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Optimizing breeding structures and related management in community-based goat breeding programs in the Borana pastoral system of Ethiopia

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HIGHLIGHTS

- Different breeding programs were simulated and evaluated for Borana goat in pastoral production system.
- Inclusion of milk yield and growth trait in the selection index resulted in a significant economic benefit.
- Further optimization of mating ratio and improving kid survival were also resulted in a substantial profit.
- Dispersed nucleus with 577 does in the nucleus and 3579 does in the base has been recommended.
- The suggested breeding program resulted in accumulated total profit of US$14,776 over 10 years.

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ABSTRACT

The study simulated different potential breeding programs to design the optimal breeding structure and operational management structure for Borana goat. It evaluated different scenarios using ZPLAN+ software to maximize the genetic gain, discounted profit and to determine the optimum size of the base population for a community-based breeding program (CBBP) nucleus. The study analyzed the different combinations of objective traits in the index, assessed the effect of changing the breeding buck to doe ratio, evaluated the impact of improved kid survival, and determined the optimum size of the base population for a CBBP. A two-tier breeding program based on 577 does in the CBBP and 1,006 does in the surrounding base flocks was assumed, where selected CBBP bucks were disseminated to the base populations. Combining the weight of kids at six months (SMWT) and the lactation milk yield of dams (LMY) in the selection index resulted in a genetic gain doe^{-1} generation^{-1} of 0.13 kg, 0.58 kg, 0.02 and 0.004 for SMWT, LMY, the number of kids that survived to market age (NKS) and the number of kids born (NKB), respectively. This also generated a total discounted profit of US$5.76 doe^{-1} over 10 year investment period. This result was 30 percent higher than when LMY was evaluated separately and 225.7 percent higher than when SMWT was evaluated separately. The addition of NKB and NKS traits in the selection index did not significantly change the genetic progress and the profit. However, further optimization of the combined SMWT and LMY by improving mating ratio only, and a combined improvement in mating ratio and kid survival rate resulted in a substantial increase in profit to US$11.13 doe^{-1} and US$15.58 doe^{-1}, respectively over 10 year investment period. The maximum discounted profit was attained when the base population size was 3,579 breeding does. This resulted in accumulated total profit of US$14,776 over the 10 year investment period. A two-tier dispersed CBBP with a unit size of about 577 does in the nucleus and 3,579 does in the base is recommended. In Borana goat community-breeding program, breeding buck need to be selected using

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an index combining at least own live weight and dam milk yield performance. Essential requirements for ensuring the sustainability of such programs are also discussed in the paper.

1. Introduction

Livestock, particularly goat and sheep, have an important contribution in marginal areas and pastoral production systems, which are less suitable for crop production, but have the potential to maintain large numbers of farm animals. Goat breeds reared by pastoral communities are well known for adapting to harsh environments. They have a vital and multipurpose role, including milk and meat production, providing a source of cash from the sale of live animals, and many cultural and social benefits such as means of expressing prestige, bride wealth and sacrifice for religious festivals (Kosgey et al., 2004; Gebreyesus et al., 2012). However, environmental factors and management practices restrict goat breed productivity. Pastoralists are therefore unable to satisfy the growing global and regional demand for livestock products (FAO 2015).

A well-structured breed improvement strategy in developed countries has resulted in high yielding animals (Sölkner et al., 1998). However, implementing a successful breeding program has proved to be far more challenging in most of the developing countries (Kosgey et al., 2006). Centralized breeding schemes, undertaken by non-profit oriented governmental farms, involving complex breeding processes (i.e. data recording, genetic evaluation, selection, distribution of genetically improved animals, and feedback to farmers), have very little success in sustainably providing the aspired genetic improvements in developing countries (Kosgey and Okeyo 2007; Haile et al., 2018a). Crossbreeding and breed replacement using exotic breeds were also used as alternative methods for fast increases in productivity (Van Arendonk 2011). However, neither approach achieved the anticipated change in low input production systems. The crossbred goat population in Ethiopia is negligible (CSA 2015). Research results indicate unsatisfactory performances due to poor adaptation and low output per unit of input (Ayalew et al., 2003; Mustefa et al., 2019) and higher disease prevalence for major health problems among the crossbred goat population in Ethiopia (Hunduma et al., 2010). These results imply the need for a shift in focus towards the participatory improvement of locally adapted breeds (Sölkner et al., 1998; Mueller et al., 2015b).

A new approach, which has gained global interest, are community-based breeding programs (CBBPs). CBBPs accommodate the features of low input smallholder production systems and farmers' needs, views, and decisions, encouraging active farmer participation from the program design through to its implementation (Sölkner et al., 1998; Wurzinger et al., 2011; Mueller et al., 2015a; Haile et al., 2018b). Results have confirmed that substantial genetic gain and socioeconomic impacts can be achieved under CBBPs in crop-livestock production systems (Haile et al., 2020). CBBPs for improved growth resulted in 0.11, 0.18, and 0.21 kg genetic gain per year in Menz, Horro and Bonga sheep breeds, respectively, at six months old (Haile et al., 2020). These values are equivalent to 16–22 percent of the live weight change over 20 years, indicating that genetics alone will meet the Ethiopian Livestock Masterplan's projected weight gain of 20 percent of body weight over 20 years in small ruminants (Shapiro et al., 2015).

