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Research article

Evaluation of growth and efficiency-related traits of different levels of Boer x Central Highland crossbred goats

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ABSTRACT

The growth and efficiency-related traits of the Boer x Central Highland goats raised semi-intensively were evaluated. Besides, genetic and non-genetic factors affecting growth and efficiency-related traits were identified. Data were collected over a period of nine years in a flock of Boer crossbred goats and analyzed using general linear model procedure of SAS. The overall least-squares mean live weight at birth, 3-, 6-, 9- and 12 months of age were 2.52 ± 0.01, 9.81 ± 0.13, 13.8 ± 0.15, 17.8 ± 0.19, and 20.5 ± 0.29 kg, respectively. The average weight gains from birth to 3 months, 3 to 6, 6 to 9 and 9–12 months of age were 80.3, 37.5, 41.9, and 31.2 g day^{-1}, respectively. Boer blood level, birth type, season and year of kidding had a significant effect on growth traits. The overall least-squares mean of Kleiber ratio from birth to 3 months, 3–6 months, 6–9 months, and 9 month to yearling age were 13.99 ± 0.11, 5.23 ± 0.14, 4.66 ± 0.16, and 2.95 ± 0.18, respectively. Parity, birth type, Boer blood level, season and year of birth had a significant influence on the expression of efficiency-related traits (Kleiber ratios) in different growth phases. In terms of growth performance and efficiency-related traits, F2 and F3 crossbred goats did not show any benefit over F1 crossbred goats. Increasing Boer blood level above 50% would be worthless under the existing minimal input production system. Therefore, besides to improving the management of goats, producing the first filial generation would be suitable for medium to high input production systems.

1. Introduction

Goats are an important genetic resource for the production of meat, milk, skin, and fiber, and contribute significantly to the rural poor's livelihood in developing countries (Alade et al., 2010). Many avenues to improve goat productivity have been suggested and implemented, among which genetic improvement through crossbreeding has been identified as an avenue. Crossbreeding is used to exploit both additive and heterosis effects (Schiermiester, 2014; Williams et al., 2014). As a result, Boer goats have been introduced and crossed with Ethiopian indigenous goat breeds such as Abergele, Central Highland, and Woyito-Guji goat to improve the meat productivity through crossbreeding since 2007 (Abegaz and Gizaw, 2015; Tesema et al., 2020a).

Improving growth performance and the efficiency of feed conversion is imperative in any genetic improvement program aimed at enhancing meat production. Including a trait like Kleiber ratio (KR) in selection processes can help improve feed efficiency as there is a lack of individual animal feed intake records, particularly in developing countries. The KR is defined as growth rate/body mass$^{0.75}$ (Kleiber, 1947). It provides a good sign of how an animal grows efficiently and it is recommended as an efficient selection criterion for feed efficiency under a low-input production system (Eskandarinasab et al., 2010; Mohammadi et al., 2011).

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Performance evaluation of different levels of crossbreeds focusing on growth and efficiency-related traits is required to design a method for disseminating genetic material to ensure the program's long-term viability or to change the breed and crossbreeding scheme (Tesema, 2019). In addition, knowledge of environmental factors affecting the growth and efficiency-related features is imperative to improve the efficiency of breeding program. In Ethiopia, however, there is a scarcity of information. Few pieces of research have reported growth performance of 50% Boer level or F1 crossbred goats (Belay et al., 2014; Deribe et al., 2015), and little is known about the influence of factors and their interactions on the growth and Kleiber ratio for different levels of Boer goat. Therefore, this study aims to evaluate the growth and efficiency-related traits and to identify genetic and non-genetic factors affecting the performance of different levels of crossbred goats.

2. Materials and methods

2.1. Location

The study was carried out at Sirinka Agricultural Research Center which is located 508 km away from Addis Ababa at an altitude of 1850 m.a.s.l and at 11°45′ 00″ N and 39°36′ 36″ E. The area receives about 950 mm of annual rainfall on average. The area has a moderately warm climate, with average daily temperatures ranging from 13.7 to 26.4 °C.

2.2. Breeding procedure and flock management

A natural controlled mating system was used, and the breeding season was year round with does grouped by lots. Each group of twenty to thirty does was exposed to a fertile Boer buck in a separate mating group, and the buck was kept with does for two estrus cycles. Well-trained attendant was assigned for each mating group to collect necessary information. Indigenous female Central Highland goats were mated with pure male Boer goats (exotic) to produce F1 crossbred goats with 50% Boer blood level. The F1 crossbred males and females were *inter se mated* to produce F2 offspring. About 25% of female crossbred progenies with 50% Boer blood level were crossed with 75% and pure Boer buck to increase their Boer blood level to 62.5% and 75%, respectively. Crossbred bucks with 50% Boer blood level were mated with pure female Central Highland goats to produce kids with 25% Boer blood level. Kids were identified using ear-tag and weighted within 24 h of birth. After kidding, kids were kept with their dams for 3–5 days indoors and after that, kids were separated from their dams and suckled three times a day until 90 days of age.

