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Economic values for traits of indigenous sheep managed under a low-input production system in north-western highlands of Ethiopia: input to design of breeding programmes

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A bioeconomic model based on a deterministic simulation was applied to estimate economic values (EVs) of different traits in indigenous sheep native to the north-western highlands of Ethiopia. Data collected on 4318 sheep were used to describe biological parameters of the model, while economic variables were surveyed in the market. In the studied production system, feed accounted for 74% of the total variable costs, while the sale of live sheep contributed to 88% of the total revenue. Profit was calculated as the difference between revenues and costs of the production variables, which were subsequently used to derive EVs. For each trait its EV was estimated after a unit change in its mean value, keeping the other traits unchanged. After a unit genetic change, the EVs (per ewe per year) for weight at weaning, six months of age, in yearlings and mature ewes were US$ 1.46, 0.60, -0.04 and -0.24, respectively. Besides, the EVs for the number of lambs weaned per ewe bred, ewe fertility rate, lambing interval, post-weaning and mature ewe survivals were US$ 0.59, 0.37, 0.16, 0.53 and 0.86, in the order given. The analysis of sensitivity of EVs to fluctuations in the price of input and output parameters revealed that the marginal change in profit was more affected in most traits when the price of live weight was altered rather than feed cost. Overall, the results of the

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present study imply that profitability of sheep production in the low-input production system can be enhanced by implementing selection on traits that have high economic importance.

KEYWORDS: breeding programme /Ethiopian highlands /feed intake/ profit function

Sheep rearing is an important component of agricultural farming practises of smallholder farmers both in Ethiopia and globally. Compared to large ruminants, sheep require less space and investment, while they are characterised by better adaptability and relatively short generation interval. For smallholder farmers sheep provide income, meat, wool and manure [Dagnew *et al.* 2017, Abebe *et al.* 2020]. Such benefits are vital to ensure food security and reduce poverty at the smallholder level. However, the current productivity of Ethiopian indigenous sheep breeds is far lower than the levels required for sustainable livelihood and improvement of the standard of living for the local community.

At the smallholder level sheep production is generally based on a low-input husbandry system, where seasonal feed shortage and disease prevalence are common challenges [Gizaw *et al.* 2010]. Nevertheless, no breeding programme suitable for such a system is available in Ethiopia. Previous attempts in sheep breed improvement were mainly based on crossbreeding between exotic sheep imported from abroad (e.g. Awassi from Israel and Dorper sheep from South Africa) and indigenous sheep breeds [Gizaw *et al.* 2013, Getachew *et al.* 2016]. However, such an approach was limited to a few indigenous sheep breeds and could not bring the anticipated improvement, mainly due to the incompatibility of genotypes with the local environment. Alternatively, community-based selective breeding programmes have been piloted in some indigenous sheep breeds and have rendered promising results [Haile et al. 2020]. With full involvement of farmers from the planning to the implementation phase, a community-based breeding programme has been deemed as a viable approach for genetic improvement in a low-input production system [Wurzinger *et al.* 2011, Mueller *et al*. 2015].

The north-western highlands of Ethiopia are among the areas that exhibit high potential for sheep production. For instance, the Farta sheep breed, with an estimated population of about 1.1 million head [CSA 2017], is widely distributed in these areas. The agricultural practise is a crop-livestock mixed farming system, in which sheep are reared in combination with other animal species [Abebe *et al.* 2020]. Sheep breeding is based on indigenous knowledge of smallholder farmers, with year-round mating and lambing of ewes. To generate income, smallholder farmers usually start selling lambs at about six months of age, implying that not all lambs born are kept until breeding age. Feed types and availability vary with seasons. From June to January sheep generally obtain their feed requirement by grazing on fragmented lands and uncultivated areas. However, from February to May crop aftermath and residues are major feed sources. Having a clear understanding of the prevailing sheep production system is vital to design a suitable breeding programme.

