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Community-based sheep breeding programs generated substantial genetic gains and socioeconomic benefits

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*Community-based breeding programs (**CBBPs**) for small ruminants have been suggested as alternatives to centralised, government-controlled breeding schemes which have been implemented in many developing countries. An innovative methodological framework on how to design, implement and sustain CBBPs was tested in three sites in Ethiopia: Bonga, Horro and Menz. In these CBBPs, the main selection trait identified through participatory approaches was 6-month weight in all three sites. In Horro and Bonga, where resources such as feed and water permitted larger litter sizes, twinning rate was included. Ten-year (2009 to 2018) performance data from the breeding programs were analysed using Average Information Restricted Maximum Likelihood method (**AI-REML**). Additionally, the socioeconomic impact of CBBPs was assessed. Results indicated that 6-month weight increased over the years in all breeds. In Bonga, the average increase was 0.21 ± 0.018 kg/year, followed by 0.18 ± 0.007 and 0.11 ± 0.003 kg/year in Horro and Menz, respectively. This was quite substantial in an on-farm situation. The birth weight of lambs did not improve over the years in Bonga and Horro sheep but significant increases occurred in Menz. Considering that there was no direct selection on birth weight in the community flock, the increased weights observed in Menz could be due to correlated responses, but this was not the case in Bonga and Horro. The genetic trend for prolificacy over the years in both Bonga and Horro flocks was positive and significant ($P < 0.01$). This increase in litter size, combined with the increased 6-month body weight, increased income by 20% 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 the livelihoods of farmers.*

Keywords: body weight, genetic parameter, genetic trend, local breeds, sheep

Implications

Community-based breeding programs 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 community-based breeding programs ensures the technical feasibility of the programs. This paper provides evidence of measurable genetic gains and the contribution of community-based breeding programs to socioeconomic benefits for the 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-organised national breeding programs. Data recording, provision of the recorded data to a data processing center, estimation of breeding values using 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, and attempts to replicate

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approaches that have been successful in developed countries have met with little success (Kosgey *et al*., 2006). The most common approach implemented in many developing countries is centralised breeding schemes entirely managed and controlled by governments with minimal, if any, participation by farmers (Haile *et al*., 2018). These centralised schemes, usually a nucleus breeding unit established at a central station, are run by a government organisation attempting to undertake all or part of the complex processes and breeding strategy roles including data recording, genetic evaluation, selection, delivery of genetic change and feedback to farmers. Although well intended, these centralised schemes have failed to sustainably provide the desired genetic improvement to small holders (continuous provision of 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 the import of improved lines in the form of live animals, semen or embryos. These are usually crossbred with the local and 'less productive' breeds to upgrade them. In most cases, this is done without sufficient pretesting of the suitability and adaptability of the exotic breeds and their resulting crosses to local production systems or conditions, and with no clear strategy concerning what the final genotype would be. Genetic erosion of these local populations and breeds has occurred where indiscriminate crossbreeding with local populations has been practiced (Haile *et al*., 2018).

An alternative approach is a community-based breeding program (**CBBP**). Such programs consider the needs, views, decisions and active participation of farmers from inception through to implementation. Their success is based upon proper consideration of farmers' breeding objectives, available infrastructure, participation and ownership (Sölkner *et al*., 1998; Wurzinger *et al*., 2011; Mueller *et al*., 2015; Haile *et al*., 2018).

The International Center for Agricultural Research in the Dry Areas, the International Livestock Research Institute and the University of Natural Resources and Life Sciences, in partnership with the Ethiopian national agricultural research system, have been implementing CBBPs in Ethiopia since 2009. Community-based breeding programs have also been implemented in Mexico and Argentina with goats, in Bolivia with llamas and in Uganda and Malawi with goats. However, the methodological framework for their implementation, genetic gains achieved and the socioeconomic impacts of such programs in Africa have not yet been reported.

This paper evaluates the success of three sheep CBBPs in Ethiopia – Bonga, Horro and Menz – using the following parameters: (1) growth and reproduction performance of Ethiopian sheep breeds within CBBPs, (2) genetic progress achieved in CBBPs and (3) socioeconomic impact of CBBPs on communities.

