Sheriff et al. Agric & Food Secur (2021) 10:49
https://doi.org/10.1186/s40066-021-00322-9

Agriculture & Food Security

RESEARCH Open Access

Morphological characterization of Arab and Oromo goats in northwestern Ethiopia

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Abstract

Background: An exploratory field research was conducted in northwestern Ethiopia, to characterize the morphological features of Arab and Oromo goat populations as an input to design community-based breeding programs. Ten qualitative and nine quantitative traits were considered from 747 randomly selected goats. All data collected during the study period were analyzed using *R* statistical software.

Results: Plain white coat color was predominantly observed in Arab goats (33.72%) while plain brown (deep and light) coat color was the most frequent in Oromo goats (27.81%). The morphometric measurements indicated that Oromo goats have significantly higher body weight and linear body measurements than Arab goats. Positive, strong and highly significant correlations were obtained between body weight and most of the body measurements in both goat populations. The highest correlation coefficients of chest girth with body weight for Arab ($r = 0.95$) and Oromo ($r = 0.92$) goat populations demonstrated a strong association between these variables. Live body weight could be predicted with regression equations of $y = -33.65 + 0.89 \times$ for Arab goats ($R^2 = 90$) and $y = -37.55 + 0.94 \times$ for Oromo goats ($R^2 = 85$), where *y* and *x* are body weight and chest girth, respectively, in these goat types.

Conclusions: The morphological variations obtained in this study could be complemented by performance data and molecular characterization using DNA markers to guide the overall goat conservation and formulation of appropriate breeding and selection strategies.

Keywords: Body weight, Body measurements, Ethiopia, Indigenous goats, Qualitative variables

Background

In developing countries, goat farming is one of the largest agricultural sectors, and about 35% of the world goat population (heads) is found in Africa [1]. In Ethiopia, the population of goats is estimated at 36.81 million heads [2]. Indigenous goats play vital roles in ensuring food and economic security and cultural benefits of resource-poor households [3]. The productivity of these genetic resources is, however, very low and hence their contribution to the national economy is far below potential [4]. Many interrelated factors including absence of sustainable goat genetic improvement program are identified as important constraints [5]. To plan such program, a good understanding of physical characteristics of goats under their production systems is required [6].

In Ethiopia, morphological characterization of indigenous goats dated back to the mid-1970s [7]. The first attempt was made by the Ministry of Agriculture in 1975 and classified Ethiopian goats into five major groups: Nubian, Highland, Afar, Somali and Long Tailed Gishe [8]. Later, FARM-Africa characterized Ethiopian and Eritrean goats and shown the presence of 14 different goat types [9]. Since then, several on-farm and on-station morphological characterization of goats have been undertaken mainly by Universities and research centers.

Benishangul Gumuz region (BGR), located in northwestern Ethiopia, is home for about 4,11,503 heads

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of goats [10] and five goat populations (Agew, Arab, Felata, Gumuz and Oromo) [11]. Among these, Agew and Gumuz goat populations are the most studied. For instance, 2 decades ago, [9] described the morphological characteristics of Gumuz goats. Later, the genetic diversity of this goat type was investigated by [12] using microsatellite DNA markers. Subsequently, [13, 14] undertook phenotypic and molecular characterization of Gumuz and Agew goats [15]. Also characterized Gumuz goats using high-density SNP CHIPs array. Very recently, [16] investigated the genetic diversity of Gumuz goats using *Caprine* SNP CHIPs array. In general, among the five goat populations found in BGR, most of the goat characterization efforts focused exclusively on Gumuz and/or Agew goat populations. However, Arab and Oromo goats, like many others, deserve to be characterized.

The Arab goats, named after the dominant tribe that generally owns this goat population, are more adaptable to semiarid areas, trypano-tolerant and considered as dual purpose (used for meat and milk production) [11]. On the other hand, the Oromo goats, named after Oromo community, inhabit the sub-humid agro-ecology and known as meat type [11]. Both goat populations provide their owners with tangible and intangible benefits such as cash, meat, manure, prestige, saving, insurance, cultural and ceremonial purposes. However, they are neglected in goat research and development endeavors of the country. The limited available information about the two goat populations, so far, has been based on on-farm survey and recall interviews. The objective of the current study was, therefore, to undertake morphological characterization of Arab and Oromo goat populations and suggest sustainable breeding program in the selected areas of BGR in northwestern Ethiopia.

Materials and methods

Description of the study area

This study was carried out in two districts of BGR from December 2017 to April 2018. The districts, Homosha and Bambasi (Fig. 1), were selected purposively because they are believed to be breeding tracts of Arab and Oromo goats, respectively. Homosha is located in semi-arid agro-ecology. It extends from 6°44′ to 6°84′ north latitude and from 37°92′ to 38°6′ east longitude [17] with an average altitude of 1373 masl [18]. The temperature ranges from 20 to 30 °C and the mean annual rainfall is 700–1200 mm. The Arab goats predominate in this district. The second study area, Bambasi, is situated in the sub-humid agro-ecology and it is positioned at 9°45′ north latitude and 34°44′ east longitude with an elevation of 1668 masl [19]. The mean annual rainfall ranges from 900 to 1500 mm and the average temperature is 28 °C. The Oromo goats are predominant in Bambasi district.

