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Full Length Research

Mapping the variation and correlation of body dimensions of Ettawa grade goats in Umejero Village, Buleleng Regency, Bali

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ABSTRACT: Morphometric traits are widely used as practical indicators for evaluating growth performance and selecting superior animals in smallholder goat production systems. This study aimed to evaluate morphometric characteristics, analyse correlations among body measurement parameters, and map the diversity of Ettawa Grade (PE) goats as a basis for breeding selection. The study was conducted in Umejero Village, Busungbiu District, Buleleng Regency, Bali, involving 81 adult PE goats, consisting of 37 females and 44 males. Twelve body morphometric variables were measured using a saturated sampling approach. Data were analysed descriptively using error bars with 95% confidence intervals and multivariate analysis using Principal Component Analysis (PCA) with biplot visualisation (SPSS v.28). The results showed no significant differences ($p>0.05$) in all morphometric traits between male and female goats. Variability analysis indicated that front cannon bone circumference was the most uniform trait (46.32%), while hip height showed the highest variability (83.57%), suggesting greater potential for selection. Most morphometric traits were positively correlated and exhibited proportional growth patterns, particularly between chest depth and withers height. Biplot mapping identified individuals in Quadrant I as potential breeding stock due to their above-average body dimensions, whereas goats in Quadrant III were categorised as animals with relatively low morphometric performance. These findings demonstrate that multivariate morphometric analysis is an effective tool for identifying superior individuals and supporting breeding strategies in smallholder PE goat production systems.

Keywords: Ettawa Grade goat, morphometric traits, principal component analysis, biplot, breeding selection.

INTRODUCTION

The livestock sector plays a strategic role in supplying high-quality animal protein, enhancing food security, and supporting rural economic development through employment opportunities and increased household income for farmers. The development of small ruminant farming, particularly goat production, represents an effective strategy for promoting sustainable livestock development due to goats' high adaptability to tropical environments, efficient utilisation of forage and agricultural by-products as feed resources, and relatively low investment requirements compared to large ruminants (Devendra and Burns, 1983; Devendra, 2013). In Indonesia, the Ettawa Grade (PE) goat is one of the most important genetic resources, developed through crossbreeding between the Jamnapari (Ettawa) goat from India and the indigenous Kacang goat. This crossbreeding has produced animals characterised by a relatively large body size, rapid growth rate, high adaptability to tropical conditions, and dual-purpose production potential for both meat and milk, making them widely raised by smallholder farmers (Mulyono *et al*., 2018; Sutama, 2008, 2009; Kurniasih *et al*., 2013; Subagyo *et al*., 2025).

The phenotypic performance of Ettawa Grade goats results from the interaction between genetic and environmental factors. Genetic factors determine the animals' inherent growth potential and body size, whereas environmental factors-including feed quality, management practices, age, sex, and health status-substantially influence phenotypic expression (Falconer and Mackay, 1996; Hardjosubroto, 1994). Therefore, morphometric evaluation is considered a vital approach for objectively assessing animal performance. Morphometric traits, including withers height, hip height, body length, heart girth, chest width, chest depth, hip width, head length, ear length, tail length, and fore cannon circumference, are practical phenotypic indicators that can be easily measured under field conditions. These measurements are closely associated with skeletal growth, body development, and overall animal productivity. Numerous studies have demonstrated that these body measurements are positively correlated with live body weight and can therefore be used as reliable predictors of body weight when weighing facilities are unavailable (Yakubu, 2010; Salako, 2006; Adeyinka and Mohammed, 2006). Beyond body weight estimation, the analysis of relationships among body measurements provides valuable information regarding growth patterns and body proportionality. Morphometric traits that exhibit strong correlations reflect biological relationships during growth and may serve as effective criteria for selecting superior breeding animals (Yakubu *et al*., 2011).

