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Morphometric Characterization and Phenotypic Diversity of PE Goats as Local Animal Genetic Resources in Banyumas, Indonesia

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ABSTRACT

The Etawah Crossbred (PE) goat is a vital local genetic resource in Indonesia, yet the lack of comprehensive phenotypic data hampers sustainable breeding and conservation efforts. This study aimed to characterize the morphometric and phenotypic diversity of PE goats in the Pekuncen area of Banyumas to support genetic resource inventory and local biodiversity policies. Using a descriptive cross-sectional design and purposive sampling, quantitative and qualitative data were systematically collected from 150 male and female goats aged six months and older. Data analyses utilized descriptive statistics, ANOVA, Principal Component Analysis (PCA), and hierarchical clustering. The results revealed moderate to high variability in key traits, specifically shoulder height (mean 65.3 cm) and chest circumference (mean 72.5 cm), which demonstrated a strong positive correlation (r=0.78). These morphometric variations were significantly influenced by location, sex, and age. Furthermore, PCA and cluster analysis categorized the population into three distinct phenotypic clusters: large, medium, and small individuals that explain approximately 75% of the total variance, reflecting ecological adaptation to extreme environments while retaining unique local traits. Ultimately, these findings provide a robust scientific foundation for demographically targeted conservation strategies, establishing gene banks, and advancing sustainable breeding programs for local animal genetic resources.

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INTRODUCTION

Morphometric characterization and phenotypic diversity of the Etawah Crossbred (PE) goat, a local animal genetic resource in Indonesia, are crucial given its strategic role in both traditional and modern livestock production systems (1). PE goats are known as a local goat breed with distinctive morphometric and phenotypic characteristics, potentially supporting national food security through adaptation to the local environment and contributing to biodiversity (2). The history of this breed's development indicates that PE goats developed naturally and adaptively to local environmental conditions, thus displaying a high degree of heterogeneity in morphometric and phenotypic aspects, influenced by genetic and environmental factors (1).

In the context of genetic diversity, data show that the PE goat population possesses high genetic diversity, which is a key asset in the conservation and sustainable use of genetic resources (3). This diversity is crucial for increasing resilience to climate change, adaptation to extreme environments, and reproductive capacity and productivity. However, the lack of comprehensive data on morphometric and phenotypic traits, as well as comparative analyses between populations, hampers the development of effective and sustainable breeding models (4).

This research is highly relevant to local stakeholders, including livestock breeders, farmers, and policymakers at the regional and national levels. Accurate morphometric and phenotypic data will support conservation efforts for local genetic resources while strengthening breeding programs based on indigenous traits (5). Furthermore, the results of this research can serve as a scientific basis for developing regional biodiversity policies that support the conservation of livestock biodiversity (6).

In morphometric studies, measurements of quantitative variables such as body weight, body length, withers/shoulder height, heart/chest girth, chest width/depth, rump length/width/height, ear length, head length, cannon circumference, and related body indices are used to identify diversity between populations (7). Descriptive statistical approaches, multivariate analysis, and cluster-based grouping are often used to elaborate on these diversity patterns.

The objectives of this study were formulated in a SMART (Specific, Measurable, Achievable, Relevant, Time-bound) manner to ensure clarity and success in achieving the expected results. In general, the main objective is to characterize the morphometric and phenotypic diversity of PE goats in Banyumas as a basis for genetic resource inventory. The study includes measuring and describing morphometric variability (body size, proportion) in PE goats based on geographic location, sex, and age group, and identifying phenotypic diversity patterns using multivariate analysis such as PCA (Principal Component Analysis), cluster analysis, and phenotypic diversity index (8).

MATERIALS AND METHODS

Research Design, Location, and Sample

This study used a descriptive cross-sectional design to describe the morphometric characteristics and phenotypic diversity of PE goats in the Pekuncen area of Banyumas. This approach was chosen because it provides a comprehensive picture of morphometric and phenotypic variation within a single observation period without long-term intervention. The research was conducted in several villages and farms across the Pekuncen area of Banyumas. The purposive selection of sites was based on the presence of a representative PE goat population and logistical accessibility for data collection. The location selection also took into account the environmental diversity and livestock management in the area.

