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ESTIMATION OF CROSSBREEDING PARAMETERS AND GROWTH PERFORMANCE OF BEGAIT × SEKOTA SHEEP CROSSBRED UNDER ON-FARM CONDITIONS OF WAG-HIMRA, NORTHERN ETHIOPIA

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ABSTRACT: Crossbreeding programs using either exotic or indigenous sires are an appropriate and rapid way to improve productivity within a shorter generation interval. Therefore, this study was designed to evaluate the growth performance traits of individual crossbreeding parameters of Sekota x Begait sheep crossbred under on-farm conditions in the lowland areas of Wag-himra, Northern Ethiopia. The cross-breeding program was conducted from 2018 to 2022 in Kasayred village of Abergele district on 699 animals. Least-squares means for weight at different ages and average daily weight gains were obtained by fitting the general linear model procedure in the SAS software. Crossbreeding parameters, including additive, heterosis, and recombination loss, were derived by fitting them as fixed covariates. The overall least square means for birth weight (BWt), three-month weight (TMWt), six-month weight (SMWt), nine-month weight (NMWt), and yearling weight (YWt) of evaluated progenies were 2.49±0.02, 11.61±0.09, 15.66±0.17, 19.27±0.18, and 23.46±0.23 kg, respectively. The overall least square means for average daily weight gain up to weaning (ADG1), six-month (ADG2), nine-month (ADG3), and yearling (ADG4) were 101.03±1.00, 45.30±1.38, 40.93±1.20, and 46.07±0.90 g/day. Only the additive effect of BWt for the Begait sheep breed was significant and it was found as 0.35±0.13 kg. Heterosis contributed 27-39 % live body weight improvement for Sekota sheep at yearling and six-month weights. In general, this pilot crossbreeding program resulted in 24% to 53% yearling weight improvement of pure Sekota breed (50%,75%, and 25% blood levels, respectively), and participating farmers in the program witnessed that it was important in terms of improvement in phenotypic traits, growth rates, and market values. Based on the result of this study, we recommend establishing a 50% crossbred ram multiplication center in the area for long-term operation and further evaluating other blood levels by incorporating carcass and reproductive performance traits.

Keywords: Begait sheep, Crossbreeding, Farmers management practice, Phenotypic traits, Sekota sheep.

INTRODUCTION

Small ruminant production has proven to be an important component of food security and the economic and social livelihoods of the rural poor in all farming systems of Ethiopia, and more specifically in the Wag-himra zone (Yiheyis et al., 2012). In this area, sheep are raised as a major source of meat and immediate sources of cash income, even though the breeds are low producers. The Sekota sheep breed, with an estimated population over 200000 (CSA, 2021), is among Ethiopia's 14 breeds (Gizaw et al., 2008) found in all agroecological zones of Wag-Himra. The breed is characterized by low productivity in terms of growth, meat production, and reproductive performance but is highly resistant to feed scarcity and drought and can thrive with less available and poor-quality feed sources (Lemma et al., 2012; Yiheyis et al., 2012). In addition, Gizaw et al. (2008) described the country's sheep populations based on their threat status, population size, and economic, cultural, and ecological values, and recommended possible genetic improvement methods. With this, Sekota sheep have an average breed merit of 0.23, which is the lowest value from the characterized breeds, exceedingly only the Adilo breed (0.17). The value suggested the implementation of selective breeding in highland areas and controlled crossbreeding programs, especially in the lowlands, by considering the infrastructure, capacity, and breeding goals of smallholder producers.

Crossbreeding is a genetic improvement method that enables the utilization of the non-genetic effects of breed genetic variations and is an appropriate and rapid way to improve productivity within a shorter generation interval (Sheridan, 1981; Vanvanhossou et al., 2025). Crossbreeding of local sheep with exotic sire breeds in the country as a whole has been adopted for the last five decades as a major breeding strategy to improve the productivity performance of local sheep breeds (Gizaw et al., 2014). This strategy was not successful in Ethiopia, except for the Awassi crossbreeding program in limited areas, owing to the high cost of importing, multiplying, and maintaining exotic sheep breeds stemming from resource limitations. In addition, exotic genotypes were not well compatible with low-input system environments.

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Crossbreeding programs using potential indigenous sheep breeds (Bonga, Washera, Farta, and Menz breeds) have been tested in the subalpine and Western parts of the Amhara region and have demonstrated several advantages over the use of exotic sires (Abebe and Alemayehu, 2019). Crossbreeding between indigenous breeds is suitable for farming communities in developing countries, such as Ethiopia, which share various sociocultural characteristics and geographical proximity. The limitation of using such indigenous breeds is the smaller performance variation, which results in the performance of crossbred progenies being parallel to that of the parents.