Implementing CBBPs remains a challenge in pastoral systems due to herd/flock mobility, recurrent drought, difficulties in delivering basic livestock services, and poor infrastructure. An earlier attempt to implement a CBBP in the pastoral system in the Afar region of Ethiopia was discontinued due to the lack of progress and failure to adapt the approach to the challenging circumstances outlined above (Getachew et al., 2018). Recently, however, erratic herd/flock mobility has been discouraged by the Ethiopian government with the aim to reduce conflict among communities. This is considered a good opportunity to set up CBBPs in the pastoral community. Additionally, a recent study by Getachew et al. (2020) showed that Borana (locally known as *Borena*) pastoralists have a clear mobility pattern. Multiple traits of interest/selection criteria, large variability in flock size, uncontrolled mating, and low kid survival are the main features of the Borana goat production system (Gebreyesus et al., 2012; Getachew et al., 2020). These hamper the implementation of successful genetic improvement programs. Thus, this study aimed to identify as few traits as possible for a selection index, optimize buck service year and mating ratio, and assess the effect of improved kid survival to maximize genetic gain and discounted profit for Borana pastoralists. This study also aimed to optimize breeding structures and operational management for CBBPs in Ethiopia's Borana pastoralist system.

2. Methodology

2.1. Target breed and selection group

A simulated breeding program was carried for pastoral goats targeting an ongoing Borana goat CBBP ($n = 577$ breeding does), which was established in 2019 by the International Center for Agricultural Research in the Dry Areas (ICARDA) in collaboration with Yabelo Agricultural Research Center. Borana goat is one of the goat breed reared by pastoral communities in southern Ethiopia. The average precipitation in the area is 551 mm per year, with a bimodal rain pattern from March to May and September to November causing very high variation throughout the year. The average temperature is 21 °C, with a low variation throughout the year. Kidding is distributed throughout the year with most kidding during the rainy seasons. The breed is distributed across the northern part of Borana district, northern Kenya, and the eastern Ethiopian Somali region. The breed is mostly pure white in color and exhibits uniform morphological characteristics, with an average mature body weight of about 32.0 kg, a market weight of 16.3 kg at about six months, and a daily milk yield of about 0.5 kg over the lactation period, which typically lasts about 100 days (Gatew et al., 2017; Getachew et al., 2020). Borana goat have a larger mature body weight than the surrounding goat populations, which are reported at 24.7 kg and 27.3 kg for Short Ear Somali and Konso goat in the Jarso area (Gatew et al., 2017; Getachew et al., 2020).

The simulated breeding program was structured into two-tiers involving the goat CBBP as a nucleus and the surrounding flock as the base population. Bucks from the CBBP were selected to be sires of the next buck generation in the CBBP, as well as in the base. This means the spread of the genetic gain to the surrounding flock/base population was assumed via the buck selected in the CBBP. Six selection groups were defined: 1) buck selected in CBBP used to produce sires for CBBP; 2) buck selected in CBBP used to produce dam for the CBBP; 3) does in CBBP used to produce sire for the CBBP; 4) does in CBBP used to produce dam for the CBBP; 5) bucks selected in the CBBP also used to produce dams for the base; and 6) does in the base used to produce dams for the base.

2.2. Input parameters

Input parameters on biological, population and genetic parameters were based on literature reports (Hailu et al., 2006; Getachew et al., 2020) and data from the ongoing Borana goat CBBP. Biological and population parameters and values for fixed and variable costs are indicated in Table 1. To represent the current system, 64 breeding bucks and 577 breeding does were considered in the simulated CBBP. About 236 proven bucks were produced with an estimated conception rate of 90 percent, a twinning rate of 1.17 kids per doe per kidding, a kidding interval of 280 days, and a sex ratio of 0.5, an estimated 63 percent of kids

Table 1
Biological and cost parameters.

Parameters	Current system	Improved mating ratio and better survival
Biological parameters		
Number of breeding does	577	577
Conception rate proportion	0.9	0.9
Kidding interval (years)	0.77	0.77
Twining rate	1.17	1.17
Kid survival to selection age (%)	63	90
Number of kids born doe^{-1} year^{-1}	1.37	1.37
Number of kids born per year	789	789
Number of does per buck	9	25
Number of candidate bucks	248	355
Males suitable for breeding	0.95	0.95
Number of proven bucks	236	337
Number of selected bucks	64	23
Culling for inferior performances (%)	35	35
Buck for base	111	40, 80, 120, 160, 200, 240, 280, 320
Breeding does in base	1006	1006, 2012, 3018, 4024, 5030, 6036, 7042, 8048
Cost parameters		
Fixed cost, US$	3.90	3.90
Variable cost in the CBBP, US $	1.96	1.62, 5.34
Variable cost in the base, US $	1.38	1.04
Price of 1 kg SMWT, US$	2.12	2.12
Price of 1 liter milk, US$	0.43	0.43
Six months weight (kg)	16.3	16.30
Price of 1 kid US$	34.48	34.48

survived to selection age and 5 percent of candidate bucks were culled for physical appearances. Out of 236 bucks proven, 64 bucks use in the CBBP and culling 35 percent for inferior performance, gives 111 breeding bucks for the base population. The base size of 1006 breeding does was then determined by the availability of bucks for the base and the male to female ratio of 1:9.

Calculated economic values, phenotypic variance, heritability, and the genetic and phenotypic correlation among traits are presented in Table 2. Input parameters on genetic and phenotypic parameters for the traits (i.e. heritabilities and genetic and phenotypic correlations) are lacking at the initial stage due to inexistence of a performance and pedigree recording. For this study, these parameters were derived from the studies by Aljumaah (2019) and Jembere et al. (2019). Economic weight of traits (goal trait values) measure the increase in revenue associated with a one unit increase in the goal trait. Economic values were calculated as the number of expressions of the trait during one year per breeding female multiplied by marginal profit following details in Mueller et al. (2021a). Marginal profit was calculated as the difference between the total revenues and total costs per doe per year. The market

Table 2
Economic values per genetic standard deviation (σ_G), phenotypic standard deviation (σ_P), heritability (diagonal) genetic (below) and phenotypic (above) correlations among traits.