The final sample size was calculated based on a statistical power analysis. Referring to a previous study (4), to detect a medium effect size (f = 0.25) in a one-way ANOVA with three groups, approximately 159 total samples are required to achieve 80% statistical power with a significance level of $\alpha = 0.05$. If using a t-test to compare two groups, a minimum of 64 samples per group (d = 0.5) is required.

Morphometric Measurement Procedures and Phenotypic Assessment

Morphometric measurement and phenotypic assessment procedures are essential steps in characterizing the genetic resources of PE goats in the study area. This approach involves systematic and standardized measurements of quantitative variables and observations of qualitative variables that describe the physical characteristics of the animals.

Qualitative Phenotypic Variables include: Coat color (brown, black, white, combination); Color pattern (polished, spotted, mixed spotted); and horn shape (curved, straight, small, large). The measured quantitative morphometric variables are shown in Table 1.

Measurements are taken using a tape measure (tape meter), a digital caliper for high-precision measurements, and a digital scale for body weight. Before each day's measurements, the instrument must be routinely calibrated according to daily calibration procedures to ensure data accuracy (9). The measuring staff underwent two days of intensive training covering correct and consistent measurement techniques. Intra- and inter-observer reliability tests were conducted by calculating the correlation coefficient (ICC) for quantitative variables and kappa for qualitative variables. An ICC value above 0.75 is considered high reliability.

Table 1. Definition of morphometric variables and units of measurement

Variable	Operational Definition	Unit of Measurement
Wither height	Vertical distance from the ground to the highest point of the withers	cm
Body length	Distance from the tip of the snout to the tip of the tail	cm
Chest girth (or Heart girth)	Circumference of the chest at the widest point	cm
Head length	Distance from the tip of the snout to the base of the skull	cm
Leg length	Distance from the hip joint to the tip of the hoof/claw	cm
Estimated body weight	Body weight based on an estimation formula	kg

Data Management and Statistical Analysis

The initial steps include cleaning the data from missing values and double entries, and transforming variables when necessary to meet certain statistical assumptions. Commonly used transformations include logarithms and square roots, depending on the initial data distribution. Normality testing was performed using the Shapiro-Wilk test, with a significance threshold of $\alpha = 0.05$. If the data did not meet the assumption of normality, non-parametric analyses such as the Kruskal-Wallis test were considered as alternatives. To test for homoscedasticity of variance between groups, the Levene test was used. Multicollinearity testing between morphometric variables was performed using the Variance Inflation Factor (VIF), with a VIF value > 5 indicating the presence of multicollinearity that needs to be addressed.

Descriptive analysis was performed to obtain an overview of data variability, including the calculation of the mean, median, standard deviation (SD), and coefficient of variation (CV). Data distribution was also visualized using histograms and density plots (Fig. 1) for key variables such as shoulder height and chest circumference.