Sampling techniques and sample size

Two districts (Homosha and Bambasi) were purposively selected for this study. Subsequently, four peasant associations (PAs)—the lowest administrative units in Ethiopia—were selected from each district. The number of sampled households in each PA was determined following the recommended formula [20]:

$$N = 0.25/(\mathrm{SE})^2,$$

where N = sample size and SE = standard error. To make the number of the sampled households from each PA proportional to the size of the corresponding PA, the probability proportional to size (PPS) sampling technique was employed. The PPS was based on the formula:

$$W = [A/B] \times N$$

[21], where W = number of households to be calculated from each selected PA; A = number of households in each selected PA; B = total number of households in all eight selected PAs and N = the calculated sample size. Detailed information on the sampling technique and the number of sampled households is given in [22]. Overall, a total of 86 households from Homosha district and 163 households from Bambasi district were selected following the steps in [20] and [21]. Finally, three goats per household were sampled for qualitative records and quantitative measurements. This gives a total of 747 goats (258 Arab and 489 Oromo goats). The goats were classified into six age groups based on their dentition, i.e., kids (< 6 months), young (6–12 months), one pair of permanent incisors (1PPI) (1 year), 2PPI (2 years), 3PPI (3 years) and 4PPI ($\geq$ 4 years) [23]. The kids and young goats were differentiated by asking the age of goats from owners while the goats in 1, 2, 3 and 4 and above years were differentiated by observing their dentition. From the total sample size, 629 (84.2%) were female goats. Pregnant does were excluded from measurement to avoid over estimation of body weight (BW) and linear body measurements (LBMs). In the current study, quantitative traits, except BW, are generally named as LBMs.

Data collection

Ten qualitative variables (coat color pattern, coat color type, head profile, horn presence, horn shape, horn orientation, ear orientation, wattle presence, ruff presence and hair type) were recorded by using the standard format adapted from [6] breed descriptor list.

Nine morphometric measurements were also taken from each goat early in the morning before they were released for grazing. The measurements were taken as described by [6]. They included body weight (BW), [the