In the northern lowlands of Ethiopia, the Begait sheep breed, known for its superior growth, is a valuable resource for crossbreeding. Its higher growth performance suggests that it has been instrumental in improving smaller sheep breeds within its geographical range. The breed is characterized by a muscular body, higher adaptation to drought, and higher prolificacy (Amare et al., 2012). The adult weight of Begait rams can reach more than 80 kg under semi-intensive management and more than 45 kg under extensive systems (Amare et al., 2019). This breed could be a potential sire line to improve the productivity and phenotypic characteristics of Sekota sheep because of environmental and food source proximity. Robison et al., (1981) described; even though considerable research has evaluated crossbreeding in farm animals, the analyses and reporting of the results have often been inadequate, especially in quantifying the individual crossbreeding parameters. Therefore, this study was designed to evaluate the growth performance and estimate individual crossbreeding parameters of Sekota × Begait sheep crossbred levels under farmer management practices in the lowland areas of Wag-Himra, Northern Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Kasayerd village in the Abergele district of the Wag-himra Zone, Amhara region, Ethiopia from to 2018-2022. The area is located geographically at 13°01'37"E 38°58'36"N with an altitude of 1270m above sea level. The average minimum and maximum temperatures ranged between 16 and 36℃. The mean annual rainfall (ten-year average) in the area is reported as 620 mm with shorter intervals (mid-July to late August) and erratic distribution. The major feed sources in the study location were natural pastures, crop residues, rangeland shrubs, and acacia tree species. Small ruminant production is the mainstay of the livelihood in the area. In the highlands, producers maintain all herds together with their cropping activities, while in the lowlands, market-oriented sheep production is commonly practiced with a continuous supply of sheep to local markets.

Description of experimental animals and their management

The Sekota sheep breed is a short fat-tailed with, predominantly fine hair coat, smaller to medium size, and rudimentary ears. It is distributed in the Tekeze Valley of Amhara and some parts of the Tigray regional states and is reared by the Agew, Amhara, and Tigray communities (Gizaw, 2008; Gizaw et al., 2008). The breed is further characterized by a smaller mature body weight, longer reproductive performance, lower prolificacy, and resistance to drought and feed shortages. The Begait sheep breed is categorized under the long thin-tailed breed groups with convex facial profile, polled horn type, long and laterally dropping ear shape, produced for both meat and milk production, large-sized, prolific (frequent twining), distributed in the northern parts of Ethiopia, and reared by Amhara and Tigray communities (Amare et al., 2019). Pure Begait rams brought from Humera were separately herded for a month before mating. Rams were provided with different vaccinations and treatments against the major diseases and parasites in the area. Experimental animals are managed under an extensive system, arranged in ranges throughout the year. Farmers practiced crop residue supplementation of pure Begait rams during the critical feed shortage season. Acacia pods and leaves, sorghum stalks, shrubs, and cowpea haulms are the major feed sources in the area. All experimental animals were vaccinated against common diseases in the area and were treated regularly. All experimental techniques, procedures, and animal care were properly applied considering ethical standards, and animal nutrition and health researchers of Sekota Dry-land Agricultural Research Center confirmed this during the annual review forum. In addition, the Center Ethical Clearance Committee approved that all the experimental procedures of this activity were conducted according to the institutional animal care guidelines of the Amhara Region Agricultural Research Institute.

Structure of the crossbreeding program

The Sekota × Begait crossbreeding program was implemented by mating pure Begait rams with pure Sekota ewes as dams for the production of 50% crossbred blood levels, as described in Figure 1. At the beginning of the crossbreeding program, 33 pure Begait rams were used as a sire line to mate a base population of 500 local Sekota ewes from 18 participating households with a 1:15 mating ratio from November 2017 to 2018 for two years. Pure Sekota rams were culled or castrated before the Begait ram distribution after an agreed consensus with participating farmers through discussion and training. Subsequently, the distributed pure Begait rams were utilized for two successive mating seasons or births within a single household before being transferred to the next household.