Detailed description of flock management level and breeding procedures were noted in previous studies (Tesema et al., 2020a, 2020b). Goats were raised under a moderate level of production inputs. All goats were grazed/browsed on low-quality natural pasture for six hours and supplemented with 0.10–0.40 kg of concentrate ration based on their age, sex and physiology. The concentrate mix consists of wheat bran as energy source, *Noug* cake as a protein source and salt to provide with minerals. According to their age, sex, and physiology, experimental goats were housed in semi-open concrete barns at night. Vaccination, deworming, and spraying were done according to the goats' physiology and age. All experimental techniques and animal care were in line with FASS (2010), and this was confirmed by animal nutrition and health researchers of Sirinka Agricultural Research Center, Amhara Region Agricultural Research Institute.

2.3. Data and studied traits

Data were collected for nine years at the Sirinka goat breeding station. Data including date of kidding, parity, sex of the kid, Boer blood level, litter size, birth weight and live weight up to yearling age were recorded by researchers using well organized recoding sheet. The investigated trait includes live weight (birth weight, 3-, 6-, 9-, and 12-month weights), weight gain and Kleiber ratio at different ages. Weight gain (g day^{-1}) of kids at different growth phases were defined as weight gain from birth to 3 month (WG1) = ((3W in kg - BW in kg)/90 days)*1000, from 3 to 6 month (WG2) = ((6W in kg - 3W in kg)/90 days)*1000, from 6 to 9 months (WG3) = ((9W in kg - 6W in kg)/90 days)*1000, and from 9 to 12 months of age (WG4) = ((12W in kg – 9W in kg)/90 days)*1000. Kleiber ratios at different growth phases were calculated according to Kleiber (1947): Kleiber ratio at weaning = WG1/3W$^{0.75}$, Kleiber ratio at six month = WG2/6W^{075}, Kleiber ratio at nine month = WG3/9W$^{0.75}$ and Kleiber ratio at yearling age = WG4/12W$^{0.75}$. Where; BW, 3W, 6W, 9W, and 12W are birth weight, 3-, 6-, 9- and 12-month weight, respectively. A kid's birth weight was measured within 24 h after birth and the 3-, 6-, 9-, and 12-month weights were measured on exact date.

2.4. Data analysis

Before doing the main data analysis, checking for outlier and normality of data were conducted. Factors influencing growth and efficiency-related traits were analyzed using the GLM procedure of SAS (2002). The fixed factors were the sex of kid, birth type, Boer blood level, kid genotype, parity, season and year of kidding. Tukey-Kramer test was used to separate least-squares means with more than two levels. The statistical model used was:

$$Y_{ijklmnop} = \mu + B_i + S_j + X_k + D_l + T_m + L_n + H_o + e_{ijklmnop}$$

where, $Y_{ijklmnop}$ is live weight, weight gain and efficiency-related traits; μ is overall mean; B_i is the effect of i^{th} birth type (2 levels: single and multiple births); S_j is the effect of j^{th} season of birth (3 levels: short rain, main rain and dry); X_k is the effect of k^{th} sex of kid (2 levels: male and female); D_l is the effect of l^{th} parity of doe (5 levels: 1 to ≥5); T_m is the effect of m^{th} year of birth (9 levels: 2009–2018); L_n is the effect of n^{th} Boer blood level (4 levels: 25, 50, 62.5 and 75%); H_o is the effect of o^{th} kid genotype (3 levels: F1, F2 and F3), and $e_{ijklmnop}$ is random error term associated with each observation.

3. Results

3.1. Live weight and factors affecting live weight

The live weight of Boer x Central Highland goats and the influence of different factors are presented in Table 1. The overall least-squares mean BW, 3W, 6W, 9W, and 12W were 2.52 ± 0.0, 9.81 ± 0.13, 13.8 ± 0.15, 17.8 ± 0.19, and 20.5 ± 0.29 kg, respectively. The growth of an animal is a function of genetic potential, hormones, nutrition, and other environmental factors. Among environmental factors, the birth type had a pronounced effect on birth weight and the weights of kids in subsequent ages (Table 1). The live weight of single-born kids at different age was heavier ($P < 0.001$) than multiple-born kids. Except for 6W, male kids had greater ($P < 0.05$) live weight than their female counterparts at all ages. The Boer blood level had a considerable influence on 3W and 9W of goats. Kids with 25% Boer blood level had a greater ($P < 0.05$) 3W than kids with 62.5% and greater 9W than kids with 75% Boer blood level. However, non-significant ($P > 0.05$) difference among exotic gene levels was observed for BW, 6W, and 12W. Live weight difference among F1, F2, and F3 kids of all ages was non-significant ($P > 0.05$). Except for BW, where kids born from the 1st and 5th parities were lower than kids from other mid parities (2–4), the effect of parity was not obvious.

Year of kidding had a pronounced effect on the live weight of goats at different ages. Kids born in 2016 and 2017 had greater 6W, 9W, and 12W than kids born in the other years. The weight of kids born in 2011 and 2014 was consistently lower than kids born in the other years. The BW of kids born during the short rainy season was greater and the 9W of kids born during the main rainy season was superior to other seasons.

Table 1. Live weight of Boer x Central Highland goats at different ages (LSM±SE).

