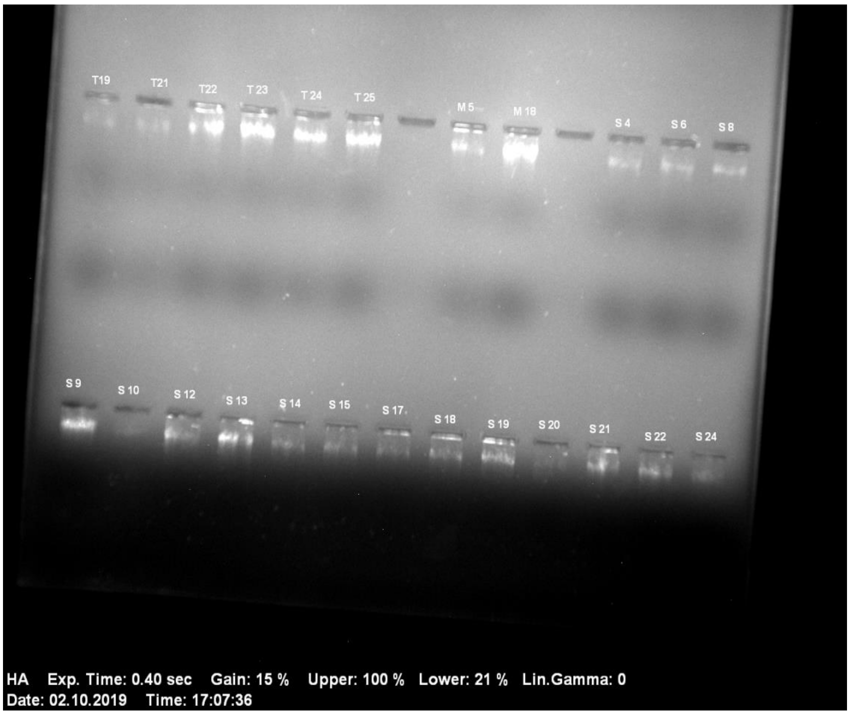
Appendix B: figure 2. Data collection on sheep quantitative and qualitative traits

Appendix B: figure 3. Local sheep Gumuz (upper left), Washera (upper right), and Rutana (bottom center)

Appendix B: figure 4. Personel interview during sheep breeding objective identification

Appendix B: figure 5. DNA extraction in ILRI laboratory, Addis Ababa, Ethiopia





Appendix B: figure 6. Photo of purified DNA after agarose gel electrophoresis

Appendix *C*: Questionnaire

Enumerator Name ____________
Code_______________Region________Zone__________District __________________ Kebele ______________ Date ____________________________

Notes to the enumerator

1. Politely introduce yourself to farmers/pastoralists.
2. Tell them briefly the objective of the study.
3. Administer questionnaires politely.
4. The respondents should be thanked for his/her time.
5. Record the response carefully.

Fill the responses in the space provided or mark alternative response (s) where appropriate with an „X".

A. General information about the area

1. Name of head of the family______________________________

2. Sex

1. Male ☐ 2. Female ☐

3. Age_____

4. Education back ground

1. Literate ☐ 2. Illiterate ☐ 3. Read and write ☐

5. If your answer is literate, what is your grade? ________

6. Marital status

1. Married ☐ 2. Single ☐ 3. Divorced ☐ 4 . Widow ☐

7. How many family members do you have? Total_________ Male_____ Female_______

8. What is your family livelihood (source of income)?

1. Agriculture ☐ 2. Trade ☐ 3. Employee ☐

4. other(specify)__________________ ☐

9. What is your major farming activity?

1. Crop ☐ 2. Livestock ☐ 3. Both ☐

10. What is your family total area of land? Local measurement________= _______ha

Crop land_________________ Local measurement = ________ha

Fallow land________________ Local measurement= ________ha

Grazing land_______________ Local measurement= ________ha

Other specify______________ Local measurement= ________ha

11. Please tell us species of livestock you have and their numbers?

11. Please tell us species of livestock you have and their numbers? Species	Number
Cattle	
Goat	
Sheep	
Donkey	
Mule	

Horse	
Camel	
Poultry	
Bee hive	

12. Please tell us the number of sheep you have at different age?

Class	Number
Ewes (> 1 years)	
ram (> 1 years)	
Young Female (< 1 years)	
Young ram (< 1 years)	
lambs (< 6 months)	
Castrated	