Defining a breeding goal is one of the first and most important stages of designing any livestock breeding programme [Fuerst-Waltl and Baumung 2009]. According to the classical selection index theory, defining a breeding goal using multiple traits requires knowing both the genetic value and economic weight of each trait. Knowledge concerning economic values (EVs) of traits is helpful to ensure that genetic improvement is proportional to the economic benefit of each trait in the breeding objectives [Tolone *et al*. 2011].

A bioeconomic model is a robust methods that has been widely applied to determine the relative economic importance of livestock traits [Abdollahy *et al.* 2012, Campos *et al.* 2014, Borzi *et al.* 2017]. As such, this study aimed to contribute to the development of sheep breeding programmes in the north-western highlands of Ethiopia by estimating the EVs of production, reproduction and survival traits using a bioeconomic model. The sensitivity of estimated EVs to possible fluctuations in input and output parameters was also investigated.

Material and methods

Data sources

To evaluate the performance of indigenous sheep at the smallholder level a data recording scheme was established in the Farta and Lay Gayient districts of the South Gondar Zone, located in the north-western highlands of Ethiopia. A detailed description of the two districts can be found in the previous study [Abebe *et al.* 2020]. Pedigree-based data collections were performed from 2015 to 2019 using trained enumerators, under close supervision of the researchers. In the Farta district performance evaluation was based on straight breeding of the Farta sheep breed. In turn, in the Lay Gayient district it was based on crossbreeding between Farta sheep and another indigenous breed, known as Washera sheep. However, preliminary results [Abebe *et al*. 2021] showed that overall performances of crossbreeds were not statistically different from the pure Farta sheep. As a result, the production, reproduction and survival data collected on 4318 sheep (1008 pure Farta sheep and 3310 crossbreeds) were combined and used as a case study to derive EVs for multiple traits. Furthermore, data on economic variables were collected using a survey.

Model assumptions

A bioeconomic model based on the deterministic approach was employed to estimate the EVs for important traits of indigenous sheep. The biological and economic variables of the model are given in Table 1. The sources of revenues were the sale of surplus lambs and yearlings, culled ewes and rams, manure and wool. Considering the prevailing sheep production system, it was assumed that about half of the male lambs were sold at six months of age, whereas all yearlings not required for breeding were sold at 12 months of age. All categories of sheep in the flock are assumed to produce manure. However, only half of the total manure is available for use due to the

Table 1. Input variables assumed for the bioeconomic model[1]

Variable (unit)	Value	Variable (unit)	Value
Production variables		Local grain supplement for breeding ewe	0.42
birth weight (kg)	3.16	Crop residues for breeding ewe	0.63
weaning weight (kg)	12.35	Crop residues for breeding ram	0.83
weight at 6 months of age (kg)	16.68	Crop residues for yearling	0.87
yearling weight (kg)	22.42	Crop residues for weaned lamb	0.83
pre-weaning daily gain (g)	99	Crop residues for lamb	0.48
birth to yearling daily gain (g)	55	Local grain feed supplement for ram	0.18
mature ewe weight (kg)	28	**Economic variables**	
breeding ram weight (kg)	31	crop residue price (US$/kg DM)	0.04
wool yield/head/year (kg)	1.12	grain feed price (US$/kg DM)	0.13
Management variables		pasture grass price (US$/kg DM)[2]	0.08
gestation length (days)	150	weaned lamb price (US$/kg LW)[3]	2.68
weaning age of lambs (months)	3	yearling price (US$/kg LW)	2.90
replacement age (months)	12	culled ewe price (US$/kg LW)	2.08
ewe annual replacement rate (%)	12	culled ram price (US$/kg LW)	3.06
ram annual replacement rate (%)	100	wool price (US$/kg)	1.17
adult sheep age (months)	24	manure price (US$/kg)	0.07
ewes kept in the flock (years)	8	lamb health care (US$/head/duration)	0.04
ram use duration (years)	1	weaned lamb health (US$/head/duration)	0.06
Daily DM intake kg per head		yearling health care (US$/head/duration)	0.4
pasture grass for breeding ewe	0.47	ewe and ram health care (US$/head/year)	0.6
pasture grass for breeding ram	0.61	herding labour (US$/100 heads/month)	50
pasture grass for yearling lamb	0.63	herding labour (US$/100 heads/month)	50
pasture grass for weaned lamb	0.59	shearing cost (US$/head/year)	0.42
pasture grass for lamb	0.34	live sheep transport cost (US$/head/year)	0.50

