Community-based sheep breeding programs in Ethiopia generated substantial genetic gains and socio-economic benefits

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Short title: Community-based sheep breeding in Ethiopia

Abstract

In small ruminants, Community-based breeding programs (CBBPs) have been suggested as an alternative to centralized government-controlled breeding schemes which were implemented in many developing countries. An innovative methodological framework on how to design, implement and sustain CBBPs was tested in three sites/breeds (Bonga, Horro and Menz) in Ethiopia. In our CBBPs, selection traits identified through participatory approaches were six-month weights in all the three sites, and in Horro and Bonga, where resources, particularly feed and water, permit larger litter sizes, twinning rate was included. Ten years (2009-2018) performance data from the programs were analyzed using Average Information Restricted Maximum Likelihood method (AI-REML). Additionally, socio-economic impact of CBBPs were assessed. Results indicated that six months weight, the major selection trait in our CBBPs, increased over the years in all breeds. In Bonga, the average increase was 0.21 ± 0.018 kg/year, followed by average increase of 0.18 ±

0.007kg/year in Horro and 0.11 ± 0.003 kg/year for Menz. This is quite substantial in an on-farm situation. The birth weight of lambs has not improved over the years in Bonga and Horro sheep. In Menz, there is significant increase. Given that we have not selected for birth weight in the community flocks we did not expect genetic change. However, there could have been a positive effect through correlated responses which was not the case in Bonga and Horro sheep. In Horro and Bonga sheep, where twinning rate was one of the selection traits, litter size increased over the years: 15.4% in Bonga and 11.6% in Horro. This increase combined with the increased six months body weight has increased income (20 percent) and farm-level meat consumption (from slaughter of one sheep per year to three). The results show that CBBPs are technically feasible, result in measurable genetic gains in performance traits and impact on the livelihood of farmers.

Key-words: body weight; genetic trend; litter size; sheep; local breeds

Implications

Community-based breeding programs (CBBP) are an attractive option to achieve genetic improvement of small ruminants in low input systems. A clear methodological framework on how to design and implement CBBPs ensures the technical feasibility of the programs. The paper provides evidence of measurable genetic gains and the contribution of CBBP’s to socio-economic benefits for rural poor.

Introduction

In developed countries and in high input animal production systems, animal breeding has been traditionally supported by the state and implemented by well-organized national breeding programs. Data recording, provision of the recorded data to a data processing center, estimation of breeding values with complex statistical methods and central decisions about the use of male breeding animals are important elements of such breeding programs.

In developing countries, the required supportive infrastructure is largely unavailable, so attempts to replicate ‘developed-country’ approaches have met with little success (Kosgey *et al.,* 2006). The most common approach implemented in many developing countries, has been centralized breeding schemes, entirely managed and controlled by governments – with minimal, if any, participation by farmers (Haile *et al.,* 2011). These centralized schemes, usually a nucleus breeding unit, established at a central station were run by a governmental organization attempting to undertake all or part of the complex processes and breeding strategy roles (i.e. data recording, genetic evaluation, selection, delivery of genetic change, and feedback to farmers). Although well intended, these centralized schemes failed to sustainably provide the desired genetic improvements to smallholders (continuous provision of a sufficient number and quality of improved males) and also failed to engage the participation of the end-users in the process.

Another widely-followed strategy has been importing improved commercial breeds in the form of live animals, semen, or embryos. These are usually crossbred with the local and ‘less productive’ breeds to upgrade them, but in most cases, it is done without sufficient pretesting of the appropriateness (suitability and adaptability) of the exotic breeds and their resulting crosses to local production systems or conditions and without a clear strategy what the final genotype would be. Where indiscriminate crossbreeding with the local populations has been practiced, genetic erosion of these local populations and breeds has occurred.

An alternative approach is a community-based breeding program (CBBP). Programs that adopt this strategy consider the farmers' needs, views, decisions, and active participation, from inception through to implementation, and their success is based upon proper consideration of farmers' breeding objectives, infrastructure, participation, and ownership (Mueller, 1991; Sölkner *et al.,* 1998; Haile *et al.,* 2011; Wurzinger *et al.,* 2011; Mueller *et al.,* 2015).