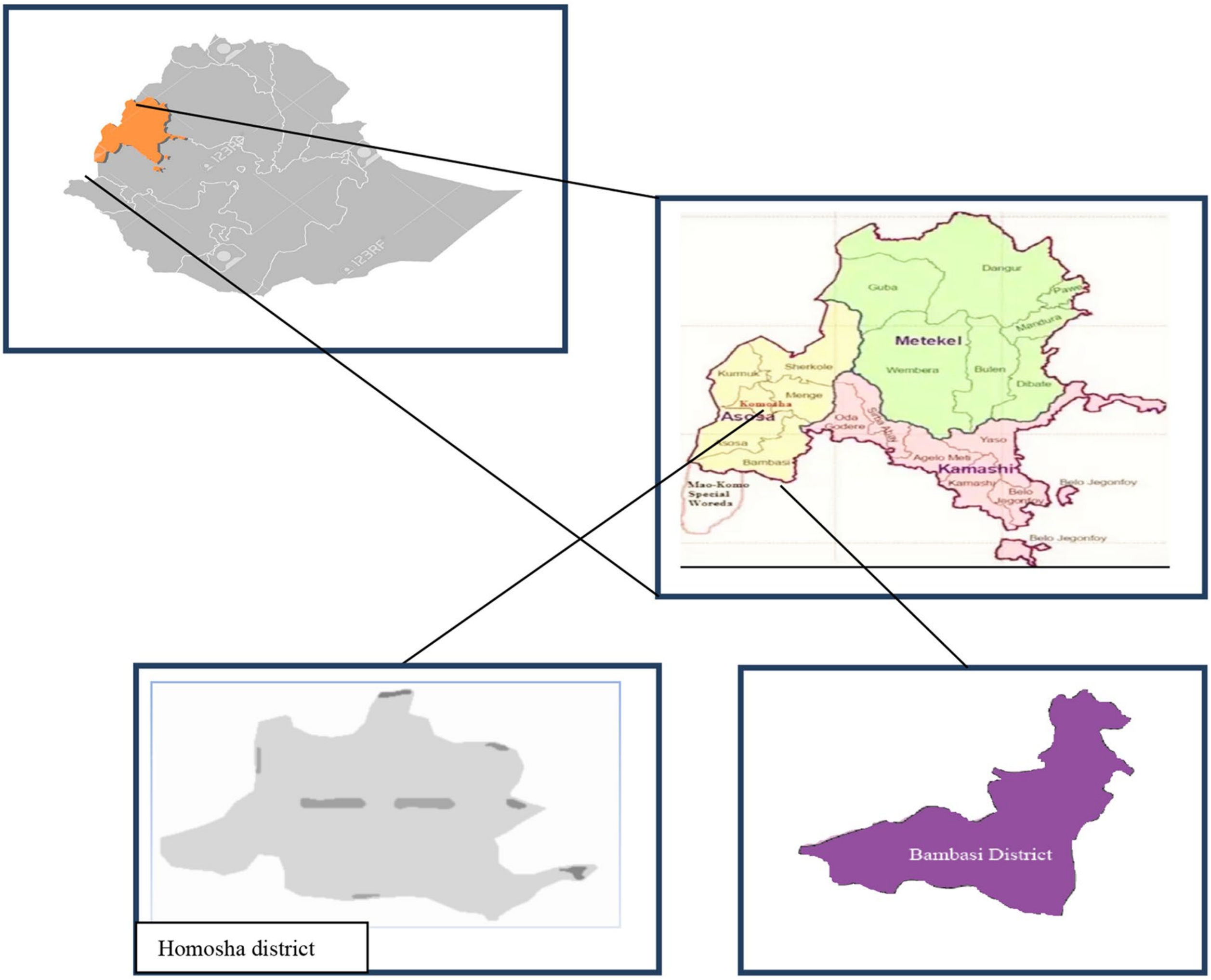

Fig. 1 Map of the study area

fasted live body weight (in kg)]; chest girth (CG), (circumference of the body (in cm) immediately behind the shoulder blades and perpendicular to the body axis); body length (BL), (horizontal distance (in cm) from the point of shoulder to the pin bone); wither height (WH), [vertical height (in cm) from the bottom of the front foot to the highest point of the shoulder]; rump height (RH), (vertical height from the bottom of the back foot to the highest point of the rump); chest width (CW), [width (in cm) of the chest between the briskets]; pelvic width (PW), [horizontal distance (in cm) between the extreme lateral points of the hook bone of the pelvis]; horn length (HL), [length of the horn (in cm) on its exterior side from its root at the poll to the tip]; and ear length (EL), [length (in cm) of the external ear from its root on the poll to the tip]. Body weight (kg) measurements were recorded using suspended spring balance in kg with a precision of 0.2 kg. The height measurements (cm) were taken using a graduated measuring stick while the length, width and circumference measurements (cm) were measured with plastic measuring tape. All measurements were taken after restraining and holding the goats in their natural position.

Statistical analyses

All the data collected during the study period were encoded and fed into MS-Excel (2010) and analyzed using *R* statistical software version 3.5.2, 2018 [24]. However, based on the nature of data, different *R* packages were used.

During the qualitative data analysis, 'gmodels package' [25] was used to calculate the frequency and percent of qualitative characteristics observed in the two goat populations. On the other hand, the quantitative data were analyzed using the 'lsmeans package' [26]. Tukey's comparison test was used to compare the sub-factors that brought significant differences.

The statistical model used was:

$$Y_{ijk} = \mu + A_i + G_j + (A \times G)_{ij} + e_{ijk},$$

where Y_{ijk} = the recorded k (body weight and linear body measurements) in the ith age and jth goat population; μ = overall mean; A_i = fixed effect of ith age (i = 1, 2, 3 and 4; 1 = 1PPI, 2 = 2PPI, 3 = 3PPI, and 4 = 4PPI); G_j = fixed effect of jth goat population (j = 1 and 2; 1 = Arab and 2 = Oromo); $(A \times G)_{ij}$ = interaction effect of age with goat population; and e_{ijk} = effect of random residual error. Due to the fact that only a few male goats at older age classes (3PPI and 4PPI) were available in the study area, male animals were excluded from the model in the analysis of BW and LBMs.

Pearson's correlation coefficient (r) values were computed to assess the relationship between BW and LBM using 'dplyr package' [27]. Live BW was regressed on LBMs using stepwise multiple linear regression analysis. The coefficient of determination (R^2) was used to assess the accuracy of prediction equations between BW and LBMs. Furthermore, MSE (mean square of error) was calculated from each fitted regression equation. In the first step, all LBMs were entered together into the equation for each goat population. Then, a group of variables having the maximum R^2 and minimum MSE were selected. In addition, Akaike's information criteria (AIC) and the Bayesian information criteria (BIC) were considered. In the second step, the variables which were selected by maximum R^2 and minimum MSE were entered together into the model to find the best fitted regression equation:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + e_i,$$

where Y_i = dependent variable (BW); β_0 = intercept; X_1,..., X_6 = independent variables (CG, BL, WH, PW, HL and EL); β_1,..., β_6 = regression coefficients of the variables X_1,..., X_6; and e_i = residual random error.

Results

Qualitative characteristics

The frequency and percent of qualitative characteristics observed in male and female goats of the two populations are presented in Tables 1, 2. The results of the study showed that plain, patchy and spotted coat color patterns were observed in both goat populations, with

Table 1 Coat color pattern and color type of Arab and Oromo goat populations by sex

Characters and attributes	Goat population						*p* value
	Arab			Oromo			
	Male	Female	Total	Male	Female	Total	
	N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	
Coat color pattern							
Plain	21 (50.00)	150 (69.44)	171 (66.28)	37 (48.68)	232 (56.17)	269 (55.01)	***
Patchy	18 (42.86)	42 (19.44)	60 (23.26)	35 (46.05)	139 (33.66)	174 (35.58)	
Spotted	3 (7.14)	24 (11.11)	27 (10.47)	4 (5.26)	42 (10.17)	46 (9.41)	
Coat color type							
White	10 (23.81)	77 (35.65)	87 (33.72)	10 (13.16)	94 (22.76)	104 (21.27)	***
Brown	7 (16.67)	36 (16.67)	43 (16.67)	32 (42.11)	104 (25.18)	136 (27.81)	
Black	1 (2.38)	9 (4.17)	10 (3.88)	–	6 (1.45)	6 (1.23)	
Gray	3 (7.14)	16 (7.40)	19 (7.36)	10 (13.16)	48 (11.62)	58 (11.86)	
White + brown	5 (11.9)	17 (7.87)	22 (8.53)	2 (2.63)	24 (5.81)	26 (5.32)	
White + black	6 (14.29)	30 (13.89)	36 (13.95)	16 (21.05)	84 (20.34)	100 (20.45)	
Brown + black	2 (4.76)	5 (2.32)	7 (2.71)	2 (2.63)	10 (2.42)	12 (2.45)	
Brown + gray	3 (7.14)	4 (1.85)	7 (2.71)	–	–	–	
Gray + black	1 (2.38)	3 (1.39)	4 (1.55)	–	–	–	
White + brown + black	3 (7.14)	9 (4.17)	12 (4.65)	–	31 (7.51)	31 (6.34)	
White + brown + gray	–	4 (1.85)	4 (1.55)	–	4 (0.97)	4 (0.82)	
White + gray + black	1 (2.38)	1 (0.46)	2 (0.78)	–	–	–	
Brown + black + gray	–	5 (2.32)	5 (1.94)	4 (5.26)	8 (1.94)	12 (2.45)	

