



Phenotypic Characterization and Canonical Correlation Analysis at Weaning and Eight Month Period of Indonesian Etawah (PE) Goats

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Abstract | The Indonesian Etawah (PE) goat breed, valued for its dual-purpose meat and milk production and high adaptability, dominates the local goat population in Indonesia and plays a crucial role in supporting smallholder farmers throughout the country. This study aimed to identify early predictors of growth and potential selection criteria for more effective breeding programs. Data were collected from 210 PE goats at weaning and eight months of age. Nine morphometric traits were measured: body weight (BW), body length (BL), withers height (WH), chest girth (CG), chest depth (CD), hip height (HH), ear length (EL), ear width (EW), and mane ruff length (MRL). The methods used in this study included descriptive statistics, Pearson correlation analysis, and canonical correlation analysis (CCA). Results showed significant sexual dimorphism, with males exhibiting larger body sizes BW (27.15 ± 5.39 kg vs. 24.53 ± 3.85 kg in females, $P \leq 0.01$), indicating potential for sex-specific breeding strategies. Strong correlations between BW and CG ($r=0.819$, $P \leq 0.01$) suggest these measurements could serve as reliable proxies for growth potential. The strong CCA (0.839, $P < 0.01$) between traits at weaning and eight months, with significant contributions from BW, CG at weaning, and MRL at eight months to the canonical variables, indicates that early measurements can effectively predict later growth. These findings provide valuable insights for optimizing PE goat breeding strategies, potentially improving production efficiency and economic returns in Indonesian goat farming.

Keywords | Canonical correlation analysis, Indonesian etawah (PE) goats, Morphometric traits, Growth prediction, Sexual dimorphism, Breeding efficiency

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INTRODUCTION

In 2023, Indonesia had a population of 18,560,835 local goats, contributing 50.95% of the total 37,844,420 goats

in Southeast Asia (BPS-Statistics, 2023; FAO, 2023). The Indonesian Etawah goat, commonly known as Peranakan Etawah (PE), a result of crossbreeding local Kacang goats with exotic Etawah goats from India, constituted the ma-

majority of the goat population (Mudawamah *et al.*, 2021; Suyadi *et al.*, 2021). Developed for both milk and meat production (Sodiq and Abidin, 2008), PE goats have been officially recognized and bred in Indonesia for more than eleven years since the Ministerial Decree of Agriculture (No.695/Kpts/PD.410/2/2013). The Indonesian government recognized PE goats as a local livestock breed, along with other goat breeds such as Senduro, Boerka Galaxy Agrinak, Gembrong, Kaligesing, Kejobong, and Saburai (Direktorat Pembibitan dan Produksi Ternak 2020).

Recent studies have highlighted the importance of morphometric traits in goat breeding. Yakubu *et al.* (2022) demonstrated strong correlations between body measurements and productivity in Red Sokoto goats, while Mekuriaw *et al.* (2016) used multivariate analysis to characterize Ethiopian goats for breeding programs. In Indonesia, Sodiq (2012), explored morphometric variations in PE goats across different regions, emphasizing the need for location-specific breeding strategies. Despite the recognized potential of morphometric analysis to improve breeding efficiency, a significant knowledge gap persists regarding the correlation between early-life measurements and subsequent growth in PE goats. Further research is needed to optimize breeding programs for PE goats.

Selection efforts are carried out through planned breeding programs to sustainably improve the genetic quality of PE goats. According to FAO (2012), phenotypic characterisation is a crucial step in designing planned breeding programmes, ensuring the selection process for local goat breeds can be achieved. Coefficient of variation (CV) is a crucial indicator in assessing genetic diversity for breeding programs. Asomah-Boaheng and Sam (2016), in their study on sheep breeds, established that a CV between 5% and 20% indicates optimal diversity for selection. This finding provides a valuable benchmark for evaluating the potential for genetic improvement in livestock populations. In the context of PE goats, Ilham *et al.* (2023) reported moderate to high CV for various morphometric traits, suggesting significant potential for genetic improvement through selective breeding.

PE goats play a crucial role in Indonesia's rural economy and food security. As a source of both meat and milk, they contribute significantly to smallholder farmers' livelihoods. Sodiq and Abidin (2008) reported that PE goats can produce 1-3 liters of milk per day, providing a vital source of nutrition in areas where cow's milk is scarce. Furthermore, Warmadewi *et al.* (2023) found that PE goat rearing can increase rural household income by up to 30%. Culturally, these goats are essential for religious festivals like Eid al-Adha, where their demand spikes annually (Baharudin *et al.*, 2023). Given their economic and cultural importance, improving PE goat breeding efficiency could have

far-reaching impacts on rural development and food security in Indonesia.

The complex interrelationships among morphometric traits at different developmental stages necessitate sophisticated analytical approaches to optimize selection criteria in animal breeding programs. While Pearson correlation has been widely employed to elucidate trait relationships, its efficacy is limited when dealing with multiple interconnected variables (Tahtila *et al.*, 2012). Canonical correlation analysis (CCA) emerges as a robust alternative, capable of describing relationships between two sets of variables by calculating maximally correlated linear combinations (Cankaya and Kaylaap, 2007). This method has been successfully applied in various contexts, including the analysis of age-related trait correlations in Merino sheep (Sahin *et al.*, 2001) and Kid goats (Mokena and Tyasi, 2021).