[1]All costs and prices are in US dollars (US$), 1 US$ ~ 30 ETB (Ethiopian birr), the average exchange rate for 2019, during which the data was collected.
[2]For sheep that remained for one year in a particular category, DM intake duration is eight months for pasture grass and four months for crop residues and was adjusted accordingly for sheep that stayed less than one year in the category.
[3]LW = live weight

difficulty in collecting the materials produced in the field during the daytime [Kosgey *et al.* 2003]. Wool shearing was assumed to be practised once a year per head [Abebe *et al.* 2020]. It was assumed that sheep at the age of 12 months and older can produce adequate wool for harvesting.

Production costs are attributed to the feed, health care and other management activities. The cost of fresh grasses was assumed to be half of the price of hay, while the prices for crop residues and local grain by-products were obtained from the local market. The costs for veterinary services are associated with deworming, vaccination, spraying and antibiotic treatments. The management costs were related to sheep rearing, marketing, wool shearing and salt block supplementations. Labour for sheep rearing depends on the size of the flock and was assumed to be the same for all categories of sheep. For all the costs and prices the average value in 2019 expressed in US dollars (US$) was used. The fixed cost was not included in the profit equation, because the use of improved technologies and facilities is not common in the study areas. Furthermore, sheep are commonly housed during night-time in shelters constructed as parts of the farmer's house, thus calculating a separate cost is very difficult, but it is assumed to be very small.

Flock composition dynamics

Flock size of 600 ewes was chosen to describe the structure and dynamics of the population for one year (Fig. 1). However, flock size can be extended to the desired size. Based on age of animals the base flock was grouped into five categories: 1) lambs (0-3 months old); 2) weaned lambs (3-6 months old); 3) yearlings (6-12 months old); 4) breeding ewes (>18 months old); and 5) breeding rams (>12 months old). It was assumed that about 50% of lambs born were males. Given the lack of estimates in the present study areas, a lambing rate of 76% reported for sheep in other parts of the country was used [Mukasa-Mugerwa *et al.* 2002]. Lambing frequency was calculated as 1.5 per year, which is equivalent to three lambings in two years. The average litter size per ewe per lambing is about 1.1 lambs. The survival rates of mature ewes and rams is about 98%, while the corresponding values for lambs from birth to weaning, weaning to six months of age and six months to 1 year of age are 91.2, 93.7 and 94.4%, respectively.

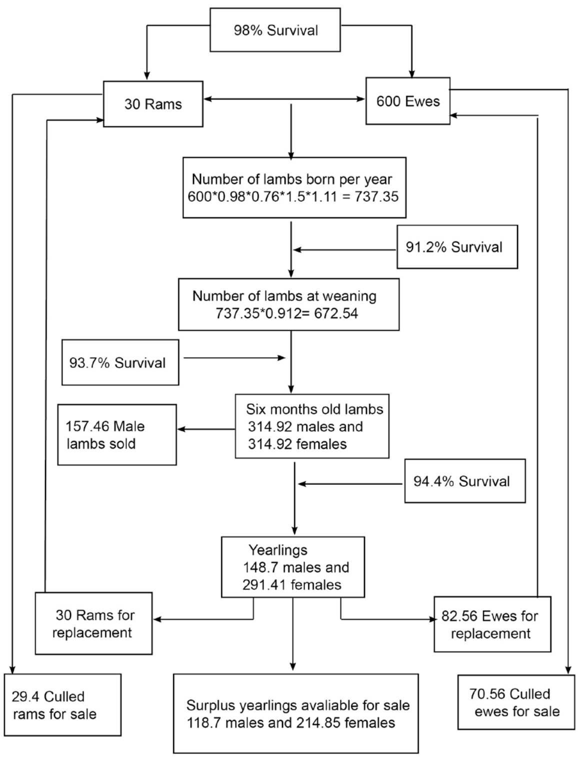

Fig. 1. Flock structure and dynamics of sheep population.