Material 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 agroecologies. Two pilot communities from each location were identified. Bonga is located in southwest Ethiopia about 460 km from Addis Ababa, with altitudes in the range of 1000 to 3400 m above sea level (masl). The mean maximum and minimum temperatures in Bonga are 24 and 12°C, respectively. The Bonga sheep breed is characterised by a wide and moderately long tail; both males and females are mostly polled, have long ears and short and smooth hair (Edea *et al*., 2009). The breed is judged good for traits such as 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 (1600 to 2800 masl) about 310 km from Addis Ababa. Horro is believed to be closer to the epicenter of the Horro sheep breeding tract. Horro sheep are fat-tailed hairy sheep with greater growth potential than 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 about 280 km north-east of Addis Ababa, with altitudes of 2700 to 3300 masl. The Menz area is considered the epicenter of distribution of the Menz breed. The Menz breed is one of the few coarse-woolled, fat-tailed sheep types, adapted to the high-altitude precipitous terrain characterised by scarcity of feed and low crop production due to extreme low temperatures 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 community-based breeding program

Implementation of the sheep CBBPs in the three locations started in 2009 involving more than 8000 head of sheep. There were six communities in the three locations, with each community having an average of 60 households when the CBBPs started. The number of households remained the same in Horro and Menz, but more than doubled in the two communities in Bonga (149 and 151). A government research station was linked with each of the sites. Local enumerators were recruited for each community to undertake animal identification, data recording and day-to-day follow up of the breeding program. Indigenous knowledge of the communities was considered at each phase of the breeding program design and implementation. For example, the communities decided how rams were managed and how they were shared and used. The core of this program is to get community members working together in ram selection, management and use.

The whole community flock was pooled and treated as one flock, and two stages of selection were applied: initial screening when traditionally sales of immature young rams occur (4 to 6 months) and final selection for admission to breeding at 12 months. Selection at the first stage was based on adjusted 6-month weight of lambs and twinning rate of ewes (for Bonga and Horro). Yearling weight and conformation were also considered in the final selection. All young rams were collected at one central place in each community on an agreed screening date. Selection was then performed based on the estimated breeding values and an index constructed that involved more than one trait.

A breeding ram selection committee composed of 3 to 5 members elected by the community was involved in the selection. If, for example, 15 rams were to be selected from 100 candidates, 20 were preselected based on their breeding values and the committee ranked these, thus culling the last 5. The committee checked the conformation, coat color, presence or absence of horns, horn type, tail type and other criteria in their decision making. The number of rams to be selected depended on the number of ewes available for mating, with a male : female allocation ratio of 1 : 30, while accounting for 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 unlike conventional breeding strategies, CBBPs use a participatory approach which involves the communities who keep the animals from the initial inception of the program to implementation and final ownership of the scheme.

Data recording and analysis

Data recording formats to collect biological data from each household were developed. Data analysed included birth weight, 6-month weight and litter size. There were too few data for yearling weight 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: (1) year of birth (10 classes, 2009 to 2018); (2) 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; and March to May, short rain season); (3) sex (two classes, male and female); and (4) birth type (three classes: single, twin and triple). 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. For genetic correlations, a bivariate model was used. WOMBAT assesses whether an analysis has converged based on the following criteria: (1) a change in log L of $<5 \times 10^{-4}$, (2) a change in parameters of $<10^{-8}$ and (3) a gradient vector norm $<10^{-3}$.

Analysis model

$$Y = X\beta + Z_1 a + Z_2 m + Z_3 pe + e$$

where Y is a $(N \times 1)$ vector of observations; β is the vector of fixed effects of contemporary groups, birth type, birth year

Figure 1 (colour online) Steps for setting up community-based breeding programs for sheep.

and sex of animal related to incidence matrix X; a is the vector of direct genetic effects related to incidence matrix Z_1; m is the vector of maternal genetic effects related to matrix Z_2; pe is the vector of maternal permanent environmental effects related to matrix Z_3; and e is the vector of random residuals.

The genetic trends were estimated by the weighted regression of the average breeding value of the animals on the year of birth. Inbreeding coefficients were derived from WOMBAT outputs.

The number of sires and dams available for the different breeds and traits varied considerably and was as expected for CBBPs. Rams available for birth weight were 544 for Bonga, 100 for Horro and 482 for Menz; and corresponding numbers of ewes were 3351, 2508 and 4293. The numbers for 6-month weight were much lower than for birth weight as the data size was smaller too. The numbers for Bonga, Horro and Menz were 214, 77 and 209 for rams, respectively; and correspondingly 1002, 949 and 1348 for ewes. Rams used for litter size in Bonga and Horro were 104 and 53, respectively, and corresponding numbers of ewes were 537 and 373.