N number of goats

***$p \leq 0.001$

Table 2 Some qualitative features of Arab and Oromo goat populations by sex

Characters and attributes	Goat population						*p* value
	Arab			Oromo			
	Male	Female	Total	Male	Female	Total	
	N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	
Head Profile							***
Straight	16 (38.10)	143 (66.20)	159 (61.63)	70 (92.11)	397 (96.13)	467 (95.50)	
Slight concave	26 (61.90)	73 (33.80)	99 (38.37)	6 (7.89)	16 (3.87)	22 (4.50)	
Horn presence							***
Horned	40 (95.24)	212 (98.15)	252 (97.67)	56 (73.68)	374 (90.56)	430 (87.93)	
Polled	2 (4.76)	4 (1.85)	6 (2.33)	20 (26.32)	39 (9.44)	59 (12.07)	
Horn shape							***
Straight	26 (61.90)	153 (70.83)	179 (69.38)	76 (100)	405 (98.06)	481 (98.36)	
Curved	16 (38.10)	63 (29.17)	79 (30.62)	–	8 (1.94)	8 (1.64)	
Horn orientation							***
Obliquely upward	2 (4.76)	4 (1.85)	6 (2.33)	20 (26.32)	39 (9.44)	59 (12.07)	
Front	–	3 (1.39)	3 (1.16)	–	13 (3.15)	13 (2.66)	
Backward	40 (95.24)	209 (96.76)	249 (96.51)	56 (73.68)	361 (87.40)	417 (85.28)	
Ear orientation							***
Forward	5 (11.9)	19 (8.80)	24 (9.30)	7 (9.21)	26 (6.30)	33 (6.75)	
Lateral	18 (42.86)	85 (39.35)	103 (39.92)	46 (60.52)	262 (63.44)	308 (62.99)	
Droopy	19 (45.24)	112 (51.85)	131 (50.78)	23 (30.26)	125 (30.27)	148 (30.27)	
Wattle presence							
Present	4 (9.52)	33 (15.28)	37 (14.34)	4 (5.26)	55 (13.32)	59 (12.07)	
Absent	38 (90.48)	183 (84.72)	221 (85.66	72 (94.74)	358 (86.68)	430 (87.93)	
Ruff presence							***
Present	18 (42.86)	11 (5.09)	29 (11.24)	30 (39.47)	36 (8.72)	66 (13.50)	
Absent	24 (57.14)	205 (94.91)	229 (88.76)	46 (60.53)	377 (91.28)	423 (86.50)	
Hair type							***
Short and smooth	36 (85.71)	198 (91.67)	234 (90.70)	62 (81.58)	389(94.19)	451 (92.23)	
Short and course	6 (14.29)	18 (8.33)	24 (9.30)	14 (18.42)	24 (5.81)	38 (7.77)	

N number of goats

***$p \leq 0.001$

maximum incidence in Arab goats (66.28% plain) and minimum incidence in Oromo goats (9.41% spotted). Thirteen types of coat colors were observed in the sampled goats, of which white in Arab (33.72%) and brown in Oromo (27.81%) goat populations were the most frequently observed coat colors followed by brown (16.67%) and white (21.27%) in Arab and Oromo goats, respectively. Plain black coat color was less frequent than plain white, brown or gray ones. However, among the mixed goat coat colors, a mixture of white and black with white dominant is the predominant coat color observed in both goat populations.

Variations between the two goat populations were also observed in other qualitative characteristics. For instance, 61.63% of Arab and 95.5% of Oromo goats were characterized by straight head. The horned goats accounted for about 97.67% and 87.93% of Arab and Oromo goats, respectively. More than two-thirds of Arab and almost all of Oromo goat populations have straight horn shape oriented backward in 96.51% of Arab and 85.28% of Oromo goats. Some characteristics, such as presence of droopy ear orientation, are also shared by roughly half of the total population in Arab goats while majorities (62.99%) of Oromo goats have lateral ears. Wattles were found in Arab (14.34%) and Oromo goats (12.07%). It was also found that 88.76% of Arab and 86.50% of Oromo goats have no ruff. Most of Arab (90.70%) and Oromo goat populations (92.23%) have short and smooth hair while the rest of goats were characterized by short and course hair. In general, results of the present study showed the presence of clear morphological variations between and within Arab and Oromo goat populations.

Body weight and linear body measurements

Goat type effect

Least-square means and standard error (LSM ± SE) for main effect of goat type on body weight and linear measurements is given in Table 3. Oromo goats have significantly ($p < 0.001$) higher average body weight, chest girth, body length, wither height and pelvic width measurements than Arab goats.

Age effect

The LSM for BW and LBMs were significantly ($p < 0.01$) influenced by age groups. Except for age classes of 2PPI and 3PPI, there were significant increases in BW and other LBMs as the age increased from the youngest (kid) to the oldest (4PPI) age group (Table 3). Results clearly indicate that BW and LBMs increase proportionately with the advancement of age. This situation is, however, expected since the size and shape of animals change as the age increases. Maximum gain on BW and LBMs was observed between 6 and 12 months of age.