Trait	Economic value (US$)		σ_P	SMWT	LMY	NKS	NKB
	Low kid survival	Imp kid survival					
SMWT	2.67	3.89	2.998	0.28	0.41	0.75	0.26
LMY	2.60	2.99	11.88	0.2	0.31	0.66	0.35
NKS	5.94	8.49	0.49	0.72	0.75	0.09	0.63
NKB	3.05	4.36	0.30	0.25	0.26	0.34	0.13

SMWT = six months weight; LMY = lactation milk yield; NKS= number of kids surviving till market age; NKB = number of kids born per breeding female per year.

price of traits and cost of inputs in October 2020 were used to calculate revenue and cost. The economic value calculation assumes that, when the trait is increased by one-unit, other traits remain constant (FAO 2010).

All costs associated with the community breeding program were considered. A total of $6167 fixed cost; salary of an enumerator recruited for animal identification and data collection ($542), costs of experts engaged in provision of training and facilitate community organization ($507), cost for construction of goat collecting yard ($1597), cost of a motorcycle ($2661) and cost of a computer for data recording and analysis ($860) were considered in the breeding program. Fixed cost per breeding does was then 3.90 which calculated as total fixed cost ($6167) divided by the total number of 1583 breeding does in the CBBP and base. Variable costs for animal treatment ($497.4), breeding ram cost in the traditional system ($299.8) and animal identification ($331.6) were considered for 577 breeding does per year in the CBBP flock which is equivalent to a variable cost of $1.96 per breeding doe per year. In the improved mating ratio, lower total variable cost of $1.62 was considered as the system need less number of rams. However, in the improved feeding scenario additional $3.72 per breeding doe per year were considered assuming supplementation of 200 g of concentrate feed and 400 g of hay per breeding doe for 90 days. In the base flock, variable cost (animal treatment and breeding ram) of $1.38 and $1.04 per doe per year was considered in the traditional and improved mating ratio system, respectively. Planning horizon of 10 years investment was considered assuming to coincide with other literatures and planning period of agricultural development plans in Ethiopia. Values other than the initial year were discounted with interest rate of 5% for costs and 7% for returns.

2.3. Simulation of the breeding program

ZPLAN+ software (Täubert et al., 2010) was used for simulating the Borana goat breeding program. The breeding objective was to maximize monetary genetic gain for milk yield and meat production. The ZPLAN+ optimization of a breeding program is based on selection index theory, which maximizes genetic progress towards a stated economic goal by considering the economic basis of the various traits (Hazel et al., 1994). The principle of geneflow is that the genetic gain will be realized in the later generation and different sub-populations (Hill 1974). Economic modeling enables the evaluation of a breeding program based on its economic efficiency, where all inputs and outputs are expressed in monetary terms. The annual genetic gain for the breeding objective, the genetic gain for a single trait, the monetary discounted return, the cost, and the profit results were used to test alternatives to the current system. The simulation aimed to start selective breeding by considering the current production system as a base and developing a step-by-step optimization process for traits in the index. The simulation also aimed to optimize the male to female ratio, the buck service year, improved kid survival scenario and the breeding program's management.

2.3.1. Breeding goal and selection index evaluation

Farmers have multiple trait preferences/selection criteria. However, the sale of live animals for income generation and consumption of milk and meat were identified as the major production objectives of Borana goat (Getachew et al., 2020). Body weight measurement at market age (around 6 months) (SMWT), lactation milk yield (LMY), number of kids surviving to selection age (NKS), and litter size (NKB) were considered as traits in the breeding goal. The kid's performance was the information source for SMWT, while the kid's dam was the information source for the other traits. Hazel (1943) defined the aggregate genotype (H) for a given individual as the sum of its genotypes for several traits, each genotype being weighted by their predicted contribution to the increase in the overall objective. The breeding objective for the Borana goat breeding program can be represented as H in the following equation:

$$H = a_1 * BV_1 + a_2 * BV_2 + a_3 * BV_3 + a_4 * BV_4$$

Where 'BV_i' represents the breeding values and 'a_i' represents the economic values for the breeding goal traits SMWT, LMY, NKB and NKS.

Six different combinations of traits were modelled and evaluated for genetic gain doe^{-1} per generation, monetary discounted return and profit doe^{-1} over 10 year of investment in the breeding program. The indices included SMWT (index 1), LMY (index 2), a combination of SMWT and LMY (index 3), a combination of SMWT, LMY, and NKB (index 4), a combination of SMWT, LMY, and NKS (index 5), and a combination of SMWT, LMY, NKB, and NKS (index 6). The selection index coefficients for the selection criteria traits in the indices were calculated using ZAPLAN+ software (Täubert et al., 2010) and can be represented as 'b' in the equation: $b = \boldsymbol{P}^{-1}\mathbf{G}a$. Where '**P**' is the phenotypic variance and covariance matrix for the traits, '**G**' is the genetic covariance matrix, and 'a' is the economic weight per unit of genetic standard deviations for the traits.

2.3.2. Mating ratio and sire use

The results for index 3 were almost the same as the results for indices 4, 5 and 6. Thus, index 3 was used in testing the effect of mating ratio and buck service year. The study evaluated the use of two traits, SMWT and LMY (index 3), with a male to female ratio of 1:25 and varying buck service between 2 and 4 years. The different scenarios were set as follows: index 3_2, index 3_3, and index 3_4 to represent index 3 with buck service years from 2 to 4. Mating ratio of 1:25 and buck service year of 2 to 4 were considered to keep the levels to the minimum and feasibility in the current practices.

2.3.3. Improved kid survival and optimization for base size

Improved kid survival from the current rate of 63 percent to 90 percent under better management was evaluated on index 3_2. Kid survival can be improved to a rate of 90 percent through better feeding management during critical times, such as supplementing the dams' feed during late pregnancy and the first weeks of suckling. Economic values of the traits were recalculated for the improved kid survival scenario (Table 2). The improved survival scenario benefits the program by increasing the availability of breeding bucks, which enables an increase in the base population. The results of increasing the base population of breeding females from 1006 to 8048 were also evaluated in the simulation.