The International Center for Agricultural Research in the Dry Areas (ICARDA), the International Livestock Research Institute (ILRI), and the University of Natural Resources and Life Sciences (BOKU), in partnership with the Ethiopian National Agricultural Research System, have implemented CBBPs in Ethiopia since 2009. CBBPs have also been implemented in Mexico and Argentina with goats, in Bolivia with Llamas, and in Uganda and Malawi with goats. The goal was to improve the productivity and income of these small-scale resource-poor sheep producers by providing access to improved animals that respond to improved feeding and management, facilitating the targeting of specific market opportunities.

This paper evaluates the success of three sheep CBBPs in Ethiopia, namely Bonga, Horro and Menz using the following parameters:

- growth and reproduction performance of Ethiopian sheep breeds kept under CBBPs;
- genetic progress achieved in CBBPs; and
- the socio-economic impact of CBBPs on communities.

Materials and methods

Description of the sites and breeds

The CBBPs were set up in three locations (Bonga, Horro and Menz) of Ethiopia representing different production systems and agro-ecologies. Two pilot communities from each location were identified (Table 1). Bonga is located in southwest Ethiopia about 460 km from Addis Ababa, with altitudes ranging from 1,000 to 3,400 meters. The mean maximum and mean minimum temperatures in Bonga area are 24°C and 12°C, respectively. Bonga breed is a sheep type characterized with wide and moderately long tail. Both males and females of the breed are mostly polled, have long ears and short and smooth hair (Edea *et al.,* 2009). The breed is judged as good for traits like growth rate, meat quality, fattening potential, twinning rate and temperament (Edea *et al.,* 2009). The prominent farming system in the area is mixed crop-livestock production.

Horro is located in the western Ethiopian mid-highland region (i.e. 1,600 to 2,800 m altitude) about 310 km from Addis Ababa. Horro is believed to be closer to the epicenter of the Horro sheep breeding tract. Horro sheep is a fat-tailed hair-type sheep with bigger growth potential compared with other indigenous breeds in Ethiopia. Farming in the Horro area is dominated by mixed crop-livestock system (Edea *et al.,* 2009).

Menz is located in the Ethiopian highlands at about 280 km north-east of Addis Ababa, with an altitude range of 2,700 to 3,300 m.a.s.l. The Menz area is considered as the epicenter of distribution of the Menz breed. The Menz breed is one of the few coarse woolly fat-tailed sheep types, adapted to the high altitude precipitous terrain with scarcity of feed and where production of crop is limited due to extreme low temperature and drought, in the cool highlands. This is a hardy small breed, which controls the level of internal parasite infection and is productive under low input production circumstances of the degraded ecosystems (Getachew *et al.,* 2010).

Methodological framework for establishment of CBBP

Implementation of the sheep CBBPs in the three locations started in 2009 involving more than 8,000 heads of sheep. There are six communities in the three locations. Each community has on average 60 households (Table 1). A governmental research organization is associated with each of the project sites. Local enumerators were recruited for each community to help the research system in animal identification and recording. Indigenous knowledge of the community is considered at each phase of the project. For example, the community decides how rams are managed and how they are shared and used. The core in this program is to get community members working together in ram selection, management and use.

Two stages of selection have been applied: initial screening when traditionally premature sales of young rams occur (4– 6 months) and final selection for admission to breeding at 12 months of age. Selection at the first stage is based on lambs adjusted6 months weight and twinning rate of ewes (except for Menz). Additionally, yearling weight and conformation were considered in the final selection. All young rams are collected at one central place in each community on an agreed screening date. Selection is then carried out based on the estimated breeding values.

A breeding ram selection committee composed of about 3–5 members elected by the community are involved in the selection. If for example 15 rams were to be selected from 100 candidates, 20 would be preselected based on their breeding values and the committee ranks the selected rams culling the last five. The committee checks at the conformation, coat colour, presence or absence of horn, horn type, tail type and other criteria in decision making. The number of rams to be selected depends on the number of ewes available for mating (we allocate male to female ration of 1 ram to 30 ewes) and the replacement rate required.

Setting up CBBPs follows the same basic steps and principles as that of conventional breeding programs (Figure 1).

The major difference as detailed in Mueller *et al.* (2015) is that CBBP uses a participatory approach, unlike the conventional breeding strategies, which involves the communities who keep the animals from the initial inception of the program to implementation and final ownership of the scheme.

Data recorded and analysis

For the biological data, we developed data recording formats to collect data from each household. Data analyzed included birth weight, six months weight and litter size. Data size for yearling weight was too small to be included in the analysis.

