

Statistical modeling of carcass traits, primal carcass cuts, body weight and morphological traits of pure Central Highland and crossbred Boer goats

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Abstract

This study was conducted to investigate the relationships among morphological traits, body weight, carcass traits, and carcass primal cuts of goats and to fit the best regression equation for goat body weight, carcass traits and carcass primal cuts prediction. Body weight, carcass traits such as slaughter weight, empty weight, hot carcass, dressing percentage and carcass primal cuts: thin cut, loin, leg, rib, and fore leg+ shoulder+ neck were the dependent variables. Morphological traits: body length carcass primal cuts (thin cut, loin, leg and leg+shoulder+neck) (BL), wither height (WH), heart girth (HG), paunch girth (PG), rump height (RH), hip width (HW), pin bone width (PBW), neck girth (NG), scrotum circumference (SC) and Scrotum length (SL) were an important parameters used for prediction of the equation. Crossbred Boer goats exhibited higher ($p < 0.05$) body weight, carcass traits, and carcass primal cuts than pure Central Highland (CH) goat except for dressing percentage. Body weight and carcass traits for both genotypes had a moderate to higher significant correlation with all morphological traits ($r = 0.42$ to 0.94) except with SL and SC. For both genotypes two principal components were extracted and which in a multiple regression analysis explained 80.17% of the total variance for CH with Central Highland goat and 82.25% of the total variance for crossbred Boer goat. HG, NG, BL, and PG were the most important ($R^2 = 0.71$) morphological traits used to predict body weight, carcass traits, and carcass primal cuts of Central Highland goat, whereas HG, BL, HW, and SL were the most important ($R^2 = 0.84$) predictor for crossbred Boer goat. Therefore, this study suggests that morphological traits could be a suitable criteria for early selection of bucks for their body weight and carcass traits without slaughtering. The prediction of body weight and carcass traits based on principal component factor scores is more reliable than the use of individual morphological traits, because the uses of factor scores in multiple regression models get rid of the problem of the interdependency of explanatory variables, thereby improve the accuracy of interpretation of the regression results.

Keywords: Genotype, morphological trait, principal component analysis, selection

Introduction

The ultimate goal of the livestock production and meat industry is to have an accurate and objective measurement method for assessing the economically important traits of animals and to determine the value and merit of the carcass while the animal is still alive (Bogass and Merkel 1993). Accordingly, the accurate functions used to predict live weight or carcass traits from live animal measurements is having an immense economic contribution to livestock production enterprises (Afolayan et al., 2006). In meat production, body measurements are indices of skeletal developments and indirectly help to determine carcass composition (Srivastava et al., 1968). Likewise, strong correlation coefficients between carcass weight and external body measurements were noted by Owen (1975). The magnitude of the correlation between live body measurements and raw meat yield was reported to be a valuable indicator for selecting high meat yielding strain of pig (Ogah et al., 2011).

Morphological trait measurements used for several purposes including prediction of growth rate, genetic improvement, body condition, conformation and carcass traits (Lambe et al., 2008; Abdel-Maged and Ghanem 2013). In this context, measurements of various morphological traits are of value in judging quantitative characteristics of meat and are also helpful in developing suitable selection criteria. Moreover, they can be used as an indirect way to estimate live weight and carcass trait because of the relative ease in measuring linear dimensions (Getachew et al, 2009). There are two

types of body measurements, these are skeletal and tissue measurements (Essien and Adesope 2003). Tissue measurements include heart girth, chest depth, punch girth, and hip width while skeletal measurements include all length and height measurements (Blackmore et al., 1958).

There are modern techniques to predict carcass composition of live animals, such as X-ray computer tomography (Lambe et al., 2003) and ultrasonic scanning (Bedhiat Romdhani and Djemali 2006). However, these methods are expensive and require high expertise and specialized equipment. Moreover, goat owners and traders depend on eye judgment to estimate live body and carcass weights. The accuracy of such subjective method depends on individual experience. A reasonable, rapid and user-friendly tool is required to predict body weight and carcass traits by goat breeders. In this regard, rapid, inexpensive and feasible body measurements could be used for predicting body weight and carcass traits of goats to be measured under field conditions. Thus, the purposes of the present study were to investigate the relationships among morphological traits, body weight and carcass traits of goats. Another aim was to establish prediction equations for body weight, carcass traits and carcass primal cuts using morphological traits of pure Central Highland and their crossbred Boer goat.

Material and methods

Experimental procedure

The study was conducted at Sirinka Agricultural Research Center, Ethiopia. A total of 48 male yearling goats (24 pure Central Highland goat and 24 crossbred Boer goats) were used in the present investigation. Central Highland goats were purchased from the local market and twenty-four crossbred Boer goats with 50% blood level were selected from Sirinka Agricultural Research Centers. Goats were quarantined for 21 days in an isolated holding yard at Station, treated for internal and external parasites, and vaccinated against pasteurellosis, sheep and goat pox, and anthrax. The animals had a period of 15 days of adaptation and finished during 90 days. Animals were allowed to grazing for 6:00 hours during daytime and placed in individually partitioned pens (1.25 x 0.9 m) that are equipped with feeding trough and watering bucket during the night. In addition to 6:00 hr grazing, goats were supplemented with a mean of 300g/day concentrate feed mixture consisting of (55.7% wheat bran, 40% noug cake, 3% limestone, and 1.3% salt).