Data from both primary and secondary sources were used for the socioeconomic evaluation. A survey was conducted to collect detailed primary data in 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 the survey was administered to a sample of 80 farmers in each of the breeding sites. This gave a total sample size of 240 farmers from the three sites. Participatory rural appraisals (PRAs), key informant interviews and informal discussions were also conducted to further understanding of the socioeconomic impact of the breeding programs in respective sites. Secondary data included biological data, publications and reports from the program.

Descriptive statistics were used to analyse primary data collected through the survey. Statistical significance tests were used to determine any 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 sheep flocks

Growth and reproductive performances of sheep flocks in CBBPs have not previously been reported. Six-month weights in our study (21.60 ± 0.20, 16.5 ± 0.54 and 14.0 ± 0.04 kg for Bonga, Horro and Menz sheep, respectively; Table 1) were higher than corresponding results for the same breeds under station management conditions: 16.7 ± 0.20 (MoA, 2018), 14 ± 2.93 (MoA, 2018) and 10.7 ± 2.2 kg (Gizaw *et al.*, 2007). This shows a clear improvement due to CBBPs. Growth performances from stations where selection and mating schemes are well structured and properly controlled are normally expected to be higher than conditions on-farm. However, we found that growth levels of lambs from CBBPs (on-farm) were higher than those reported from on-station conditions. Inferiority of the on-station growth of lambs could be assigned to two reasons. First, the perceived better feeding and management of sheep on-station does not necessarily happen and is influenced by many factors. Through repeated training and awareness in CBBPs, owners care for their animals and feed and manage them better than in the traditional smallholder system. Second, some stations, for example, Horro and Menz, were located out of the breeding tract of the populations. This may present an issue of genotype by environment interaction.

Weight differences for the different sexes were all significant ($P < 0.01$) except for 6-month weight in Menz (Table 1). For both Bonga and Horro, the males were heavier than females at birth and at 6 months of age. In Menz, although males were heavier than females at birth, this difference was not significant ($P > 0.05$) at 6 months. Many reports in literature (e.g. Tibbo, 2006; Saghi *et al.*, 2007) concur with our observations that favor male sheep and could be related to inherent physiological variations.

Table 1 *Least squares means (kg) for effects of birth season, lamb sex and birth type on birth weight (BWT) and 6-months weight (SMW) for Bonga, Horro and Menz sheep*

	Birth season				Sex			Birth type							
Site	Long rain	Dry	Short rain	*P*-value	Male	Female	*P*-value	1	2	3	*P*-value	MSE	*n*	Overall	CV%
Bonga															
BWT	3.28^{a}	3.27^{a}	3.36^{b}	**	3.34	3.24	**	3.57^{a}	3.28^{b}	3.03^{c}	**	0.44	8389	3.29	13
SMW	21.3^{a}	22.0^{b}	21.5^{a}	**	22.9	20.3	**	23.4^{a}	21.3^{b}	20.0^{c}	**	3.60	3298	21.60	16
Horro															
BWT	2.55^{a}	2.49^{b}	2.50^{ab}	**	2.55	2.47	**	2.66^{a}	2.53^{b}	2.34^{b}	**	0.56	3426	2.51	21
SMW	16.5	16.2	16.5		16.7	16.1	**	17.3^{a}	15.9^{b}	16.0^{b}	**	3.06	1615	15.9	16
Menz															
BWT	2.76	2.74	2.74	NS	2.81	2.69	**	NA				0.79	6269	2.75	29
SMW	14.1^{a}	13.8^{b}	14.2^{a}	**	14.0	14.0	NS	NA				2.66	4799	14.0	19

NA = not applicable; MSE = mean square error; N = number of observations; CV = coefficient of variation.
**$P < 0.01$; NS, $P > 0.05$.
^{a,b,c}Different letters in the same row within effect represent statistical differences ($P < 0.05$).

Birth type had a significant effect ($P < 0.01$) on weights of all sheep (birth and 6-month weight). Single born lambs had greater weight at all ages than twins and triplets. Sheep in Menz give birth to singles in most cases and so this trait was not further considered for Menz.