Multivariate statistical analysis has become one of the most widely applied approaches for evaluating phenotypic diversity because it can simultaneously analyse numerous correlated variables. One of the most commonly used techniques is Principal Component Analysis (PCA), a dimensionality reduction method that transforms correlated variables into a smaller number of principal components while retaining most of the original information contained in the dataset (Jolliffe, 2002). The graphical representation of PCA results using a biplot enables the simultaneous visualisation of relationships among variables and the distribution of individual animals, thereby facilitating the identification of animals with superior morphometric characteristics as well as individuals that deviate from the population (Gabriel, 1971; Sartono *et al*., 2003). Furthermore, a biplot analysis of the diversity and correlations of Ettawa Grade goats in Umejero Village, Busungbiu District, Buleleng Regency, Bali, can illustrate the strength of correlations among morphometric traits through the angles between vectors, quantify the variability of each variable through vector lengths, and reveal similarities among individual animals based on the proximity of observation points. Such information is highly valuable for breeding selection, genetic resource conservation, and the development of phenotype-based breeding strategies (Sartono *et al*., 2003; Rencher, 2002).

Therefore, research on mapping the diversity and correlations of body measurements in Ettawa Grade goats using Principal Component Analysis and biplots is essential. The findings are expected to provide scientific information regarding the principal morphometric traits contributing to body conformation, the relationships among body measurements, and the grouping of animals according to morphometric similarity. This information can serve as a scientific basis for identifying superior breeding stock, selecting animals suitable for fattening programs, and determining individuals that should be removed from the population (culling), thereby supporting breeding programs and improving the productivity of Ettawa Grade goats under smallholder farming systems.

Umejero Village, located in Busungbiu District, Buleleng Regency, Bali, is one of the centres of Ettawa Grade goat production managed under traditional smallholder farming systems. Although the goat population in this area has continued to develop, scientific information regarding morphometric characteristics, relationships among body measurements, and phenotypic diversity remains limited. This lack of information has resulted in breeding stock selection being conducted primarily based on farmers' subjective judgment and experience, potentially limiting genetic improvement within the population.

Research objectives

This study aimed to identify the morphometric characteristics, analyse the correlations among body measurements, and map the diversity of Ettawa Grade goats in Umejero Village. Furthermore, the study intends to provide a scientific basis for breeding stock selection, fattening programs, and culling strategies to support genetic improvement in smallholder Ettawa Grade goat populations. The results are expected to contribute to evidence-based selection decisions by identifying animals suitable for breeding, fattening, or removal from the population, thereby ensuring the sustainable improvement of genetic quality in community-based goat production systems.

METHODOLOGY

The study was conducted in Umejero Village, Busungbiu District, Buleleng Regency, Bali, involving 81 adult PE goats consisting of 37 females and 44 males. Twelve body morphometric variables were measured using a saturated sampling approach.

Data collection

Body dimension data were collected using a total sampling

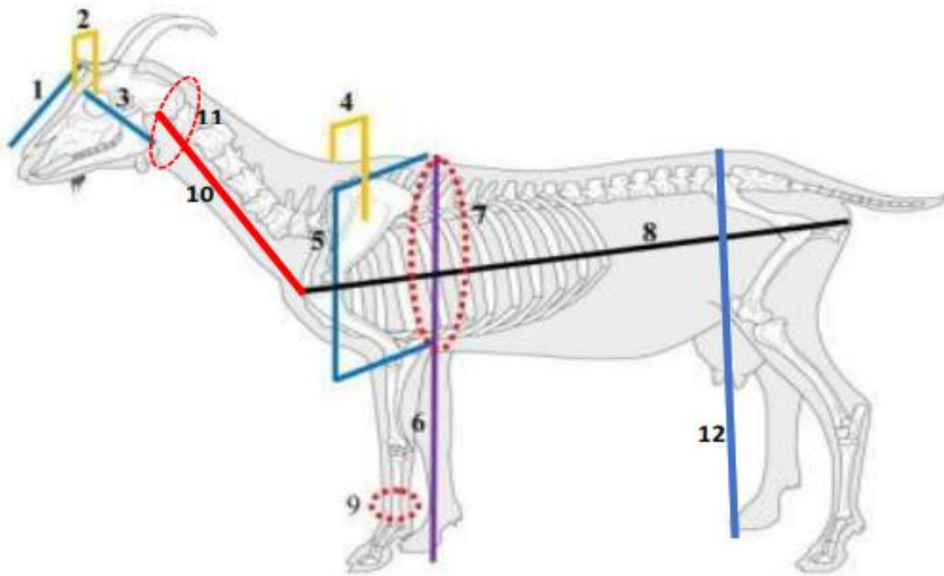

Figure 1. Body dimensions points of Ettawa crossbreed goats.