Data collection

Body weight and morphological trait measurements

Prior to slaughtering and after 16 hours fasting, body weight was measured along with the following ten morphological traits on each animal: Body length (BL), measured diagonally from the lateral tuberosity on the scapula to the pin bone; wither height (WH), vertical distance from the highest point of the shoulder (withers)

to the ground surface at the level of the forelegs; heart girth (HG), the body circumference at a point immediately posterior to the front leg and shoulder and perpendicular to the body axis; paunch girth (PG), circumference of the body was measured immediately after the abdomen just before the hind legs; rump height (RH), measured vertically from the ground to the top of the pelvic girdle; hip width (HW), the distance between two hip bones or distance between the two tuber coxae; pin bone width (PBW), the distance between two pin bones; neck girth (NG), taken as the distance round the mid region of the neck; scrotum circumference (SC), was obtained while the buck was in a standing position and by pushing the testicles to the bottom of the scrotum, then measuring the greatest circumference with a flexible metal tape and Scrotum length (SL), the distance between the tip of the scrotal sack and its neck. The reference points and procedure for the morphological trait measurements were as prescribed elsewhere by Salako and Ngere (2002), Sarma (2006), and Yakubu (2010).

A graduated measuring stick was used for the height measurements, while the length and circumference measurements were done using a flexible tape; and a special wooden calipers was used for the width measurements. All measurements were taken early in the morning before grazing or receiving feed in order to avoid undesirable variations due to weight and rumen volume change. In order to avoid intra-individual variations, all measurements were taken by the same person. The experimental protocol used in this study, including animal management, housing, and slaughter procedures was conducted based on NRC (2011).

Carcass traits and carcass primal cut measurements

The carcass traits taken from each animal were: Slaughter body weight (SBW); the weight before slaughter and after 16:00 hr fasting except water which was freely allowed to animals (Tilahun et al, 2014). Empty body weight (EBW) was computed by subtracting the weight of gut content from slaughter weight. Hot carcass (HC) weights were taken immediately after slaughter and removal of non-carcass components. The hot carcass comprised the body after removing the skin, head, forefeet (at the carpal-metacarpal joint), hind feet (at the tarsal-metatarsal joint), viscera and fat depots. Internal organs (kidneys, liver, heart, lungs, spleen and pancreas) and fat depots such as scrotal fat, pelvic, kidney and gut fat (omental + mesenteric fat) were also removed. Dressing percentage (DP) was defined as the hot carcass weight expressed as a percentage of slaughter body weight (SBW). After weighting, carcasses fabricated into five primal cuts: leg, loin, ribs, thin cut and foreleg+ shoulder+ neck. All carcass trait measurement except for primal cuts were computed according to Asizua et al. (2014).

Statistical analyses

Data collected on body weight, morphological traits, carcass traits and carcass primal cuts were analyzed using the general linear model (GLM), a procedure of the statistical analysis system (SAS 2002). Independent sample T-Test was used to compare mean values of two genotypes. Prediction of carcass traits, carcass primal cuts, and body weight from morphological traits using

the stepwise multiple regression procedure was carried out using the model:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + e \dots \dots \dots \text{Model 1}$$

Where, Y is the dependent/ response variable; body weight, carcass traits, and carcass primal cuts; α is the intercept of the regression equation, β_1 , β_2 and β_n are regression coefficient of the variables X_1 , X_2 and X_n ; X_1 , X_2 , and X_n are the explanatory variables or morphological traits and e = the residual random error.

In order to reduce the number of morphological traits which used to estimate body weight and carcass traits, an analysis of principal components was carried out by using the factor programme SPSS version 16.0. Principal component analysis according to Everitt et al. (2001) is a method for transforming variables in a multivariate data set into new variables, which are uncorrelated with each other. In addition, PCA of morphological traits has been used as a tool in the assessment of animal body size and shape in goats (Okpeku et al., 2011). Thus, multiple regression procedure was also used to predict carcass traits and body weight from principal component factor scores according to the following the word "equation" should be substituted with "model":

$$Y = \alpha + \beta_1 PC_1 + \beta_2 PC_2 + \dots + \beta_n PC_n + e \dots \dots \dots \text{Model 2}$$

Where, Y is the dependent/ response variable; body weight, carcass traits, and carcass primal cuts; α is the intercept of the regression equation, β_1 , β_2 and β_n are regression coefficient of scores PC_1 , PC_2 and PC_n ; PC_1 , PC_2 and PC_n are the explanatory variables or principal components and e = the residual random error. The coefficient of determination (R^2) indicates the accuracy of the equations. Anti-image correlations, Kaiser-Meyer- Olkin measures of sampling adequacy and Bartlett's Test of Sphericity (to test the null hypothesis that the original correlation matrix is an identity matrix) were computed to test the validity of the factor analysis of the data sets. The appropriateness of the PCA was further tested using communalities and ratio of cases to variables. To enhance the interpretability of the principal components, the varimax criterion of the orthogonal rotation method was employed in the rotation of the factor matrix.