Interaction effect

The interaction effect of age with goat type significantly ($p < 0.001$) affected BW, CG, BL and WH, but it affected PW and HL moderately ($p < 0.05$). When same age class Arab and Oromo goats were compared to each other, Oromo goats had significantly ($p < 0.001$) higher measurements in most of the variables. In general, 4PPI Oromo goats had the highest measurements; whereas Arab kids had the lowest measurement in all variables.

Correlation between BW and LBMs

In both Arab and Oromo goat populations, BW had positive and highly significant ($p < 0.001$) correlations with all LBMs except with EL in Arab goats (Table 4). Similarly, most of the quantitative traits in both goat populations showed positive and highly significant ($p < 0.001$) associations with one another. The strongest positive and highly significant correlation was between BW and CG in both goat populations ($r = 0.95$ in Arab goats and 0.92 in Oromo goats).

Prediction of BW from LBMs

Equations predicting BW from LBM of Arab and Oromo goats are presented in Table 5. In the prediction of BW, the multiple stepwise regressions found seven parameters (CG, BL, RH, PW, HL, WH and EL) to be significant ($p < 0.05$) for Arab goats and five parameters (CG, EL, CW, BL and HL) to be significant ($p < 0.05$) for Oromo goats. In the present study, high coefficient of determination (R^2) that ranged between 90 and 96% in Arab goats and 85–86% in Oromo goats and low residual mean square (MSE) values between 2.11 and 5.00 in Arab goats and 2.72 to 3.04 in Oromo goats were recorded using the regression analyses.

Discussion

This study was exclusively based on qualitative records and quantitative measurements to characterize and identify the morphological features of Arab and Oromo goat populations of BGR in northwestern Ethiopia.

The result revealed the presence of relatively more number of female goats sampled than male goats. This could be attributed to the fact that female goats are normally retained in flocks for reproduction while the males are more frequently put up for sale and more importantly slaughtered for food more often [22]. Indigenous goats thus make an important contribution in ensuring food security and alleviating poverty by providing animal source foods directly or from sale indirectly [28]. Documented that goats contribute to food security through direct access to animal source foods and providing cash income from sales, which can be used to purchase food.

Regarding coat color, the sampled goats were characterized by wide ranges of coat color patterns and types. Yet, white color in Arab and light brown color in Oromo goats were the predominant colors and they are reflections of the goats' adaptability to the study area (which is relatively warm and humid during most parts of the year). As reported by [29], animals with higher percentage of light color, such as white and brown, have better resistance to heat in areas characterized by higher solar radiation. In other words, the relatively high proportion of light colors observed in the two goat populations is an indication that the goats were not thermal stressed and their productivity could not be compromised. Horn presence is an advantage for self-defense, thermoregulation [30] and better reproductive performance [31]. Majority of the goats sampled were horned (Table 2), an indication of their ability to defend themselves, fight competitors for feed and water and even for does during mating. Likewise, presence of wattle is associated with thermoregulatory function, milk yield and reproductive performance such as higher prolificacy, litter size, fertility and conception rate [32] and higher body measurements [33]. Hair type is also an important economic trait in that smooth hair has an advantage as it permits conventional heat loss from the animal surface and also ensure easy disposal of dirt [34]. Overall, in order to set up sustainable genetic improvement strategies such as community-based breeding programs (CBBPs) in the study area, qualitative traits such as coat color pattern and type, presence of horn and

Table 3 Least squares means and standard error for body quantitative traits for different goat population and age groups