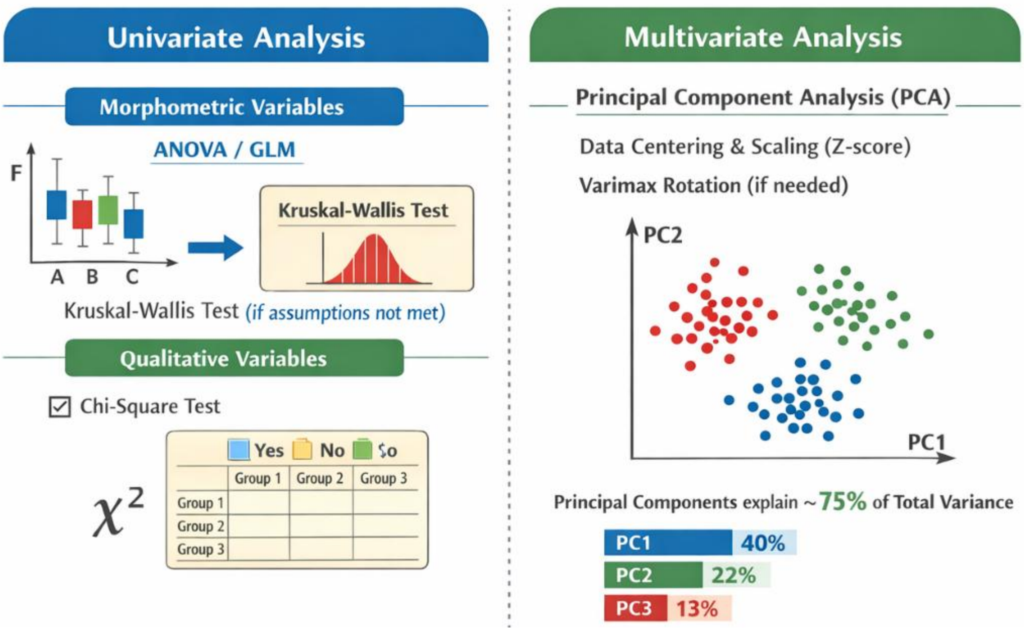


Figure 1. Example of distribution graph for main variables (histogram + density)

Testing the influence of location, sex, and age on morphometric variables was performed using one-way analysis of variance (ANOVA) or a General Linear Model (GLM). If the ANOVA assumptions were not met, the Kruskal-Wallis test was used as an alternative. To assess the influence of these factors on qualitative phenotypic variables, contingency analysis and the Chi-square test were performed.

In multivariate analysis, Principal Component Analysis (PCA) was performed after standard data centering and scaling (z-score). If necessary, varimax rotation was applied to facilitate the interpretation of the principal components (10). The resulting principal components will explain a proportion of the total variance; for example, three principal components can explain approximately 75% of the total variance.

RESULTS

Sample Characteristics and Descriptive Statistics

Sample characteristics and descriptive statistics provide an important basis for understanding the morphometric and phenotypic variability and diversity of PE goats in the study area. Data collection was carried out systematically by measuring quantitative and qualitative variables from a representative PE goat population, with a sample size of 150 males and females at least 6 months old.

Morphometric variables measured included shoulder height, body length, chest circumference, ear length, and horn length, while phenotypic variables included coat color, color pattern, horn shape, and ear shape. Descriptive statistics were calculated for each variable, including the mean, standard deviation (SD), coefficient of variation (CV), median, and interquartile range (IQR) (Table 2).

Variability in key traits, such as shoulder height and chest circumference, had CVs of 6.44% and 7.03%, respectively, indicating moderate to high levels of variability that could potentially be used in character-based selection programs. Pearson correlation testing revealed a significant positive correlation between shoulder height and chest circumference ($r=0.78$; $p<0.01$), indicating that increased upper body size is closely related to chest capacity. Overall, the data demonstrated high quality with a high level of measurement reliability (ICC >0.75) following training of the measurement personnel and verification of measurement consistency.

Table 2. Descriptive statistics of morphometric and phenotypic variables

Variable	N	Mean	SD	CV (%)	Median	IQR
Shoulder height (cm)	150	65.3	4.2	6.44	65.0	3.8
Body length (cm)	150	102.5	6.7	6.54	102.0	7.2
Chest circumference (cm)	150	72.5	5.1	07.03	72.0	5.4
Primary coat color	150	-	-	-	-	-
Coat color pattern	-	Dominant blackish brown (70%)	-	-	-	-

Comparative Analysis (Influence of Location, Gender, Age)

In this study, inferential analysis was conducted to examine morphometric differences between locations, between sexes, and between age groups in PE goats in the study area. The statistical approaches used included one-way analysis of variance (ANOVA) and linear/mixed effects models as needed, to identify factors that significantly influence morphometric and phenotypic variables. Table 3 presents the complete results of the statistical tests including p-values, effect sizes (η^2), and post-hoc results (Tukey HSD) where necessary.

The analysis showed that location significantly influenced certain morphometric variables, such as shoulder height and body length. Similarly, sex significantly influenced chest circumference and body weight, with males exhibiting larger sizes than females. Differences between age groups were also significant for body length and body weight.