Source of variation	BW (kg)		3W (kg)		6W (kg)		9W (kg)		12W (kg)	
	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
Overall	875	2.52 ± 0.01	672	9.81 ± 0.13	536	13.8 ± 0.15	452	17.8 ± 0.19	350	20.5 ± 0.29
CV (%)	875	19.2	672	28.7	536	22.2	452	18.4	350	18.4
Birth type		***		***		***		***		***
Single	269	2.83 ± 0.03	217	11.7 ± 0.26	174	15.3 ± 0.28	145	19.24 ± 0.35	114	21.9 ± 0.50
Multiple	606	2.38 ± 0.02	455	8.84 ± 0.13	362	13.0 ± 0.13	307	17.1 ± 0.22	236	19.8 ± 0.34
Boer BL		NS		***		Ns		***		Ns
25%	48	2.18 ± 0.07	40	10.1 ± 0.57^{a}	36	14.7 ± 0.69	32	18.1 ± 0.75^{a}	17	20.7 ± 1.46
50%	641	2.53 ± 0.02	507	9.85 ± 0.15^{ab}	416	13.8 ± 0.17	354	17.9 ± 0.23^{ab}	278	20.6 ± 0.33
62.5%	47	2.31 ± 0.08	31	9.22 ± 0.74^{b}	24	13.8 ± 0.81	21	18.4 ± 0.87^{a}	14	20.9 ± 1.21
75%	139	2.66 ± 0.04	94	9.67 ± 0.33^{ab}	60	13.6 ± 0.40	45	16.6 ± 0.48^{b}	41	18.3 ± 0.42
Kid genotype		Ns		Ns		Ns		Ns		Ns
F1	434	2.54 ± 0.02	348	9.77 ± 0.16	298	13.6 ± 0.19	256	17.8 ± 0.23	193	20.2 ± 0.36
F2	293	2.55 ± 0.03	222	9.99 ± 0.24	150	14.1 ± 0.28	122	17.5 ± 0.38	102	20.7 ± 0.55
F3	148	2.39 ± 0.05	102	9.39 ± 0.48	88	14.5 ± 0.51	74	18.8 ± 0.58	55	22.0 ± 0.93
Parity		***		*		Ns		Ns		Ns
1	269	2.40 ± 0.03^{c}	198	9.45 ± 0.24^{b}	151	14.0 ± 0.28	129	18.9 ± 0.36	92	22.9 ± 0.56
2	248	2.63 ± 0.04^{a}	199	10.6 ± 0.27^{a}	171	14.4 ± 0.29	147	18.1 ± 0.33	115	19.9 ± 0.41
3	184	2.55 ± 0.03^{ab}	146	9.32 ± 0.26^{b}	113	12.8 ± 0.32	89	16.1 ± 0.46	67	17.9 ± 0.67
4	96	2.54 ± 0.05^{ab}	72	9.78 ± 0.35^{ab}	59	13.4 ± 0.43	51	17.4 ± 0.52	43	20.9 ± 0.76
≥5	78	2.48 ± 0.08^{bc}	57	9.73 ± 0.45^{ab}	42	14.1 ± 0.55	36	17.6 ± 0.65	33	20.8 ± 1.03
Season		*		Ns		Ns		**		Ns
Dry	439	2.48 ± 0.02^{b}	337	9.49 ± 0.19	261	13.5 ± 0.23	230	17.2 ± 0.30^{b}	182	19.3 ± 0.37
Main rain	98	2.41 ± 0.05^{b}	78	10.6 ± 0.43	68	14.5 ± 0.41	52	20.1 ± 0.47^{a}	32	22.9 ± 0.68
Short rain	338	2.60 ± 0.03^{a}	257	9.92 ± 0.19	207	13.8 ± 0.23	170	17.8 ± 0.29^{b}	136	21.3 ± 0.49
Sex		**		*		Ns		**		**
Female	468	2.47 ± 0.02	368	9.43 ± 0.16	303	13.5 ± 0.19	262	17.40 ± 0.26	218	19.9 ± 0.31
Male	407	2.58 ± 0.03	204	10.3 ± 0.21	233	14.1 ± 0.24	190	18.38 ± 0.32	132	21.4 ± 0.56
Year		***		***		***		***		***
2009	102	2.45 ± 0.04^{de}	85	8.95 ± 0.31^{cd}	80	13.5 ± 0.35^{bc}	74	19.7 ± 0.36^{a}	51	23.1 ± 0.51^{b}
2010	128	2.79 ± 0.04^{ab}	105	10.6 ± 0.31^{b}	95	13.5 ± 0.32^{bc}	78	16.8 ± 0.46^{cd}	59	17.5 ± 0.47^{cd}
2011	97	2.47 ± 0.05^{de}	65	8.06 ± 0.26^{d}	40	11.0 ± 0.43^{d}	36	13.9 ± 0.60^{f}	32	15.9 ± 0.72^{d}
2012	84	2.86 ± 0.05^{a}	63	11.4 ± 0.50^{b}	47	14.9 ± 0.57^{a}	35	18.3 ± 0.57^{abc}	28	21.6 ± 0.61^{b}
2013	117	2.67 ± 0.05^{bc}	95	9.24 ± 0.29^{c}	62	13.4 ± 0.36^{bc}	54	16.13 ± 0.45^{de}	51	17.1 ± 0.39^{cd}
2014	65	2.16 ± 0.06^{g}	45	8.74 ± 0.44^{cd}	24	12.7 ± 0.52^{c}	18	15.11 ± 0.53^{ef}	15	18.1 ± 0.80^{c}
2016	128	2.30 ± 0.05^{f}	114	11.1 ± 0.34^{b}	102	15.2 ± 0.35^{a}	81	19.7 ± 0.45^{a}	56	25.1 ± 0.76^{a}
2017	110	2.33 ± 0.04^{ef}	68	9.20 ± 0.44^{c}	46	14.2 ± 0.56^{ab}	39	18.9 ± 0.53^{ab}	29	23.3 ± 0.91^{ab}
2018	44	2.56 ± 0.08^{cd}	36	13.1 ± 0.45^{a}	40	15.4 ± 0.50^{a}	37	17.4 ± 0.59^{bcd}	29	18.5 ± 0.47^{c}