2.4. Operational design to enhance optimization

The operational breeding structure was designed by considering the results of this simulation study, the size of the current CBBP, the biological parameters, flock mobility, recurrent drought, poor infrastructure, interest of the pastoral community, the engagement of cooperatives and youth groups, and the links to markets. Optimizing the operational design of the breeding structure required data collection, animal evaluation, selection, mating, and supplementation of animals (kids and flock) during critical times, such as droughts.

3. Results

3.1. Genetic gain and economic benefit

3.1.1. Breeding objectives

The genetic gain achieved per generation for each goal trait, the discounted return, and the profit per doe over the 10 year CBBP's investment period for six different indices are presented in Table 3. A male to female ratio of 1:9 and buck service year of two were considered in all the indices. The highest genetic gain per generation per does for SMWT (0.198 kg) and LMY (0.59 kg) was attained for the single trait of SMWT (index 1) and LMY (index 2), respectively. When both SMWT and LMY were combined (index 3) the genetic gain for SMWT and LMY was 0.125 kg and 0.583 liter, respectively. Due to the low heritability of the traits, inclusion of NKB and NKS only induced very small changes in the annual genetic change of any other trait. Evaluation of the breeding program, based on discounted profit over the investment period, showed that use of LMY (index 2) generated \$4.43 discounted profit doe^{-1} over the 10 year. This was a 225.7 percent increase compared to selection based on SMWT alone (index 1). The combination of SMWT and LMY (index 3) resulted in a higher monetary genetic gain and discounted profit doe^{-1} compared to the models for each trait alone (index 1 and index 2). Combining SMWT and LMY (index 3) improved the profit by an additional 30 percent compared to LMY only (index 2) and by 255.7 percent compared to SMWT only (index 1). Small genetic response per year was found for NKB (in the range of 0.003 to 0.004 and for NKS in the range of 0.01 to 0.02 (Table 3). The addition of NKB and NKS did not significantly change the genetic progress or the discounted profit. The combination of SMWT, LMY, and NKB improved the genetic progress by 0.35 percent, while the combination of SMWT, LMY, and NKS improved the genetic progress by 2.43 percent compared to index 3. Finally, the combination of all four traits in the index improved the profit by 2.94 percent compared to index 3.

3.1.2. Mating ratio and buck service year

Simulation based on the currently practiced male to female ratio of 1:9, the use of a sire for two productive years, kid survival of 63 percent and the combination SMWT and LMY traits (index 3) resulted in a discounted profit per breeding doe of \$5.76 (Table 3). Using the same scenario but increasing the male to female ratio from 1:9 to 1:25 (index 3_2) increased the profit to \$10.86 (Table 4), which is an 88.5 percent increase compared to index 3. The discounted profit decreased as the buck service year increased from 2 to 4 years (Table 4).

Table 3
The genetic gain achieved per generation doe^{-1} achieved per unit of genetic standard deviation for each trait and the total discounted return and profit doe^{-1} over the 10 year community-based breeding program investment period (US\$), reflecting different selection indices.

Index	Accuracy	Genetic gain				Total discounted return					TDP	% change in TDP
		SMWT (kg)	LMY (kg)	NKS (%)	NKB	SMWT (kg)	LMY (kg)	NKS (%)	NKB	Total		
Index 1	0.23	0.198	0.165	0.013	0.003	2.57	2.08	0.38	0.05	5.08	1.36	–
Index 2	0.37	0.028	0.590	0.010	0.003	0.37	7.46	0.28	0.04	8.15	4.43	225.7
Index 3	0.43	0.125	0.583	0.015	0.004	1.62	7.38	0.43	0.06	9.49	5.76	30.0
Index 4	0.43	0.126	0.584	0.015	0.004	1.62	7.39	0.44	0.06	9.51	5.78	0.35
Index 5 SMWT, SUR	0.43	0.128	0.590	0.0156	0.004	1.65	7.4768	0.44	0.06	9.63	5.90	2.08
Index 6	0.44	0.128	0.591	0.015	0.004	1.66	7.49	0.45	0.06	9.66	5.93	0.51

Index 1 = six months weight (SMWT) only; index 2 = lactation milk yield (LMY) only; index 3 = SMWT and LMY; index 4 = index 3 plus number of kids born doe^{-1} (NKB); index 5 = index 3 plus number of kids survived to six months age (NKS); index 6 = all traits in the index. The buck:doe ratio = 1:9 and the productive life for sires and dams were 2 and 5, respectively. TDP = total discounted profit in 10 years. Proportion of bucks selected in CBBP and used in CBBP is 0.27 and buck selected in CBBP and used in the base is 0.47. Generation interval = 2.55 years.

Table 4
Discounted return and profit doe^{-1} over the 10 year investment period (US$) using a male to female ratio of 1:25 with the number sire service years varied in both the community-based breeding program nucleus and base.

Alternatives	Generation interval	Buck proportion used in nucleus/base	Accuracy	Discounted return					Discounted profit
				SMWT (kg)	LMY (kg)	NKS (%)	NKB	Total	
Index 3_2	2.56	0.097/0.169	0.428	2.43	11.19	0.66	0.09	14.37	10.86
Index 3_3	2.77	0.097/0.169	0.429	2.13	9.63	0.57	0.07	12.40	8.89
Index 3_4	2.97	0.097/0.169	0.430	1.87	8.34	0.49	0.06	10.77	7.26

Index 3_2, index 3_3, and index 3_4 represent the six-month weight and lactation milk yield in the index with a varied buck service year of 2 to 4, respectively. SMWT = six months weight (kg), LMY =lactation milk yield (liter), NKB = number of kids born doe^{-1}, NKS = number of kids that survived to selection age.