Results and Discussions

The effect of genetic group on zoometrical traits, body weight and carcass traits

The means and standard error of morphological traits, body weight, and carcass traits of pure Central Highland and their cross with Boer goats are presented in Table 1. Crossbred Boer goats exhibited higher ($p < 0.05$) body weight, carcass traits, and carcass primal cuts than pure Central Highland goat except for dressing percentage. The observed variation in body weight and carcass traits among geneotypes can be attributed to

the genetic potential and type of breeds. Likewise, morphological traits such as heart girth, punch girth, hip width, and neck girth for crossbred Boer goat was higher ($p < 0.05$) than for pure Central Highland goats. This may not be surprising as Boer is specialized meat type goat while Central Highland goat is dual purpose. Salako (2006) noted that balance index which include Heart/ chest girth, chest depth, punch girth, and hip width could be indicators of carcass yield expected from animals. Thus, these morphological traits bespeak the superiority of crossbred Boer goat in terms of body weight and carcass traits.

Phenotypic correlation of morphological traits with body weight

The phenotypic correlation between body weight and morphological traits are presented in Table 2. In this study, body weight for pure Central Highland goat had a higher positive correlation with NG (0.87), HG (0.85), BL (0.85), WH (0.76), and HW (0.76), whilst lowest with SL (0.23). Body weight of crossbred Boer goats highly ($p < 0.001$) correlated with HG, BL, HW, NG, PG, and PBW with correlation coefficient ranged between $r = 0.87$ and $r = 0.94$. Based on the magnitude of correlation, there is a potential use of morphometric characteristics as selection criteria and predicting body weight in livestock (Assan 2013), thus allowing breeders to make more informed selection decision. These results suggests that producers who lack scales for weighing goat can estimate body weight of their goats using morphometric measures; that is, they can use a tape rule instead of a

weighing scale, a practice that is much easier to perform under field conditions and during marketing.

Correlation of morphological traits with carcass traits and carcass primal cuts

In this study, morphological traits for pure Central Highland goat except for SC and SL had higher positive and significant correlation with carcass traits and carcass primal cuts with a range between $r=0.58$ and $r=0.96$ (Table 2).

The moderate to high correlation would imply morphological traits can be used as indirect selection criteria to improve meat production. Likewise, Bene et al. (2007) and Agamy et al. (2015) noted that meat production can better be estimated based on morphological traits. Therefore, live goat purchaser can predict weight of carcass trait and primal carcass cuts from the aforementioned morphological traits. Dressing percentage is an important parameter for both meat trader and consumer (Akcapinar 2000). This study demonstrates that dressing percentage for CH goats did not correlate with morphological measurements while it was correlated with all morphological measurements for crossbred Boer goat. The non-significant correlation obtained for CH was in line with Yaprak et al. (2008) who noted that body length, wither height, and heart girth of Red Karaman lambs were not significantly correlated with dressing percentage. The result obtained for crossbred Boer goat partly agreed with that of Attah et al. (2004) who noticed that chest girth of Red Sokoto and West African Dwarf yearling goats slaughtered at 10 and 20 kg

body weights was highly correlated ($p<0.01$) with dressing percentage.

Except for rump height, all morphological measurements had moderate to high ($r=0.58$ to $r=0.96$) positive correlation with all carcass traits and carcass primal cuts of crossbred Boer goats. According to Assan (2013), high positive relationships among traits suggest that an increase in one could lead to a corresponding increase in the other trait. As a result of such high correlations, it is possible to predict body weight and carcass traits of goat from highly correlated morphometric traits. Moreover, the results of the relationship between morphometric characteristics and carcass parameters could be exploited in designing appropriate management and selection programs. In terms of feasibility, morphometric traits can be recorded in a single assessment which makes them cheaper and more practicable to measure in the field than body weight and carcass traits. Thus, morphometric traits could assist the producer to make informed management decision, which includes the provision of adequate nutrition, correctly administer medication and better estimate of potential profit.

Principal component analysis

Principal components are a weighted linear combination of correlated variables, explaining a maximal amount of variance of the variables (Truxillo 2003). The exploitation of the multivariate techniques especially the principal components has been found useful for a quantitative measure of animal conformation which is

desirable as it will enable reliable genetic parameters for these traits to be estimated and permits its inclusion in breeding programmes (Mavule et al., 2012; Silva et al 2013; Yakubu 2013). In this study; Anti-image matrices and Kaiser-Meyer-Olkin measure of sample adequacy (0.734 for CH goat and 0.566 for crossbred Boer goat) was higher than Kaiser (1974) recommendation i.e the acceptable value of 0.5 for sample adequacy. Bartlett's test for sphericity ($P < 0.0001$, Chi-square -125.15 for CH and $P < 0.0001$, Chi-square -140.40 for crossbred Boer goat) as well as the large values of communalities (0.39 to 0.95 for CH and 0.41 to 0.97 for crossbred Boer goat) observed in the present investigation (Table 5) indicate that a large number of variance has been shared by the variables and the need to permitting the PCA to classify them.