Begait rams were rotated by considering their previous mating history to avoid inbreeding. A total of 196 first filial (F1) generation crossbred lambs were produced during the first two years of the study. From these F1 progenies, fourteen 50% crossbred rams were selected for the production of next generation progenies. Then, F2 generations of 25% were produced from 50% crossbred rams and pure Sekota ewes, and 75% blood levels produced from pure Begait rams and 50% crossbred ewes, whereas 50% blood levels in this generation were produced from the inter se mating of 50% crossbreds. Pure Sekota lambs raised and monitored in the adjacent village with local practices served as the base population for pure Sekota sheep. The production of all blood levels for evaluation was critically managed by proper ram rotation and culling of unselected young lambs. The production of all three blood levels was conducted by considering the availability of the required reproductive ewes or rams in that household that would be appropriate for the production of the desired blood level. During the selection period of these rams, unselected ones were culled from the population by castration or selling to the local market. Breeding sire rotations were performed based on the drafted bylaw, considering the previous mating history of the pure Begait rams and the purpose of producing the desired blood levels. Subsequently, 28 pure Begait rams (an initial 33 minus 5 that died) and 14 crossbred (50%) rams were distributed among the participating households. These rams, both purebred and 50% crossbred, were used to sire the second-generation (F2) progeny. The resulting F2 generation, exhibiting 50%, 25%, and 75% Begait blood levels, was born within the targeted participating households. This variation in blood levels arose from mating the purebred and 50% crossbred rams with the existing first-generation (F1) ewes, which were all 50% crossbred ewes.

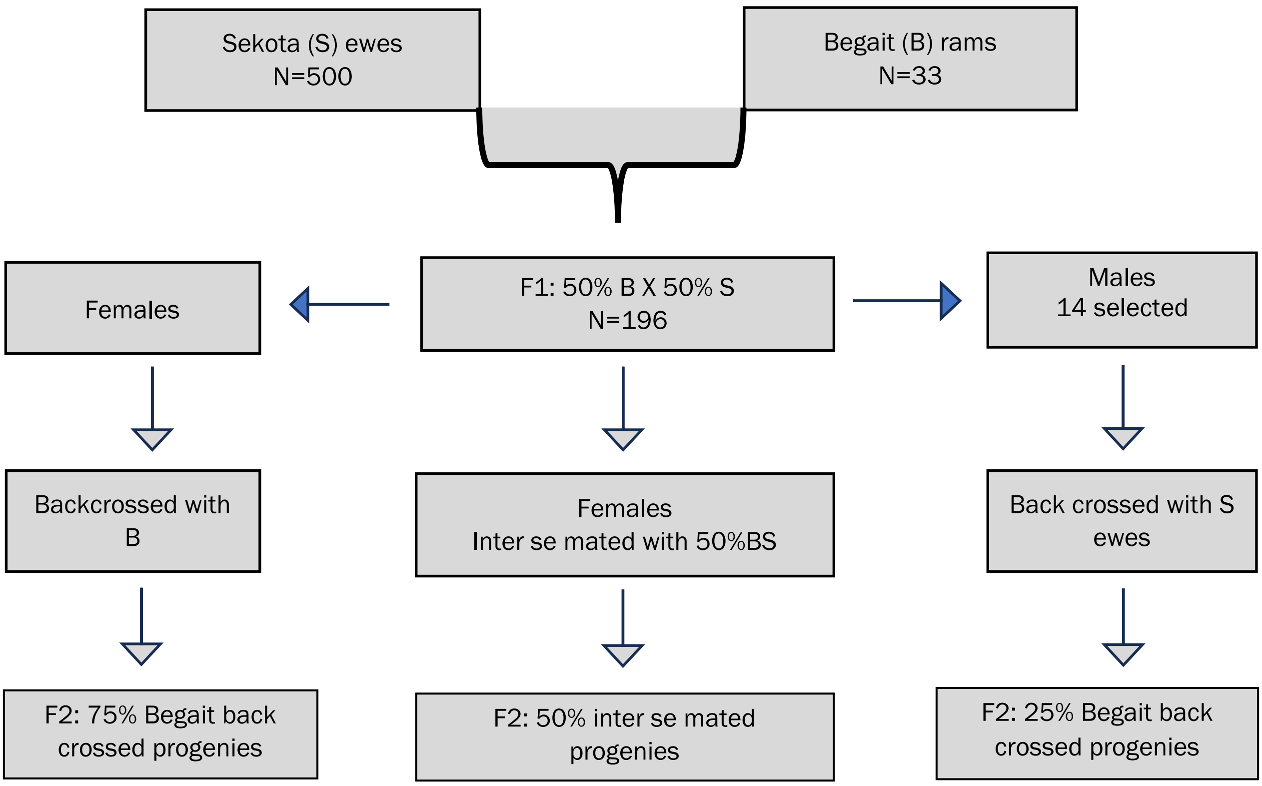

Figure 1 - Schematic presentation of Sekota X Begait sheep crossbreeding scheme in farmer flocks