technique (census), involving the entire population of adult male and female goats managed by farmers at the research location. Subjects met specific inclusion criteria, including physical health, anatomical completeness, and age suitability. Measurements were conducted directly at the farmers' pens. The variables measured consisted of the following body dimensions: head length, head width, head height, chest circumference, chest depth, chest width, neck circumference, neck length, shoulder height, and cannon bone circumference. The measurement scheme of PE goat body dimensions is as shown in Figure 1.

Notes on Figure 1 and measurement procedures

- **Head length:** The distance from the tip of the head to the posterior point of the skull, measured with a measuring stick (cm).
- **Head width:** The distance between the outermost lateral projections of the skull (cm).
- **Head height:** The distance from the dorsal point of the skull to the lowest lateral point of the jaw (cm).
- **Chest width:** The distance between the midpoints of the left and right sternum (cm).
- **Chest depth:** Measured between the highest point of the withers and the sternum, measured behind the elbow (cm).
- **Shoulder height (Withers height):** Measured from the highest point of the withers to the ground along a vertical line (cm).
- **Chest circumference (Heart girth):** Measured by encircling a measuring tape around the chest behind the shoulder blade (*Os scapula*) (cm).
- **Body length:** Measured from the point of the shoulder (*tuberositas humeri*) to the point of the buttock (*tuber ischii*) (cm).
- **Front cannon circumference:** Measured around the midpoint of the front cannon bone (*metacarpus*) (cm).
- **Neck length:** Measured from the *ramus mandibulae* to the vertical line drawn from the *tuberositas lateralis* of the humerus (shoulder joint/*articulatio scapulo-humeri*) (cm).
- **Neck circumference:** Measured by encircling the neck in front of the shoulder joint (*articulatio scapulo-humeralis*), perpendicular to the median plane of the body (cm).
- **Hip height:** Measured by drawing a straight line from the highest region of the hips to the ground (cm).

Data analysis

Data were analysed using descriptive and multivariate statistical methods. Descriptive statistics, including the mean and margin of error, were computed to summarise body size measurements, and the results were presented in tables and error bar graphs to illustrate the variation between male and female groups. To investigate the underlying structure and interrelationships among the body size variables, Principal Component Analysis (PCA) with Varimax rotation was performed. Furthermore, biplot analysis was employed to simultaneously visualise the associations between body size variables and individual specimens, thereby facilitating the interpretation of clustering patterns and the relative contributions of the measured variables. All statistical analyses were conducted using IBM SPSS Statistics version 28, with significance evaluated at the 95% confidence level where applicable.

Table 1. Mean and standard error of body dimensions in Ettawa crossbreed (PE) goats.

Body Dimensions (cm)	Gener			
	Femile		Male	
	Mean	Standard Error of Mean	Mean	Standard Error of Mean
Head length	21.3	0.4	20.7	0.3
Head width	11.5	0.2	11.4	1.2
Head height	16.2	0.2	16.6	0.2
Chest width	11.9	0.2	11.9	0.3
Chest depth	36.5	0.5	37.7	0.6
Shoulder height	80.3	0.9	81.5	1.0
Chest circumference	77.0	1.1	75.6	0.9
Body length	69.2	0.8	68.1	1.0
Front cannon bone circumference	12.3	0.1	12.9	0.2
Neck length	33.5	0.7	30.3	0.8
Neck circumference	33.2	0.5	38.1	0.9
Hip height	89.0	1.0	88.0	1.0

RESULTS AND DISCUSSION

The mean values and standard errors of body measurements of adult Ettawa Grade (PE) goats (n = 81; 37 females and 44 males) raised in Umejero Village, Busungbiu District, Buleleng Regency are presented in Table 1. Based on the comparison between sexes, several body dimensions of females were slightly larger than those of males, including head length, head width, chest circumference, body length, neck length, and hip height. In contrast, males exhibited higher values in head height, chest depth, withers height, front cannon bone circumference, and neck circumference.