The PBW for CH and SL for crossbred Boer goat showed low commonality, that is, contributed little towards explaining the total accumulated variation in the factors. After varimax rotation of the component matrix, two PCs were extracted for two goat genotypes which accounted for 80.17 and 82.25% of the total variance for CH goat and for crossbred Boer goat respectively. There were variations in the pattern of loadings of the morphological measurements on each PC. For CH goat; first PC1 was characterized by HG, WH, BL, RH, HW, NG, PG, and PBW and contributed the largest portion of the total variance (61.94 %), which could be considered as body size factor. The second (PC2) was influenced by SC and SL, which contributed 18.22% to the total variance. For crossbred Boer goat; PC1 comprised of

seven body measurements (HG, BL, HW, NG, PG, PBW, and SC) and contributed the largest portion of the total variance (53.17%), whilst the second PC (PC2) comprised of three body measurements (WH, RH, and SL) and contributed 29.08 % of the total variance. Several authors (López-Carlos et al., 2010; Okpeku et al, 2011; Yakubu et al, 2011) noted that the first PC represents general body size, while the second PC represents body shape or conformation. According to Khargharia et al. (2015), the candidate traits loaded in the same component were classified together and it could be concluded that the elements present in the same cluster probably have common genomic sites for their genetic control; therefore pleiotropy may be implicated. In addition, correlations between principal components are zero (Pinto et al., 2006) and the selection of animals for any principal component will produce an independent response in terms of other principal components. These all suggests that the principal components could be used for prediction of body weight and carcass traits and also for selection of Central Highland and their cross with the Boer goats.

Prediction of body weight and carcass traits from interdependent morphological traits and their unrelated independent PC

The interdependent original morphological measurements and their independent principal component scores were used to predict body weight, carcass traits, and carcass primal cuts of goats (Tables 6; for CH and Table 7; for crossbred Boer goat). HG, NG, BL, and PG were the most important ($R^2 = 0.71$)

Table 1. Means and standard error for different morphological traits of Central Highland and their cross with Boer goat

| Traits | Central Highland goat | Crossbred Boer goat | Significance level |
|------------------------------------|-----------------------|---------------------|--------------------|
| Body weight (BW) kg | 24.5±1.25 | 30.6±1.72 | 0.009 |
| Morphological traits | | | |
| Wither height (WH) cm | 66.7±0.83 | 63.8±1.26 | 0.066 |
| Heart girth (HG) cm | 65.8±0.91 | 69.2±1.23 | 0.036 |
| Body length (BL) cm | 58.2±1.00 | 59.1±0.91 | 0.565 |
| Punch girth (PG) cm | 67.9±0.63 | 72.5±1.29 | 0.009 |
| Rump height (RH) cm | 65.8±1.09 | 64.0±1.07 | 0.245 |
| Hip width (HW) cm | 14.2±0.57 | 16.6±0.66 | 0.015 |
| Pin bone width (PBW) cm | 20.0±0.24 | 20.8±0.45 | 0.127 |
| Neck girth (NG) cm | 38.1±0.92 | 42.9±1.18 | 0.004 |
| Scrotum circumference (SC) cm | 22.6±0.59 | 24.0±0.32 | 0.058 |
| Scrotum length (SL) cm | 10.0±0.21 | 10.7±0.44 | 0.149 |
| Carcass traits | | | |
| Slaughter body weight (SBW) kg | 22.5±1.03 | 28.2±1.55 | 0.006 |
| Hot carcass (HC) kg | 10.7±0.52 | 14.0±0.91 | 0.005 |
| Empty body weight (EBW) kg | 20.9±0.97 | 26.0±1.54 | 0.012 |
| Dressing percentage (SBW) | 47.6±0.63 | 49.2±0.70 | 0.103 |
| Carcass primal cuts | | | |
| Thin cut (TC) kg | 0.50±0.04 | 0.76±0.06 | 0.001 |
| Fore leg + shoulder+ neck (FSN) kg | 3.96±0.20 | 5.15±0.34 | 0.007 |
| Rib kg | 2.17±0.11 | 2.77±0.19 | 0.014 |
| Loin kg | 0.76±0.04 | 1.01±0.07 | 0.012 |
| Leg kg | 3.50±0.14 | 4.30±0.27 | 0.017 |

Table 2. Correlation coefficient of morphological traits with body weight and carcass traits of Central Highland and their crossbred with Boer goat