Study design, data management and analysis

A cross-sectional study involving the purposive selection of completeness of study traits and records was conducted. From the implementation of the crossbreeding program, data were recorded on the first ram distribution date, lambing dates, ram rotation, breeding ram survival, body weight of lambs at different ages, sex, birth type, and other biological performances by trained enumerators. All animals were identified using plastic ear tags at the start of the program. A total of 699 births (231 pure Sekota sheep) were monitored and recorded for the evaluation of progeny growth performance. The number of animals was significantly reduced during the nine month and yearling stages due to the practice of selling young animals in these stages. The growth performance of the pure Sekota breed at different age groups was monitored and collected from adjacent villages with zero crossbreeding threat. All the collected biological data were checked for normality, and data structures not suitable for the analysis were corrected if possible or discarded when incomplete and inconsistent.

Continuous data, such as weight at different ages and average daily weight gains of crossbred blood levels, were analyzed using the general linear model procedures of Statistical Analysis Software (SAS, 2002). Mean separation was conducted using Tukey's HSD test for significant fixed effects. Linear correlation analysis using Pearson's method was employed to evaluate the relatedness of progeny weights at different age groups. The fixed effects fitted in the evaluation model included genotype (Pure Sekota, 25%, 50%, and 75% crossbreeds), sex of the lamb (male, female), birth type (single, twin), and season of birth (wet from June to November and dry from December to May based on feed availability in the area). It was difficult to estimate parity for all pure Sekota ewes at the start of the crossbreeding program by asking the owners; therefore, it was excluded from the analysis. The statistical model fitted for the least squares estimation of various growth performance traits is as follows:

$$Y_{ijklm} = \mu + G_i + S_j + B_k + T_l + e_{ijklm} \quad (1)$$

Where Y_{ijklm} is the dependent variable (weight at different ages, average daily weight gains), G_i is the effect of i^{th} genotype, S_j is the effect of j^{th} sex of lamb, B_k is the effect of k^{th} birth type, T_l is the effect of ^{lth} season of birth and e_{ijklm} is the residual error term.

The coefficient of individual crossbreeding parameters including breed additive (gi), heterozygosity (hij), and recombination (rij) were analyzed using a multiple regression procedure developed by (Robison et al., 1982) by fitting them as fixed covariates instead of breed/genotypes. The expected coefficients used for crossbreeding parameters estimation for growth performance traits (Table 1) were derived using the formula:

$$g_i = 1/2(GBs+GBd) \quad (2)$$

$$h_{ij} = GBs*GSd+GSs*GBd \quad (3)$$

$$r_{j=} 4\ gB *gB - h_{ij} \quad (4)$$

The coefficients of individual crossbreeding parameters, including breed additive (gi), heterozygosity (hij), and recombination (rij), were analyzed using a multiple regression procedure developed by Robison et al. (1982) by fitting them as fixed covariates instead of breed/genotypes. The expected coefficients used for crossbreeding parameter estimation for growth performance traits (Table 1) were derived using the following formula:

Table 1 - Genetic coefficients of Begait breed used for the estimation of cross-breeding parameters of growth traits in Sekota X Begait sheep breed

Genetic group	Blood level/Generation	Number of progenies born	g_c	h_c	r_c
SXS	Pure Sekota	231	0	0	0
BXS	F1 (50%)	311	0.5	1	0
BXBS	Back cross (75%)	68	0.75	0.5	0.25
BSXS	Back cross (25%)	89	0.25	0.5	0.25

Where; S= Sekota sheep; B= Begait sheep; BS= Sekota × Begait first filial generation (50%); BXBS= 50% females back cross with pure Begait ram producing 75% Begait; BSXS= pure Sekota ewes back cross with 50% crossbred rams to produce 25% Begait blood level; and the sires' breed is mentioned first; $g_{c=}$ coefficient of breed additive; $h_{c=}$ coefficient of heterosis and $r_{c=}$ coefficient of recombination loss effects