3.1.3. Improved kid survival

An additional feed cost of $3.72 per doe per year was therefore estimated as a variable cost (Table 1) assuming to improve kid survival. The economic values for each trait were adjusted accordingly (Table 2). Increasing the survival rate to 90 percent resulted in a discounted profit of $15.58 (Table 5), which is 43.5 percent higher than the discounted profit of $10.86 identified for a 63 percent survival rate (Table 4). The improved kid survival scenario was also reflected in an increment of the discounted return and (percent change) of $4.27 (75.7 percent), $14.09 (25.9 percent), $1.07 (62.12 percent) and $0.14 (55.6 percent), respectively for traits SMWT, LMY, NKS and NKB, respectively compared to the corresponding values of $2.43, $11.19, $0.66 and $0.09 obtained for the 63 percent kid survival. The total discounted profit in the whole breeding program over 10 years of investment was estimated ($259) when considering six months weight only in the index in the traditional system while the discounted profit substantially increased at each optimization options and reached $10,142 in combination of six months and milk yield in the index under improved mating ratio and pre weaning kid survival (Fig. 1A).

3.1.4. Selection index

Index coefficients (b) values generated from ZPLAN^{+} software for the combination of six months weight and lactation milk yield index with optimized mating ratio and buck service year, and improved kid survival were 1.89 and 0.94 for SMWT and LMY, respectively. The index coefficient b's for all trait indices were 1.85, 0.91, 3.60 and 2.52 for SMWT, LMY, NKS and NKB, respectively. Then, based on the selection index theory, a linear selection that maximizes the breeding goal (H) based on the two traits and all traits are as follows:

$$I = 1.89\,PV\_SMWT + 0.94\,PV\_LMY$$
$$I = 1.85\,PV\_SMWT + 0.91\,PV\_LMY + 3.60\,PV\_NKS + 2.52\,PV\_NKB$$

where PV_SMWT, PV_LMY, PV_NKS, PV_NKB are phenotypic values for traits six months weight, lactation milk yield, number of kids survived and number of kids born per doe per kidding, respectively.

3.1.5. Optimum base population size

The discounted return and profit doe^{-1} over 10 year ($) based on an improved kid survival rate of 90 percent and a varied number of breeding does in the base population are shown in Table 5. The selection intensity in the base population decreased from 1.69 to 0.18, when the size of the doe population in the base increased from 1006 to 8048. Accordingly, discounted profit per breeding doe also declined from $15.58 to $8.66 when the number of does in the base increased. However, the overall profit, which is discounted profit multiplied by the number of animals involved in both the CBBP and the base, showed a quadratic increasing trend (Fig. 1B). A quadratic expression of the discounted profit (y) for the population size of breeding does on the breeding program was $-0.0007671x^2 + 5.491x + 4950$, where x is the total doe population size in the breeding program. The maximum discounted profit was calculated based on the derivative of the quadratic equation $-5.491/(2*-0.0007671)$ and the discounted profit of the breeding program was maximized at $14,776 over the 10 year investment period with 3579 breeding does in the base. The resulting total discounted return and profit per doe for 3579 breeding does in the base was found to be $15.27 and $11.06 (Table 5). Realizing this profit with more size in the base or achieving higher profit with similar base size could be possible by increasing selection intensity through reproductive technologies like estrus synchronization and artificial insemination (Smulders et al., 2007; Mueller et al., 2019). However, their technical and economic feasibility in the context of an extensive pastoral system needs to be investigated.

Proposed operational design of the breeding program

A two-tier breeding program is recommended to improve the target population, in which CBBPs produce the best bucks and disseminate the bucks to improve the surrounding flocks/base population (Fig. 2). Animal identification, recording and genetic evaluation need to be carried out in the CBBP/nucleus. The base population always acquires bucks from the CBBPs. Based on the simulation results, with 577 breeding does

Table 5
Discounted return and profit doe^{-1} over 10 year (US$) based on an improved kid survival rate of 90 percent and a varied number of breeding does in the base population.

Base population size of breeding does	Proportion selected/selection intensity of bucks used in the base	Accuracy	Discounted return					Discounted profit
			SMWT (kg)	LMY (kg)	NKS (%)	NKB	Total	
1006	0.11/1.69	0.44	4.27	14.09	1.07	0.14	19.56	15.58
2012	0.23/1.33	0.44	3.82	12.61	0.96	0.13	17.52	14.49
3018	0.34/1.08	0.44	3.48	11.48	0.87	0.11	15.96	13.43
4024	0.45/0.88	0.44	3.19	10.56	0.80	0.11	14.67	12.45
5030	0.56/0.69	0.44	2.94	9.73	0.74	0.10	13.51	11.50
6036	0.67/0.52	0.44	2.71	8.98	0.68	0.09	12.46	10.60
7042	0.79/0.36	0.44	2.48	8.23	0.63	0.08	11.42	9.69
8048	0.90/0.18	0.44	2.24	7.43	0.57	0.07	10.31	8.66
3579*	0.42/0.94	0.44	3.33	10.99	0.84	0.11	15.27	11.06

All results were based on the combination of SMWT and LMY in the index with a 1:25 male to female ratio and buck service of 2 years. SMWT = six months weight (kg), LMY = lactation milk yield (litter), NKB = number of kids born doe^{-1}, NKS = number of kids that survived to market age. The proportion selected and selection intensity in the community-based breeding program nucleus was 0.068/1.929. The generation interval is 2.55 years. *recommended base size where profit was maximized.