The present study extends this analytical framework to PE goats, addressing a significant gap in the literature. By applying CCA to estimate relationships between nine morphometric traits measured at weaning and eight months, this research offers a more comprehensive understanding of PE goat growth patterns than previous studies relying on simple correlation or regression analyses (Dakhlan *et al.*, 2021; Yakubu *et al.*, 2022). This study aims to address the knowledge gap regarding the relationship between early-life morphometric measurements and later growth patterns in PE goats by characterizing traits at weaning and eight months, analyzing trait correlations across ages, and evaluating early measurements as predictors of future growth, thereby potentially optimizing selection criteria for PE goat breeding programs.

MATERIALS AND METHODS

EXPERIMENTAL DESIGN

All animals were handled with minimal stress during measurements, and all procedures conducted were non-invasive. Throughout the study period, the animals were provided with adequate nutrition, water, and shelter, alongside regular health checks performed by licensed veterinarians to ensure their well-being. Ethical approval for this research was granted by Brawijaya University under ethical number 003-KEP-UB-2024. The research was conducted at BPTU-HPT Pelaihari, Sungai Jelai, Tambang Ulang, Tanah Laut Regency, South Kalimantan coordinates at (3°41'54.4"S 114°44'11.8"E) in Figure 1. This area was selected due to its large population of PE goats, making it one of the breeding centres in Indonesia. This study involved a sample of 210 PE goats, determined based on FAO (2012) guidelines for phenotypic characterization and representing approximately 10% of the PE goat population at the breeding center, comprising 105 weanlings (52 males and

53 females) as shown in Figure 2, and 105 eight-month-old goats (54 males and 51 females) as presented in Figure 3.

Table 1: Reference points of body weight and morphometric measurements in PE Goats.

Variable	Measurement Scale
Body Weight (BW)	Measurement using hanging digital scale with kilograms (kg) as the unit of measurement.
Body Length (BL)	Measure the length in centimeters (cm) from the point of the WHoulder (<i>tuberositas humeri</i>) to the pin bone (<i>tuber ischii</i>) using a measuring stick
Withers Height (WH)	Measure straight-line length in centimeters (cm) from the ground to the highest point of the withers behind the hump, parallel to the forelegs.
Chest Girth (CG)	Measured around the chest behind the hump using a measuring tape with the unit in centimeters (cm).
Chest Depth (CD)	Measured vertically on the side of the chest directly behind the hump using a measuring tape with the unit in centimeters (cm).
Hip Height (HH)	Measure the high in centimeter (cm) from the ground to the top of the hip bone (<i>tuber coxae</i>).
Ear Length (EL)	Measure the length in centimeter (cm) from the base to the tip of the ear using a measuring tape.
Ear Width (EW)	Measured at the widest part of the ear, with the ear naturally spread, using a measuring tape with the unit in centimeters (cm).
Mane Ruff Length (MRL)	Measured by selecting several strands of mane hair at the longest part, from the base of the hair to the tip, using a measuring tape with the unit in centimeters (cm).

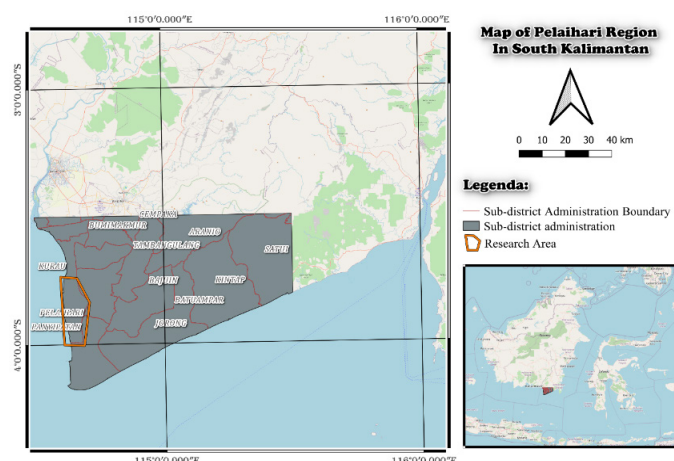


Figure 1: Location of the study area at BPTU-HPT pelaihari, South Kalimantan.



Figure 2: Indonesian etawah (pe) goat at weaning age.

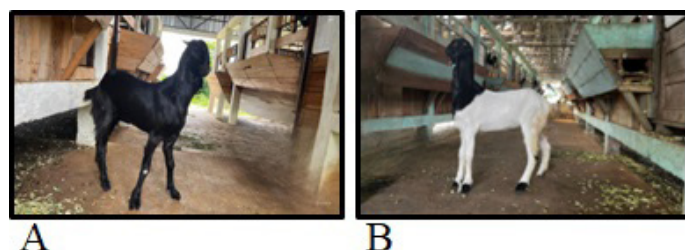


Figure 3: Indonesian etawah (PE) goat at eight month of age.

This sample size allows for population parameter estimation with a 95% confidence level and $\pm 6\%$ margin of error. It also considers the variability of morphometric traits observed in preliminary studies, ensuring adequate statistical power ($>80\%$) to detect biologically significant differences between groups. While generalization should be approached with caution, this sample size is sufficiently large to provide a representative overview of PE goat morphometric characteristics at the research location, balancing statistical robustness with logistical constraints. The management system used was flock management, where the animal population was divided based on age, sex, and health. Water was provided ad libitum, and feeding was done twice daily (morning and afternoon). Concentrate feed was given in the morning, followed by *Pennisetum purpureum* cv. *Mott* forage, and in the afternoon, gamal forage was provided.