These findings indicate that male goats tend to have a more robust and taller body conformation, whereas females tend to have relatively longer bodies and greater body capacity. Such morphological differences are commonly observed in livestock populations and are associated with sex-related growth patterns and hormonal influences on skeletal development.

The differences between male and female body measurements can be further interpreted through the error bar graph and margin of error analysis (Figure 2). The graph illustrates the mean morphometric values with 95% confidence intervals (CI) for each sex. The results show that the confidence intervals of all measured variables overlap between male and female goats. The overlap of the 95% confidence intervals indicates that there are no statistically significant differences ($P>0.05$) between the two sexes for all morphometric parameters.

According to Cumming (2009) and Sampurna and Nindhia (2023), overlapping error bars at the 95% confidence level generally indicate the absence of statistically significant differences. Similarly, Krzywinski and Altman (2013) reported that overlapping error bars suggest that individual variability within groups is greater than the treatment effect. Comparable results were also reported by Khasanah *et al*. (2020) and Mudawamah *et al*. (2021), who found that in certain local Indonesian goat breeds, the body size differences between adult males and females are relatively small compared with exotic breeds that exhibit stronger sexual dimorphism.

The coordinates and vector lengths representing the variability of PE goat body dimensions are presented in Table 2. In multivariate analysis, vector length reflects the degree of variability of each variable. Shorter vectors indicate more homogeneous traits within the population, whereas longer vectors represent greater phenotypic variability.

Based on the principal component analysis, the most uniform trait in the population was front cannon bone circumference (46.32%), followed by body length (49.34%), chest width (54.80%), neck circumference (60.20%), head length (68.99%), withers height (70.56%), chest circumference (72.65%), head height (76.39%), chest depth (78.52%), head width (79.82%), and neck length (82.01%). The highest variability was observed in hip height (83.57%).

The relatively low variation in front cannon bone circumference suggests that this trait reaches physiological maturity earlier than other body parts. This observation is consistent with Khasanah *et al*. (2020) and Ofori *et al*. (2021), who reported that the cannon bone belongs to early-developing skeletal components, resulting in lower variation within adult populations. Conversely, the high variation in hip height indicates considerable phenotypic diversity in skeletal size, which provides opportunities for genetic improvement through selection (Mattjik and Sumertajaya, 2011).

The direction and length of vectors in the biplot (Figure 3) also provide information on correlations among morphometric traits. In biplot interpretation, the angle