RESULT AND DISCUSSION

Growth performances of Sekota sheep and its crosses with Begait breed

The overall least square means for birth weight (BWt), three-month weight (TMWt), six-month weight (SMWt), nine-month weight (NMWt), and yearling weight (YWt) of evaluated progenies were 2.49±0.02, 11.61±0.09, 15.66±0.17, 19.27±0.18, and 23.46±0.23 kg, respectively, as presented in Table 2. The pre-weaning growth performance obtained in this study was slightly higher than the values reported by (Mekuriaw et al., 2013) for Washera × Farta, (Lemma et al., 2012) for Washera × Menz and Bonga × Menz crossbred lambs, and (Abebe et al., 2016) for Dorper × Afar crossbreds under station management, but lower than the performances of Dorper × Wollo crossbred sheep (Lakew and Haile-Melekot, 2014), Dorper × Tikur crossbreds in the highlands of North Wollo (Tilahun et al., 2016), and (Abebe et al., 2016) for Dorper × Menz sheep crossbreds in the cool highlands of North Shewa. This is in agreement with the results reported by Habtegiorgis et al. (2025), who reported that the growth performance of Dorper × Local sheep crossbred in the southern region at birth and weaning age were 2.43±0.03 and 11.59±0.49 kg, respectively. The growth performance of crossbred lambs during the post-weaning period was also greater in this study than that reported in previous studies.

Blood level exerted a significant effect ($P < 0.0001$) on the growth performance of lambs at all growth stages, in which crossbred lambs were heavier than local counterparts (from birth to yearling weight). Half-cross crossbred lambs (50%) were heavier than the other blood levels up to weaning age and then beaten by 25% and 75% blood levels. In this study, 25% of the crossbred lambs outperformed their 50% and 75% counterparts at all post-weaning ages (from SMWt to YWt). Crossbred lambs with 25%, 50%, and 75% blood levels were 29.09, 31.23%, and 30.26% heavier than pure Sekota lambs at weaning age, respectively.

Table 2 - Least square means (±SE) for growth performances of Sekota X Begait crossbred sheep (kg) at different growth stages

Variables	N	BWt LSM±SE	N	TMWt LSM±SE	N	SMWt LSM±SE	N	NMWt LSM±SE	N	YWt LSM±SE
Overall mean	699	2.49±0.02	588	11.61±0.09	508	15.66±0.17	443	19.27±0.18	344	23.46±0.23
CV		15.73		13.58		10.74		9.85		10.99
Blood level		***		***		***		***		***
Pure Sekota	231	2.15±0.02[c]	151	8.48±0.03[b]	144	10.57±0.03[b]	134	14.14±0.08[c]	120	19.25 ±0.15[c]
25% Begait	89	2.35±0.04[b]	88	11.96±0.17[a]	55	17.97±0.31[a]	30	23.32±0.48[a]	21	29.6±0.34[a]
50% Begait	311	2.64±0.03[a]	287	12.33±0.11[a]	250	17.66±0.12[a]	233	20.67±0.13[b]	176	25.16±0.23[b]
75% Begait	68	2.55±0.06[a]	62	12.16±0.19[a]	59	18.39±0.29[a]	46	22.53±0.38[a]	27	28.14±0.62[a]
Lamb sex		ns		ns		ns		ns		ns
Male	334	2.41±0.03	285	11.27±0.13	247	16.16±0.23	217	20.12±0.24	165	25.49±0.32
Female	365	2.43±0.02	303	11.19±0.13	261	16.14±0.24	226	20.21±0.26	179	25.64±0.32
Birth type		ns		*		ns		ns		ns
Single	682	2.47±0.02	575	11.56±0.09[a]	495	16.07±0.17	432	20.35±0.18	335	25.34±0.23
Twin	17	2.37±0.13	13	10.91±0.62[b]	13	16.24±1.05	11	19.98±0. 98	9	25.75± 0.22
Season of birth		***		**		*		ns		ns
Dry	269	2.34±0.03	233	11.05±0.13[b]	212	16.32±0.23[b]	183	20.00±0.27	128	25.58±0.41[a]
Wet	430	2.50±0.02	355	11.41±0.13[a]	296	15.98±0.22[a]	260	20.34±0.23	216	25.73±0.26[b]

Where; BWt= Birth weight; TMWt= Three-month weight; SMWt= Six-month weight; NMWt= Nine-month weight; YWt= Yearling weight; LSM= least squares mean; SE= standard error and CV= coefficient of Variation; ns= P >= 0.05; *= P < 0.05; **= P < 0.01; and ***= P < 0.001

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In addition, 25% and 75% of crossbred lambs had superior yearling weights than 50% and local counterparts. The reason for the higher post-weaning weight of all blood level crossbred lambs compared to the pure Sekota lambs could be connected with the positive effects of the crossbreeding program. This crossbreeding program also demonstrated that when the blood levels of pure Begait are reduced, the growth performance of produced progenies gets higher due to the compatibility of these genotypes to the existing environment which is in line with the report of Getachew et al., (2016) who reported the superiority of crossbreds in various aspects such as growth and market price.