Least squares analysis (SAS, 2002) was carried out to study performance of sheep and examine fixed effects. The fixed effects fitted for the weights were: year of birth (10 classes: 2009-2018); lambing season, grouped into three classes, based on the pattern of annual rainfall distribution in the area (November-February: dry period; June to October: wet season; March to May: short rain); sex (two classes: male and female); and birth type (three classes: single, twin, triple). For litter size the fixed effect of year of lambing was considered. A fixed effect model was fitted. The Tukey–

Kramer test was used to separate least squares means with more than two levels.

The Average Information Restricted Maximum Likelihood method (AI-REML) of WOMBAT (Meyer, 2007), fitting univariate animal models for each trait was used to estimate breeding values. WOMBAT assesses whether an analysis has converged, based on the following criteria: 1) a change in log L of $< 5\times10^{-4}$, 2) a change in parameters of $< 10^{-8}$ and 3) a gradient vector norm $<10^{-3}$.

Analysis Model:

$$Y = X\beta + Z_1a + Z_2m + Z_3pe + e$$

Where Y is a (Nx1) vector of observations; β, the vector of fixed effects of contemporary groups, birth type, birth year, sex of animal related to incidence matrix X; a, the vector of direct genetic effects, related to incidence matrix Z_1; m, the vector of maternal genetic effects, related to matrix Z_2; pe, the vector of maternal permanent environmental effects, related to matrix Z_3; and e, the vector of random residuals.

The genetic trend was estimated by the weighted regression of the average breeding value of the animals on the year of birth.

For the socio-economic evaluation, data from both primary and secondary sources were used. Survey was used to collect detailed primary data in March and April 2015. The survey was conducted in the two sheep breeding communities, in each site, as well as in two sheep-keeping communities not involved in CBBP in each site for comparison purposes. Simple random sampling was used to draw 40 sample farmers from each of the participant and non-participant households and hence the survey was administered on a sample of 80 farmers in each of the project sites. This gave a total sample size of 240 farmers from the three sites Participatory rural appraisals (PRA), key informant interviews, and informal discussions were also collected to have further understanding of the socioeconomic impact of the breeding programs in respective sites. Secondary data included biological data collected by the project, and publications and reports of the project.

Descriptive statistics were used to analyse primary data collected through the survey. Statistical significance tests were used to see if there was significant variation between members of the breeding cooperatives and non-members as well as within members of the cooperatives.

Results and Discussion

Growth performances of the sheep flocks

Growth and reproductive performances of sheep flocks in CBBPs have not been reported in literature. The performance found in our study for six months weight (21.60±0.20, 16.5±0.54 and 14.0±0.04 for Bonga, Horro and Menz sheep, respectively; Table 2) were better than results (16.7±0.20 (MoA, 2018), 14±2.93 (MoA, 2018) and 10.7±2.2 (Gizaw *et al.,* 2007) for Bonga, Horro and Menz sheep, respectively) obtained for the same breeds under station management condition. This is obviously an improvement achieved due to CBBPs. Growth performances from stations are normally expected to be better than on farm condition. However, to our surprise, we found the growth levels of lambs from CBBPs to be higher than those reported from on-station conditions. Inferiority of the on-station growth of lambs could possibly be because of two reasons: first, the perceived better feeding and management of sheep on station condition does not necessarily happen and is influenced by many factors. In CBBPs, through repeated training and awareness, owners care for their animals and therefore feed and manage them better than the traditional smallholder management system. Second, some of the stations (for example for Horro and Menz) are located out of the breeding tract of the populations. Therefore, there could be an issue of genotype by environment interaction.

Weight differences for the different sexes were all significant ($p<0.01$) except for six months weight in Menz (Table 2). For both Bonga and Horro, males were heavier than females at birth and six months of age. Whereas, in Menz, although males were heavier than females at birth, this difference was lost ($p>0.05$) at six months. Many reports in literature (for example Tibbo, 2006; Saghi *et al.,* 2007) concur with our observations that favour male sheep which could obviously be related to inherent physiological variations.

Birth type had significant ($p<0.01$) effect on weights (both birth and six months weight) of all sheep. Single born lambs had heavier weights at all ages than twins and triplets. Sheep in Menz give birth to singles in most cases and this trait was not considered.