DATA COLLECTION PROCESDURES

Data were measured based on nine morphometric traits according to the BSN (2015) and FAO (2012) descriptors for the phenotypic characterisation of goats. Prior to data collection, the research team underwent an intensive one-week training program to standardize measurement techniques. This training included practical demonstrations, inter-rater reliability tests, and instrument calibration. To minimize variability, each measurement was performed three times by two independent observers, with the average value used as the final measurement. If the difference between measurements exceeded 5%, the measurement was repeated. All measurements were conducted at the same time each day to avoid diurnal variations. This rigorous approach ensures high reliability and reproducibility of the morphometric data collected. The traits measured were Body Weight (BW), Body Length (BL), Withers Height (WH), Breast Girth (BG), Breast Depth (BD), Hip Height (HH), Ear Length (EL), Ear Width (EW), Mane Ruff Length (MRL) in Table 1. Livestock measuring stick was used to measure WH and HH. BW was measured using a metal frame scale with a capacity of 100 Kg. All other linear measurements were taken using a textile measuring tape. Measurements were carried out in the morning before the goats were fed, and only healthy, non-defective goats were measured.

The selection of statistical methods was predicated on the research objectives and the nature of the data. To summarize the distribution of morphometric traits across all variables, descriptive statistics such as the mean, standard deviation, and coefficient of variation were utilized. For comparing sex differences, the t-test was employed due to its effectiveness in comparing two independent groups, with significance determined at the $P < 0.01$ threshold. Levene's test for equality of variances was applied to assess the homogeneity of variances between male and female groups for each morphometric trait. The test is essential for ensuring that the assumption of equal variances is met, as a significant result ($P < 0.05$) would indicate a violation of this assumption, requiring adjustments to the interpretation of t-test results.

Pearson correlation was chosen for its ability to quantify the strength and direction of linear relationships between pairs of morphometric variables. This method is appropriate for continuous, normally distributed data as present in this study. Canonical Correlation Analysis (CCA) was chosen for its suitability in exploring relationships between two sets of multidimensional variables, especially for comparing morphometric traits at distinct growth stages. Specifically, CCA was applied to examine the correlations between the linear combinations of independent variables at weaning (X-set) and dependent variables at eight months (Y-set) in the total population of PE goats ($n = 210$). The mathematical model for CCA can be represented as follows (Hotelling, 1936):

$$\begin{aligned} (\sum_{xy}^T \sum_{xx}^{-1} \sum_{xy} - \rho^2 \sum_{yy})y &= 0 \\ (\sum_{xy} \sum_{yy}^{-1} \sum_{xy}^T - \rho^2 \sum_{xx})x &= 0 \end{aligned}$$

Where;

$\sum_{xy}^T$: Denotes the transpose of $\sum_{xy}$ represents the covariance matrix between variable sets X and Y.

$\sum_{xx}^{-1}$ and $\sum_{yy}^{-1}$: Represent the covariance matrices within each variable set.

ρ : Denotes the canonical correlation, and x and y are vectors of canonical coefficients.

CCA seeks to determine linear combinations of variables from each set (U for set X and V for set Y) that optimize the correlation between the two groups. This method allows for uncovering intricate multivariate relationships that may not be easily observed through more straightforward analyses (Gunderson and Muirhead, 1997). The results of the CCA satisfy several essential properties, including $\text{Corr}(U_i, V_j) = 0$, $\text{Corr}(U_i, U_j) = 0$, $\text{Corr}(V_i, V_j) = 0$ for $i \neq j$, $\text{Corr}(U_i, V_i) = \rho_i$ for $i = j$, where ρ_i is the canonical correlation coefficient, representing the strength of the relationship between the i -th pair of canonical variables (Tuzhilina *et al.*, 2023).

This comprehensive statistical analysis, conducted using R Studio 4.4.1, facilitated an in-depth examination of the complex interrelations among morphometric traits and their developmental patterns in PE goats, thus providing a robust foundation for understanding their growth. The statistical procedures were executed through various R packages, including 'CCA', 'tidyverse', 'assertthat', 'dplyr' for descriptive analysis, and 'stats' for conducting t-tests. In the canonical correlation analysis (CCA), the first set of variables ($X_{n \times p}$) comprised nine morphometric traits measured at weaning, while the second set ($Y_{n \times q}$) represented the same nine traits assessed at eight months of age. This approach allowed for a precise comparison of morphometric development between these two critical growth stages.

LIMITATIONS

Despite offering key insights into the morphometric traits of PE goats, this study has several limitations that should be recognized. The sample being sourced from a single breeding site may affect the broader applicability of the findings to the overall PE goat population in Indonesia. Site-specific environmental and management factors may have influenced the goats' growth and development, variables that were not fully controlled within the study. Additionally, measurements were collected at only two specific points in time (weaning and eight months), which might not fully reflect the continuous and complex growth dynamics throughout the animals' lifespan. The study also did not include genetic variation analysis, limiting the exploration of genetic contributions to the observed morphometric traits. Even though rigorous training and standardized protocols were followed, potential measurement biases associated with manual morphometric measurements cannot be entirely excluded. Future research should aim to overcome these limitations by expanding the study to multiple locations, conducting more frequent measurements, and including genetic analysis. Nonetheless, this research serves as a solid starting point for understanding PE goat morphometric traits and their developmental patterns, paving the way for further exploration in the field of animal breeding.