The growth performances of crossbred progenies were not significantly affected P > 0.05 by the sex of lambs at all growth stages in this study. The non-significant effect of sex on the growth performance of traits in different growth stages was reported in (Habtegiorgis et al., 2025; Tilahun et al., 2016) whereas (Abebe et al., 2016; Lakew and Haile-Melekot, 2014) reported the significant effect of sex. This variation could be connected with environmental, management, population size, and breed variations under investigation. In addition, this phenomenon could also be connected with breed specificity, uniform management practice, nutrient equivalence, and age of measurement variations. The birth type of lambs did not exert a significant effect, except at weaning age. The non-significance of birth type in this study was in contrast to other reports due to the extreme sample size variations observed in this study. The proportion of twin kids in this study were very small (2.43%) and that could affect the significance of type of birth in this study. On the other hand, the season of birth significantly affected the growth performance of lambs up to six-month weight then after, season did not affect nine month and yearling weight growth performance.

The observed growth performance differences in this study are in agreement with farmers' opinions regarding the crossbreeding program gathered during field visits and researcher observations at individual households. With this, Farmers are very interested in the performance of the overall program. Phenotypically they preferred 25% crossbred lambs due to increased ears size and short twisted tails. They are also interested in the meat quality of the crossbreds. In addition, the market price of crossbred lambs was maximum at six-month age whereas the local lambs were not reached for the market even at yearling age. And also, the program drawn project interests in the area and they are willing to scale out the technology to other villages.

Growth rate (daily weight gains) of lambs

The overall least square means for average daily weight gain from birth to three-month (ADG1), from three-month to six-month (ADG2), from six-month to nine-month (ADG3), and from nine-month to yearling weight (ADG4) of different blood levels were 101.03±1.00, 45.30±1.38, 40.93±1.20, and 46.07±0.90g, respectively (Table 3). Pre-weaning and post-weaning average daily gain performances of lambs were significantly (P < 0.0001) affected by blood level. Lamb sex and birth type did not show significant effect (P > 0.05) at all stages even though male and twin lambs exhibit higher values. Season of birth was not significant at all stages of growth except in ADG2. During the pre-weaning growth phase, crossbred lambs exhibited higher average daily weight gain compared to pure local breeds, with this increase positively correlated to their body weight. However, during the post-weaning period, 50% crossbred lambs showed lower ADG even underperforming local lambs—likely due to the pronounced influence of environmental factors on their growth performance. The pre-weaning daily weight gain of this study is in accordance with the report of (Tilahun et al., 2016) for Awassi X Tikur crossbred sheep, (Habtegiorgis et al., 2025) for 50% Dorper × Indigenous sheep in the southern Ethiopia who reported 98.16±13.4g/day, The result that the lower ADG of 50% crossbreds is also reported in Awassi X Wollo sheep crossbreeding program (Tesema et al., 2020). The pre-weaning average daily gain values obtained in this study are higher than the reports of (Lemma et al., 2012) for pure Menz, 50% Washera × Menz and 50% Bonga X Menz breeding groups which were 65±1.8, 66±1.7, and 70±1.7 g, respectively.

Table 3 - Phenotypic correlation values (with significant difference level) of weight at different age in Sekota X Begait sheep crossbreeding program.

	BWt	TMWt	SMWt	NMWt	Ywt
BWt	1	0.27 (***)	0.27 (***)	0.30 (***)	0.24 (***)
TMWt		1	0.74 (***)	0.64 (***)	0.52 (***)
SMWt			1	0.82 (***)	0.70 (***)
NMWt				1	0.82 (***)
Ywt					1

Where; BWt= birth weight; TMWt= three-month weight; SMWt= six-month weight; NMWt= nine-month weight; YWt= yearling weight; ns= P >= 0.05; *= P < 0.05; **=P < 0.01; and ***= P < 0.001

Phenotypic correlation of growth performance traits of crossbreds

Understanding the magnitude of genetic and phenotypic correlations is important for multiple trait evaluation, particularly when predicting correlated responses to selection. Phenotypic correlations are better at evaluating the effect of both genetic and environmental variations in populations. The phenotypic correlation of growth performance traits for

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crossbred lambs at different weights is presented in **Error! Reference source not found.**. Phenotypic correlations of BWT with later growth stages were moderate and inline when compared to other various studies in sheep and goats. On the other hand, correlation values for TMWT-SMWT, SMWT-NMWT and NMWT-YWT are higher and positive which are comparable with the results of various studies in small ruminants. These higher phenotypic correlation values suggest that heavier weight of kids at weaning tend to attain heavier weights at later stages of growth.