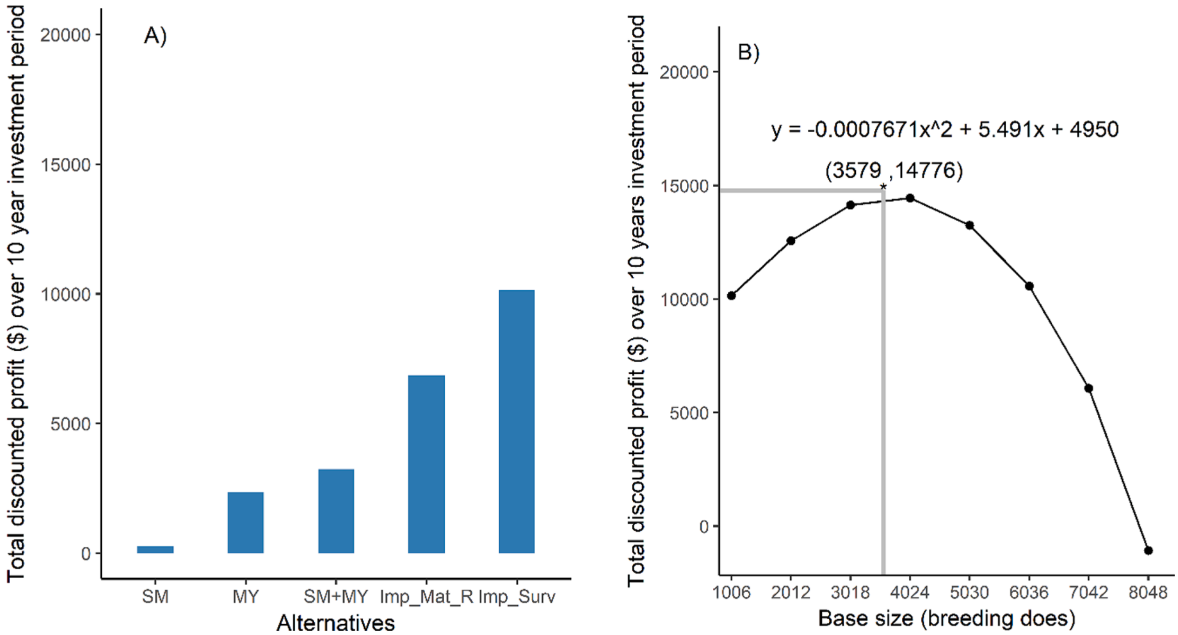

Fig. 1. Total discounted profit (US$) in the breeding program for different breeding schemes (A) and varied base population size (B). MY = lactation milk yield only included in the index, SM+MY = a combination of SM and MY included in the index. For SM, My, SM+MY traditional male to female ratio of 1:9 and kid survival of 60 percent considered. Imp_mat_R = improved mating ratio in which male to female ratio of 1:25 and SM and MY traits considered, and Imp_Surv = improved survival rate in which 90 percent of pre weaning kid survival considered over Imp_mat_R.

in a CBBP/nucleus, the maximum discounted profit per female over a 10 year investment period was generated with 3579 does in the base.

The CBBP flocks can be encompassed in breeders' cooperatives and the base flocks (3579 breeding does) need to be organized into different producer cooperatives to ease operation. Size of producer cooperative shall be flexible depending on feasibility for management and follow-up. Flock size in the base can be larger compared to the breeder cooperative (577 breeding does) as no need to have intensive animal identification and recording. However, shall not be too big as it might be difficult for management. We suggested five producer groups each have around 715 breeding does and 28 breeding bucks. Further, goat flocks in both the CBBPs and base populations need to be organized into different mating groups to facilitate buck sharing within a mating group and buck rotation among different groups. Selected bucks should be assigned to mating groups in a way that minimizes the mating of related animals. Bucks should also be rotated among the mating groups after one-year of service to avoid inbreeding. All males born in the base, non-selected animals from the CBBP need to be sold for meat at younger age or isolated to protect from unwanted mating. Selected bucks used for breeding and have to be culled and sold for meat after their breeding service years.

4. Discussion

The step-by-step optimization process involves identifying the best selection index, improving the male to female ratio, increasing the number of available bucks for breeding, and designing a feasible goat breeding program that fits the pastoral production system. The optimal criteria were selected based on the genetic gain per time unit, and the total discounted return and profit over the 10 year investment period. Substantial discounted profit was attained at each step of the optimization (Fig. 1A). Finally, the optimum size of the base doe population was also determined using a simulation (Fig. 1B).

4.1. Identification of selection traits

The identification of traits in a total merit index is crucial when the breeding goal is defined with the main purpose to maximize the economic benefit from multiple traits (Hazel, 1943). The results of this study showed that the inclusion of all traits (six months weight, milk yield, kid survival and litter size) in the index gave the highest economic benefit. However, due to the low margin in benefit from all four traits (Table 3) compared to two traits and the expected computational and measurement difficulties under a low input system, it is strongly advisable to consider at least six months weight and milk yield in the index. This finding agrees with research by Abegaz et al. (2014), Gebre et al. (2019) and Mueller at al. (2021a), which found that six months weight and milk yield were the highest contributing traits in Abergelle and Afar goat breed improvement. Gebre et al. (2019) found that profit per doe increased when the milk yield was considered in Afar goat. Woldu et al. (2016) also identified the high economic importance of milk yield in pastoral and agro-pastoral systems. However, many authors suggest that milk yield should not be considered in the selection index due to the difficulty in recording milk yields under low input pastoral systems (Abegaz et al., 2014; Gebre et al., 2019; Woldu et al., 2016). Although milk yield is more difficult to measure than other traits, it is not impossible, and the very high economic contribution of milk yield identified in this study and other research, suggests that milk yield should not be omitted from the selection index. This recommendation is also strongly supported by the breeding objective of the pastoral community, which values small ruminant milk consumption as highly important in their production system (Gebreyesus et al., 2013; Wodajo et al., 2020; Getachew et al., 2020). Labor intensiveness and the movement of goat from place to place may be considered as challenges to recording milk yield. Nevertheless, weekly milk yield measurements have been implemented successfully in the ongoing Abergelle goat CBBPs and gave an indication of the total lactation milk yield (unpublished data), which promise the possibility of including milk yield in the selection index.