RESULTS AND DISCUSSION

MORPHOMETRIC MEASUREMENTS OF PE GOAT

Weaning age morphometric parameters identified differences between male ($n=52$) and female ($n=53$) goats Table 2. Body Weight (BW) of males (15.19 ± 2.60 kg) and females (14.72 ± 2.98 kg) exhibited no significant difference ($t = 0.863$, $p = 0.39$). Levene's test confirmed homogeneous variance ($F = 2.654$, $p = 0.106$). Body Length (BL) of males (54.60 ± 3.62 cm) and females (53.32 ± 3.87 cm) showed no significant difference. Withers Height (WH) demonstrated similar development in males (56.97 ± 3.37 cm) and females (56.30 ± 3.34 cm). Significant differences ($P \leq 0.01$)

Table 2: Sexual Dimorphism in Morphometric Measurements of PE Goats at Weaning and Eight Months.

Variable	Parameters	Weaning Period			Eight-Month Period		
		Levene's test (P.Value)	Male (n=52)	Female (n=53)	Levene's test (P.Value)	Male (n=54)	Female (n=51)
Body Weight (Kg)	Mean±SD	0.106	15.19±2.60	14.72±2.98	0.023	27.15±5.39 ^a	24.53±3.85 ^b
Body Length (Cm)	Mean±SD	0.177	54.60±3.62	53.32±3.87	0.000	67.80±6.80 ^a	63.63±3.42 ^b
Withers Height (Cm)	Mean±SD	0.771	56.97±3.37	56.30±3.34	0.002	68.02±5.31 ^a	64.73±3.58 ^b
Chest Girth (Cm)	Mean±SD	0.065	53.23±2.83 ^a	51.91±3.66 ^b	0.053	64.81±4.59 ^a	62.02±3.33 ^b
Chest Depth (Cm)	Mean±SD	0.849	24.58±2.03 ^a	23.62±2.04 ^b	0.002	29.69±3.81 ^a	26.86±2.65 ^b
Hip Height (Cm)	Mean±SD	0.587	58.77±3.43	58.13±3.51	0.002	70.31±5.45 ^a	66.84±3.78 ^b
Ear Length (Cm)	Mean±SD	0.001	25.39±2.45	25.10±1.58	0.447	28.82±2.54	28.99±2.92
Ear Width (Cm)	Mean±SD	0.052	7.77±1.00	7.52±0.71	0.237	8.98±.93	8.89±1.02
Mane Ruff Length (Cm)	Mean±SD	0.874	5.58±1.39	5.21±1.36	0.762	9.93±1.60	9.95±1.57

Note: a.b Means in rows with different superscripts differ significantly ($P \leq 0.01$) between sexes.

emerged in Chest Girth (CG), males (53.23±2.83 cm) exceeding females (51.91±3.66 cm), and Chest Depth (CD), males (24.58±2.03 cm) surpassing females (23.62±2.04 cm). Hip Height (HH), Ear Length (EL), Ear Width (EW), and Mane Ruff Length (MRL) parameters revealed no significant intersexual differences at weaning age.

Eight-month-old goats exhibited pronounced sexual dimorphism between males (n=54) and females (n=51) **Table 2.** BW₈ demonstrated significant differences ($t = 2.859$, $p = 0.005$) between males (27.15±5.39 kg) and females (24.53±3.85 kg). Levene's test indicated significantly different variances ($F = 5.344$, $p = 0.023$). BL₈ in males (67.80±6.80 cm) significantly exceeded females (63.63±3.42 cm) ($P \leq 0.01$). WH₈ in males (68.02±5.31 cm) significantly surpassed females (64.73±3.58 cm) ($P \leq 0.01$). CG₈ in males (64.81±4.59 cm) exceeded females (62.02±3.33 cm) ($P \leq 0.01$). CD₈ in males (29.69±3.81 cm) surpassed females (26.86±2.65 cm) ($P \leq 0.01$). HH₈ in males (70.31±5.45 cm) significantly exceeded females (66.84±3.78 cm). EL₈, EW₈, and MRL₈ exhibited no significant intersexual differences.

Boxplot visualization in **Figure 4** illustrates morphometric parameter differences. Weaning age data revealed outliers in BW, CD, and EW, indicating greater intragroup variation, while parameters like HH and BL exhibited relatively small variability ranges. Eight-month data showed significant outliers in BW₈ and EL₈, highlighting individuals with values deviating substantially from the mean. Parameters CG₈ and CD₈ exhibited clear differences, potentially indicating variations in growth patterns at this stage.

PEARSON CORRELATION

The Pearson correlation analysis of morphometric measurements in PE goats revealed significant associations ($P < 0.01$) among various parameters across developmental stages, as shown in **Table 3**. At weaning age, body weight

(BW) displayed strong positive correlations ($P < 0.01$) with key morphometric traits: chest girth (CG) ($r = 0.819$), body length (BL) ($r = 0.782$), withers height (WH) ($r = 0.776$), and hip height (HH) ($r = 0.719$). These robust correlations suggest a proportional increase in various body dimensions concurrent with weight gain. This aligns with the biological expectation of coordinated growth during early developmental stages. Particularly, the strong correlation between WH and HH ($r = 0.922$) indicates synchronized vertical growth, potentially reflecting coordinated skeletal development along the animal's longitudinal axis.