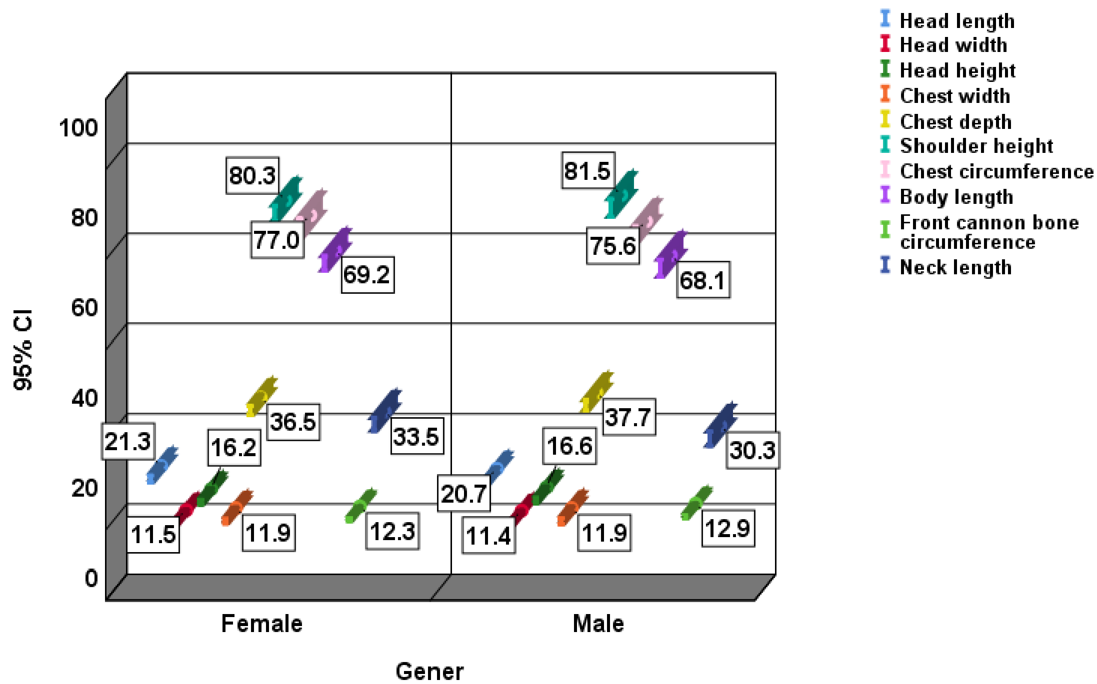

Figure 2. Error-bar graph of mean values and margin of error for PE goat body dimensions.

Table 2. Coordinates and vector length (variation) of body dimensions in Ettawa crossbreed (PE) goats (Rotated Component Matrixa).

Dimensions (cm)	Component		Vector Length (Variation)
	1 (Absis /X)	2 (Ordinat/Y)	
Head length	0.469	0.506	0.6899
Head width	0.231	0.764	0.7982
Head height	0.398	0.652	0.7639
Chest width	0.359	0.414	0.5480
Chest depth	0.770	0.154	0.7852
Shoulder height	0.689	0.152	0.7056
Chest circumference	0.663	0.297	0.7265
Body length	0.423	0.254	0.4934
Front cannon bone circumference	0.455	-0.087	0.4632
Neck length	-0.176	0.801	0.8201
Neck circumference	0.566	0.205	0.6020
Hip height	0.780	0.300	0.8357

between two vectors indicates the relationship between variables: an acute angle (<90°) represents a positive correlation, an obtuse angle (>90°) indicates a negative correlation, and an angle close to 90° indicates little or no correlation.

Most body dimensions formed acute angles, indicating positive correlations and proportional growth patterns among skeletal traits. Strong positive relationships were observed between neck circumference and hip height as well as between chest depth and withers height. This pattern suggests that skeletal growth occurs synchronously, where increases in one dimension tend to be accompanied by increases in others. Similar findings were reported in recent studies (Chaudhary *et al*., 2026; Karna *et al*., 2024; Tyasi *et al*., 2020), which stated that linear body measurements are positively correlated with body weight and can therefore be summarised into a small number of principal components to evaluate growth performance.