Pastoralists keep goat for multiple purposes. Adaptation traits like heat tolerance, walking ability, disease tolerance, and tolerance of feed and water scarcity are more important in pastoral areas (Gebreyesus et al., 2012; Kosgey et al., 2004). However, breeding programs in low input smallholder and pastoral systems should consider as few traits as

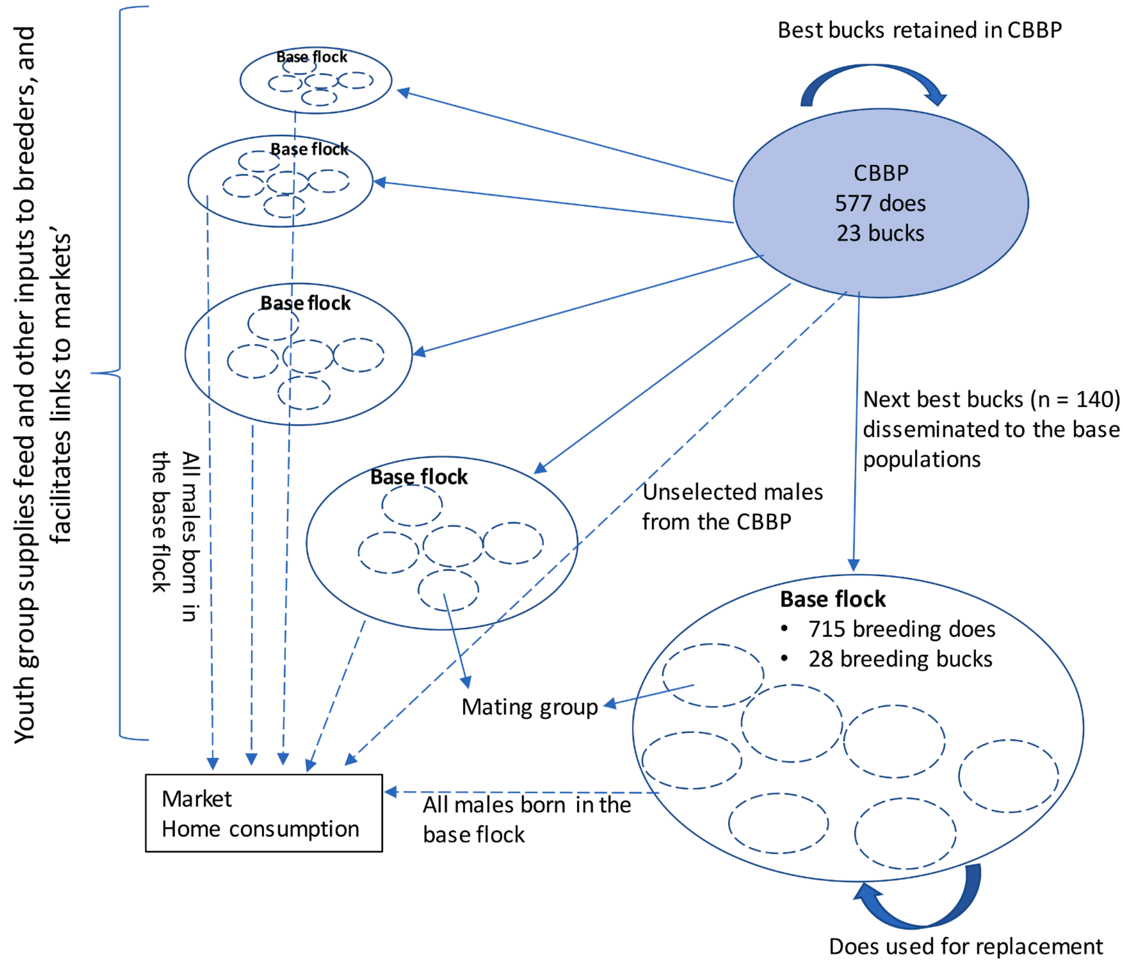

Fig. 2. Suggested breeding structure for Borana goat breed in the pastoral community. A total of 4156 (3579 breeding does in the base and 577 in CBBP nucleus) should be considered in the breeding program. The base population can be organized into 5 producer cooperatives, each with about 715 breeding does and 28 bucks. In each cooperative, five to eight mating groups need to be organized to facilitate buck use and rotation (small, dotted circles). All buck kids in the base will be castrated/sold before breeding age, while females will be used for doe replacement in the base.

possible (Haile et al., 2018a).) Therefore, performance measurement should be tailored to these two traits and other traits like number of kids born and number of kids survived to market age could be considered during visual assessment after selection and may also possibly benefit from a correlated response to selection on the measured traits. In the long run, when the computation is possible, the inclusion of kid survival to market age and the number of kids born in the selection index can be considered and will slightly increase the benefit from the breeding program.

4.2. Optimizing selection intensity

4.2.1. Increased doe to buck ratio

A substantial increase in the discounted profit per doe (88.5%) which was achieved by increasing the number of females per buck from 9 to 25 (Table 4) suggest that the current smaller flock size potentially hampers the anticipated genetic progress and economic benefit of breeding programs. Thus, measures to increase the number of breeding does per buck are crucial. The mixing of goat flock, as practiced by 70 percent of pastoralists in the Borana area (Getachew et al., 2020), can be considered a good opportunity to implement a buck sharing strategy. This can easily be achieved with training and the organization of farmers into mating groups, as suggested by Haile et al. (2018). The simulation study revealed that the discounted monetary genetic and profit decreased as a buck's productive life increased (Table 4). This finding agrees with the research of Gebre et al. (2019), which indicated that the use of buck for 2 years resulted in a higher gain compared to the use of sire for 4 and 5 years. The number of sire service years might vary depending on the cultural context and production system. In some areas, farmers prefer to keep their best sires for a long time, while in areas where there is an attractive market for younger animals, farmers tend to sell their goat at an earlier age. Keeping bucks with highest estimated breeding values regardless of their age need to be designed by imposing across-age selection whenever the pedigree allows calculation of population-wide best linear unbiased prediction of breeding values (Mueller et al., 2021b).