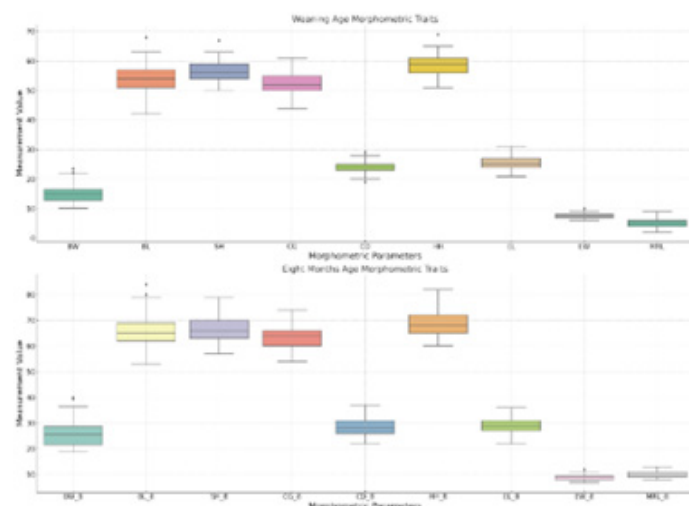


Figure 4: Distribution of morphometric traits at weaning and 8 months age.

At eight months of age, correlation analysis consistently demonstrated highly significant relationships between body weight (BW₈) and morphometric parameters. BW₈ was strongly correlated with hip height (HH₈) ($r = 0.885$), chest girth (CG₈) ($r = 0.852$), withers height (WH₈) ($r = 0.843$), and body length (BL₈) ($r = 0.811$). The persistence of these strong correlations suggests that the proportional growth pattern observed at weaning is maintained as

Table 3: Pearson Correlations Between Body Weight and Morphometric Traits in PE Goats.

	BW	BL	WH	CG	CD	HH	EL	EW	MRL	BW_8	BL_8	WH_8	CG_8	CD_8	HH_8	EL_8	EW_8	MRL_8
BW	1																	
BL	.782**	1																
WH	.776**	.580**	1															
CG	.819**	.728**	.650**	1														
CD	.469**	.516**	.290**	.686**	1													
HH	.719**	.559**	.922**	.545**	.239*	1												
EL	.380**	.287**	.355**	.205*	0.000	.383**	1											
EW	.298**	0.185	.355**	.222*	0.056	.364**	.580**	1										
MRL	.215*	0.138	.269**	0.040	-.290**	.294**	.296**	.220*	1									
BW_8	.345**	.269**	.250*	.359**	.198*	0.131	0.057	0.063	0.041	1								
BL_8	.227*	0.164	.208*	.296**	0.133	0.102	0.073	0.005	0.032	.811**	1							
WH_8	.315**	.239*	.261**	.331**	.192*	0.187	0.030	0.053	0.017	.843**	.802**	1						
CG_8	.215*	.193*	0.188	.283**	0.179	0.069	-0.055	-0.035	0.009	.852**	.800**	.779**	1					
CD_8	0.176	0.155	0.114	.202*	0.098	0.041	-0.056	-0.142	0.061	.580**	.660**	.597**	.684**	1				
HH_8	.328**	.277**	.251**	.361**	.201*	0.182	-0.013	0.019	0.004	.855**	.796**	.972**	.778**	.600**	1			
EL_8	.279**	.239*	.207*	.331**	0.125	0.120	0.136	0.157	0.087	.468**	.343**	.367**	.332**	.207*	.382**	1		
EW_8	0.163	0.172	0.113	0.173	0.012	0.117	0.099	0.161	-0.018	.345**	.244*	.291**	.328**	.197*	.301**	.563**	1	
MRL_8	.788**	.670**	.574**	.721**	.433**	.539**	.281**	.277**	.212*	.290**	0.105	.211*	0.126	-0.019	.243*	.336**	0.162	1

** Correlation is highly significant at the 0.001 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). If high correlated > 0.5.

the animals mature. Furthermore, the exceptionally strong correlation between WH_8 and HH_8 ($r = 0.972$) at eight months supports the concept of synchronized vertical growth during this critical developmental phase.

While these correlations offer valuable insights into PE goat growth patterns, it is crucial to interpret them within the context of their limitations and biological implications. The strong associations between body weight and morphometric traits suggest coordinated growth, likely reflecting underlying physiological processes such as synchronized skeletal development and proportional organ growth. To address these limitations and improve the robustness of the findings, future studies should aim to control for confounding factors and apply more advanced statistical approaches, such as multivariate analyses or longitudinal studies. These methods would not only refine the interpretation of the observed correlations but also help elucidate the complex interactions influencing growth and development in PE goats.

CANONICAL CORRELATION ANALYSIS (CCA)

The results of the Canonical Correlation Analysis (CCA) on PE goats indicate a highly significant relationship ($P < 0.01$) between growth parameters at weaning and eight months of age. As shown in Table 4, the first pair of canonical variables (U_1V_1) exhibits a strong positive correlation ($r = 0.839$, $P < 0.001$), reflecting a robust association between morphometric traits at these two developmental stages.