Estimation of crossbreeding parameters

The estimates of additive and non-additive genetic (heterosis and recombination) effects are presented in Table 4. Only the additive effect of BWt for Begait sheep breed was significant and it was found 0.35±0.13 kg in this study. Weights of the crossbred lambs producing in this crossbreeding program other than birth weight are small and non-significant. Lower additive genetic effects in this study given the clear genetic distance between the two breeds might be related to the smaller sample size and the adverse effects of the experimental environment. However, all the additive effects of Begait breed were not significantly different for all the average daily weight gains and even for the later growth stages the additive genetic effect from the larger breed was negative. This could be explained by smaller to non-significant additive effects for most of the growth performance traits confirmed the lower level of breed difference between indigenous breeds compared to using exotic sire sources and indigenous breeds are more adapted to the locality than other breeds out of the area. However, higher and significant individual additive effects were reported in milk, growth and reproduction performance improvement of dairy cattle in Central Ethiopia (Birhanu et al., 2015).

The effect of heterosis for most of the growth performance and daily weight gain traits were positive and significant except for ADG3 and ADG4 which exerted negative values. These positive and highly significant heterosis values imply that heterosis contributed a positive effect on the improvement of the pure Sekota sheep breed. For instance, heterosis contributed 27-39 % live body weight improvement for Sekota sheep which is parallel to 7.20 and 6.77 kg improvement for yearling and six-month weights, respectively. Other positive effects for heterosis are also presented in various livestock crossbreeding studies as described in (Tesema et al., 2023).

In this study, the estimates of recombination showed a positive and significant effect on most of the growth and average daily weight gain traits except for BWt. This result is in argument with the empirical principle that this effect should be negative and small rather. The reason for this result might be connected with the smaller data size in this study but the limitation here could be the difficulty to discuss these results in the existing condition. However, other scholars reported that recombination loss's effect was negative in most of the growth and reproductive traits of livestock species.

Table 4 - Least square means (±SE) for average daily weight gains (g) of Sekota X Begait crossbred sheep at different growth stages

Variables	N	ADG1 LSM±SE	N	ADG2 LSM±SE	N	ADG3 LSM±SE	N	ADG4 LSM±SE
Overall mean	588	101.03±1.00	508	45.30±1.38	443	40.93±1.20	344	46.07±0.90
CV		18.04		54.55		60.87		36.90
Blood level		***		***		**		***
Pure Sekota	151	70.19±0.38[b]	144	23.72±0.37[c]	134	42.42±0.89[a]	120	50.66±0.83[ab]
25% Begait	88	106.65±2.00[a]	55	67.42±4.77[ab]	30	49.90±4.72[a]	21	59.05±2.95[a]
50% Begait	287	107.66±1.32[a]	250	58.43±1.73[b]	233	34.87±1.86[b]	176	43.93±1.52[b]
75% Begait	62	106.64±2.15[a]	59	69.37±4.10[a]	46	46.97±5.06[a]	27	55.24±4.38[a]
Lamb sex		ns		ns		ns		ns
Male	285	98.29±1.45	247	54.36±2.03	217	42.82±1.70	165	51.84±1.32
Female	303	97.28±1.38	261	54.91±1.86	226	44.27±1.70	179	52.60±1.35
Birth type		ns		ns		ns		ns
Single	575	100.98±1.01	495	49.70±1.39	432	44.65±1.23	335	49.90±0.96
Twine	13	94.60±6.34	13	59.58±9.29	11	42.44±4.56	9	54.54±5.01
Season of birth		ns		**		ns		ns
Dry	233	96.75±1.45	212	58.62±2.27[a]	183	41.06±2.19	128	51.58±1.94
Wet	355	98.82±1.35	296	50.66±1.57[b]	260	46.03±1.35	216	52.86±6.97