Effects and levels	*N*	BW (kg) LSM ± SE	CG (cm) LSM ± SE	BL (cm) LSM ± SE	WH (cm) LSM ± SE	RH (cm) LSM ± SE	CW (cm) LSM ± SE	PW (cm) LSM ± SE	HL (cm) LSM ± SE	EL (cm) LSM ± SE
Overall		24.7 ± 0.2	65.4 ± 0.3	55.5 ± 0.4	61.8 ± 0.4	63.5 ± 0.5	15.9 ± 0.1	13.9 ± 0.1	11.3 ± 0.4	13.9 ± 0.1
CV percent		22.69	9.10	10.66	9.50	9.65	6.58	6.05	23.72	5.60
Goat type		***	***	***	***	***	***	***	NS	NS
Arab	216	22.9 ± 0.4	63.3 ± 0.4	53.5 ± 0.4	60.1 ± 0.4	61.5 ± 0.4	15.6 ± 0.1	13.6 ± 0.1	11.0 ± 0.2	13.8 ± 0.1
Oromo	413	26.4 ± 0.3	67.9 ± 0.3	57.3 ± 0.3	64.4 ± 0.3	66.1 ± 0.3	16.1 ± 0.1	13.9 ± 0.1	11.3 ± 0.1	13.9 ± 0.1
Age		***	***	***	***	***	***	***	***	***
Kids	88	11.6 ± 0.3^{a}	51.6 ± 0.4^{a}	42.0 ± 0.5^{a}	48.4 ± 0.4^{a}	49.8 ± 0.5^{a}	14.5 ± 0.1^{a}	12.6 ± 0.1^{a}	8.6 ± 0.3^{a}	12.9 ± 0.1^{a}
Young	126	19.6 ± 0.2^{b}	62.2 ± 0.3^{b}	52.4 ± 0.3^{b}	59.3 ± 0.3^{b}	60.9 ± 0.3^{b}	15.6 ± 0.1^{b}	13.3 ± 0.1^{b}	9.8 ± 0.2^{b}	13.2 ± 0.1^{a}
1PPI	50	25.8 ± 0.2^{c}	66.5 ± 0.2^{c}	56.2 ± 0.3^{c}	63.3 ± 0.2^{c}	64.8 ± 0.3^{c}	15.7 ± 0.1^{b}	13.7 ± 0.1^{c}	11.3 ± 0.2^{c}	13.7 ± 0.1^{b}
2PPI	63	28.1 ± 0.2^{d}	69.8 ± 0.2^{d}	58.6 ± 0.2^{d}	66.4 ± 0.2^{d}	67.9 ± 0.2^{d}	16.2 ± 0.1^{c}	14.2 ± 0.1^{d}	12.0 ± 0.2^{d}	14.1 ± 0.1^{b}
3PPI	82	30.7 ± 0.2^{e}	70.9 ± 0.3^{de}	60.8 ± 0.3^{e}	66.5 ± 0.3^{de}	68.5 ± 0.4^{de}	16.7 ± 0.1^{d}	14.4 ± 0.1^{d}	12.1 ± 0.3^{d}	14.6 ± 0.1^{d}
4PPI	220	32.8 ± 0.4^{f}	72.4 ± 0.7^{e}	63.3 ± 0.7^{f}	67.9 ± 0.7^{f}	70.3 ± 0.8^{f}	16.9 ± 0.2^{d}	15.1 ± 0.1^{e}	13.8 ± 0.5^{e}	15.5 ± 0.1^{e}
Age × goat type		***	***	***	***	***	***	*	*	NS
Kid × Arab	30	9.4 ± 0.2^{a}	49.4 ± 0.3^{a}	40.0 ± 0.5^{a}	46.2 ± 0.5^{a}	48.4 ± 0.5^{a}	14.0 ± 0.2^{a}	12.4 ± 0.1^{a}	8.8 ± 0.4^{b}	12.8 ± 0.1
Kid × Oromo	58	14.4 ± 0.2^{b}	54.3 ± 0.4^{b}	44.4 ± 0.5^{b}	50.9 ± 0.5^{b}	51.6 ± 0.6^{b}	15.1 ± 0.2^{b}	12.8 ± 0.1^{b}	8.4 ± 0.5^{a}	13.0 ± 0.1
Young × Arab	43	16.1 ± 0.2^{c}	56.2 ± 0.3^{c}	46.8 ± 0.5^{c}	53.4 ± 0.4^{c}	54.2 ± 0.5^{c}	15.2 ± 0.1^{b}	13.0 ± 0.1^{b}	10.3 ± 0.4^{d}	12.9 ± 0.1
Young × Oromo	82	21.1 ± 0.1^{d}	64.8 ± 0.2^{d}	54.8 ± 0.3^{d}	61.9 ± 0.3^{d}	63.8 ± 0.3^{e}	15.7 ± 0.1^{cd}	13.5 ± 0.1^{c}	9.5 ± 0.3^{c}	13.3 ± 0.1
1PPI × Arab	17	22.8 ± 0.2^{e}	63.9 ± 0.3^{d}	53.9 ± 0.4^{d}	61.8 ± 0.4^{d}	62.4 ± 0.5^{d}	15.5 ± 0.1^{c}	13.5 ± 0.1^{c}	10.4 ± 0.4^{d}	13.7 ± 0.1
1PPI × Oromo	33	26.6 ± 0.1^{f}	67.2 ± 0.2^{e}	56.8 ± 0.2^{e}	63.7 ± 0.2^{e}	65.4 ± 0.2^{ef}	15.8 ± 0.1^{d}	13.7 ± 0.1^{cd}	11.5 ± 0.2^{e}	13.7 ± 0.1
2PPI × Arab	22	25.9 ± 0.1^{f}	66.5 ± 0.3^{e}	56.3 ± 0.4^{e}	63.8 ± 0.4^{e}	64.9 ± 0.4^{e}	15.8 ± 0.1^{d}	13.9 ± 0.1^{d}	11.8 ± 0.4^{e}	14.0 ± 0.1
2PPI × Oromo	41	28.7 ± 0.1^{g}	70.7 ± 0.1^{fg}	59.2 ± 0.2^{f}	67.0 ± 0.2^{g}	68.7 ± 0.2^{h}	16.3 ± 0.1^{e}	14.3 ± 0.1^{e}	12.1 ± 0.2^{f}	14.1 ± 0.1
3PPI × Arab	28	29.3 ± 0.1^{g}	69.7 ± 0.2^{f}	59.7 ± 0.3^{f}	65.4 ± 0.3^{f}	67.4 ± 0.4^{g}	16.2 ± 0.1^{e}	14.3 ± 0.1^{e}	11.9 ± 0.3^{ef}	14.5 ± 0.1
3PPI × Oromo	54	32.8 ± 0.2^{h}	72.7 ± 0.3^{h}	62.5 ± 0.4^{g}	68.3 ± 0.4^{h}	70.2 ± 0.5^{i}	17.4 ± 0.1^{g}	14.3 ± 0.1^{e}	12.3 ± 0.4^{f}	14.7 ± 0.1
4PPI × Arab	76	31.7 ± 0.2^{h}	71.1 ± 0.5^{g}	61.6 ± 0.7^{g}	66.7 ± 0.6^{g}	69.3 ± 0.7^{hi}	16.6 ± 0.2^{f}	14.8 ± 0.1^{f}	13.3 ± 0.6^{g}	15.3 ± 0.1
4PPI × Oromo	145	37.0 ± 0.5^{i}	77.0 ± 0.9^{i}	69.5 ± 1.3^{h}	72.2 ± 1.2^{i}	74.0 ± 1.4^{j}	18.2 ± 0.4^{h}	16.2 ± 0.3^{g}	15.8 ± 1.2^{h}	16.0 ± 0.3

