



Characterization and Correlation of Udder Morphology with Milk Production of Peranakan Etawah (PE) Goat

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Abstract. The Peranakan Etawah (PE) Goat demonstrated potential as a commercial dairy goat in tropical regions susceptible to heat stress. However, information regarding milk production and udder-teat morphology in PE goats was limited. This study aims to characterize udder-teat morphology and evaluate its relationship with milk production. Data were collected from 105 lactating female PE goats at BPTU-HPT Pelaihari, South Kalimantan. Nine variables were measured: daily milk yield (DMY), teat length before and after milking (TLB, TLA), udder length before and after milking (ULB, ULA), udder width before and after milking (UWB, UWA), and udder circumference before and after milking (UCB, UCA). The study employed t-tests, single-factor ANOVA followed by Duncan's test for significant results, and Pearson correlations for statistical analysis. Results showed that milk production significantly decreased ($P < 0.01$) from early lactation (616.53 ± 243.86 mL) to late lactation (438.33 ± 187.37 mL). Dams with singleton births showed higher production (592.11 ± 144.26 mL/day) compared to twins (557.05 ± 229.67 mL/day) and triplets (568.75 ± 346.24 mL/day). Udder morphological measurements demonstrated significant correlations with milk yield, particularly pre-milking measurements of udder width ($r=0.31$), length ($r=0.25$), and circumference ($r=0.36$). These findings suggest that pre-milking udder dimensions could serve as potential indicators for milk production in PE goats, providing valuable insights for breeding and management strategies.

Keywords: Characterization, Etawah Crossbred Goat, Udder-Teat Production, Milk Production.

1 Introduction

The goat population in Indonesia is predominantly composed of Etawah Crossbreed (PE), a result of upgrading from local breeds (Kacang) and the exotic Etawah breed from India [1,2]. The development of PE goats has become one of the most promising dairy goat breeds in tropical regions. Their adaptability to heat stress and dual-purpose characteristics (meat and milk production) make them valuable to smallholder farmers [3]. With the increasing global demand for goat milk due to its nutritional benefits

and lower allergenicity compared to cow milk [4], understanding the factors influencing milk production in PE goats becomes crucial. FAO [5] emphasizes that phenotypic characterization is critical in developing planned breeding strategies, enabling more targeted selection processes for local breeds such as PE goats.

Studies on udder morphology and milk production have been conducted across various goat breeds. Ciappesoni et al. [6] found that udder morphological traits are heritable and have significant genetic correlations with milk production traits, suggesting the potential for genetic improvement through selection based on udder characteristics. Similarly, Mavrogenis et al. [7] reported a strong correlation between udder circumference and milk production in Damascus goats. Research by Abu et al. [8] found a similar relationship in West African Dwarf goats, while Tilki et al. [9] observed that udder depth and width were significantly associated with milk production in Akkaraman goats.

Information on factors such as age lactation and type of birth concerning udder morphology, teats, and milk production in PE goats remains scarce. Recent studies by Geldsetzer-Mendoza et al. [10] documented that milk production typically peaks at 4–8 weeks post-partum, followed by systematic decline reflecting secretory cell activity modifications. The milk production pattern shows consistent decreases after the lactation peak, particularly in goats lactating beyond 90 days post-weaning [11]. Furthermore, birth type has been reported to influence both milk production and udder morphology, with multiple births generally associated with increased mammary gland development and altered milk production patterns [12].

This study aims to examine the morphological characteristics of the udder and determine the relationship between udder characteristics and milk production in 105 lactating PE goats at BPTU-HPT Pelaihari, South Kalimantan. The results of this research are expected to provide valuable insights for developing more effective breeding and management strategies. Ultimately, this will enhance the productivity and sustainability of PE goat farming in Indonesia, particularly in regions with extreme environmental conditions.