Feed intake

No specific nutrient requirements for Ethiopian indigenous sheep are available. In this study, the energy requirements for maintenance, growth, pregnancy and lactation of sheep were derived based on the methods of Gatenby [1986] and Kosgey *et al.* [2003]. The chemical composition and nutritional values of feed sources were taken from the study of Gashaw and Defar [2017]. Accordingly, the average metabolisable energy (ME) contents of pasture grasses, crop residues and local grain by-products are 10, 7 and 13 mega joule per kg of the dry matter (MJ kg-1 DM), respectively. Similarly, in-vitro dry matter digestibility (IVDMD) of pasture grasses is about 67% of the DM, while the corresponding values for crop residues and local grain by-products are 47% and 86.4%, respectively. The assumptions made for the distribution of lamb mortality and feed requirements during the growth period were similar to those in Kosgey *et al*. [2003]. Information concerning milk productivity of Ethiopian indigenous sheep is lacking. For this study it was assumed that the average daily milk yield of sheep is approximately equal to the values reported by Abdollahy *et al*. [2012], i.e. 0.32 and 0.37 litter per day for single and twin bearing ewes, respectively.

Profit equations

The annual profit per ewe (Pe) was calculated as the difference between total revenues and costs of the production system based on equation 1, modified from Kosgey *et al.* [2003].

$$P_e = R_e - C_e \tag{1}$$

where R_e and C_e are revenues and variable costs per ewe per year, respectively.

Using equation 2, R_e was calculated as follows:

$$R_e = \sum_{i=1}^{5}[N_i F_i(1 - MR_i)LW_i Pr_s] + 0.5\sum_{i=1}^{5}[N_i F_i TM_i Pr_m] + \sum_{i=1}^{5}[N_i F_i W_i Pr_w] \tag{2}$$

where i is one of the five categories described above, N_i in this and subsequent equations is the number of animals present in the i^{th} category/ewe, F_i is the fraction of sheep sold or produced manure or wool in the i^{th} category, MR_i is mortality rate, LW_i is live weight in kg, Pr_s is the price of sheep/kg live weight, TM_i is total manure production in kg/head/duration and was predicted as the number of days per year in the category x daily DM intake x (1-roughage IVDMD), Pr_m is the price of manure/kg, W_i is wool yield in kg/head/year and Pr_w is wool price/kg.

The C_e was calculated following equation 3:

$$C_e = F_c + HC_c + M_c \tag{3}$$

where F_c is feed cost, HC_c is health care cost and M_c is the management cost.

The F_c was calculated as the sum of costs of grass pasture, crop residue and local grain by-products using equation 4.

$$F_c = \sum_{i=1}^{5} N_i[(D_g\, dDMI_g Pr_g) + (D_{cr} dDMI_{cr} Pr_{cr}) + (D_{lg} dDMI_{lg} Pr_{lg})] \quad (4)$$

where D_{gi}, D_{cri} and Dl_{gi} are the number of days per year in the i^{th} category fed with pasture grass, crop residue and local grain by-products, respectively, and $dDMI_{gi}$, dMI_{cri} and $dDMI_{lgi}$ are daily DM intakes and Pr_g, Pr_{cr} and Pr_{lg} are prices of 1 kg of pasture grass, crop residue and local grain by-product, respectively.

The health care cost (HC_c) was calculated using equation 5:

$$HC_c = \sum_{i=1}^{5}(N_i C(hd)^{-1}) \quad (5)$$

where C(hd)-1 is the cost per head per duration in the group.