This high correlation suggests that body mass and other key morphometric traits at weaning are closely linked to growth patterns at eight months. The variability observed in the data, consistent with the relatively high coefficients of variation (CV) for several traits, highlights the inherent diversity within the population.

Table 4: Summary result for the CCA.

Pair of Canonical	Canonical Correlation	Square Canonical	Eigen-value	df	Like-lihood Ratio	Prob-ability Pr>F
U_1V_1	0.839	0.704	2.377	81	0.146	0.000
U_2V_2	0.470	0.221	0.283	64	0.493	0.385
U_3V_3	0.412	0.170	0.205	49	0.633	0.708
U_4V_4	0.341	0.116	0.131	36	0.763	0.901
U_5V_5	0.252	0.063	0.068	25	0.863	0.963
U_6V_6	0.240	0.057	0.061	16	0.921	0.956
U_7V_7	0.130	0.017	0.017	9	0.977	0.988
U_8V_8	0.065	0.004	0.004	4	0.994	0.966
U_9V_9	0.043	0.002	0.002	1	0.998	0.675

Furthermore, Table 4 demonstrates that the first canonical pair (U_1V_1) shows a canonical correlation of 0.839, with a squared canonical correlation of 0.704 (70.4%). This indicates that a substantial portion of the variance in one set of variables is explained by the variance in the other set. The eigenvalue of 2.377 underscores the significant contribution of the first canonical pair in explaining the rela-

tionship between the two sets of variables. Figure 5 visually supports these findings, presenting a scatterplot of the canonical correlation that illustrates the strong relationship between the first canonical variables of both sets. The Likelihood Ratio of 0.146, coupled with the highly significant p-value ($P < 0.001$), confirms that the CCA model fits the data well, justifying the rejection of the null hypothesis for the first canonical pair. In contrast, the subsequent pairs, such as U2V2 ($r = 0.470$), display smaller and statistically non-significant correlations, indicating that only the first canonical pair contributes meaningfully to explaining the variance between the two sets of variables.

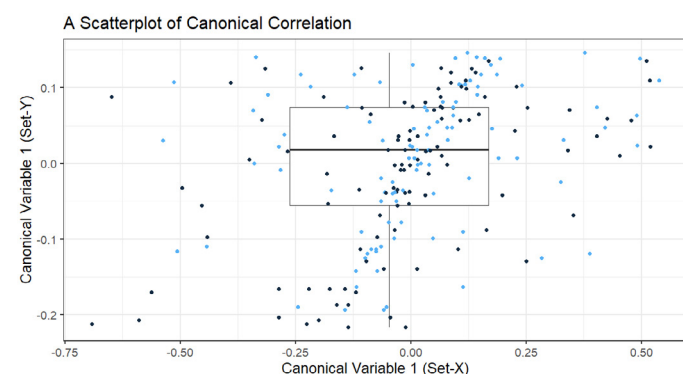


Figure 5: Canonical correlation scatterplot between set-X and set-Y for morphometric traits in pe goats.

The standardized canonical coefficients for the first canonical pair (U_1V_1), as presented in Table 5, reveal that the first canonical variable (U_1) is primarily influenced by body weight (BW) and chest girth (CG) at weaning, while the second canonical variable (V_1) at eight months is dominated by mane ruff length (MRL₈). These findings suggest that early growth factors, such as body mass and chest girth, strongly influence subsequent development, with secondary traits like mane ruff length becoming more pronounced as the animals mature. The following canonical equations represent the optimal linear combinations of these variables:

$$U_1 = (-0.72 BW) - (0.09 BL) + (0.23 WH) - (0.38 CG) + (0.03 CD) - (0.07 HH) + (0.06 EL) - (0.04 EW) - (0.12 MRL)$$

$$V_1 = (0.07 BW_8) - (0.07 BL_8) - (0.05 WH_8) + (0.08 CG_8) - (0.24 CD_8) - (0.05 HH_8) + (0.02 EL_8) - (0.02 EW_8) - (0.97 MRL_8)$$

Interpretation of these equations indicates that decreases in BW, BL, CG, HH, and EW at weaning age tend to be associated with similar decreases in these variables at eight months, suggesting a consistent pattern of growth. The biological significance of these relationships lies in the fact that early development, characterized by body mass and skeletal growth, is maintained throughout later stages of growth. At weaning, traits like BW and CG strongly influ-

ence the overall body structure, while at eight months, secondary traits such as mane ruff length (MRL₈) become more pronounced, likely reflecting maturity and secondary development characteristics.

The canonical loadings and cross-loadings detailed in Tables 6 and Tables 7 substantiate the significant influence of body weight (BW) and chest girth (CG) in shaping the first canonical variable (U_1) at weaning age, while mane ruff length (MRL₈) emerges as the dominant contributor to the second canonical variable (V_1) at eight months. This progression underscores the transition from primary growth traits, such as body mass, to secondary traits, including hair growth, as the animals mature. Furthermore, as indicated in Table 8, the first canonical variable (U_1) accounts for 43% of the total variance in morphometric traits at weaning, with a redundancy of 14% for traits at eight months. This finding suggests that while U_1 captures a substantial portion of the variance in early-stage morphometric traits, it also explains a moderate amount of variance in traits associated with later growth. The results highlight the pivotal roles of BW, CG, and MRL in driving the overall growth trajectory and development of PE goats between weaning and eight months of age.