Column means within each sub-class with different superscript letter are statistically different

NS non-significant; *BW* body weight; *CG* chest girth; *BL* body length; *WH* wither height; *RH* rump height; *CW* chest width; *PW* pelvic width; *HL* horn length; *EL* ear length; *PPI* pair of permanent incisors; *SE* standard error

*$p \leq 0.05$; ***$p \leq 0.001$

Table 4 Coefficient of correlation between body weight and linear body measurements (above diagonal for Arab and below diagonal for Oromo goat populations)

	BW	CG	BL	WH	RH	CW	PW	HL	EL
BW		0.95***	0.93***	0.89***	0.89***	0.65***	0.75***	0.38***	0.10^NS
CG	0.92***		0.88***	0.86***	0.86***	0.60***	0.70***	0.36***	0.05^NS
BL	0.82***	0.87***		0.86***	0.86***	0.62***	0.69***	0.31***	0.13*
WH	0.83***	0.90***	0.78***		0.85***	0.62***	0.67***	0.32***	0.03^NS
RH	0.81***	0.89***	0.77***	0.85***		0.59***	0.65***	0.24***	0.11^NS
CD	0.44***	0.42***	0.30***	0.39***	0.40***		0.81***	0.21***	0.13^NS
PW	0.58***	0.56***	0.53***	0.52***	0.51***	0.76***		0.27***	0.16*
HL	0.40***	0.37***	0.31***	0.32***	0.35***	0.19***	0.25***		− 0.29***
EL	0.35***	0.32***	0.25***	0.29***	0.28***	0.15***	0.20***	0.12*	

NS non-significant; *BW* body weight; *CG* chest girth; *BL* body length; *WH* wither height; *RH* rump height; *CW* chest width; *PW* pelvic width; *HL* horn length; *EL* ear length; *PPI* pair of permanent incisors; *SE* standard error

*$p \leq 0.05$; ***$p \leq 0.001$

Table 5 Multiple regression analysis of live BW on different body measurements of Arab and Oromo goats in all age groups

Breed	Model	Parameters								Adj. R^2	AIC	BIC	MSE
		β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7				
Arab	CG	− 33.65	0.89							0.90	922.15	932.14	5.00
	CG + BL	− 33.09	0.54	0.41						0.94	809.18	822.49	2.86
	CG + BL + RH	− 34.03	0.47	0.34	0.14					0.95	791.72	808.36	2.60
	CG + BL + RH + PW	− 40.16	0.44	0.32	0.14	0.73				0.95	776.47	796.43	2.39
	CG + BL + RH + PW + HL	− 40.74	0.41	0.31	0.16	0.70	0.18			0.96	764.88	788.18	2.24
	CG + BL + RH + PW + HL + WH	− 40.84	0.39	0.28	0.13	0.66	0.17	0.09		0.96	758.55	785.17	2.15
	CG + BL + RH + PW + HL + WH + EL	− 42.13	0.39	0.27	0.12	0.60	0.21	0.10	0.12	0.96	756.51	786.46	2.11
Oromo	CG	− 37.55	0.94							0.85	1676.19	1688.34	3.04
	CG + EL	− 42.52	0.92	0.47						0.85	1665.31	1681.50	2.95
	CG + EL + CW	− 45.32	0.89	0.46	0.30					0.86	1656.16	1676.39	2.87
	CG + EL + CW + BL	− 45.41	0.77	0.48	0.35	0.13				0.86	1645.29	1669.57	2.78
	CG + EL + CW + BL + HL	− 44.76	0.74	0.48	0.34	0.13	0.09			0.86	1637.51	1665.84	2.72

CG chest girth; *BL* body length; *RH* rump height; *PW* pelvic width; *HL* horn length; *WH* wither height; *EL* ear length; *CW* chest width; R^2 coefficient of determination; *AIC* Akaike's information criteria; *SBC (BIC)* Bayesian information criteria; *MSE* mean square error

wattle, and hair type should be part of the selection criteria of breeding males and females.

[35] reported that on the basis of wither height; adult goats can be classified as large (> 65 cm), small to medium (51–65 cm) and dwarf (< 50 cm). According to the current results, both Arab and Oromo goats can be grouped under small to medium sized breeds. However, Oromo goats had significantly higher averages of BW and LBMs, showing that animals belonging to this population have better body conformation for meat production than animals in Arab goat population. The variation between the two goat populations could arise due to difference in genetic characteristics and/or environmental conditions that may affect phenotypic variance [34]. The relatively harsher environment, in terms of feed and water shortage and high environmental temperature, under which the Arab goats are raised could have been largely responsible for their lower body dimensions. Because these stress factors could have prevented the Arab goats from expressing their genetic potential. This is in line with what has been reported by [36]. The authors documented that temporal and spatial variation in weather, plant productivity and subsequent nutrition could have major impacts on physical growth of animals. However, at the scope of the present study, it is difficult to associate body size, shape and conformation to any genetic background. Future studies could look in to genetic differences of the two goat populations. The coefficients of variation (CV) obtained for quantitative traits such as BW, CG, BL, WH, RH and HL were relatively higher. This could be due to absence of

systematic selection, or the body parts are affected more by the environment than others [37].