Season of birth was also a significant source of variation for both birth and 6-month weight of sheep. In Bonga and Horro, weight was inferior in the long rainy season to those of the dry and short rainy seasons. Lambs born in the dry season in Horro had greater weight than those born in the wet season ($P < 0.01$). This was unexpected because more feed is believed to be available in the rainy seasons. Better feeding of ewes in the wet season might have resulted in greater birth weight of lambs in the dry season.

Genetic trends in growth performance and prolificacy

The birth weight of lambs did not improve over the years in Bonga and Horro sheep (Figures 2 and 3), but there was a significant increase in Menz (Figure 4). Considering that there was no direct selection for birth weight in the community flock, the increased weights in Menz could be due to correlated responses, which was not the case in Bonga and Horro. 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 growth traits. Many studies have shown weak correlations between birth weight and later weights (e.g. Gürsoy *et al.*, 1995; Duguma *et al.*, 2002;

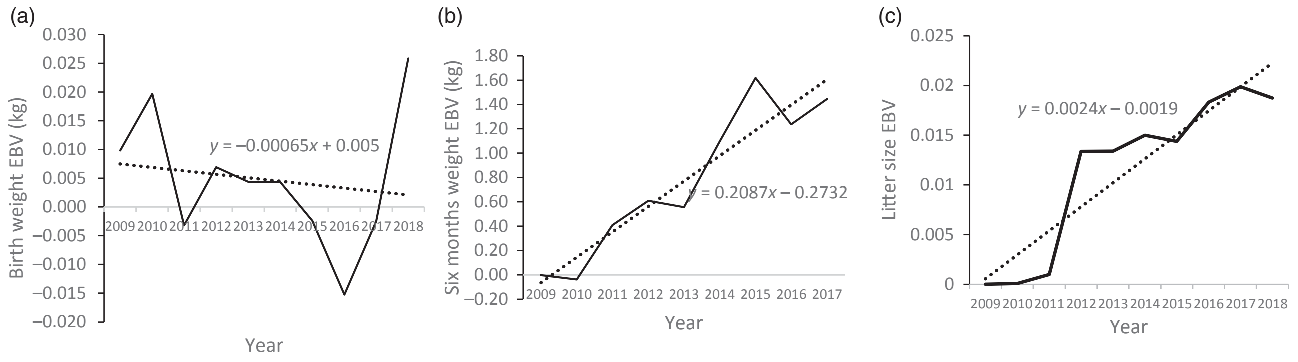

Figure 2 Genetic trend of estimated breeding values (EBV) for body weight at birth (a), 6 months of age (b) and litter size (c) in Bonga sheep.

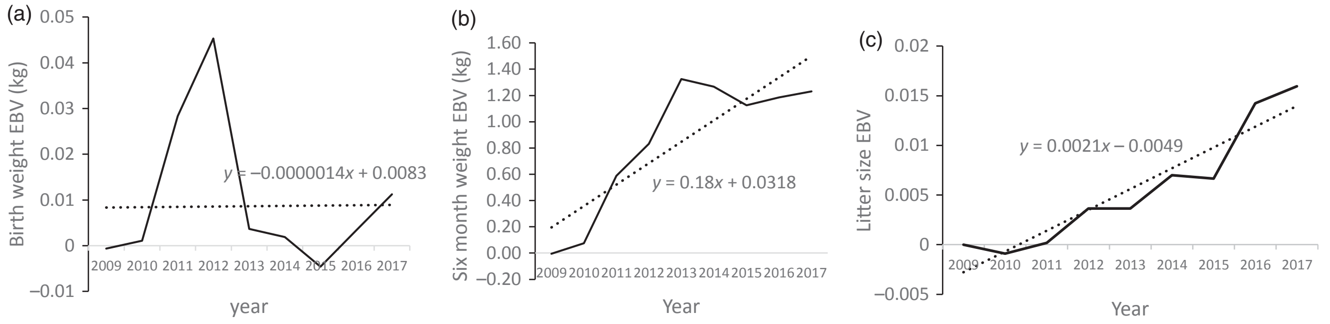

Figure 3 Genetic trend of estimated breeding values (EBV) for body weight at birth (a), 6 months of age (b) and litter size in Horro sheep.