| ZM | BW | SBW | HC | EBW | DP(SBW) | TC | FSN | Rib | Loin | Leg |
|------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|----------|---------|
| Central Highland goat | | | | | | | | | | |
| WH | 0.76*** | 0.92*** | 0.94*** | 0.92*** | 0.36 ns | 0.84*** | 0.89*** | 0.83*** | 0.74** | 0.92*** |
| HG | 0.85*** | 0.92*** | 0.96*** | 0.94*** | 0.43 ns | 0.83*** | 0.95*** | 0.88*** | 0.73** | 0.94*** |
| BL | 0.85*** | 0.94*** | 0.96*** | 0.96*** | 0.36 ns | 0.75** | 0.92*** | 0.85*** | 0.88*** | 0.96*** |
| PG | 0.56** | 0.93*** | 0.76** | 0.75** | 0.34 ns | 0.59* | 0.72** | 0.56 ns | 0.71*** | 0.70* |
| RH | 0.53** | 0.80*** | 0.83*** | 0.84*** | 0.342ns | 0.64* | 0.83*** | 0.65* | 0.72** | 0.80** |
| HW | 0.76*** | 0.86*** | 0.93*** | 0.88*** | 0.52ns | 0.75** | 0.95*** | 0.88*** | 0.73** | 0.91*** |
| PBW | 0.42* | 0.52 ns | 0.57 ns | 0.55ns | 0.36ns | 0.23 ns | 0.59* | 0.58* | 0.59* | 0.62* |
| NG | 0.87*** | 0.87*** | 0.95*** | 0.88*** | 0.57 ns | 0.77** | 0.93*** | 0.95*** | 0.72** | 0.95*** |
| SC | 0.55** | 0.38ns | 0.46ns | 0.42 ns | 0.43 ns | 0.27ns | 0.46 ns | 0.50 ns | 0.40 ns | 0.56ns |
| SL | 0.23 ns | 0.06 ns | 0.09ns | 0.05ns | 0.17 ns | 0.22ns | 0.04 ns | 0.17 ns | -0.14 ns | 0.19 ns |
| Crossbred Boer goat | | | | | | | | | | |
| WH | 0.78*** | 0.69* | 0.68* | 0.67* | 0.60* | 0.62* | 0.77** | 0.59* | 0.61* | 0.76** |
| HG | 0.94*** | 0.94*** | 0.96*** | 0.92*** | 0.88*** | 0.91*** | 0.92*** | 0.92*** | 0.93*** | 0.94*** |
| BL | 0.91*** | 0.94*** | 0.95*** | 0.95*** | 0.81** | 0.95*** | 0.93*** | 0.94*** | 0.91*** | 0.92*** |
| PG | 0.89*** | 0.92*** | 0.94*** | 0.89*** | 0.92*** | 0.88*** | 0.91*** | 0.89*** | 0.86*** | 0.93*** |
| RH | 0.65*** | 0.58* | 0.57 ns | 0.57 ns | 0.47 ns | 0.56 ns | 0.60* | 0.50 ns | 0.54ns | 0.64* |
| HW | 0.89*** | 0.89*** | 0.88*** | 0.91*** | 0.66*** | 0.87*** | 0.79** | 0.92*** | 0.89*** | 0.85*** |
| PBW | 0.87*** | 0.85*** | 0.87*** | 0.84*** | 0.78** | 0.86*** | 0.81** | 0.82*** | 0.81** | 0.87*** |
| NG | 0.88*** | 0.91*** | 0.93*** | 0.88*** | 0.87*** | 0.86*** | 0.91*** | 0.88*** | 0.88*** | 0.92*** |
| SC | 0.46* | 0.75** | 0.74** | 0.73** | 0.65* | 0.71* | 0.77** | 0.69* | 0.75** | 0.72** |
| SL | 0.45* | 0.71*** | 0.65* | 0.73** | 0.26 ns | 0.72** | 0.66* | 0.63* | 0.65* | 0.68* |

Ns =Not significant; ***= p<0.001; ** = p<0.01; * = p<0.05; ZM=Zoometric measurements; BW= Body weight; SBW= slaughter weight; HC=Hot carcass weight; DP=Dressing percentage; TC= Thin cut; FSN= Fore leg + shoulder+ neck; WH=Wither height; HG=Heart girth; BL=Body length; PG=Paunch girth; RH=Rump height; HW=Hip width; PBW=Pin bone width; NG=Neck girth; SC=Scrotum circumference; SL=Scrotum length

Table 3. Phenotypic correlations among morphological traits of Central Highland goats

| | WH | HG | BL | PG | RH | HW | PBW | NG | SC | SL |
|-----|---------|---------|---------|---------|---------|---------|--------|--------|--------|------|
| WH | 1.00 | | | | | | | | | |
| HG | 0.89*** | 1.00 | | | | | | | | |
| BL | 0.78*** | 0.83*** | 1.00 | | | | | | | |
| PG | 0.82*** | 0.63** | 0.62** | 1.00 | | | | | | |
| RH | 0.83*** | 0.71*** | 0.64** | 0.83*** | 1.00 | | | | | |
| HW | 0.75*** | 0.85*** | 0.71*** | 0.59* | 0.74*** | 1.00 | | | | |
| PBW | 0.28ns | 0.32ns | 0.42* | 0.25ns | 0.31ns | 0.50* | 1.00 | | | |
| NG | 0.68*** | 0.85*** | 0.85*** | 0.40ns | 0.38ns | 0.70*** | 0.33ns | 1.00 | | |
| SC | 0.46* | 0.47* | 0.50* | 0.28ns | 0.29ns | 0.46* | 0.21ns | 0.57* | 1.00 | |
| SL | 0.34ns | 0.38ns | 0.26ns | 0.19ns | 0.25ns | 0.28ns | 0.22ns | 0.37ns | 0.36ns | 1.00 |