The management cost (M_c) was calculated according to equation 6:

$$M_c = \sum_{i=1}^{5} N_i[HLC_i + (FM_i MLC_i) + (FS_i SLC_i) + BC_i] \quad (6)$$

where HLC_i represents the average herding labour cost/head/duration in the i^{th} category, FM_i is the fraction of marketed sheep, MLC_i is the average marketing labour cost/head, FS_i is the fraction of sheep available for shearing, SLC_i is wool shearing labour cost/head/year and BC_i is the average salt block cost/head/duration.

Derivation of economic values

Economic values were estimated for the following traits: 1) production (weight at weaning, six months of age, 1 year of age and in mature ewes); 2) reproduction (number of lambs weaned per ewe bred (NLW/EB), ewe fertility rate and lambing interval); 3) survival (post-weaning lambs and mature ewe survivals). For each trait the EV was calculated by increasing the mean of that trait by a unit change, while all the other traits were kept constant. Due to biological reasons, however, the unit for NLW/EB was set at 0.01 lamb. Mathematically, the EV was estimated as:

$$EV_n = P' - P$$

where EV_n is the EV of trait *n, P* and *P'* are profits per ewe per year before and after increasing trait *n* by trait units, respectively.

Sensitivity analysis

The sensitivity of EVs was investigated by changing the cost of feed and the price of live weight by a rate of $\pm$20%. Changes in the current market values of the two variables were made separately, while all the other variables remained constant.

Results and discussion

Revenues and costs for the base situation

An overview of costs, revenues and profit per ewe per year for the base situation with a fixed number of breeding ewes is given in Table 2. The values are weighted by the number of animals present in each category relative to the number of ewes. The average profit per ewe per year was about US$ 10.28. Feed accounted for 74% of the total variable costs, while the sale of live sheep contributed to 88% of the total revenue. The results imply that the price of locally available feed sources and the market price of sheep are the most important factors that determine profitability of sheep breeding in low-input production systems. This finding is in agreement with the reports of Abdollahy *et al.* [2011] and Kosgey *et al.* [2003].

Table 2. Costs, revenues and profit in each animal category per breeding ewe per year for the base situation

Variables	Sheep categories					Total (US$)	Percentage of the total
	lamb	weaned lamb	yearling	ewe	ram		
Proportion of animals per breeding ewe	1.229	1.121	0.787	1.0	0.05		
Sources of costs							
feed	1.76	4.35	6.49	28.61	1.27	42.47	74
health care	0.05	0.06	0.31	0.59	0.03	1.04	2
management[a]	1.77	1.85	3.01	6.92	0.37	13.92	24
total cost/ewe	3.58	6.25	9.81	36.12	1.67	57.43	100
Sources of revenue							
sale of live sheep	0.00	11.81	36.13	6.86	4.66	59.46	88
manure	0.37	0.90	1.33	3.14	0.19	5.93	9
wool	0.00	0.00	0.98	1.29	0.06	2.33	3
total revenue/ewe/year	0.37	12.71	38.44	11.29	4.91	67.71	100
Profit/ewe/per year	-3.21	6.46	28.64	-24.83	3.23	10.28	

[a]Management cost: 85% for sheep herding, 6% mineral lick supplementation, 5% sheep marketing and 4% wool shearing.

Economic values

A bioeconomic model based on a low-input production system was employed to estimate EVs for traits of indigenous sheep. This was achieved via a deterministic simulation of a hypothetical flock containing 600 breeding ewes for one production year. Economic values were positive for all the traits studied except for weaning and mature ewe weights (Table 3). A positive EV implies that the marginal changes in revenue associated with one-unit genetic improvement are larger than the corresponding changes in costs [Kosgey *et al.* 2003, Afshar and Aboozari 2018].