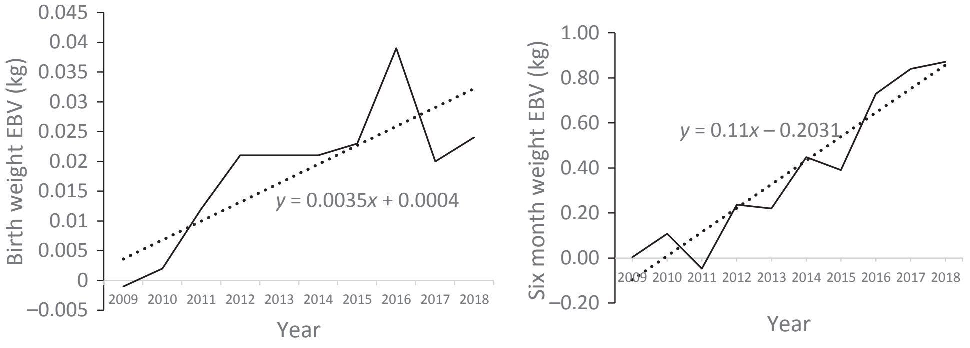

Figure 4 Genetic trend of estimated breeding values (EBV) for body weight at birth (left) and 6 months of age (right) in Menz sheep.

Gizaw and Joshi, 2004). Therefore, selection for each trait could be affected independently of the others and selection for weaning weight or gain would not increase birth weight.

For all the three sites, 6-month weight, the major selection trait in our CBBPs, increased ($P < 0.05$) over the years (Figures 2, 3 and 4). In Bonga, the average increase was 0.21 ± 0.018 kg/year, followed by 0.18 ± 0.007 and 0.11 ± 0.003 kg/year in Horro and Menz, respectively. This is quite substantial for an on-farm situation. The increases were more pronounced in the larger Horro and Bonga breeds compared to the smaller Menz sheep.

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, a substantial response was evident (Gizaw *et al.*, 2007). Positive changes have also been reported for purebred Tsigai and improved Valachian and Lacaune sheep in the Slovak Republic (Oravcová and Peškovičová, 2008), for Lohi sheep of Pakistan (Javed *et al.*, 2013) and for Malpura sheep of India (Arora *et al.*, 2010). However, these reports all referred to on-station performance and there are no reports from on-farm, community managed flocks.

Prolificacy, defined as the number of lambs born per ewe lambing, is strongly influenced by management decisions and is of paramount economic importance. The genetic trend for prolificacy over the years in both Bonga and Horro flocks was positive and significant ($P < 0.01$; Figures 2 and 3). Given the low heritability of reproduction traits, genetic changes reported in literature are non-significant in most cases (Haile *et al.*, 2018; Abdoli *et al.*, 2019). However, our results, where prolificacy was one of the selection traits in both sites, indicated that positive trends were achieved in the cases that structured selection was implemented. Where resources, such as feed and water, permit improvement in prolificacy, substantial impact on sheep production could be expected. With new genomic tools, faster genetic gains and introgression of genes into new populations can be achieved. For this to happen, it is very important to investigate novel and known genomic regions affecting fertility/prolificacy in these populations. Previous studies identified causative genetic variants with major effects associated with reproductive traits linked to prolificacy, especially ovulation rates and litter size in sheep (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 5, 6 and *X* (Davis, 2005), respectively, involved Eurasian breeds of sheep. New variants are continually discovered in other breeds, suggesting variations between breeds (Lassoued *et al.*, 2017). Therefore, we will investigate mutations for prolificacy in Bonga and Horro sheep breeds in the future.

Inbreeding, heritability and genetic correlation

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. The CBBPs aimed at reducing the effect of inbreeding through controlled mating, ram rotation and increase in flock size by bringing households who owned small flock sizes together.