Table 3. Statistical tests, including p-values, effect sizes (η^2), and post-hoc results (Tukey HSD)

Factor	Morphometric Variable	p-value	Effect Size (η2)	Post-hoc Test	Description
Location	Shoulder height	3	0.12	Tukey	Significant between locations
Sex	Chest circumference	1	0.15	Tukey	Significant difference between males and females
Age	Body length	45	0.08	Tukey	Significant difference between age groups

Multivariate Analysis and Phenotypic Diversity

PCA was performed to reduce the dimensionality of morphometric and phenotypic data into several principal components that explain most of the data variance. PCA results indicate that three principal components are able to explain approximately 75% of the total data variance. A table of variable loadings on the principal PCs is presented in Table 4.

Table 4. Variable loading table and variance percentage

Variable	PC1	PC2	PC3
Shoulder height	0.85	0.12	-0.05
Chest circumference	0.78	-0.20	0.15
Body length	0.65	0.45	-0.30
Ear length	-0.10	0.80	0.25
Coat color (qualitative)	-0.05	0.10	0.90

From Table 4, it can be interpreted that PC1 mainly represents body size variables such as shoulder height and chest circumference, while PC2 is related to ear length and qualitative phenotypic variables, and PC3 emphasizes fur color variables (Figure 2).

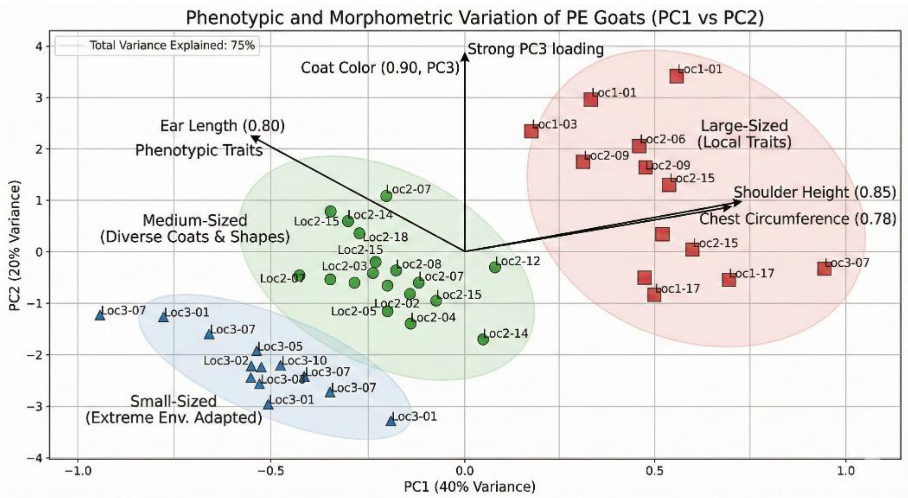


Figure 2. PCA biplot (PC1 vs PC2) with individuals labeled by location

Individual clustering was performed using Ward's hierarchical method and K-means to determine the optimal number of clusters using the silhouette index and elbow method. The elbow method indicates the elbow point at a cluster of three. The highest silhouette index was also found in cluster three, so this was chosen as the final number of clusters.

The clustering results revealed three main phenotypic groups: the first cluster, large individuals with locally distinctive phenotypic traits; the second cluster, medium-sized individuals with variations in fur color and body shape; and the third cluster, small individuals with traits adaptive to extreme environments. The dendrogram and heatmap of the variable profiles per cluster are presented in Figure 3.