ADG1= average daily weight gain from birth to three-month weight; ADG2= daily weight gain from three-month to six-month weights; ADG3= daily weight gain from six-month to nine-month weight; ADG4= weight gain from nine-month to yearling weights; Min= minimum; Max= maximum; ns= not significant/P >= 0.05; *= P < 0.05; **= P < 0.01; and ***= P < 0.0001

Table 5 - Estimates of individual crossbreeding effects with standard errors of Sekota and Begait sheep breeds

Traits	N	Sekota means/Intercept	Additive	Heterosis	Recombination
BWt	699	2.24±0.03	0.35±0.13***	0.28±0.07**	-0.28±0.18^{ns}
TMWt	588	8.87±0.13	0.30±0.53^{ns}	3.65±0.31***	6.06±0.75***
SMWt	508	10.39±0.14	0.78±0.63^{ns}	6.77±0.36***	15.98±0.97***
NMWt	443	14.43±0.16	-1.41±0.89^{ns}	7.15±0.49***	22.72±1.45***
YWt	344	19.19±0.24	-2.77±1.50^{ns}	7.20±0.81***	28.55±2.33***
ADG1	588	73.60±1.48	-0.55±6.05^{ns}	37.61±3.54***	70.19±8.59***
ADG2	508	16.92±2.08	2.56±9.35^{ns}	34.42±5.36***	118.69±14.43***
ADG3	443	45.10±2.18	-3.32±11.71^{ns}	-7.06±6.45^{ns}	31.10±19.00^{ns}
ADG4	344	48.97±1.55	-7.35±9.87^{ns}	-3.44±5.33^{ns}	43.75±15.34**

Where; BWt= birth weight; TMWt= three-month weight; SMWt= six-month weight; NMWt= nine-month weight; YWt= yearling weight; ADG1= average daily gain from birth to three-month weight; ADG2= average daily gain from three-month to six-month weight; ADG3= average daily gain from six-month to nine-month weight; ADG4= average daily gain from nine-month to yearling weight; ns= not significant; **= P < 0.001; and ***= P < 0.0001

CONCLUSION AND RECOMMENDATIONS

Based on the findings of this study, it can be concluded that all crossbred types demonstrated improved growth rates compared to the local sheep breeds in the area. Specifically, the crossbred types with 25% and 75% blood levels showed superior performance compared to the F1 (50%) crossbred level. However, it is important to note that significant variation in number was observed in the 25% and 75% crossbred types, which might introduce bias to these results. However, it is crucial to acknowledge the existing gaps for further research. In addition to growth, overall productivity and benefits, it is important to consider other factors such as lamb survival and reproductive performances. These aspects should be taken into account when assessing the overall success and viability of crossbreeding programs. Further studies should aim to address these areas of concern and provide a comprehensive understanding of the potential benefits and limitations of crossbreeding in terms of lamb survival and reproductive performance. It is also essential that future recommendations build upon the findings of this study while acknowledging the need for additional research to bridge existing knowledge gaps and provide a more comprehensive understanding of the impact of crossbreeding on various aspects of sheep productivity.

Individual crossbreeding parameters especially the heterosis effects were higher in this study which enables the utilization of non-additive genes from breed combination. The households involved in this program showed keen interest in crossbreeding programs when they found it beneficial to them. Thus, from the pilot results obtained in this study, we recommend; the distribution of 50% crossbred rams by establishing a 50% crossbred multiplication site. In addition, further research needs to be done on the performance evaluation of other blood levels including carcass, lamb survival and reproductive performance traits addressing site-specific farmer interests.

DECLARATIONS

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical approval

Sekota Dry-land Agricultural Research Center Ethical Clearance Team confirmed that all the experimental procedures of this activity were conducted by the institutional animal care guidelines of the Amhara Region Agricultural Research Institute under SDARC/EEC/2019/01-minute number.

Authors' contributions

Conceptualization: Mulatu Gobeze and Bekahegn Wondim; **Data Curation:** Mulatu Gobeze, Wubneh Aklog, Bekahegn Wondim, Adane Bahiru, Yeshiwas Walle, Tigabu Limenh, Alemu Demlie and Tesfaye G/Mariam; **Data analysis and Writing-original draft:** Mulatu Gobeze; **Writing – review & editing:** Mulatu Gobeze, Wubneh Aklog, Bekahegn Wondim, Adane Bahiru, Yeshiwas Walle, Tigabu Limenh, Alemu Demlie and Tesfaye Gebremariam

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Competing interests

The authors declare no competing interests in this research and publication.

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