The estimated inbreeding coefficients we obtained (<1%; Table 2) confirmed our proposition that the levels recorded over years for all breeds were lower than the critical level of 6.25% (Li *et al.*, 2011). Many studies have reported higher inbreeding coefficients than ours: for example, MacKinnon (2003) in a closed population of crossbred sheep (range 2.2 to 3.8%), Pedrosa *et al.* (2010) in Santa Inês sheep of Brazil (2.33%) and Ghavi Hossein-Zadeh (2012) in Moghani sheep of Iran (2.93%). In our CBBPs, rams mated in one mating group for one year and were rotated to another. Additionally, rams remained in breeding for 2 years and were either sold as breeding animals to communities far from the CBBP sites or sold for slaughter. These measures assisted in reducing inbreeding coefficients; therefore, inbreeding is not 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 and 6-month weight were moderate to high, except for Menz sheep which showed low heritability (Table 3). The moderate to high heritability estimates for growth traits indicate that sufficient additive genetic variance existed for these traits, which could be used for selection within the population as was done in our CBBPs. Heritability estimates for growth traits are generally moderate to high (Duguma *et al.*, 2002; Masood Tariq *et al.*, 2010; Mekuriaw and Haile, 2014). However, these previous 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 worthy of report and indicate the within-population genetic variability that could be exploited through selection. These populations had never

Table 2 *Inbreeding level over years in Bonga, Horro and Menz sheep flocks*

	Inbreeding (%)		
Year	Bonga	Horro	Menz
Overall	0.34 ± 0.044	0.24 ± 0.037	0.31 ± 0.038
Year			
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 3 *Genetic parameter estimates for birth weight (BWT), 6-months weight (SMW) and litter size for Bonga, Horro and Menz sheep flocks*

	Bonga			Horro			Menz	
Genetic parameters	BWT	SMW	Litter size	BWT	SMW	Litter size	BWT	SMW
σ_a^2	0.06	5.75	0.018	0.04	4.19	0.015	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	0.017	0.0261	0.35	0.006	0.001	0.002
σ_{res}^2	0.11	4.46	0.200	0.2144	2.92	0.160	0.37	4.64
σ_{pheno}^2	0.19	11.85	0.235	0.278	7.14	0.181	0.42	4.90
h_a^2	0.29 ± 0.047	0.49 ± 0.067	0.08 ± 0.041	0.16 ± 0.040	0.59 ± 0.109	0.08 ± 0.046	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
r	–	–	0.148	–	–	0.114	–	–

experienced systematic selection before the setting up of the CBBPs; therefore, the high heritability indicates the high genetic variability expected in non-selected populations.

Direct heritability estimates for litter size were generally low for both Bonga (0.018) and Horro (0.015) sheep. Most reproduction traits, including litter size, have low heritability estimates (Rashidi *et al*., 2011; Haile *et al*., 2018). In other words, additive genetic effects have little effect on reproduction traits, but environmental and non-additive genetic effects have considerable influence. Low heritability indicates low possibility of achieving rapid genetic progress through phenotypic selection.

Genetic correlations between birth weight and 6-month weight were low in both Bonga (−0.058 ± 0.142) and Horro (0.131 ± 0.009) breeds. However, relatively high genetic correlation (0.450 ± 0.225) was observed in Menz sheep. As we previously alluded, increase in birth weight is not desirable in local populations. Therefore, in flocks where strong genetic relationships between birth weight and 6-month weight exist, other selection criteria should be sought if the objective is to increase 6-month weight or other traits without adversely affecting birth weight.

Socioeconomic impacts of community-based breeding program: income and consumption

The potential impact of the CBBP on market participation and sheep meat consumption of farmers was explored. Market participation of CBBP members measured by the number of sales per year was higher ($P < 0.01$) than for non-participants (Table 4). This could be attributed to the improved production and productivity of the flock kept by members of the CBBP, resulting in more sheep for sale.

Slaughtering sheep for household consumption was also more common ($P < 0.01$) among CBBP participants (Table 4). Similarly, this variation could be explained by improved performance. Discussion with members of CBBPs 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 favored better-off households because only farmers with a sheep flock size of four or more were considered for membership.

The majority of CBBP participants reported that consumption of mutton in the household had increased after introduction of the CBBP, but a considerable proportion of households showed no change in mutton consumption (Table 4). A possible explanation for increased mutton consumption is that the breeding program resulted in increased productivity and income from sheep production.

A comparison of annual mean income from sheep production revealed that participants in the CBBP earned Ethiopian Birr (**ETB**) 3100 per household per year on average, while non-participants earned ETB2486 (USD1 = ETB27.25 in June 2018) (Table 4). The difference between CBBP participants and non-participants was statistically significant in Bonga and Menz ($P < 0.05$) but not in Horro. It was also confirmed by the PRA work with CBBP participants that income from sheep keeping had improved. The positive impact of the CBBP on farmers' incomes explains the huge interest of non-members in joining the breeding cooperatives. However, interpretation of the figures should be carefully considered because these income data were recorded from farmers' memory recall. In the CBBPs, biological data were recorded but no financial records were kept.