Conversely, neck length showed negative correlations

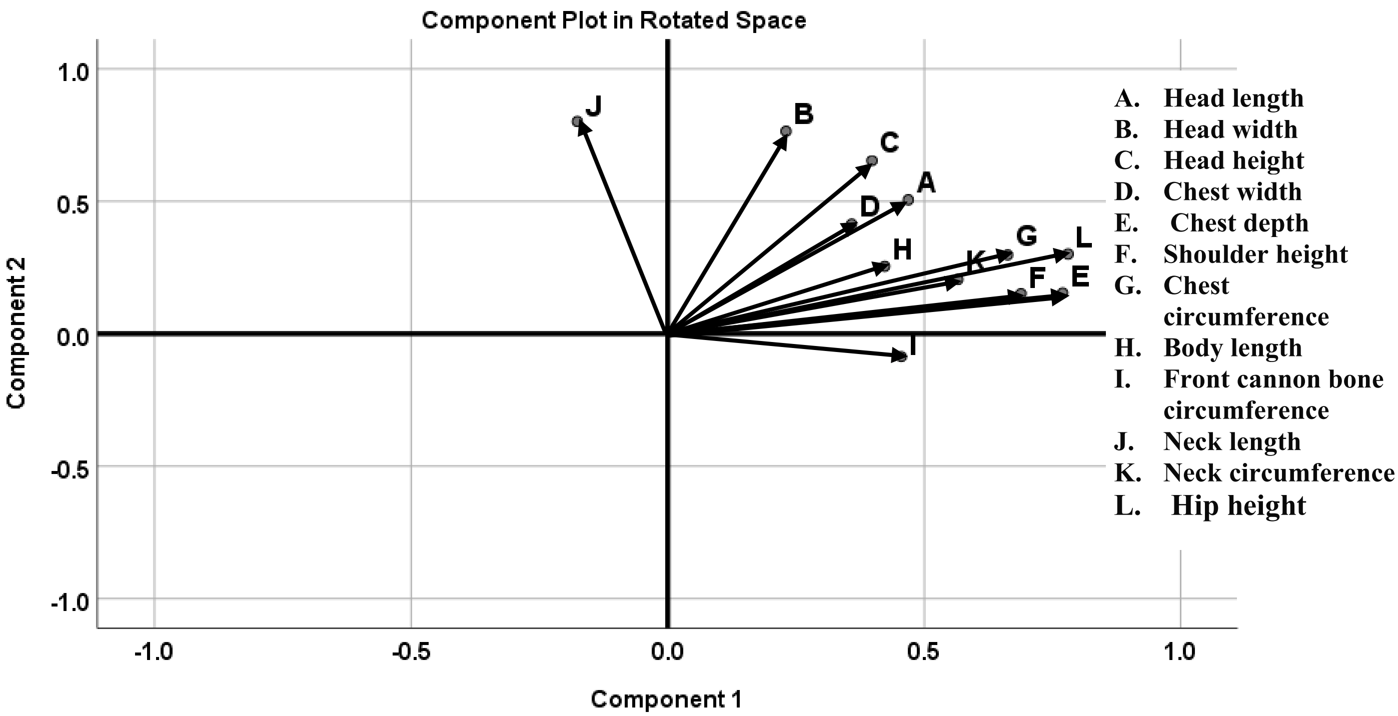

Figure 3. Graph of variance and correlation of PE goat body dimensions.

with front cannon bone circumference, chest depth, and withers height. This indicates that increases in skeletal capacity and body depth may be associated with relatively shorter neck proportions. Such patterns reflect allometric growth, where different body parts grow at different rates depending on their functional importance. This observation aligns with the quantitative genetic theory (Falconer and Mackay, 1996), which states that major skeletal traits often show positive correlations, while secondary body components may exhibit negative relationships.

Based on the observed variability and correlations, hip height can be considered an important indicator trait representing overall skeletal size due to its high variability. Traits showing similar vector directions may represent similar biological information and therefore can be simplified in selection programs. In contrast, traits with perpendicular or opposite vectors should be retained to maintain the biological diversity of morphometric characteristics (Groeneveld, 1994).

The diversity and correlation of body dimensions were further visualised using a biplot graph, which simultaneously displays objects (individual goats) and variables (body measurements) in a two-dimensional space. This method allows visualisation of similarities among individuals, the magnitude of variable variation, and correlations among morphometric traits, as described by Sartono *et al*. (2003) and Jolliffe (2002).

The biplot in Figure 4 shows that the goat population is distributed across four quadrants separated by the diagonal line Y = −X. Individuals located in the direction of a vector and near its tip have body measurements above the population mean, whereas individuals positioned near the origin or in the opposite direction have relatively smaller measurements.

Goats located in Quadrant I represent individuals with body dimensions above the population mean and therefore can be classified as large-frame animals. In contrast, goats located in Quadrant III represent individuals with body measurements below the average. Quadrants II and IV reflect combinations of specific body traits, indicating variations in body proportions among individuals.

The use of principal component analysis (PCA) with Varimax rotation improves the clarity of factor structure by maximising variable loadings within the same factor, thereby facilitating interpretation of body size grouping without altering the total variance in the data (Sampurna *et al*., 2020).

From a practical breeding perspective, goats located in Quadrant I are recommended as potential breeding stock, while individuals in Quadrants II and IV may be more suitable for fattening purposes. Meanwhile, individuals in Quadrant III, which exhibit below-average morphometric performance, may be considered for culling or slaughter purposes. Animals with larger skeletal frames, wider chest capacity, and stronger limbs generally have higher growth potential and carcass yield, which is strongly supported by recent predictive morphometric models (Dakhlan *et al*., 2020; Dakhlan *et al*., 2021; Rashijane *et al*., 2021).