Ns =Not significant; *** = p<0.001; ** = p<0.01; * = p<0.05; WH=Wither height; HG=Heart girth; BL=Body length; PG=Paunch girth; RH=Rump height; HW=Hip width; PBW=Pin bone width; NG=Neck girth; SC=Scrotum circumference; SL=Scrotum length

Table 4. Phenotypic correlations among morphological traits of crossbred Boer goat

| | WH | HG | BL | PG | RH | HW | PBW | NG | SC | SL |
|-----|---------|---------|---------|---------|--------|---------|---------|--------|-------|------|
| WH | 1.00 | | | | | | | | | |
| HG | 0.77*** | 1.00 | | | | | | | | |
| BL | 0.85*** | 0.87*** | 1.00 | | | | | | | |
| PG | 0.78*** | 0.88*** | 0.85*** | 1.00 | | | | | | |
| RH | 0.83*** | 0.61** | 0.74*** | 0.67*** | 1.00 | | | | | |
| HW | 0.65** | 0.82*** | 0.81*** | 0.81*** | 0.49* | 1.00 | | | | |
| PBW | 0.67*** | 0.86*** | 0.71*** | 0.74*** | 0.58** | 0.73*** | 1.00 | | | |
| NG | 0.68*** | 0.92*** | 0.75*** | 0.76*** | 0.53** | 0.72*** | 0.86*** | 1.00 | | |
| SC | 0.36ns | 0.51* | 0.42* | 0.46* | 0.22ns | 0.43* | 0.37ns | 0.49* | 1.00 | |
| SL | 0.34ns | 0.34ns | 0.41* | 0.41* | 0.13ns | 0.52** | 0.32ns | 0.25ns | 0.44* | 1.00 |

Ns =Not significant; *** = p<0.001; ** = p<0.01; * = p<0.05; WH=Wither height; HG=Heart girth; BL=Body length; PG=Paunch girth; RH=Rump height; HW=Hip width; PBW=Pin bone width; NG=Neck girth; SC=Scrotum circumference; SL=Scrotum length.

Table 5. Eigenvalues, total variance, factor and factor loadings after varimax rotation with Kaiser Normalization in Central Highland and their cross with the Boer goat

| Traits | Trait | | | Crossbred Boer goat | | |
|------------------------------|-------|-------|---------------|---------------------|-------|---------------|
| | PC1 | PC2 | Communalities | PC1 | PC2 | Communalities |
| HG | 0.96 | - | 0.95 | 0.91 | - | 0.97 |
| WH | 0.95 | - | 0.93 | - | 0.83 | 0.84 |
| BL | 0.93 | - | 0.93 | 0.77 | - | 0.89 |
| RH | 0.92 | - | 0.84 | - | 0.93 | 0.89 |
| HW | 0.91 | - | 0.87 | 0.89 | - | 0.82 |
| NG | 0.88 | - | 0.92 | 0.88 | - | 0.91 |
| PG | 0.85 | - | 0.74 | 0.85 | - | 0.94 |
| PBW | 0.51 | - | 0.39 | 0.75 | - | 0.81 |
| SC | - | 0.85 | 0.79 | 0.83 | - | 0.73 |
| SL | - | 0.79 | 0.64 | | 0.47 | 0.41 |
| Eigenvalues | 6.19 | 1.82 | | 5.31 | 2.91 | |
| Percentage of total variance | 61.94 | 18.22 | | 53.17 | 29.08 | |
| Cumulative % | 61.94 | 80.17 | | 53.17 | 82.25 | |

WH=Wither height; HG=Heart girth; BL=Body length; PG=Paunch girth; RH=Rump height; HW=Hip width; PBW=Pin bone width; NG=Neck girth; SC=Scrotum circumference; SL=Scrotum length

Table 6. Prediction equations for body weight (kg) and carcass traits (kg) from original and orthogonal morphological traits of Central Highland goat

| Traits | Prediction equation | SE | R ² | p-value |
|---|--|------|----------------|---------|
| Original morphological traits as independent variables | | | | |
| BW | $BW = -23.2 + 1.25 NG$ | 6.07 | 0.86 | <.0001 |
| SBW | $SBW = -29.2 + 0.88 BL$ | 6.11 | 0.87 | <.0001 |
| HC | $HC = -25.6 + 0.55 HG$ | 3.09 | 0.93 | <.0001 |
| | $HC = -22.7 + 0.31 HG + 0.22 BL$ | 2.31 | 0.97 | <.0001 |
| EBW | $EBW = -29.0 + 0.86 BL$ | 4.74 | 0.92 | <.0001 |
| Thin cut | $Thin\ cut = -2.23 + 0.04 WH$ | 0.55 | 0.71 | 0.0006 |
| FSN | $FSN = -10.1 + 0.21 HG$ | 1.38 | 0.91 | <.0001 |
| Rib | $Rib = -2.47 + 0.12 NG$ | 0.49 | 0.89 | <.0001 |
| | $Rib = 0.24 + 0.15 NG - 0.05 PG$ | 1.18 | 0.94 | <.0001 |
| | $Rib = 2.35 + 0.18 NG - 0.09 PG - 0.05 SC$ | 1.01 | 0.97 | <.0001 |
| Loin | $Loin = -1.52 + 0.04 BL$ | 0.38 | 0.78 | <.0001 |