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

Table 4 *Number of sheep sold and consumed, trend in consumption and mean annual income from sales of sheep during the last year by community-based breeding program members and non-members*

Number of sheep	CBBP	Median	*P*-value for Mann-Whitney U test
Sold in a year	Members	5	0.004
	Non-members	3	
Slaughtered for consumption in a year	Members	3	0.000
	Non-members	1	
Income from CBBP			

Site	CBBP	Mean annual income (Ethiopian Birr)	*P*-value for Mann-Whitney U test
Bonga	Members	2697 ± 2080	0.03
	Non-members	1637 ± 1561	
Horro	Members	2488 ± 2277	0.25
	Non-members	2233 ± 3272	
Menz	Members	4116 ± 2512	0.02
	Non-members	3587 ± 4685	
Total	Members	3100 ± 2408	0.00
	Non-members	2486 ± 3489	

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

USA Dollar 1 = Ethiopian Birr 27.25 in June 2018; CBBP = community-based breeding program.

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Declaration of interest

The authors declare that they have no conflicts of interest.

Ethics statement

ICARDA does not have ethics committee. However, this study is based on data collected from a breeding program and does not present any ethical concerns.

Software and data repository resources

The data used in this study are deposited in the ICARDA repository with permanent identifier http://hdl.handle.net/20.500.11766.1/PVA8NA. The license follows the CGIAR Open Access Open Data policy and implementation guidelines (http://hdl.handle.net/10947/4489) with an embargo of up to 12 months of completion of data collection or appropriate project milestone, or within 6 months of publication of the information products underpinned by that data.

References

Abdoli R, Zamani P, Mirhoseini SZ, Hossein-Zadeh NG and Almasi M 2019. Genetic parameters and trends for litter size in Markhoz goats. Revista Colombiana de Ciencias Pecuarias 32, 58–63.

Arora AL, Gowane GR, Prince LLL and Prakash V 2010. Genetic trends for performance traits of Malpura sheep. Indian Journal of Animal Sciences 80, 937–939.

Davis GH 2005. Major genes affecting ovulation rate in sheep. Genetics Selection Evolution 37, 11–23.

Duguma G, Schoeman SJ, Cloete SWP and Jordaan GF 2002. Genetic and environmental parameters for productivity in Merinos. South African Journal of Animal Science 32, 154–159.

Edea Z, Haile A, Tibbo M, Sharma AK, Sölkner J and Wurzinger M 2009. Morphological Characterization of Bonga and Horro Indigenous Sheep Breeds under Smallholder conditions in Ethiopia. Ethiopian Journal of Animal Production 9, 117–133.

Getachew T, Haile A, Tibbo M, Sharma AK, Sölkner J and Wurzinger M 2010. Herd management and breeding practices of sheep owners in a mixed crop-livestock and a pastoral system of Ethiopia. Journal of Agricultural Sciences 5, 685–691.

Ghavi Hossein-Zadeh N 2012. Inbreeding effects on body weight traits of Iranian Moghani sheep. Archiv fur Tierzucht 55, 171–178.

Gizaw S and Joshi BK 2004. Estimates of genetic parameters for growth traits in Menz and Awassi × Menz crossbred sheep in Ethiopia. Indian Journal of Animal Sciences 74, 864–867.

Gizaw S, Lemma S, Komen H, Johan AM and Arendonk V 2007. Estimates of genetic parameters and genetic trends for live weight and fleece traits in Menz sheep. Small Ruminant Research 70, 145–153.

Gürsoy O, Kirk K, Cebeci Z and Pollot GE 1995. Genetic evaluation of growth performance in Awassi sheep. In Strategies for sheep and goat breeding (ed. D Gabiña), 193–201. CIHEAM, Zaragoza, Spain.

Haile A, Getachew T and Rischkowsky B 2019. Community-based sheep breeding programs in Ethiopia generated substantial genetic gains and socio-economic benefits-preliminary results. Technical report for CGIAR Research Program on Livestock Agri-Food Systems, ICARDA, Beirut, Lebanon.

Haile A, Hilali M, Hassen H, Lobo R and Rischkowsky B 2018. Estimates of genetic parameters and genetic trends for growth, reproduction, milk production and milk composition traits of Awassi sheep. Animal 13, 1–8.