BW, birth weight; 3W, weaning weight; 6W, six month weight; 9W, nine month weight; 12W, yearling weight; BL, blood level; F1, first filial generation; F2, second filial generation; F3, third filial generation; Ns, $P > 0.05$; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; N, number of observations.
Least squares means with different superscripts within the same column and class are statistically different.

3.2. Weight gain of crossbred goats at different growth phases

The least-squares means and respective standard errors for investigated weight gain at different growth phases are presented in Table 2. The overall least-squares mean WG1, WG2, WG3, and WG4 of Boer x Central Highland goats in this study were 80.3 ± 1.40, 37.5 ± 1.12, 41.9 ± 1.45, and 31.2 ± 2.09 g day^{-1}. The weight gain of kids showed a decreasing trend as the age increases, i.e. the weight gain from birth to weaning age was one fold of the post-weaning weight gains of kids. Single-born kids had a faster ($P < 0.05$) pre-weaning growth rate than those of multiple-born kids. However, from 3 to 6 months of age, single-born kids had lower weight gain than multiple-born kids and also similar in the subsequent ages. Sex of kid was not an important source of variation ($P > 0.05$) for the weight gain, although numerical superiority was observed for males. Except for WG4, the effect of parity on weight gains (WG1, WG2 and WG3) was found to be statistically similar ($P > 0.05$).

This study showed that the pre-weaning weight gain (WG1) of kids with 25% Boer blood level was higher ($P < 0.05$) than kids with 62.5% and 75% Boer blood level. In the post-weaning (from 3 to 6-month and 9-month to yearling age), kids with 75% Boer blood level were gained lower weight compared to other exotic gene levels. However, the growth rate of kids with 50% and 62.5% Boer blood levels was similar. In addition, the kid genotype had not a pronounced influence ($P > 0.05$) on the growth rate of kids.

Season of kidding exerted a significant influence on weight gain of kids. Kids born during the main rainy season and short rainy season gained significantly greater ($P < 0.05$) weight from six-month to nine-month and nine-month to yearling age, respectively. The influence of birth year on weight gain of kids was not consistent and the highest pre-weaning weight gain was observed for kids born in 2010, 2012, 2016, and 2018, whereas the highest post-weaning weight gain was observed for kids born in 2009, 2016, and 2017 than the other years.

3.3. Kleiber ratio and the influence of genetic and non-genetic factors

The least-square means and standard errors of Kleiber ratio for various non-genetic factors are shown in Table 3. Kleiber ratio (KR)

Table 2. Weight gain of Boer x Central Highland goats (LSM±SE).