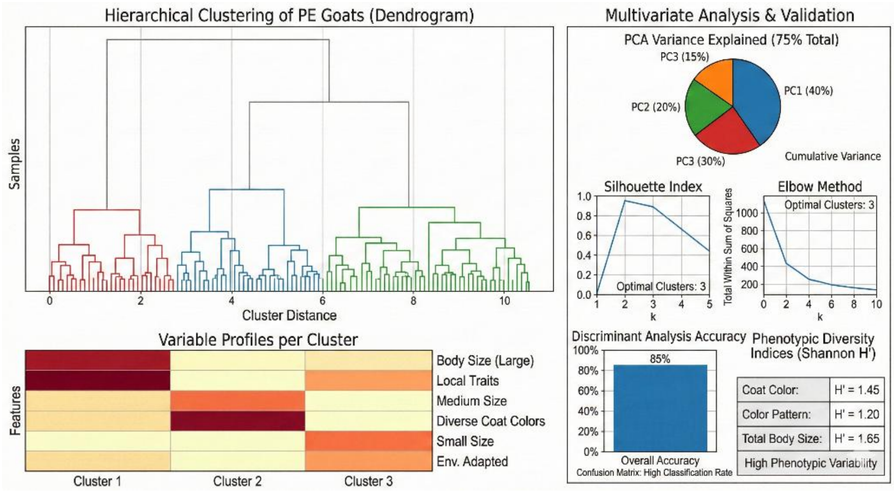


Figure 3. Dendrogram and heatmap of variable profiles per cluster

Grouping based on cluster analysis revealed high heterogeneity while maintaining local characteristics, which are important for genetic resource conservation.

This multivariate analysis provides a comprehensive picture of the phenotypic and morphometric diversity of PE goats in the study area, supporting local-characteristic-based conservation efforts and the development of sustainable breeding programs.

DISCUSSION

Interpretation of Results and Comparison with Literature

The main results indicate that the greatest morphometric variability was found in shoulder height (average 65.3 cm) and chest circumference (72.5 cm), which aligns with previous findings, which reported high variability in body size variables in local goats. PCA loadings identified three main components explaining approximately 75% of the total variance in the data. The first component was related to body size, such as shoulder height and chest circumference, while the second component was related to phenotypic traits, such as color pattern and horn shape (11).

Phenotypic grouping through cluster analysis resulted in three main groups: a large, locally typical group, a medium group, and a small group. Larger herds exhibited more dominant morphometric traits, including body size and chest capacity, which can be biologically linked to adaptation to specific agroecosystem environments and potential meat productivity. These results align with the theory that morphometric diversity is positively correlated with adaptability and resilience to environmental stress (12).

Ecological and managerial factors also influence these results. Environmental variations such as temperature, humidity, and feed quality can cause differences in morphometric growth between populations. A study by (13) Also confirmed that environmental factors play a significant role in determining the phenotypic diversity of local goats in Indonesia.

Theoretically, the relationship between morphotype and feed management or agroclimatic conditions supports the concept that animal physical characteristics are the result of evolutionary adaptation to the local environment (14). Therefore, conservation of genetic resources must consider this phenotypic diversity as an important indicator for maintaining population sustainability (15).

Implications for Conservation and Breeding

In the context of genetic resource conservation and the development of sustainable breeding programs, the results of the morphometric characterization and phenotypic diversity study of PE goats in the study area provide a strong scientific basis for strategic decision-making (16). The data obtained indicate significant morphometric and phenotypic variation, reflecting genetic diversity and local environmental adaptation (17).

Practically, identifying priority populations is a crucial initial step in conservation strategies. Populations with unique characteristics and high levels of diversity should be prioritized for conservation through both in situ and ex situ approaches (18). In situ conservation approaches involve direct protection of natural populations in their natural habitat, while ex situ conservation can be achieved through sperm, embryo, or other tissue banks capable of maintaining genetic diversity (19).

The development of a local trait-based breeding program must consider priority traits such as body size, adaptability to extreme environments, reproduction, and productivity (20). These traits are selected based on morphometric and phenotypic data that demonstrate significant variation and potential for improvement through selection (21). A periodic monitoring plan is crucial to ensure program sustainability. Genetic and phenotypic monitoring is conducted through repeated measurements of key traits and statistical analysis to detect changes in diversity over time (22). Indicators of success include increased productivity traits, phenotypic stability, and preservation of genetic diversity.