Investigation on the effect of age on quantitative measurements of goats indicated that BW and LBMs increase proportionately with the advancement of age. Similar findings were reported by [38] for goats found in western Ethiopia. However, the maximum body gain was observed between 6 and 12 months. This may be due to natural increase in dry matter intake after the goats reached age at puberty. Study by [39] also found maximum body gain at 9 months of age for Rohilkhand goats in India. The current average body measurements of goats in different age classes are higher than previous findings from similar age western lowland goats reported by [15].

The correlations among quantitative traits were generally positive and highly significant that ranged from 13 to 95% in Arab and 12 to 92% in Oromo goats with the highest correlation between BW and CG in both goat populations ($r = 0.95$ in Arab and 0.92 in Oromo goats). In agreement with this finding, several authors [13, 38, 40, 41] reported the highest correlation between BW and CG for some Ethiopian goats. This specifies that CG could be the best trait in predicting BW.

The positive and significant correlations among quantitative traits obtained in this study also indicate that both goat populations have harmonious body conformation, reflecting balanced physical growth. Furthermore, it shows that the traits are under the same genetic influence due to additive genetic effect [42]. This implies selection for one or more of these traits may consistently increase other traits that have positive association with the selected trait/s. In addition, selection of positively correlated traits would have paramount importance in designing breeding programs in that the selection will lead to significant improvement of body weight and other body measurements that are of economic importance [37].

The regression analyses of BW with LBMs in the present study identified seven traits in Arab and five traits in Oromo goats to predict BW. Similarly, [38] found seven traits in female ($R^2 = 83\%$) and five traits in male ($R^2 = 88\%$) to predict BW of western Ethiopian goats [41]. Also reported are five traits to estimate BW of Woyto-Guji and Central Highland goats with R^2 values of 84% and 79%, respectively. Nevertheless, CG was found to be the most appropriate variable to explain more variation in both Arab (adjusted $R^2 = 90\%$) and Oromo goat populations (adjusted $R^2 = 85\%$). The high coefficients of determination (R^2) in the current study indicated the strong association and success of LBMs in describing more variation in BW. This may be helpful for local goat keepers to make selection and cull decisions as it can be relatively low cost, high accuracy and consistency [43]. Body measurements in some cases can be more reliable than modern weighing machines as the latter can give biased results caused by gut fullness [44]. As shown in Table 5, addition of a new variable to the model did not always increase the adjusted R^2. However, AIC, BIC and MSE decreased as a new variable was added with little or no influence on the adjusted R^2. On the other hand, addition of unnecessary variables to the model may increase the error. Therefore, addition of other LBMs to CG did not result in significant increase in adjusted R^2, though it improved the accuracy of prediction by decreasing the error.

In the study area, where formal breed data recording schemes are not well established [22] and goat keepers could not easily access weighing scales and understand complex formula, BW could be predicted from the regression equation $y = -33.65 + 0.89x$ for Arab goats and $y = -37.55 + 0.94x$ for Oromo goats, where y and x are BW and CG measurements, respectively. These formulas indicate that an increase of one cm of CG would result in an increase of 0.89 and 0.94 kg of BW in Arab and Oromo goat populations, respectively, which is comparable with the findings on goats elsewhere in Ethiopia [13, 38, 41]. The possibility of using simple body measurements that can easily be measured in the field to predict important economic traits have been demonstrated by [45, 46]. Overall, assessment of BW and LBMs in both goat populations based on the expressed regression equations remains very important for avoiding errors of visual determination of animal weights in the study area where weighing balance cannot be easily accessed.

Conclusion and recommendation

The significance of morphological characterization of indigenous goat genetic resources cannot be over emphasized. The present study is based on qualitative records and quantitative measurements of Arab and Oromo goat populations. The results revealed the presence of morphological variations within and between the goat populations in the studied agro-ecological zones of BGR in northwestern Ethiopia. It was also found that the goat populations in the study area have developed diverse qualitative traits such as white and brown coat colors, presence of horn and wattle, and short and smooth hair. Compared to Arab goats, Oromo goats are on average not only wider and bigger in size, but also show considerably higher variation in body size. This indicates that there would be a good opportunity to select best young breeding males for genetic improvement of goats in the study area. The correlation analysis has shown that chest girth had the highest association with body weight and hence it can be used as a marker to estimate weight using regression equations. Overall, it would be useful if the present characterization work is supported by performance data to understand which genotype has comparative advantage within an agro-ecological zone. Furthermore, an investigation on the molecular characterization using molecular markers like SNP will complement the results obtained from morphometric differentiation and also be helpful in high resolution characterization, conservation and formulation of breeding and selection strategies.

Acknowledgements
The corresponding author gratefully acknowledges the Federal Ministry of Education, Ethiopia, for the PhD fellowship award, Biotechnology Research Institute of Bahir Dar University for funding this research, farmers who allowed their goats free for inventory purpose and all experts and development agents in the study area for their cooperation during data collection.

Authors' contributions
OS performed the data collection and analysis and wrote this paper. KA and AH participated in coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Funding
The financial support for this study was provided by Biotechnology Research Institute (BRI) of Bahir Dar University, Ethiopia.

Availability of data and materials
All data generated or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The paper meets all applicable standards with regard to ethics and integrity. The corresponding author along with the co-authors submitted this paper with full responsibility and following due ethical procedure. There are no duplicate publications, fraud or plagiarism. Furthermore, the manuscript does not contain clinical studies or patient data.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Received: 11 September 2020 Accepted: 8 July 2021
Published online: 15 November 2021

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