Season of birth is also significant source of variation for both birth and six months weight of sheep. In Bonga and Horro, weights in the long rainy season are inferior to those of the dry and short rainy season. Lambs born in the dry season in Horro had better weights than those born in the wet season ($p<0.01$). This is indeed unexpected as more feed is believed to be available in the rainy seasons. Indeed, for birth weight, better feeding in the wet seasons might have resulted in bigger lambs at birth in the dry season.

Genetic trends in growth performance

The birth weight of lambs has not improved over the years in Bonga and Horro sheep (Table 3 and Figures 2 and 3). In Menz, there is significant increase (Figure 4). Given that we have not selected for birth weight in the community flock we did not expect change. However, through correlated responses there could have been effect, but that was not found in Bonga and Horro. The lack of increase in birth weight in Bonga and Horro is particularly advantageous because improvement in this trait beyond a particular level may be associated with dystocia and loss of productivity. Thus, care should be taken when undertaking selection in birth weight. Indeed, many studies (Gürsoy *et al.,* 1995; Duguma *et al.,* 2002; Gizaw and Joshi, 2007) have shown that genetic correlation between birth weight and later weights is weak. Therefore, selection for each trait could be effected independently of the other and selection for weaning weight or gain would not increase birth weight.

For all the three sites, six months weight, the major selection trait in our community-based breeding programs, increased ($P<0.05$) over the years (Table 3; Figures 2, 3 and 4). In Bonga the average increase was 0.21±0.018kg/year, followed by average increase of 0.18±0.007kg/year in Horro and 0.11±0.003kg/year for Menz. This is quite substantial in an on-farm situation. The increases were more pronounced in larger framed breeds (Horro and Bonga) compared to Menz sheep, which is relatively small.

Genetic responses in selective breeding experiments have been reported in many studies. For example, in an experiment set up to evaluate the response of Menz sheep to selection for yearling live weight, it was evident that substantial response was observed (Gizaw *et al.,* 2007). Positive changes have also been reported by Martha and Dana (2008) for purebred Tsigai, improved Valachian and Lacaune sheep in Slovak Republic; by Javed *et al.* (2013) for Lohi sheep of Pakistan; by Arora *et al.* (2010) in Malpura sheep of India. However, these reports have all referred to on station performance; there are no reports from on-farm, community managed flocks.

Prolificacy

Prolificacy, defined as the number of lambs born per ewe lambing is strongly influenced by management decisions, but is also of paramount economic importance. Prolificacy increased ($p<0.01$) over the years in both Bonga and Horro flocks (Table 4). The increase was 15.4% in Bonga and 11.6% in Horro. Prolificacy is one of the selection traits in both sites and its increase over years is expected. Where resources, particularly feed and water, permit improvement in prolificacy substantial impact in sheep production could be expected. With the new genomic tools, faster genetic gains and introgression of genes in to new population could be done. For this to happen, it is of paramount importance that we investigate novel and known genomic regions affecting fertility/prolificacy in these populations. Previous studies have identified causative genetic variants with major effects associated with reproductive traits linked to prolificacy especially ovulation rates and litter size in sheep (see review by Davis, 2005). Most of these studies, which have identified the causative variants in three major prolificacy genes, *GDF9*, *BMPR1B* and *BMP15*, located on ovine chromosomes (Oar) 5, 6 and X (Davis 2005), respectively, have involved Eurasian breeds of sheep. New variants are continuously being discovered in other breeds suggesting variations between breeds (see Lassoued *et al.,* 2017). Therefore, we will investigate mutations for prolificacy in Bonga and Horro sheep breeds.

Inbreeding and heritability estimates

One of the major challenges in smallholder sheep and goat management is the high risk of inbreeding because of smaller flock size and uncontrolled mating. CBBPs aim at reducing the effect of inbreeding through controlled mating, ram rotation and increase in flock size by bringing households who own small flock sizes together. The estimated inbreeding coefficients we obtained in our analysis (<1%; Table 5) confirm our proposition in that the levels recorded over years for all breeds were lower than the critical level of 6.25% (Li *et al.,* 2011). Many studies, for example, MacKinnon (2003) in a closed population of crossbred sheep (ranged from 2.2% to 3.8%), Pedrosa *et al.* (2010) in Santa Inês sheep of Brazil (2.33%), Ghavi Hossein-Zadeh (2012) in Moghani sheep of Iran (2.93%) have reported higher inbreeding coefficients than ours. In our CBBPs, rams mate in one mating group for one year and are rotated to another. Additionally, rams remain in breeding for 2 years and are either sold as breeding animals to communities far from the CBBP sites or are sold for slaughter. These measures have assisted in reducing inbreeding coefficients and therefore inbreeding is not of an immediate concern. However, the inbreeding coefficient needs to be monitored continuously to prevent significant decrease in growth performance. It is also advisable that rams with the lowest relationship with ewes in the flock are used for mating to decrease the rate of inbreeding in the population.