4.2.2. Improved kid survival

Due to the long dry season and recurrent drought, feed storage is considered the major constraint in goat production, affecting goat productivity and farm profitability in pastoral areas (Gebreyesus et al., 2013; Getachew et al., 2010). A very low average kid survival rate of about 63 percent (88.3 percent during the wet season and 42.4 percent in the dry season) is documented in the Borana pastoral goat production system (Hailu et al., 2006; Getachew et al., 2020) and considered one of the major production challenges. In agreement with Gebre et al. (2019) and Kosgey et al. (2004), this study found unsatisfactory genetic progress per year in the range of 0.01 to 0.015 (Table 3) in the kid survival rate and this might be attributed to low heritability and increased environmental influences. Improving feeding management during critical times (pregnancy and first weeks of suckling) is therefore suggested to improve kid survival (Mekuriaw 2007; Hailu et al., 2006; Kulkarni

et al. 2014). Improving kid survival through better feeding management increased the number of available candidate bucks for breeding and thereby improved the proportion of bucks from 0.097 to 0.068 for bucks selected and used in the CBBP and from 0.169 to 0.11 for bucks selected in the CBBP and used in the base population (Table 4 and 5). Consequently, this resulted in a substantial increase of the discounted profit per doe over the investment period ($10.86 to $15.58) which is a 43.4 percent increase. These results agree with research findings that highlight the impact of selection intensity on genetic progress in dairy cattle (Oltenacu and Young 1973) and Manchega sheep (Smulders et al., 2007), and the impact of increasing available male candidates for selection on increased genetic progress in Menz sheep (Mueller et al., 2019). Improving kid survival is therefore a crucial element to be considered in pastoral breeding programs.

4.3. Operational design of the breeding program

It is not only the technical design of the breeding program that leads to the expected genetic progress. The operational design, availability of the necessary infrastructure, and applicability of the program to the context are very important (Sölkner et al., 1998; Mueller et al., 2015b). Operational difficulties and developing recording facilities are more challenging in pastoral communities due to herd mobility, high temperatures, erratic weather conditions, and high mortality, associated with the dry season and recurrent droughts (Kosgey et al., 2006; Kosgey and Okeyo 2007; Bett et al., 2009). Previous attempts to implement a sheep CBBP in the pastoral area were discontinued due to the failure to adapt the approach to the pastoral system. However, community-based breeding program has been successful in many sedentary communities in Ethiopia, and in other African, Asian and Latin American countries (Mueller et al., 2015a,b). Pastoral communities in different parts of the country are keen to participate in breeding programs (Gebre et al., 2019; Gebreyesus et al., 2013; Getachew et al., 2020), however, they are discouraged and lose interest when their flocks are affected by drought. Thus, a detailed planning of the breeding program structure, including the organization of breeder and producer cooperatives both in the CBBP and base flocks is crucial. An innovative and flexible approach that enables animal identification, data collection, animal evaluation, selection, and mating, while considering mobility patterns and the supplementation of kids and flock during critical times, such as drought, is crucial for pastoral systems. Additionally, linking the CBBP with base populations in the mating design and organizing a buck sharing system is essential. Its success relies on the full participation of the community and all stakeholders from the beginning.

Enumerators for data collection should be selected from the community, live with them, and commit to moving with the flock to accomplish routine animal identification and recording (Mueller et al., 2015b). Similarly, to other CBBPs, as outlined by Haile et al. (2018), breeding value estimation and ranking need to be handled by local research institutions. Using this approach, candidate approval will be done with the full participation of the pastoral community. The participation of the pastoral community in the selection process will give breeders the chance to consider physical appearances, walking ability, and morphological characteristics, like coat color, which are very important in pastoral systems.

Mobility is considered as a coping mechanism by pastoralists. It has improved the rate of kid survival in the pastoral community to some extent (Getachew et al., 2020), but mobility should only be adopted as a temporary solution to rescue life during critical times. Mobility has been discouraged by the Ethiopian government as it is a source of conflict among communities. It has also reduced significantly over time due to development interventions, like water dam development and rangeland management programs (Homann et al., 2008). A recent study also showed that Borana pastoralists have clear mobility patterns. Usually, they migrate to riversides, but have a permanent house in the settlement area. Part of the family takes the goats, spending some of the year by the riverside, and then returning with their animals when the availability of feed and water improves (Getachew et al., 2020). This ease data collection and implementation of breeding program in the pastoral system.

Researchers, extension organizations, development organizations and organized cooperatives should work hand-in-hand in rangeland management to avail feed during critical times. Organized cooperatives or youth groups may engage in a profit-oriented business by supplying feed and other inputs to breeders. Such groups initially need to be capacitated by government and non-governmental organizations. They can bring feed from other parts of the country and sell it to the pastoral community during the dry season and droughts. At the same time, the breeder cooperative/youth group can also engage in fattening activities using surplus males (all males from the base flock and unselected males from the CBBP nucleus). This group can also serve as a bridge to create market links between the CBBP nucleus and the base flocks for breeding bucks, and between the breeding cooperatives and live animal traders for the culled animals. Input supply, feeding animals during the dry season, and creating market links for breeding and selling surplus animals for meat is of equal importance for long-term sustainability.

5. Conclusion

Different scenarios were evaluated to optimize the breeding structure in the indigenous Borana goat breeding program under a pastoral production system. The milk yield of lactating dams and the weight of kids at six months should be considered in the selection index to maximize genetic gain and profit. Changing the current male to female ratio from 1:9 to 1:25 and improving kid survival through better feeding management increases selection intensity and, thereby, genetic and economic gains. Based on the total discounted profit, a dispersed breeding program with a CBBP nucleus of about 577 breeding does and a base flock of about 3579 does, organized into about five producer cooperatives, is recommended. The integration of different institutions to facilitate and ensure the formation of breeder and producer cooperatives, data collection, the estimation of breeding values, candidate selection, mating arrangements, veterinary support and feed supply is crucial.

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Author statement

We wish to confirm that there are no known conflicts of interest associated with this publication.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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