Among production traits, a 1 kg genetic improvement of yearling weight had resulted in an EV of US$ 1.46 per ewe per year (Tab. 3). Given its high EV, selection based on higher yearling weight would be desirable to maximize the economic gain from breeding programmes implemented at the smallholder level. The EV of yearling weight obtained in the present study is close to a value of US$ 1.26 reported for the same trait by Kosgey *et al.* [2004]. However, Haghdoost *et al.* [2008] found a relatively small EV for yearling weight in Arabic sheep, which is about US$ 0.19. Such differences could likely be linked to the variations in the cost of genetic improvement of the trait. Having an estimated EV of US$ 0.60, increasing the genetic merit of weight at 6 months of age had shown high economic importance, next to yearling weight.

Table 3. Economic values (EVs) and associated costs and revenues after a unit change in each trait

Traits	Costs			Revenues			EVs
	feed	other[a]	total	SLS[b]	other[c]	total	
Initial	42.47	14.96	57.43	59.46	8.26	67.71	
Weaning weight	0.050	0.001	0.051	0.000	0.010	0.010	-0.04
Weight at 6 months of age	0.132	0.003	0.135	0.708	0.027	0.735	0.60
Yearling weight	0.181	0.004	0.186	1.612	0.037	1.649	1.46
Mature ewe weight	0.537	0.010	0.547	0.245	0.065	0.310	-0.24
NLW/EB[d]	0.159	0.083	0.242	0.789	0.046	0.835	0.59
Ewe fertility	0.375	0.097	0.472	0.791	0.054	0.845	0.37
Lambing interval	0.047	0.027	0.074	0.225	0.013	0.238	0.16
Post-weaning survival	0.091	0.047	0.138	0.642	0.030	0.673	0.53
Mature ewe survival	0.351	0.119	0.470	1.256	0.071	1.327	0.86

[a] Other costs include management and health care costs; [b] SLS = sale of live sheep; [c] other revenue sources include sale of manure and wool; [d] NLW/EB = number of lambs weaned per ewe bred.

Contrary to the weight at six months and 1 year of age, improving weaning and mature ewe weights by the same order of magnitude resulted in EVs of US$ -0.04 and -0.24, respectively. At the weaning age, marginal changes in both costs and revenues were very small. Furthermore, live animals were not assumed to be sold at the weaning age, which could be the possible reason for the low EV of this trait observed in the present study. The negative EV estimated for mature ewe weight is in agreement with Lôbo *et al.* [2011] and Gebre *et al.* [2012]. Changing the weight of mature ewe by 1 kg was connected with a much larger feed cost incurred than in the case of the other production traits.

In the present study, the EV associated with genetic improvement of the NLW/EB trait by 0.01 lamb was about US$ 0.59. Given its high contribution to lamb production, NLW/EB is often considered as an important measure of reproductive efficiencies of breeding ewes [Yavarifard *et al.* 2015]. It has also been reported that NLW/EB shows high genetic correlations with pre-weaning lamb survival and litter size at birth [Afolayan *et al.* 2008]. Such facts could well justify the importance of incorporating NLW/EB in the breeding goal of sheep genetic improvement programmes, particularly in low-input husbandry systems. For comparison purposes, no direct estimate of EV for NLW/EB is available in the literature.

For the ewe fertility rate, an EV of US$ 0.37 was obtained following a 1% genetic change. Tolone *et al*. [2011] estimated a value of € 2.64 (US$ ~3.17) for the ewe fertility rate in Valle del Belice dairy sheep, which is higher than the present finding. Differences in the assumption of revenue sources may be the reason for such a variation. For instance, milk yield was not considered as a revenue source in the present study, while it had been included in the referred work. The EV of lambing interval was about US$ 0.16. Compared to the other reproduction traits, improving the mean lambing interval of ewes by one unit showed relatively low economic importance. This could imply that further genetic improvement may not be the priority given that the current mean lambing interval for indigenous sheep in the study areas is reasonably adequate, which is about 243 days or 1.5 lambings per year.