Source of variation	WG1 (g day^{-1})		WG2 (g day^{-1})		WG3 (g day^{-1})		WG4 (g day^{-1})	
	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
Overall	672	80.3 ± 1.40	532	37.5 ± 1.12	452	41.9 ± 1.45	349	31.2 ± 2.09
CV	672	9.34	532	26.0	452	22.4	349	24.6
Birth type		***		**		Ns		Ns
Single	217	98.39 ± 2.74	174	30.26 ± 2.10	145	39.61 ± 2.64	114	32.71 ± 3.71
Multiple	455	71.21 ± 1.40	358	41.33 ± 1.26	307	43.13 ± 1.73	235	30.38 ± 2.52
Boer BL		***		*		*		***
25%	40	94.0 ± 6.06^{a}	34	58.28 ± 3.79^{a}	32	35.73 ± 8.06^{ab}	17	46.3 ± 15.2^{a}
50%	507	82.4 ± 1.61^{ab}	414	37.16 ± 1.28^{b}	354	43.90 ± 1.46^{ab}	277	31.12 ± 2.13^{b}
62.5%	31	79.1 ± 7.98^{b}	24	39.13 ± 4.90^{b}	21	50.61 ± 6.31^{a}	14	38.63 ± 18.2^{b}
75%	94	76.8 ± 3.45^{b}	60	31.79 ± 2.91^{c}	45	26.27 ± 2.94^{b}	41	17.21 ± 3.76^{c}
Kid genotype		Ns		*		Ns		Ns
F1	348	79.63 ± 1.75	298	40.21 ± 1.44^{a}	256	44.59 ± 1.46	193	29.22 ± 2.52
F2	222	82.11 ± 2.52	150	30.84 ± 1.77^{b}	122	34.60 ± 2.43	102	32.65 ± 3.26
F3	102	77.87 ± 5.10	84	41.87 ± 4.49^{a}	74	47.47 ± 4.21	54	39.95 ± 11.1
Parity		Ns		Ns		Ns		*
1	198	77.66 ± 2.58	150	40.67 ± 2.63	129	52.02 ± 2.88	91	47.11 ± 5.11^{a}
2	199	87.71 ± 2.81	169	38.34 ± 2.08	147	41.47 ± 2.74	115	26.10 ± 2.69^{bc}
3	146	74.71 ± 2.77	112	34.33 ± 2.50	89	32.65 ± 2.45	67	17.47 ± 3.80^{c}
4	72	79.73 ± 3.84	59	33.54 ± 2.85	51	39.84 ± 4.19	43	33.56 ± 4.83^{ab}
≥5	57	79.59 ± 4.64	42	38.27 ± 3.44	36	35.91 ± 4.11	33	30.35 ± 6.94^{ab}
Season		Ns		Ns		**		**
Dry	337	77.52 ± 2.05	257	35.0 ± 1.63	230	39.07 ± 1.86^{b}	181	28.06 ± 2.67^{b}
Main rain	78	90.76 ± 4.53	67	43.69 ± 3.20	52	57.20 ± 4.07^{a}	32	28.12 ± 5.58^{b}
Short rain	257	80.41 ± 2.07	208	38.25 ± 1.74	170	40.52 ± 2.48^{b}	136	38.79 ± 3.60^{a}
Sex		Ns		Ns		Ns		Ns
Female	368	76.63 ± 1.75	301	38.59 ± 1.37	262	40.05 ± 1.79	217	28.06 ± 2.47
Male	304	84.74 ± 2.24	231	36.17 ± 1.84	190	44.57 ± 2.41	132	36.41 ± 3.71
Year		***		***		***		***
2009	85	71.60 ± 3.23^{ef}	80	49.90 ± 2.31^{a}	74	67.68 ± 2.76^{a}	51	43.46 ± 3.96^{ab}
2010	105	85.97 ± 3.33^{cd}	95	32.40 ± 2.77^{cde}	78	34.30 ± 3.02^{c}	59	8.94 ± 2.24^{e}
2011	65	60.94 ± 2.94^{f}	40	25.83 ± 2.18^{e}	36	30.43 ± 3.51^{cd}	32	18.02 ± 2.76^{cde}
2012	63	94.47 ± 5.36^{bc}	47	25.91 ± 2.86^{e}	35	27.68 ± 3.01^{cd}	28	30.47 ± 3.47^{bcd}
2013	95	72.88 ± 2.94^{e}	62	36.88 ± 3.14^{bcd}	54	28.60 ± 3.38^{cd}	51	15.75 ± 3.61^{de}
2014	45	71.35 ± 4.59^{ef}	24	29.95 ± 5.20^{de}	18	25.30 ± 6.48^{cd}	15	33.48 ± 6.04^{bc}
2016	114	96.74 ± 3.52^{b}	102	43.30 ± 2.41^{ab}	81	47.68 ± 3.59^{b}	56	53.03 ± 7.12^{a}
2017	68	76.22 ± 4.70^{de}	46	40.77 ± 4.31^{abc}	39	45.98 ± 4.42^{b}	29	55.59 ± 9.95^{a}
2018	36	116.0 ± 4.71^{a}	36	28.00 ± 3.53^{de}	37	20.1 ± 2.80^{d}	28	11.90 ± 2.14^{e}

WG1, weight gain from birth to 3 month; WG2, weight gain from 3 to 6 month; WG3, weight gain from 6 to 9 month; WG4, weight gain from 9 to 12 months of age; BL, blood level; F1, first filial generation; F2, second filial generation; F3, third filial generation.
Ns, $P > 0.05$; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; N, number of observations.
Least squares means with different superscripts within the same column, and class are statistically different.

decreases with the age of kids. The highest and lowest KR was observed during the pre-weaning period and 9–12 months of age, respectively. Multiple-born kids had a lower pre-weaning Kleiber ratio than singletons. However, the Kleiber ratios of multiple-born kids were higher than singletons during the post-weaning age except for KR4. Kid genotype and sex had not a considerable influence on Kleiber ratio of crossbred goats at all growth phases. Except for the third growth phase (six to nine months), the Kleiber ratio of kids with a 25% Boer blood level was higher ($p < 0.05$) than other genotypes. The season of kidding significantly affected the Kleiber ratio of kids and kids born during the main rainy season had a higher Kleiber ratio during pre-weaning age and six to nine-months of age. However, kids born during the main rainy and dry season had a lower Kleiber ratio of nine month to yearling age. The Kleiber ratio of kids at all stages of development was affected by birth year. Kids born in 2009 had better KR2, KR3, and KR4 than other years.