13. What are the major objectives of sheep production in your family? (Give rank in their importance)

Use	Tick	Rank (Top three)
Income		
Home consumption (Meat)		
Saving		
Wealth status		
Manure		
Skin		
Other (specify)		

14. Household Income contribution of different farming activities (in ranking order)

Farming activities	Rank
Goat production	
Cattle production	
Field crop production	
Sheep production	
Apiculture	
Vegetable production	

15. Which species of livestock are more important for your livelihoods (in ranking order)?

Species	Rank
Cattle	
Goat	
Sheep	
Equine	
Poultry	
Bee	

B. Reproductive performance (Specific to Gumz and washera sheep)

1. What is the average age of 1st mating of female sheep? _____________
2. What is the average age of 1st mating of male sheep? _______________
3. What is the average age of 1st lambing? ____________________
4. Do you fix age at first mating for the females?
   1. Yes ☐ 2. N o ☐
5. Do you fix age at first mating for the males?
   1. Yes ☐ 2. No ☐
6. What is the average lambing interval? ______________________________
7. What is the frequent type of birth?
   1. Single ☐ 2. Twin ☐ 3. Triple ☐
8. How long the average reproductive age of the ewes? _______________Year
9. How many lambs are born in the life time of one ewe? ____________

10. Please tell us the months where frequent lambing is happening. Month	Tick	Rank (Top three)
September		
October		
November		
December		
January		
February		
March		
April		
May		
June		
July		
August		

C. Mating and breeding management

1. Do you have your own ram?
   1. Yes ☐ 2.No ☐

2. If your answer is no, where do you get ram?

1. From neighbors ☐ 2. By rent ☐ 3.Other (specify) ____________

3. If yes, how many ram do you have?_________

4. If you have more than one, why do you need to keep more than one?____________

5. How your ram give mating service?

1. For my flock only ☐ 2. For my flock and neighbors ☐ 3. Rent out ☐

4. Not fixed ☐

6. Is their any special management for breeding ram? 1. Yes ☐ 2. No ☐

7. If yes, specify type of management? _______________________________

8. What is your purpose of keeping ram?

1. Mating ☐ 2. Socio-cultural ☐ 3. Fattening ☐

4. Other Specify ______________________________

9. How long the same ram give service in flock? __________

10. How mating is practice in your sheep flock?

1. Mixing of ram with ewes ☐ 2. Introduction of ram with fixed ☐ time

3. Other (specify)___________________

11. Do you practice control mating?

1. Yes ☐ 2. No ☐

12. If you answer is yes, how?

1. Introduction of ram at fixed time (ram isolation) ☐

2. Castrate unwanted ram ☐ 3. Others (Specify)______ ☐

13. If your answer is no, why?

1. Sheep grazes together ☐ 2. Lack of ram ☐

3. Lack of awareness ☐ 4. Other specify _____________

14. Where do you get replacement ram?

1. From young lambs of my own flock ☐ 2. From young lambs of other flock ☐

3. Purchased from market ☐ 4. Others (specify)

15. With what time interval do you replace your ram ?

16. Do you select best female sheep as parent of the next generation within your sheep?

1. Yes ☐ 2. No ☐

17. If your answer is yes, what are your selection criteria for female sheep (ewes)?

Criteria	Tick as mentioned	Rank (Top three)
Size/ appearance		
Color		
Lamb growth		
lamb Survival		
Lambing frequency		
Twining ability		
Mothering ability		
Milk yield		

Age at first maturity		

18. Do you select best male sheep as parent of the next generation within your sheep?

1. Yes ☐ 2. No ☐

19. If your answer is yes, at what age?________

20. If your answer is yes, what are your selection criteria for male sheep (ram)?

Criteria	Tick as mentioned	Rank (Top three)
Appearance/conformation		
Colour		
Horns		
Character		
Growth		
Libido		
Ability to walk long distance		
Age at first maturity		
Pedigree		
Adaptability		

21. Do you allow a ram to mate his

	Yes	No	Reason
1. Mother	☐	☐	________________
2. Daughter	☐	☐	________________
3. Sister	☐	☐	________________