Genetic improvement strategies for the conservation and sustainable utilization of Indonesian indigenous livestock genetic resources must be predicated on phenotypic characterization assessments of extant populations. Indonesia possesses a large and diverse small ruminant population, contributing significantly to rural livelihoods and national income (Tiesnamurti *et al.*, 2020). Recent studies by Baharuddin *et al.* (2023) revealed a 34% increase in goat production from 2020 to 2022, primarily driven by demand for religious ritual such as Eid al-Adha and Aqiqah. This productivity enhancement in PE goats implies sustained population growth, underscoring the necessity for selective breeding efforts to improve production performance efficiently. For instance, selection based on breeding values for economically important traits such as growth rate and milk production can be applied to enhance overall productivity. These findings align with global trends in small ruminant development, as reported by Monau *et al.* (2020) in Botswana, emphasizing the importance of genetic and phenotypic characterization in sustainable breeding programs.

This research focused on the morphometric analysis of PE goats, revealing significant differences in body measurements ($P < 0.01$) between males and females, particularly at eight months of age. These findings confirm pronounced sexual dimorphism in this breed, with males consistently exhibiting larger body dimensions compared to females across critical parameters. This phenomenon aligns with the findings of Ma`rufah *et al.* (2023) in PE goat populations in Indonesia. However, it is noteworthy that some

Table 5: Standardized canonical coefficients for canonical variables.

X-Variable Set										Y-Variable Set									
BW	BL	WH	CG	CD	HH	EL	EW	MRL		BW_8	BL_8	WH_8	CG_8	CD_8	HH_8	EL_8	EW_8	MRL_8	
U ₁	-0.72	-0.09	0.23	-0.38	0.03	-0.07	0.06	-0.04	-0.12	V ₁	0.07	-0.07	-0.05	0.08	-0.24	-0.05	0.02	-0.02	-0.97

Table 6: Canonical loadings of the original variables with their canonical variables.

X-Variable Set										Y-Variable Set									
BW	BL	WH	CG	CD	HH	EL	EW	MRL		BW_8	BL_8	WH_8	CG_8	CD_8	HH_8	EL_8	EW_8	MRL_8	
U ₁	-0.97	-0.82	-0.71	-0.90	-0.53	-0.65	-0.32	-0.28	-0.26	V ₁	-0.43	-0.29	-0.38	-0.28	-0.23	-0.41	-0.37	-0.21	-0.96

studies, such as that conducted by Sodiq *et al.* (2019), found smaller variations between sexes in certain PE goat populations, indicating the potential influence of environmental or management factors on the expression of sexual dimorphism. The observed sexual dimorphism has important implications for breeding strategies, as discussed by Manzi *et al.* (2019) in their study of Red Sokoto goats in Nigeria. They suggest that morphometric differences between sexes should be considered in developing gender-specific selection indices to maximize the genetic potential of both sexes.

The analysis of morphometric variability revealed coefficients of variation (CV) ranging from 5.32% to 22.28% across the studied parameters, indicating substantial phenotypic diversity within the PE goat population. These moderate to high CV values suggest considerable genetic variability, a crucial prerequisite for effective selective breeding programs. However, it is important to acknowledge that this phenotypic variability is also influenced by environmental factors. A study by Lopes *et al.* (2012) on goats in Brazil demonstrated that factors such as management systems, feed availability, and climatic conditions can significantly contribute to morphometric variation. Consequently, breeding programs should consider genotype-environment interactions to optimize outcomes. The observed range of CV is consistent with the findings from recent multivariate characterization studies on PE goats by Guntoro *et al.* (2023) and Ilham *et al.* (2023), which reported diverse moderate CV (5% to 20%) for male and female cohorts. This phenotypic plasticity, as evidenced by the moderate CV values, implies that genetic improvement through directed selection can yield significant responses in morphometric traits. These findings are corroborated by Mekuriaw *et al.* (2016) study on Ethiopian goats, which demonstrated that high phenotypic variability can be leveraged for effective breeding programs, particularly when combined with genomic information.

The morphometric characteristics of PE goats exhibited strong positive correlation between body weight (BW) and most other morphometric traits, both at weaning and eight months of age. Three primary body measurements, namely body length (BL), withers height (WH), and chest girth

(CG), showed very strong correlation with BW at weaning BL ($r = 0.782$); WH ($r = 0.776$); CG ($r = 0.819$). At eight months, BW strongly correlated with WH ($r = 0.843$); CG ($r = 0.852$); and HH ($r = 0.855$). All observed correlations were highly significant ($P < 0.01$), with stronger correlations at eight months, indicating that these relationships intensify as the goats mature. This research supports the findings of Talukder and Choudhury (2018), Dige *et al.* (2021), and Yakubu *et al.* (2022), which reported strong positive correlations between BW and morphometric traits across various goat breeds. The high correlation values for certain morphometric traits can be used to develop selection criteria, as demonstrated by Dakhlan *et al.* (2021) in predicting adult body weight. Furthermore, a recent study by Ofori *et al.* (2021) on West African Dwarf goats suggests that strong morphometric correlations can be used to develop more accurate selection indices for genetic improvement.