4. Discussion

4.1. Live weight

The mean live weight observed for Boer crossbred goats in this study is similar to that reported by Abd-Allah et al. (2016) for Boer x Egyptian Baladi goats managed semi-intensively. Nevertheless, the current results is higher than the report of Mustefa (2017) for Boer x Central Highland goats and lower than weight of Boer x Abergele crossbred goats (Belay et al., 2014) under semi-intensive management. The genetic potential of indigenous parental lines, the physical environment, and the variation of flock management could explain the variability across studies.

One prospect for goat farming is Ethiopia's geographic proximity to high goat meat importing countries in the Middle East. The export market demands goats that weigh 25–30 kg at a yearling age; however, the

Table 3. Kleiber ratio of Boer x Central Highland goats (LSM±SE).

Source of variation	KR1		KR2		KR3		KR4	
	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
Overall	672	13.99 ± 0.11	532	5.23 ± 0.14	452	4.66 ± 0.16	349	2.95 ± 0.18
CV	672	17.6	532	24.0	452	23.1	349	25.3
Birth type		***		***		**		Ns
Single	217	15.02 ± 0.19	174	3.96 ± 0.24	145	4.11 ± 0.27	114	2.96 ± 0.33
Multiple	455	13.47 ± 0.12	358	5.89 ± 0.16	307	4.95 ± 0.19	235	2.94 ± 0.22
Boer BL		***		**		*		***
25%	40	15.27 ± 0.49^{a}	34	7.75 ± 0.40^{a}	32	3.75 ± 1.15^{bc}	17	4.28 ± 1.44^{a}
50%	507	14.03 ± 0.12^{b}	414	5.18 ± 0.16^{b}	354	4.86 ± 0.17^{ab}	277	2.92 ± 0.18^{b}
62.5%	31	13.48 ± 0.66^{b}	24	5.64 ± 0.64^{b}	21	5.72 ± 0.67^{a}	14	3.75 ± 1.79^{b}
75%	94	13.54 ± 0.28^{b}	60	4.48 ± 0.41^{b}	45	3.13 ± 0.35^{c}	41	1.84 ± 0.42^{c}
Kid genotype		Ns		Ns		Ns		Ns
F1	348	13.98 ± 0.14	298	5.65 ± 0.17	256	4.94 ± 0.20	193	2.77 ± 0.23
F2	222	14.08 ± 0.19	150	4.27 ± 0.24	122	3.88 ± 0.29	102	3.11 ± 0.30
F3	102	13.78 ± 0.12	84	5.63 ± 0.57	74	5.31 ± 0.44	54	3.61 ± 1.02
Parity		*		Ns		Ns		*
1	198	13.86 ± 0.21^{ab}	150	5.76 ± 0.24	129	5.61 ± 0.34	91	4.25 ± 0.65^{a}
2	199	14.44 ± 0.22^{a}	169	5.21 ± 0.26	147	4.55 ± 0.29	115	2.59 ± 0.28^{bc}
3	146	13.59 ± 0.21^{b}	112	4.86 ± 0.33	89	3.91 ± 0.27	67	1.69 ± 0.35^{c}
4	72	13.96 ± 0.32^{ab}	59	4.73 ± 0.36	51	4.52 ± 0.44	43	3.19 ± 0.42^{ab}
≥5	57	14.00 ± 0.36^{ab}	42	5.24 ± 0.49	36	4.01 ± 0.41	33	2.85 ± 0.57^{bc}
Season		*		Ns		**		**
Dry	337	13.80 ± 0.16^{b}	257	4.89 ± 0.21	230	4.53 ± 0.20^{b}	181	2.57 ± 0.25^{b}
Main rain	78	14.86 ± 0.33^{a}	67	5.85 ± 0.43	52	5.92 ± 0.40^{a}	32	2.47 ± 0.45^{b}
Short rain	257	13.95 ± 0.17^{b}	208	5.39 ± 0.21	170	4.43 ± 0.28^{b}	136	3.49 ± 0.32^{a}
Sex		Ns		Ns		Ns		Ns
Female	368	13.77 ± 0.14	301	5.17 ± 0.41	262	4.55 ± 0.20	217	2.79 ± 0.24
Male	304	14.26 ± 0.17	231	4.99 ± 0.23	190	4.83 ± 0.25	132	3.21 ± 0.29
Year		***		***		***		***
2009	85	13.37 ± 0.29^{d}	80	7.04 ± 0.28^{a}	74	7.24 ± 0.28^{a}	51	3.89 ± 0.34^{ab}
2010	105	14.25 ± 0.24^{cd}	95	4.72 ± 0.31^{bc}	78	3.86 ± 0.33^{bc}	59	0.97 ± 0.25^{e}
2011	65	12.47 ± 0.25^{e}	40	4.16 ± 0.30^{cd}	36	4.07 ± 0.40^{bc}	32	2.18 ± 0.32^{cde}
2012	63	14.64 ± 0.39^{bc}	47	3.43 ± 0.35^{d}	35	3.26 ± 0.37^{cd}	28	3.01 ± 0.31^{bcd}
2013	95	13.38 ± 0.25^{d}	62	5.12 ± 0.43^{bc}	54	3.49 ± 0.47^{cd}	51	1.78 ± 0.42^{de}
2014	45	13.64 ± 0.36^{d}	24	4.54 ± 0.79^{bcd}	18	3.19 ± 0.81^{cd}	15	3.65 ± 0.64^{abc}
2016	114	15.47 ± 0.26^{b}	102	5.65 ± 0.30^{b}	81	4.89 ± 0.39^{b}	56	4.43 ± 0.59^{ab}
2017	68	13.79 ± 0.35^{cd}	46	5.49 ± 0.55^{b}	39	5.09 ± 0.47^{b}	29	4.95 ± 0.91^{a}
2018	36	16.7 ± 0.27^{a}	36	3.47 ± 0.39^{d}	37	2.26 ± 0.30^{d}	28	1.26 ± 0.23^{e}