Table 6. Prediction equations for body weight (kg) and carcass traits (kg) from original and orthogonal morphological traits of Central Highland goat (ታላቅ)

| Traits | Prediction equation | SE | R ² | p-value |
|---|-----------------------------------|------|----------------|---------|
| Leg | Leg = -3.95 + 0.13 BL | 0.66 | 0.92 | <.0001 |
| | Leg = -3.51 + 0.07 BL+ 0.07 NG | 0.47 | 0.97 | <.0001 |
| Orthogonal morphological traits as independent variables | | | | |
| BW | BW = 24.55 + 3.55 PC1 | 2.59 | 0.67 | 0.001 |
| SBW | SBW = 22.5 + 3.28 PC1 | 1.49 | 0.84 | <.0001 |
| HC | HC = 10.75 + 1.72 PC1 | 0.57 | 0.91 | <.0001 |
| | HC = 10.75 + 1.72 PC1 + 0.43 PC2 | 0.37 | 0.96 | 0.004 |
| EBW | EBW = 20.94 + 3.16 PC1 | 1.23 | 0.88 | <.0001 |
| Thin cut | Thin cut = 0.503 + 0.101 PC1 | 0.09 | 0.57 | 0.004 |
| FSN | FSN = 3.962 + 0.66 PC1 | 0.25 | 0.88 | <.0001 |
| | FSN = 3.962 + 0.66 PC1 + 0.16 PC2 | 0.20 | 0.93 | <.0001 |
| Rib | Rib = 2.175 + 0.34 PC1 | 0.24 | 0.67 | 0.001 |
| | Rib = 2.175+0.34 PC1+0.15 PC2 | 0.19 | 0.81 | 0.001 |
| Loin | Loin = 0.767 + 0.14 PC1 | 0.09 | 0.68 | 0.001 |
| Leg | Leg = 3.50 + 0.46 PC1 | 0.21 | 0.84 | <.0001 |
| | Leg = 3.50 + 0.46 PC1 + 0.18 PC2 | 0.09 | 0.97 | <.0001 |

BW= Body weight; SBW= slaughter weight; HC=Hot carcass weight; DP=Dressing percentage; TC= Thin cut; FSN= Fore leg + shoulder+ neck; WH=Wither height; HG=Heart girth; BL=Body length; PG=Paunch girth; NG=Neck girth; SC=Scrotum circumference.

Table 7. Prediction equations for body weight (kg) and carcass traits (kg) from morphological traits and Orthogonal traits of crossbred Boer goat

| Traits | Prediction equation | SE | R ² | p-value |
|---|--|------|----------------|---------|
| Original morphological traits as independent variables | | | | |
| BW | BW = -72.8 + 1.75 BL | 11.5 | 0.88 | <.0001 |
| | BW = -72.5 + 0.92 BL+ 0.69 HG | 9.06 | 0.94 | <.0001 |
| | BW = -66.3 + 0.53 BL+ 0.81 HG + 0.82 SL | 7.70 | 0.96 | <.0001 |
| SBW | SBW = -54.7 + 1.19 HG | 9.24 | 0.88 | <.0001 |
| | SBW = -53.0 + 0.99 HG + 1.18 SL | 4.29 | 0.98 | <.0001 |
| EBW | EBW= -67.4 + 1.58 BL | 9.93 | 0.89 | <.0001 |
| | EBW= -50.4 + 1.04 BL + 0.90 HW | 9.55 | 0.95 | <.0001 |
| HC | EBW = -35.5 + 0.71 HG | 4.46 | 0.92 | <.0001 |
| | EBW = -34.6 + 0.62 HG + 0.52 SL | 3.05 | 0.97 | <.0001 |
| | EBW = -38.5 + 0.44 HG + 0.36 SL+ 0.29 BL | 2.90 | 0.98 | <.0001 |

Table 7. Prediction equations for body weight (kg) and carcass traits (kg) from morphological traits and Orthogonal traits of crossbred Boer goat (♂)