Heritability estimates, both additive and maternal, for birth weight and six months weight were moderate to high, except for Menz sheep where low (0.07±0.027 and

0.06±0.032, additive heritalilities for birth and six months weights, respectively) heritabilities were recorded (Table 6). The moderate to high heritability estimates for growth traits indicate that sufficient additive genetic variance exists for these traits that could be used for selection within the population as has been done in our CBBPs. Heritability estimates for growth traits are generally moderate to high (Duguma *et al.,* 2002; Gizaw *et al.,* 2007; Muhammad *et al.,* 2010; Mekuriaw and Haile, 2014). However, these reports, unlike ours, are all based on on-station management where environmental variances are expected to be minimal. Our favorable on-farm results where larger environmental influences on growth performances are expected are commendable and point to the within genetic variability that could be exploited through selection. These populations have never gone through systematic selection before we set up CBBPs and the high heritability indicated the high genetic variability expected to exist in non-selected populations.

Socio-economic impacts of CBBP: Income and consumption

The potential impact of the CBBP on farmers' market participation and sheep meat consumption was explored. Market participation of CBBP participants measured by the number of sales per year was higher than non-participants and the variation was statistically significant (Table 7). The comparatively higher market participation by members of the CBBP could be attributed to the observed variation in flock size and performance of sheep kept by members of the CBBP.

Slaughtering sheep for household consumption is also more common among CBBP participants and the variation was statistically significant (Table 8). This variation could be again explained by the flock size and performance difference reported. Discussion with members of CBBP participants also revealed that farmers, particularly in Menz and Horro, usually slaughter sheep for consumption during important (religious) festivities. It is also important to consider the fact that initial selection of CBBP participants had favoured better-off households as only farmers with a sheep flock size of greater than or equal to four were considered for membership.

The majority of CBBP participants reported that consumption of mutton in the household had increased after the introduction of CBBP, but there were a considerable proportion of households with no change in mutton consumption (Table 8). A possible explanation for increased mutton consumption could be that the breeding program resulted in increased productivity and hence income from sheep production and consumption of mutton increased.

A comparison of annual mean income from sheep production revealed that participants of the CBBP earned Ethiopian Birr 3,100 (1USD= 20.5 Ethiopian Birr in June 2015) per household, per year, on average, while non-participants earned Birr 2,486 (Table 9). The difference between CBBP participants and non-participants was statistically significant ($P<0.05$) in Bonga and Menz, but not in Horro. It was also confirmed by the PRA work with CBBP participants that income from sheep keeping has improved. The positive impact of the CBBP on farmers' income explains the huge interest of non-members to join the breeding cooperatives. However, interpretation of the figures should be carefully considered as these income data were recorded from farmers' memory recall. In the CBBPs biological data are being recorded but no financial records are kept.

Conclusions

In the three study sites, CBBPs were found to be technically feasible to implement, economically rewarding, as reflected in increased income and meat consumption, and result in substantial genetic gain in biological traits. The level of inbreeding was found to be within the acceptable limits because of our managerial interventions. Therefore, where centralized breeding programs fail, we strongly recommend implementing CBBPs for sheep and goats particularly in low-input systems like those of the Ethiopian highlands.

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Declaration of interest

The authors declare that they have no conflicts of interest.

Ethics statement

ICARDA doesn’t have ethics committee. However, this study is based on data collected from a breeding program and no ethical concerns.