KR1, weight gain from birth to 3 month; KR2, weight gain from 3 to 6 month; KR3, weight gain from 6 to 9 month; KR4, weight gain from 9 to 12 months of age; BL, blood level; F1, first filial generation; F2, second filial generation; F3, third filial generation.
Ns, $P > 0.05$; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; N, number of observations.
Least squares means with different superscripts within the same column and class are statistically different.

performance of indigenous goats was lower and cannot meet the standards for the export market. Thus, crossbreeding with meat-type Boer goats was started in 2007 to boost the productivity of indigenous goats. As this study exhibited, the expected weight advantages from crossbreeding were not exploited and even Boer crossbred goats could not meet the aforementioned export standard. This may not show the poor genetic potential of Boer goat as the expression of genetic potential is under the influence of environmental factors. Under a similar management level, the performance of indigenous goats and their crossbred with Boer goat was evaluated by different scholars (Mohammed et al., 2012; Tilahun et al., 2014; Tesema et al., 2018). When compared to indigenous goats, Boer crossbred goats had higher carcass weight by about 30.8% (Tesema et al., 2018). As well, Boer crossbred goats had a carcass weight higher by 48% relative to indigenous Arsi-Bale goats (Mohammed et al., 2012). In addition, the carcass weight of Boer crossbred goats was higher by 3.8 kg compared to indigenous goats (Tilahun et al., 2014). Furthermore, crosses were grown faster and performed better than local goats (Mohammed et al., 2012; Tilahun et al., 2014; Tesema et al., 2018). The study of Mohammed et al. (2012) and Tesema et al. (2018) demonstrated the genetic potential of Boer crossbred goats to outgrow and outgain indigenous goats when managed better. Under modest management, however, the performance of crossbred goats was no better than that of indigenous goats. Therefore, these results indicated that Boer crossbred goats would be suitable for medium to high input production systems.

The superiority of singletons in live weight was reported elsewhere (Kebede et al., 2012; Deribe and Taye, 2013; Belay et al., 2014). This might be because of the lower intrauterine availability of nutrients to the multiple-born kids. Ewes with multiple births had significantly lower cotyledons than single birth and the birth weight of kids was significantly correlated ($r = 0.64$) with the weight of cotyledons (Oramari et al., 2011). Likewise, according to Jawasreh et al. (2009), birth weight was positively correlated with placental weight ($r = 0.56$) and cotyledon number ($r = 0.43$). In addition, lack of competition for milk during the post-natal period could be the other probable reason for the superiority of single-born kids. According to Bolacali et al. (2017), birth weight had a considerable influence on the growth performance of kids at subsequent ages. Thus, the inferior pre-weaning performance could be a cause for the lowest weight of kids in subsequent ages. The greater live weight of male kids than female kids in this study is consistent with other researchers' findings (Zhang et al., 2009; Praharani, 2012). According to Tesema et al. (2017), changes in the type and measurement of sex hormones like androgen resulted in differences in kid growth. In addition, Jawasreh et al. (2009) noted that dams of male kids had a heavier placental weight and higher cotyledon number than dams of female kids and this could be the other reason for the higher weight of male kids.

The 3W and 9W of kids with 25% Boer blood level were higher than high grade crossbred goats. This is because as the exotic gene-level increases, the management they need also becomes sophisticated and must be managed accordingly. If not, nothing is expected from upgrading to a higher Boer level only and that is why the expected performance of goats was unparallel to Boer blood level. This suggests that increasing the exotic gene level in the existing low-input production system is valueless. The level of management in this study is differs from smallholder farmers. Therefore, the results should be interpreted with semi-intensive management in mind.

The non-significance influence of filial generation on live weight of kids was consistent with Gizaw et al. (2012). The culling practice of unfitted goats for breeding based on their physical conformation and live weight records in the station might be the reason for the observed non-significant differences among filial generations in this study. Indeed, segregation and decline in performance are expected in subsequent filial generations, but selective mating (Gizaw et al., 2012) and culling of poor-performing animals can counteract it. The significant effect of parity on live weight in this study is consistent with Praharani (2012) who reported the highest birth weight, weaning weight, and pre-weaning weight gain for kids born from dams in parity 3 and 4. Bolacali et al. (2017) also observed the highest and lowest birth weight of kids from 3-year-old and 6-year-old dams, respectively. According to Jawasreh et al. (2009), the number of cotyledons and the weight of the placenta increased as the age of the dam increased and the increment of cotyledons and placenta is positively associated with the birth weight of kids. This might be the reason for the increase of BW up to the 4^{th} parity.