22. Do you allow your ram to serve ewes other than yours?

Reason

1. Yes ☐ ________________

2. No ☐ ________________

23. Do you allow your ewe to be served by anyone else ram?

Reason

1. Yes ☐ ________________

2. No ☐ ________________

24. Do you practice sheep castration?

1. Yes ☐ 2. No ☐

25. If your answer is yes what are the reasons?

1. Control mating ☐ 2. Fattening ☐

3. Better Temperament ☐ 4. Others (specify)____ ☐

26. At what age do you castrate your sheep? _________

27. At what season do you castrate your sheep?

1. Wet season ☐ 2.Dry season ☐ 3. Anytime ☐

28. Do you provide special feed for castrated sheep?

1. Yes ☐ 2. No ☐

29. If your answer is yes, what type of feed you provide and how long?

Type of feed	length of time
1. ______________________________	________________________
2. ______________________________	________________________
3.______________________________	________________________

30. What type of method you use for sheep castration?

1. Traditional ☐
(specify)____
2. Modern ☐
(specify)____

D. Culling

1. Do you practice culling of female sheep?

1. Yes ☐ 2. No ☐

2. If your answer is yes, what is the reason?

1. Disease ☐ 2. Old age ☐ 3. Sterility ☐
4. Poor physical condition ☐ 5. Low milk yield ☐
6. Poor mothering ability Other(specify)__________________

3. Do you practice culling of male sheep? 1. Yes ☐ 2. No ☐

4. If your answer is yes, what is the reason?

1. Disease ☐ 2. Old age ☐ 3. Poor physical condition ☐
4. Bad color ☐ 5. Poor libido ☐ 6. Poor horn ☐

5. At what age ewe and ram culled?

1. Ewe_________ year 2. Ram ________year

E. Market

1. What is average market age of male sheep? ______________
2. What is average market age of female sheep?_____________
3. Which class of sheep do you sell first in case of cash needed?

Class	Rank
Male lamb (<6 month)	
Female lamb (<6 month)	
Male (6 to 12 months)	
Female (6 to 12 months)	
Breeding ewe	
Breeding ram	
Old ewe	
Castrated	

F. Feeds and Feeding

1. What are the major sheep feed resource in your area?

Feed Resource	Dry season	Rank(Tope 3)	Wet season	Rank (Tope 3)
Communal grazing				
Private grazing land				
Grazing after math				
Grazing fallow land				
Crop residue				
Cut grass and				
Improved forage				
Concentrate				
Hay				
Enbaz				
Atella				
Other (specify)				

2. What are the grazing methods in your area in different seasons?
3. Do you provide concentrate for your sheep?
   1. Yes ☐   2. No ☐

4. If your answer is yes, what type of concentrate and for which type of sheep?

Type of concentrate	Class of sheep				Name	Rank
	lambs	ewe	ram	Castrate		
Grazing Methods						
Free grazing						
Herded						
Cut and carry						
Tethering						
Home made grain						
Bran						
Oil seed cake						
Embaz						
Atella (local brewery by product)						

5. When do you provide concentrate for your sheep?
   1. Dry season ☐ 2. Wet season ☐ 3. Both ☐ 4. Other ☐
6. If you don’t provide concentrate feed, what are the reasons?
   1. Expensive ☐ 2. Not Available ☐ 3. Not want to offer ☐

4. Other(specify)_-------

G. Housing

1. What type of shelter do you have for your sheep?

1. No shelter ☐ 2. Separate house for sheep ☐
3. Shelter constructed in side main house ☐
4. Shelter constructed expansion of the main houses. ☐
5. Open barn ☐ 6. Other ☐

2. Are lambs housed together with adult sheep?

1. Yes ☐ 2. No ☐

3. Are sheep housed together with other animals?

1. Yes ☐ 2. No ☐

4. If your answer is yes which type of animals housed together with sheep?

1. Goats ☐ 2. Cattle ☐ 3. Equine ☐ 4. All ☐ species

H. HERDING AND OTHER MANAGEMENT ACTIVITIES

1. How are your sheep herded during grazing time?

1. With other species ☐
2. Separately ☐
3. No control ☐

2. If they are herded separately; in which season and the reason?

Season	**Reason**
1.__________________	__________________________
2.__________________	__________________________

3. If they are graze together with other species, with what species, when and reason?

Type of species		**Season**	**Reason**
1. Cattle	☐	_________________	________________
2. Goat	☐	_________________	________________
3. Equines	☐	_________________	________________
4. All species	☐	_________________	________________