| Traits | Prediction equation | SE | R ² | p-value |
|---|--|------|----------------|---------|
| DP(SBW) | DP(SBW) = 16.6 + 0.46 PG | 4.59 | 0.84 | <.0001 |
| | DP(SBW) = 15.1 + 0.54 PG - 0.46 SL | 3.78 | 0.90 | <.0001 |
| Thin cut | Thin cut = -3.29 + 0.07 BL | 0.39 | 0.91 | <.0001 |
| FSN | FSN = -15.3 + 0.34 BL | 2.56 | 0.86 | <.0001 |
| | FSN = -12.6 + 0.21 BL+ 0.12 NG | 2.38 | 0.92 | <.0001 |
| Rib | Rib = -8.69 + 0.19 BL | 1.30 | 0.88 | <.0001 |
| | Rib = -6.30 + 0.12 BL+ 0.13 HW | 1.15 | 0.95 | <.0001 |
| Loin | Loin = -2.81 + 0.05 HG | 0.49 | 0.86 | <.0001 |
| | Loin = -2.75 + 0.04 HG + 0.04 SL | 0.39 | 0.92 | <.0001 |
| Leg | Leg = -10.4 + 0.21 HG | 1.67 | 0.88 | <.0001 |
| | Leg = -10.1+ 0.81 HG + 0.18 SL | 1.16 | 0.95 | <.0001 |
| | Leg = -11.7 + 0.16 HG + 0.16 SL+ 0.04 RH | 1.07 | 0.97 | <.0001 |
| Orthogonal morphological traits as independent variables | | | | |
| BW | BW= 30.6 + 5.0 PC1 | 3.37 | 0.71 | 0.001 |
| | BW = 30.6 + 5.0 PC 1+ 2.99 PC2 | 1.27 | 0.96 | <.0001 |
| SBW | SBW = 28.25 + 4.58 PC1 | 2.97 | 0.72 | <.0001 |
| | SBW = 28.25 + 4.58 PC1 + 2.59 PC2 | 1.26 | 0.95 | <.0001 |
| EBW | EBW = 26.02 + 4.48 PC1 | 3.04 | 0.71 | 0.001 |
| | EBW=26.02+4.48 PC1+2.53PC2 | 1.56 | 0.93 | <.0001 |
| HC | HC = 14.0 + 2.72 PC1 | 1.67 | 0.74 | <.0001 |
| | HC = 14.0 + 2.72 PC1+1.48 PC2 | 0.67 | 0.96 | <.0001 |
| DP(SBW) | DP(SBW) = 49.2 + 1.87 PC1 | 1.63 | 0.59 | 0.003 |
| Thin cut | Thin cut = 0.78 + 0.19 PC1 | 0.13 | 0.69 | 0.001 |
| | Thin cut = 0.78 + 0.19 PC1 + 0.11 PC2 | 0.08 | 0.90 | 0.002 |
| FSN | FSN = 5.16 + 0.95 PC1 | 0.75 | 0.63 | 0.002 |
| | FSN =5.16 +0.95 PC1 + 0.64 PC2 | 0.37 | 0.92 | <.0001 |
| Rib | Rib = 2.77 + 0.57 PC1 | 0.34 | 0.75 | <.0001 |
| | Rib = 2.77 + 0.57 PC1 + 0.25 PC2 | 0.23 | 0.89 | <.0001 |
| Loin | Loin = 1.01+0.22 PC1 | 0.13 | 0.73 | <.0001 |
| | Loin = 1.01 + 0.22 PC1 + 0.10 PC2 | 0.09 | 0.89 | <.0001 |
| Leg | Leg = 4.30+0.77 PC1 | 0.59 | 0.64 | <.0001 |
| | Leg = 4.30+ 0.77 PC1 + 0.53 PC2 | 0.21 | 0.96 | <.0001 |

BW= Body weight, SBW= slaughter weight, HC=Hot carcass weight, DP=Dressing percentage, TC= Thin cut, FSN= Fore leg + shoulder+ neck. HG=Heart girth, BL=Body length, PG=Paunch girth, RH=Rump height, HW=Hip width, NG=Neck girth, SL=Scrotum length.

morphological traits used to predict body weight, carcass traits, and carcass primal cuts of Central Highland goat, whereas HG, BL, HW, and SL were the most important ($R^2 = 0.84$) predictor for crossbred Boer goat. This study demonstrated that the variation explained by interdependent explanatory variables ($R^2 = 0.71$ to 0.98) were higher than the use of orthogonal traits ($R^2 = 0.57$ to 0.97) for body weight, carcass trait, and carcass primal cut prediction. However, the use of interdependent explanatory variables should be treated with caution since multi-collinearity has been shown to be associated with unstable estimates of regression coefficients (Malau-Aduli et al., 2004; Ogah 2011). Moreover, Oga (2011) noted that prediction of carcass components based on single linear body measurements is unreliable. Thus, The use of principal component score (orthogonal traits) gave a better and reliable assessment of body weight and carcass traits since it was able to break multicollinearity (Yakubu et al., 2009; Yakubu et al., 2012), a problem associated with the use of interdependent original body dimensions.

Conclusions

Crossbred Boer goats exhibited higher body weight, carcass traits, and carcass primal cuts than pure Central Highland goat except for dressing percentage. Likewise, morphological traits such as heart girth, punch girth, hip width, and neck girth for crossbred Boer goat were higher than for pure Central Highland goats. Moderate to high and positive correlations of morphological traits with body weight, carcass traits, and carcass primal cuts suggested the suitability of morphological traits as criteria for early selection of bucks for their body weight and carcass traits without slaughtering. The

prediction of body weight and carcass traits based on principal component factor scores is more reliable than the use of individual morphological traits because the uses of factor scores in multiple regression models get rid of the problem of the interdependency of explanatory variables, thereby improve the accuracy of the interpretation of the prediction results. The information obtained in the present study will be useful to support genetic improvement, marketing, feeding, and veterinary service.

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