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Table 1. Number of households and mean flock size in the different locations

Location	Community	№ of HH when CBBPs started	Current number of HH	Average flock size when CBBPs started	Current average flock size
Bonga	Boqa	63	149	9.4	12.8
	Shuta	64	151	7.5	10.1
Horro	Gitlo	59	66	18.4	18.8
	Lakku-Iggu	63	69	16.5	12.5
Menz	Mehal-Meda	64	63	22.7	25.7
	Molale	58	54	16.5	26.9

Table 2. Least squares means (± SE) for effects of birth season, lamb sex and birth type on birth weight (BWT) and six months weight (SWT) for Bonga, Horro and Menz sheep

Effect level	Bonga		Horro		Menz	
	BWT (kg)	SWT (kg)	BWT (kg)	SWT (kg)	BWT (kg)	SWT (kg)
N	8389	3298	3426	885	6269	4799
Overall	3.29±0.012	21.60±0.20	2.51±0.037	15.9±0.27	2.75±0.011	14.0±0.04
CV%	12.86	15.96	20.96	16.01	28.62	19.02
Birth season	***	***	***	NS	NS	**
Long rain	3.28±0.014 [a]	21.3±0.22[a]	2.55±0.039 [a]	16.5±0.54	2.76±0.015	14.1±0.05[a]
Dry	3.26±0.016 [b]	22.0±0.22 [b]	2.49±0.039 [b]	16.2±0.54	2.74±0.017	13.8±0.06[b]
Short rain	3.35±0.016 [c]	21.5±0.23 [a]	2.50±0.042 [a,b]	16.5±0.58	2.74±0.024	14.2±0.09[a]
Sex	***	***	**	**	**	NS
Male	3.34±0.014	22.9±0.21	2.55±0.038	16.7±0.54	2.81±0.013	14.0±0.05
Female	3.24±0.014	20.3±0.22	2.47±0.039	16.1±0.54	2.69±0.018	14.0±0.07
Birth type	***	***	***	***	NA	NA
1	3.57±0.007[a]	23.4±0.09[a]	2.66±0.009[a]	17.3±0.40[a]		
2	3.28±0.007[b]	21.3±0.10[b]	2.53±0.012[b]	15.9±0.41[b]		
3	3.03±0.037[c]	20.0±0.60[c]	2.34±0.094[b]	16.0±1.16[b]		

** P<0.01; NS P>0.05; different letters in the same column within effect represent statistical differences (P<0.05); NA not applicable

Table 3. Estimated average breeding values (± standard error) over years for birth and six months weight in Bonga, Horro and Menz CBBPs

	Bonga		Horro		Menz	
	BWT (kg)	SWT (kg)	BWT (kg)	SWT (kg)	BWT (kg)	SWT (kg)
Overall	0.005±0.0022	0.38±0.050	0.010±0.0069	0.62±0.022	0.018±0.001	0.26±0.011
2009	0.010±0.0110	0±0.231	-0.001±0.001	0±0.071	-0.001±0.0042	0±0.026
2010	0.020±0.0102	-0.04±0.217	0.001±0.0038	0.07±0.044	0.002±0.0030*	0.11±0.019
2011	-0.003±0.0065	0.41±0.231	0.028±0.0036*	0.59±0.039	0.012±0.0033*	-0.05±0.028
2012	0.007±0.0075	0.61±0.146	0.045±0.0078*	0.83±0.088	0.021±0.0033*	0.24±0.022
2013	0.004±0.0053	0.56±0.078	0.004±0.0062	1.32±0.069	0.021±0.0034*	0.22±0.023
2014	0.004±0.0042	1.1±0.055	0.002±0.0043	1.27±0.052	0.021±0.0036*	0.45±0.02
2015	-0.002±0.0043	1.62±0.06	-0.005±0.0042	1.13±0.043	0.023±0.0034*	0.39±0.02
2016	-0.015±0.0042*	1.24±0.07	0.003±0.0041	1.19±0.055	0.039±0.0033*	0.73±0.02
2017	-0.002±0.0046	1.45±0.095	0.011±0.0075	1.23±0.096	0.020±0.0041*	0.84±0.033
2018	0.026±.0063*				0.024±0.005*	0.87±0.078

Table 4. Least squares means (± standard errors) for litter size for the Bonga and Horro flocks over the years

Year	Bonga	Horro
Overall	1.56±0.011	1.37±0.008
Year	**	**
2009	1.42±0.041	1.29±0.029
2010	1.44±0.038	1.38±0.016
2011	1.55±0.029	1.34±0.015
2012	1.57±0.040	1.37±0.033
2013	1.58±0.024	1.32±0.026
2014	1.59±0.020	1.36±0.018
2015	1.61±0.019	1.38±0.017
2016	1.58±0.020	1.42±0.017
2017	1.59±0.022	1.44±0.031
2018	1.64±0.030	