The marginal profit linked to a 1% genetic change on the survival of mature ewes was US$ 0.86, while the corresponding estimate for the post-weaning lamb survival was about US$ 0.5. When the survival rate of mature ewes is increased, more sheep would be available for sale due to the reduced number of female replacements as compared to the base situation, thereby increasing profit per ewe per year. The EV estimated for the survival rate of mature ewes in the present study is within the range of EVs reported in other studies. For instance, Abdollahy *et al.* [2012] reported an EV of US$ 1.49 for the survival rate of mature ewe, while Kosgey *et al.* [2003] found an EV of US$ 0.5 for the same trait. Such studies could indicate that improving the survival rate of mature ewes would provide better economic benefits in different sheep breeds.

Sensitivity of economic values

Evaluating sensitivity of EVs of traits to changes in price levels for input and output parameters is essential to understand the possible directions for future genetic improvement [Kosgey *et al.* 2003]. Similarly to most tropical areas, seasonal variation in the market price of live animals is common in Ethiopia. For example, during the dry season when the availability of feed is low, many farmers may prefer to sell their animals, thus the price could drop due to the excess supply. The reverse could happen during the wet season. Overall, price fluctuations are not expected to be high unless a prolonged drought is experienced. In the present study moderate climatic conditions were assumed and sensitivity of EVs was evaluated by changing the cost of feed and the price of live weight with a value of ±20% (Tab. 4). As expected, increasing the cost of feed led to a reduction in the EV of mature ewe weight by 45.4%. Following a unit genetic change on this trait, the highest cost was incurred for feed, thus a further rise in feed costs is more likely to have an undesirable effect on EV. Lowering of feed costs by the same level showed a positive effect on the EV of mature ewe weight. However, EVs for the majority of the study traits were fairly stable to alterations of feed cost by up to 20%.

Table 4. Sensitivity of economic values of traits before and after changing feed cost and live weight price by ±20%

Traits	Initial EVs	Costs			Revenues		
		+20%	-20%	sensitivity +/- (%)	+20%	-20%	sensitivity +/- (%)
Weaning weight	-0.04	-0.05	-0.03	24.4	-0.04	-0.04	0.0
Weight at 6 months of age	0.60	0.57	0.63	4.4	0.74	0.46	23.6
Yearling weight	1.46	1.43	1.50	2.5	1.79	1.14	22.0
Mature ewe weight	-0.24	-0.34	-0.13	45.4	-0.19	-0.29	20.7
NLW/EB[a]	0.59	0.56	0.62	5.4	0.75	0.43	26.6
Ewe fertility	0.37	0.30	0.45	20.1	0.53	0.22	42.3
Lambing interval	0.16	0.15	0.17	5.7	0.21	0.12	27.3
Post-weaning survival	0.53	0.52	0.55	3.4	0.66	0.41	24.0
Mature ewe survival	0.86	0.79	0.93	8.2	1.11	0.61	29.3

[a] NLW/EB – number of lambs weaned per ewe bred.

Varying the price of live weight caused a relatively larger change on the EV of ewe fertility. For the other traits, except for weaning weight, the deviation of EVs over the base situation was within the range of 20 to 30% after changing the price of live weight of sheep by a margin ±20%. Generally, altering feed costs showed an inverse effect on EVs, while changes made on the price of live weight produced a direct effect. Furthermore, when comparing the sensitivity of EVs to changes in the feed cost and live weight price, the majority of the traits were more affected by the changes in the latter variable. It could imply that EVs of the studied traits may change in the future depending on the levels of outputs and prices.

In conclusion, sheep rearing at the smallholder level is profitable under the existing low-input production system in economic terms, even without taking into account the socio-cultural and other intangible benefits. The profitability can be improved by implementing selection towards traits that have high economic importance. However, combining all the traits that have high economic benefits into a single breeding goal depends on the genetic relationship between traits. Some traits may have a negative genetic correlation, in which selection towards one of the traits may adversely affect the other. In this regard, the results of the present study are useful to optimise breeding schemes for sustainable genetic improvement of indigenous sheep in the north-western highlands of Ethiopia.

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