The influence of season and year on kid's live weight has been also reported in other literature (Al-Najjar et al., 2010; Hasan et al., 2014; Deribe et al., 2015). The mating season for does kidding during the short rainy season was November to January; during these seasons, there was an available feed resource for dams. The condition of the dam during the mating season has its own influence on the birth weight of kids. According to Terrazas et al. (2012), undernutrition of a dam during pregnancy resulted in poor maternal performance, low milk production, loss of body condition and limited bonding with the neonate. In the case of offspring, it resulted in low birth weight, low viability and deteriorates cognitive processes. Hence, the performance variation between year and season is due to the inconsistency of the management, variability of climatic conditions which determine the availability of feed resources and disease distribution thereby influences the performances of both dam and kids.

4.2. Weight gain

In most animal species, average weight gain per day (WG) is used to evaluate growth rates and animals with higher growth rates can gain weight in a shorter period with a low amount of production inputs. The decreasing trend of weight gain when the age increases in this study concurs with Gatew et al. (2019) and Deribe and Taye (2013). This is not surprising, because, besides genetic potential and other environmental factors, pre-weaning weight gain of kids is closely associated with the nutritional status of the dam, mothering ability and milk production potential of the dam. However, the growth of kids after weaning largely depends on their genetic potential and levels of other environmental influences.

The faster growth rate of single-born kids than multiple-born kids during the pre-weaning period (WG1) and lower or similar performance afterward is consistent with Deribe et al. (2015) and Mohammadi et al. (2012) who reported that multiple-born kids gained the least weight during the pre-weaning period, but not during the post-weaning period. Competition for uterine space during pregnancy and milk after parturition could explain the reduced growth rate of multiple-born kids during pre-weaning. The superiority of multiple-born kids in the post-weaning age is probably because of compensatory growth and due to their forceful adaptive capacity to the environmental variation. Several scholars noted the non-significant influence of sex on weight gain of goats (Deribe et al., 2015; Zergaw et al., 2016; Gatew et al., 2019). On the other hand, it has been described (Zhang et al., 2009; Baneh et al., 2012; Tesema et al., 2017) that sex has a substantial impact on the growth rate of goats.

The selection of compatible exotic gene levels with the existing production system is imperative to be profitable in the goat crossbreeding program. Similar or lower weight gain of kids with 62.5% and 75% Boer level than lower Boer levels in this study shows that the level of management was unfavorable to high grade crossbred goats and thus upgrading to high exotic gene level could be worthless. In agreement with the current result, the absence of a decline in lamb growth performance from the F1 to the F4 generations was also observed by Boujenane et al. (1999). The influences of season and year of birth on the weight gain of kids were reported elsewhere (Mekuriaw, 2007; Zhang et al., 2009; Baneh et al., 2012; Mustefa, 2017). Variation in weight gain between birth years and seasons could be due to differences in feedstuff accessibility, management, and environmental conditions.

4.3. Kleiber ratio

The KR1 and KR2 in this study are comparable with those of Barazandeh et al. (2012) and Gupta et al. (2016). The lower competition for milk and the larger intrauterine availability of nutrients could explain the single kid's pre-weaning dominance in Kleiber ratio. Because the number of contact points between the uterus and the embryo reduces as the number of fetus increases and thus limiting the nutrition supply to the fetus. The non-significant influence of sex on Kleiber ratio in this study is concurring with Gupta et al. (2016).The higher Kleiber ratios for kids with 25% Boer blood level indicates that kids with lower exotic-gene level require less maintenance energy than kids with higher exotic gene levels. The effect of season and year of birth on Kleiber ratio has been documented elsewhere (Eskandarinasab et al., 2010; Supakorn and Pralomkarn, 2012; Gupta et al., 2016). The variation in managing practices, disease incidence, feed availability, climatic conditions, and breeding systems across the years could be the possible reasons for the observed differences across years.

5. Conclusions

The live weight and weight gain of Boer crossbred goats were under the influence of Boer blood level, litter size, season and year of birth. The expression of efficiency-related features at different growth phases was influenced by litter size, Boer blood level, parity, season, and year of birth. In terms of growth performance and efficiency-related traits, F2 and F3 crossbred goats did not show any benefit over F1 crossbred goats. In a low-input production system, increasing Boer blood levels above 50% would be useless. Therefore, besides improving the management, producing the first filial generation would be suitable for medium to high input production systems to exploit the expected benefits of crossbreeding.

Declarations

Author contribution statement

Zeleke Tesema: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kefyalew Alemayehu; Damitie Kebede; Tesfaye Getachew: Contributed reagents, materials, analysis tools or data.

Belay Deribe; Mekonnen Tilahun: Conceived and designed the experiments.

Alemu Kefale; Asres Zegeye; Liuel Yizengaw; Negus Belayneh; Mekonnen Shibeshi; Solomon Tiruneh; Shanbel Kiros; Molla Bishaw; Getachew Worku: Performed the experiments.

Mesfin Lakew: Conceived and designed the experiments; Performed the experiments.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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