** $P< 0.01$

Table 5. Inbreeding level over years in Bonga, Horro and Menz sheep flocks

Year	Inbreeding (%)		
	Bonga	Horro	Menz
Overall	0.34±0.044	0.24±0.037	0.31±0.038
2009	0.00±0.210	0.00±0.137	0.00±0.137
2010	0.21±0.194	0.10±0.076	0.00±0.097
2011	0.00±0.124	0.29±0.072	0.28±0.106
2012	0.14±0.144	0.26±0.157	0.17±0.112
2013	0.56±0.100	0.23±0.123	0.40±0.116
2014	0.57±0.081	0.33±0.085	0.53±0.107
2015	0.81±0.080	0.91±0.084	0.10±0.107
2016	0.28±0.081	0.00±0.082	0.60±0.105
2017	0.26±0.087	0.00±0.151	0.58±132
2018	0.53±0.120		0.48±0.171

Table 6. Genetic parameter estimates for Bonga, Horro and Menz sheep flocks

Genetic parameters	Bonga		Horro		Menz	
	BWT	SMWT	BWT	SMWT	BWT	SMWT
σ_a^2	0.06	5.75	0.04	4.19	0.03	0.28
σ_m^2	0.02	4.87	0.01	1.10	0.017	0.014
σ_{am}	-0.03	-4.08	-0.02	-1.15	0.01	-0.03
σ_{pe}^2	0.02	0.86	0.0261	0.35	0.001	0.002
σ_{res}^2	0.11	4.46	0.2144	2.92	0.37	4.64
σ_{pheno}^2	0.19	11.85	0.278	7.14	0.42	4.90
h_a^2	0.29±0.047	0.49±0.067	0.16±0.040	0.59±0.109	0.07±0.027	0.06±0.032
h_m^2	0.12±0.053	0.41±11.05	0.04±0.053	0.15±0.126	0.03±0.037	0.003±0.049
r_{am}	-0.74	-0.77	-0.80	-0.66	0.39	-0.52
h_T^2	0.15	0.17	0.09	0.42	0.10	0.048
Pe^2	0.12 ±0.035	0.07±0.073	0.09 ±0.040	0.05 ±0.083	0.003±0.032	0.0002±0.036

σ_a^2 = Direct additive variance, σ_m^2 = maternal additive variance, σ_{am} = direct-maternal additive genetic co-covariance, σ_{pe}^2 = variance of permanent environment due to dam as proportion of phenotypic variance, , σ_{res}^2 = residual variance, σ_{pheno}^2 = total phenotypic variance, h_a^2 = direct animal heritability, h_m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, h_T^2 = total heritability, Pe^2 = permanent maternal environments

Table 7. Number of sheep sold and consumed during the last year by CBBP members and non-members

Number of sheep	CBBP	Median	p-value for Mann-Whitney U test
Sold in a year	Participant	5	0.004
	Non participant	3	
Slaughtered for consumption in a year	Participant	3	0.000
	Non participant	1	

Table 8. Distribution of CBBP participants by consumption of mutton after the start of the breeding program

Consumption of mutton in the household after the program	Frequency	Percent
Increased	60	52.6
No change	46	40.4
Decreased	8	7
Total	114*	100

*this figure represents CBBP participants

Table 9. CBBP participants' and non-participants' mean annual income from sales of sheep

Site	CBBP	Mean annual income (Ethiopian Birr)	p-value for Mann-Whitney U test
Bonga	Participants	2,697 ± 2,080	0.03
	Non-participants	1,637 ± 1,561	
Horro in Gitlo	Participants	2,488 ± 2,277	0.25
	Non-participants	2,233 ± 3,272	
Menz in Molale	Participants	4,116 ± 2,512	0.02
	Non-participants	3,587 ± 4,685	
Total	Participants	3,100 ± 2,408	0.00
	Non-participants	2,486 ± 3,489	

1 USD= 20.5 Ethiopian Birr in June 2015

Figure 1. *Steps for setting up CBBPs*

Figure 2. Genetic trend of body weight at birth (left) and six months of age (right) in Bonga sheep

Figure 3. Genetic trend of body weight at birth (left) and six months of age (right) in Horro sheep

Figure 4. Genetic trend of body weight at birth (left) and six months of age (right) in Menz sheep