Haile A, Wurzinger M, Mueller J, Mirkena T, Duguma G, Rekik M, Mwacharo J, Mwai O, Sölkner J and Rischkowsky B 2018. Guidelines for Setting Up community-based small ruminants breeding programs in Ethiopia. ICARDA—Tools and guidelines No. 1, Beirut, Lebanon.

Javed K, Iram A, Abdullah M, Sattar MA and Akhtar M 2013. Genetic trends for some productive traits of Lohi sheep in Pakistan. Pakistan Journal of Science 65, 292–295.

Kosgey IS, Baker RL, Udod JAM and van Arendon JAM 2006. Successes and failures of small ruminant breeding programmes in the tropics: a review. Small Ruminant Research 61, 13–28.

Lassoued N, Benkhlil Z, Woloszyn F, Rejeb A, Aouina M, Rekik M, Fabre S and Bedhiaf-Romdhani S 2017. FecXBar a novel BMP15 mutation responsible for prolificacy and female sterility in Tunisian Barbarine sheep. BMC Genetics 18, 43.

Li MH, Strandén I, Tiirikka T, Sevón-Aimonen ML and Kantanen J 2011. A comparison of approaches to estimate the inbreeding coefficient and pairwise relatedness using genomic and pedigree data in a sheep population. PLoS ONE 6, e26256.

MacKinnon KM 2003. Analysis of inbreeding in a closed population of crossbred sheep. MSc Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.

Masood Tariq M, Ahmad Bajwa M, Abbas F, Waheed A, Abbas Bokhari F and Rafiq M 2010. Heritability of pre-weaning growth performance traits in Mengali sheep in (Balochistan) Pakistan. International Journal of Biodiversity and Conservation 2, 284–288.

Mekuriaw S and Haile A 2014. Genetic parameter estimates for growth and reproductive trait of sheep for genetic improvement and designing breeding program in Ethiopia: a review. Open Access Library Journal 1, e589. http://dx.doi.org/10.4236/oalib.1100589

Meyer K 2007. WOMBAT — a tool for mixed model analyses in quantitative genetics by REML. Journal of Zhejiang University SCIENCE B 8, 815–821.

Ministry of Agriculture (MoA) 2018. Livestock breeding strategy for Ethiopia: small ruminant breeding strategies (2015–2030). MoA, Addis Ababa, Ethiopia.

Mueller JP, Rischkowsky B, Haile A, Philipsson J, Mwai AO, Besbes B, Valle Zárate A, Tibbo M, Mirkena T, Duguma G, Sölkner J and Wurzinger M 2015. Community based livestock breeding programs: essentials and examples. Journal of Animal Breeding and Genetics 132, 155–168.

Oravcová M and Peškovičová D 2008. Genetic and environmental trends for milk production traits in sheep estimated with test-day model. Asian-Australian Journal of Animal Sciences 21, 1088–1096.

Pedrosa VB, Santana ML, Oliveira J, Eler JP and Ferraz JBS 2010. Population structure and inbreeding effects on growth traits of Santa Ines sheep in Brazil. Small Ruminant Research 93, 135–139.

Rashidi A, Bishop S and Matika O 2011. Genetic parameter estimates for pre-weaning performance and reproduction traits in Markhoz goats. Small Ruminant Research 100, 100–106.

Saghi DA, Khadivi H, Navidzadeh M and Nikbakhti M 2007. Study on influence of environmental effect on birth weight, weaning weight and daily growth of Baluchi sheep. Pakistan Journal of Nutrition 6, 436–437.

SAS 2002. Statistical Analysis Systems for mixed models. Statistical Analysis Systems Institute Inc., Cary, NC, USA.

Sölkner J, Nakimbugwe H, Valle-Zárate A 1998. Analysis of determinants for success and failure of village breeding programmes. In Proceedings of the 6th World Congress on Genetics Applied to Livestock Production, 12–16 January 1998, Armidale, Australia.

Tibbo M 2006. Productivity and health of indigenous sheep breeds and crossbreds in the central Ethiopian highlands. PhD thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Wurzinger M, Sölkner J and Iñiguez L 2011. Important aspects and limitations in considering community-based breeding programs for low-input smallholder livestock systems. Small Ruminant Research 98, 170–175.