4. Do you practice mixing of your sheep flock with other flocks?

1. Yes ☐ 2. No ☐

5. If your answer is yes, how many household mix their sheep together? ________

I. Health

1. Please specify (describe) the major sheep disease, their symptoms, season of occurrences, and cultural treatment (please include the predator)

Local name of disease	symptoms	Season of occurren ces	Reason of occurrenc es	Is it contagiou s	Which age group mostly affecte	Local treatm ent	Service provide by govern ment

					d		

Service: 1.Vaccination 2. Diagnosis 3. Treatment 4. Others (Specify)

2. Do you get vaccination service for your sheep?

1. Yes ☐ 2. No ☐

3. If your answer is yes, when the service is given?

1. When disease out brake occur ☐ 2. Any time in a year ☐
3. Before disease out break ☐ 4. Others (specify)

____

4. Where you get medicine and vaccination?

1. Agricultural office ☐ 2. NGO ☐
3. Private veterinary house ☐ 4. Others (specify)

5. How many sheep are died in the last year (Previous 12 months) in your flock?

Category	Number of death	Reason of death			
		Disease	Predator	Mech anical	Others (specify)
Ewe					
Ram					
Young ewe					
Young ram					
lambs					
Castrate					

L. Product utilization

1. Do you slaughter sheep for household consumption?

1. Yes ☐ 2. No ☐

2. If your answer is yes how frequent?

1. For festivals ☐ 2.Whenever slaughter age animals available ☐
3. Wedding ☐ 4.Births in family ☐ 5.For guests ☐
6. Circumcise ☐ 7. At funeral ☐ 8.Others,

3. Which sex you usually slaughter?

1. Intact Male ☐ 2. Female ☐ 3. Castrate ☐

4. What is the average age of slaughter? Male ________ Female_________

5. Do you practice weaning? 1. Yes ☐ 2. No ☐

6. Average weaning age of lambs?

1. < 3 months ☐
2. 3–4 months ☐
3. 5–6 months ☐
4. > 6 months ☐

M. Gender and Labour Source for Sheep Production

1 Comparison of gender role in sheep production

2. Which gender plays a great role in sheep production?

1. Male 2. Female 3. Both almost equally

3. -Do you use daily laborers for sheep production?

1. Yes 2. No

4. If no, reasons for not hiring labor for sheep production

1. Have enough labor 2.Too expensive 3. No labor for hiring 4. Others

5. Rank[2] the responsibility of the household for the following activities

Activities	Adult male	Adult female	Children Male	Childre female	Other family members	Hired Labor
Herding						
Cleaning sheds						
Caring for lambs/kids						
Feeding and watering						
Selling products						
Breeding decisions						
Purchasing and selling						

[2] Rank: 1. Most 2. More 3. Medium 4. Low 5. Not at all 6. Others

N. Production constraint

1. What are the major problems of sheep production in your area? (Rank according to their severity)?

Constraint	Tick as mentioned	Rank (Top three)
Disease		
Feed shortage		
Water Shortage		
Labor shortage		
Market problem		
Predator		
Genotype		
Lack of input		
Lack of extension service		
Drought		

Thank you very much!

Appendix *D*: Author's biography

The author of the present dissertation, Sisay Asmare Belachew, was born in 1971 G.C in Merawi town, West Gojjam Administrative Zone of Amhara Region. He has attended and completed Elementary, Junior Secondary and High school educational levels in Merawi. After joining the then Alemaya University of Agriculture, currently Haramaya University in 1987, he completed his first degree in Animal science granted in 1991 G.C. Then he has served his country by working in different governmental organizations. He has serving in Ministry of Agriculture offices of West and East Gojjam Administrative Zones of Amhara Region in different responsibilities, as an instructor in Burie ATVET College, as an expert in Metekel ranch, for more than 20 years. Then he joined Bahir Dar University to continue his M.sc program in 2008/09 G.C and completed his M.sc degree in Animal Production and Technology in 2010 G.C. After serving as instructor in Burie ATVET College and Debre Markos University, he joined Bahir Dar University to pursue his PhD study in 2016 G.C. The author after completing the course work, he carried out a research on 'Quantifying genetic diversity and designing community - based breeding program for indigenous sheep in Northwestern Ethiopia' for partial fulfillment of the requirements for the degree of Doctor of Philosophy in Animal Genetics and Breeding.