Further confirmation of the Pearson correlation values for the nine parameters was obtained through Canonical Correlation Analysis (CCA), which elucidating the reciprocal relationship between variables measured at weaning and eight months of age. The first canonical correlation (U_1V_1) exhibited a highly significant value (0.839, $P < 0.01$), accounting for 70.4% of the variation in the data, thus indicating a strong relationship between the two sets of variables, as presented in Table 5. These results are consistent with findings by Çankaya and Kayaalp (2007) and Tahtali *et al.* (2012), who reported significant canonical correlations ($P < 0.01$) between morphometric measurements at different growth stages. The standardised canonical coefficients for the first pair of canonical variables (U_1V_1), shown in Table 6, indicate that increases in WH, CD, and EL at weaning are associated with decrease in BL_8, WH_8, CD_8, HH_8, EW_8, and MRL_8 at eight months of age, while BW_8, CG_8, and EL_8 at eight months of age increase. These findings expand our understanding of PE goat growth dynamics, aligning with a recent study by Boujenane *et al.* (2016) on Draa goats in Morocco, which employed CCA to identify complex growth patterns and their relationship to productivity.

Variables with higher canonical loadings contributed more significantly to the multivariate relationship between

Table 7: Cross loading of the original variables with opposite canonical variables.

X-Variable Set										Y-Variable Set									
BW	BL	WH	CG	CD	HH	EL	EW	MRL		BW_8	BL_8	WH_8	CG_8	CD_8	HH_8	EL_8	EW_8	MRL_8	
U ₁	-0.81	-0.69	-0.59	-0.75	-0.44	-0.55	-0.27	-0.24	-0.22	V ₁	-0.36	-0.24	-0.32	-0.24	-0.20	-0.35	-0.31	-0.18	-0.81

morphometric measurements at weaning and eight months, as demonstrated in Table 6. Loadings for eight-month variables indicated that MRL_8 and BW_8 have a more substantial influence in shaping V₁, while BW and CG had more influence in forming U₁. Cross-loadings analysis Table 7 revealed that BW and MRL_8 provide the largest contributions to the variance of U₁ and V₁, respectively. This suggests that weaning age influences BW as a growth characterisation metric, while eight-month of age impacts MRL_8, which is used as a criterion in local goat competitions. CCA results reveal that canonical variables explain 20% of the total variation at eight months, with a redundancy size of 14% for U₁ variables. At weaning, 43% of the variation was explained by canonical U₁, with a redundancy size of 30% for V₁ variables, as demonstrated in Table 8.

Table 8: The explained total variation ratio by canonical variables for the variable sets.

X-Variable Set				Y-Variable Set			
Variance Extracted		Redundancy		Variance Extracted		Redundancy	
U ₁	0.43	V ₁	0.30	V ₁	0.20	U ₁	0.14

These findings enrich our understanding of PE goat growth patterns and provide valuable insights for developing more targeted breeding strategies. For future research, we recommend: (1) Longitudinal studies tracking individual PE goat development from birth to adulthood to better understand growth trajectories; (2) Genomic analyses to identify genetic markers associated with key morphometric traits; (3) Investigations into genotype-environment interactions to determine how factors such as nutrition and management influence the expression of morphometric traits; and (4) Evaluation of the economic impact of various selection strategies based on morphometric traits to guide decision-making in commercial breeding programs. A recent study by Pan *et al.* (2015) on Black Bengal goats also employed a CCA approach to uncover complex relationships between morphometric traits and productivity, affirming the utility of this method in livestock breeding research.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this study identified a significant relationship between the morphometric traits of Indonesian Etawah (PE) goats measured at weaning and eight months of age. Body weight (BW), chest girth (CG), and mane ruff

length (MRL) emerging as key predictors of future growth. The strong positive correlation (0.839) between measurements at both stages suggests that early traits can serve as reliable indicators for predicting subsequent growth, aiding in the selection of superior livestock at weaning to enhance production efficiency. Additionally, males exhibited larger body sizes, suggesting the potential benefits of sex-specific breeding strategies. While this research provides valuable insights into PE goat breeding, it is important to acknowledge the limitations of sampling from a single location and the absence of genetic variation analysis. Future studies should involve multiple locations and include genetic analysis. These findings imply that farmers can use morphometric measurements at weaning as early selection criteria and should aim to reduce generation intervals to enhance the effectiveness of breeding programs.

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NOVELTY STATEMENT

This study applies Canonical Correlation Analysis (CCA) to assess the relationship between morphometric traits in Indonesian Etawah (PE) goats at weaning and eight months. Results indicate that body weight and chest girth at weaning can predict growth and mane ruff length at eight months. This approach provides new insights into early selection criteria for breeding programs, enhancing genetic improvement strategies for PE goats in Indonesia.

AUTHOR’S CONTRIBUTIONS

Ahmad Fahrudin Husen: Conceptualization, drafting the original manuscript, collecting data, analyze statistics.
Suyadi: conceptualization, supervision.
Yudi Parwoto: Collecting data and supervision.
Muhammad Sairi: Collecting data and supervision.
Veronica Margareta Ani Nurgartiningih: Conceptualization, supervision.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest with stakeholders related to the material written in this manuscript.

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