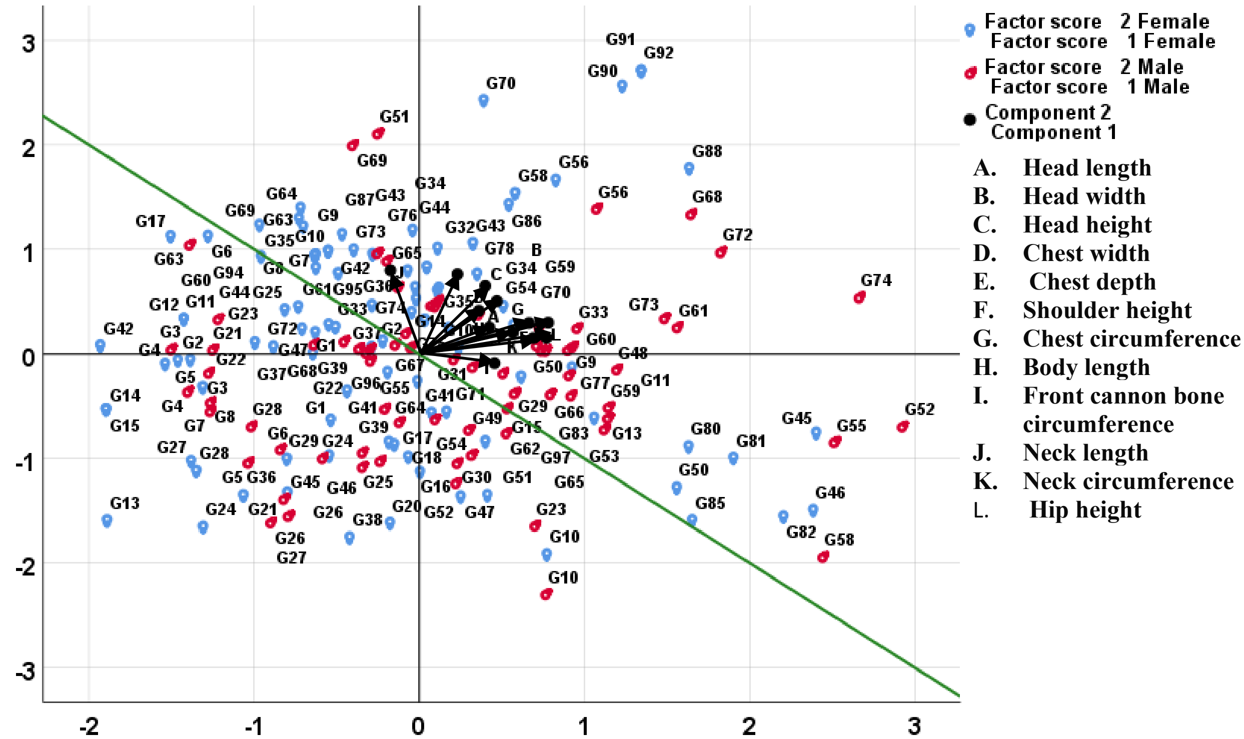

Figure 4. Biplot of variation and correlation mapping for PE goat body dimensions.

Conclusion

1. Statistically, no significant differences (p>0.05) were observed between male and female PE goats; however, males tended to show a more robust body conformation, whereas females tended to have relatively longer bodies.
2. The PE goat population in the study area exhibited varying levels of morphometric diversity. Front cannon bone circumference (46.32%) and body length (49.34%) were the most uniform traits, while hip height (83.57%) and neck length (82.01%) showed the highest variability, indicating greater potential for selection.
3. Most morphometric traits showed positive correlations and proportional growth patterns, except neck length, which exhibited negative correlations with front cannon bone circumference, chest depth, and withers height.
4. The biplot analysis effectively identified superior individuals in Quadrant I (above the population mean) as potential breeding stock and identified animals in Quadrant III as individuals with relatively lower performance that may be considered for culling.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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