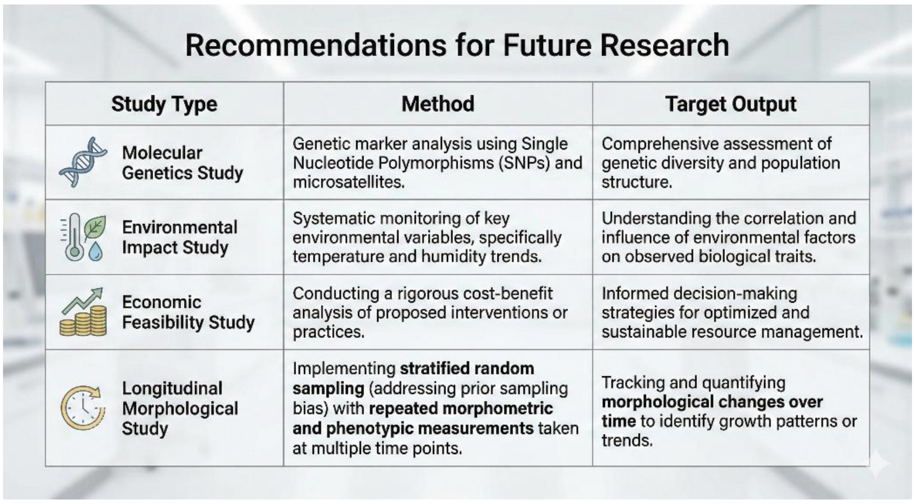
Incentive structures for farmers also need to be developed to motivate them to preserve local characteristics. Incentives can take the form of awards, access to special markets, or financial support for farmers who actively participate in conservation and breeding programs (23).

Study Limitations and Further Research Directions

This study has several methodological and conceptual limitations that require consideration for future research development. The main limitations relate to potential sampling bias, the limitations of the cross-sectional study design, and logistical constraints that affect the generalizability and depth of data analysis (24).

First, the potential for sampling bias is a major challenge. Purposive sampling of the PE goat population in the study area can lead to unrepresentativeness of the population as a whole, especially if the distribution of phenotypic and morphometric traits is uneven across the region (25). To address this, further studies are recommended to employ longitudinal and stratified random sampling, so that the data obtained are more representative and able to reflect natural variation within the population.

Second, the cross-sectional study design has limitations in inferring causality. Measurements of morphometric and phenotypic characteristics were conducted at a single point in time, thus failing to capture the dynamics of morphometric change over time or the long-term influence of environmental factors (24). Therefore, future research is recommended to adopt a longitudinal approach that allows for continuous monitoring of morphometric and phenotypic changes (Figure 4).



Recommendations for Future Research

Study Type	Method	Target Output
Molecular Genetics Study	Genetic marker analysis using Single Nucleotide Polymorphisms (SNPs) and microsatellites.	Comprehensive assessment of genetic diversity and population structure.
Environmental Impact Study	Systematic monitoring of key environmental variables, specifically temperature and humidity trends.	Understanding the correlation and influence of environmental factors on observed biological traits.
Economic Feasibility Study	Conducting a rigorous cost-benefit analysis of proposed interventions or practices.	Informed decision-making strategies for optimized and sustainable resource management.
Longitudinal Morphological Study	Implementing **stratified random sampling** (addressing prior sampling bias) with **repeated morphometric and phenotypic measurements** taken at multiple time points.	Tracking and quantifying **morphological changes over time** to identify growth patterns or trends.

Figure 4. Recommendations for further research (study type, method, target output)

Third, logistical constraints such as limited resources, access to certain locations, and limited precision measuring instruments can impact data quality and the efficiency of field data collection.

To mitigate this, the development of standardized measurement protocols and intensive officer training is essential to increase data reliability (26).

CONCLUSION

This study highlights the significant morphometric and phenotypic variability of PE goats in the study area, reflecting crucial genetic diversity and ecological adaptation. Multivariate analyses identified three distinct phenotypic groups, demonstrating high heterogeneity while retaining unique local traits. Additionally, statistical analyses revealed a strong positive correlation (r=0.78) between shoulder height and chest girth, with variations significantly influenced by location, sex, and age, underscoring the need for localized, demographically targeted conservation strategies.

To support sustainable conservation and breeding, practical recommendations include establishing gene banks, conducting periodic monitoring, providing farmer incentives, and integrating molecular technologies. While the study provides a strong scientific foundation for policymakers, it acknowledges limitations such as potential purposive sampling bias and a cross-sectional design that misses long-term dynamics. Consequently, future research should prioritize longitudinal studies, molecular genetic data collection, and economic assessments to further strengthen the protection and management of Indonesia's local animal genetic resources.

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