2 Materials and Methods

2.1 Experimental Design

Ethical approval for this research was granted by Brawijaya University (Ethical number 003-KEP-UB-2024). The study was conducted at BPTU-HPT Pelaihari, Sungai Jelai, Tambang Ulang, Tanah Laut Regency, South Kalimantan (coordinates: 3°41'54.4"S 114°44'11.8"E). This area was selected based on the large population of Peranakan Etawah (PE) goats, which serves as one of the breeding centers in Indonesia. A total of 105 lactating PE goats were used in the study, with ages less than 90 days post-weaning and more than 90 days post-weaning. Data collection was conducted over a period of three months from June to August 2024, consisting of 19 goats with single births, 66 with twin births, and 20 with triplet births.

The management system implemented was flock management, where the livestock population was divided based on factors such as age during lactation, mating group,

and health status. Each mating group consisted of 12 females and 1 male. Clean drinking water was provided ad libitum, while feed was supplied twice daily (in the morning and afternoon). Concentrate feed was provided in the morning, followed by *Pennisetum purpureum* cv. Mott forage, while in the afternoon, Gamal forage was given.

2.2 Statistical Analysis

Data Collection Procedures. Milk production data were collected through a once-daily milking system, performed at 08.00 in the morning. The milking process followed a standardized protocol, including proper udder sanitation with individual clean towels before milking. Trained personnel performed hand milking, and milk yields were measured using calibrated measuring cups with 1-liter capacity and 10ml graduation accuracy. Daily milk yield (DMY) was recorded immediately after milking completion. To account for daily variations, milk production data were collected for seven consecutive days each month. Udder and teat morphometric measurements were conducted before morning milking at 07.30 and 30 minutes after milking completion.

To ensure measurement consistency and reliability, all morphometric data were collected by the same trained technician. Udder measurements were performed using a textile tape measure with ± 0.1 cm accuracy, while teat measurements utilized digital calipers with ± 0.01 cm precision. Each measurement was taken in triplicate and averaged to minimize measurement error. Birth type data were obtained from comprehensive farm records and verified through individual goat eartag identification, which included detailed information about kidding dates and number of offspring.

All measurements strictly adhered to the standardized descriptors established by Upadhyay et al. [13] and Makamu et al. [14] for phenotypic trait characterization. Environmental conditions, including temperature (average $28 \pm 2^\circ\text{C}$) and relative humidity ($75 \pm 5\%$), were monitored and recorded during measurement periods to account for potential environmental effects on milk production. Nine variables were measured and described in Table 1, including daily milk yield (DMY), teat length before and after milking (TLB, TLA), udder length before and after milking (ULB, ULA), udder width before and after milking (UWB, UWA), and udder circumference before and after milking (UCB, UCA).

Table 1. Reference points of milk production and morphometric of the udder-teat measurements in PE Goats.

Variable	Measurement Scale
Daily milk yield (DMY)	Measured using a calibrated milk meter or weight scale, with milliliter (mL) as the unit of measurement. Recorded daily for each milking session and summed for total daily yield.
Teat length before milking (TLB)	Measured from the base of the teat at the udder to the tip of the teat using a caliper or measuring tape, with centimeters (cm) as the unit of measurement. Performed immediately before milking.
Udder length before milking (ULB)	Measured from the front attachment of the udder to the rear attachment, along the bottom of the udder, using a flexible measuring tape. Recorded in centimeters (cm) immediately before milking.
Udder width before milking (UWB)	Measured at the widest point of the udder, from side to side, using a flexible measuring tape. Recorded in centimeters (cm) immediately before milking.
Udder circumference before milking (UCB)	Measured around the widest part of the udder using a flexible measuring tape. Recorded in centimeters (cm) immediately before milking.
Teat length after milking (TLA)	Measured from the base of the teat at the udder to the tip of the teat using a caliper or measuring tape, with centimeters (cm) as the unit of measurement. Performed immediately after milking.
Udder length after milking (ULA)	Measured from the front attachment of the udder to the rear attachment, along the bottom of the udder, using a flexible measuring tape. Recorded in centimeters (cm) immediately after milking.
Udder width after milking (UWA)	Measured at the widest point of the udder, from side to side, using a flexible measuring tape. Recorded in centimeters (cm) immediately after milking.
Udder circumference after milking (UCA)	Measured around the widest part of the udder using a flexible measuring tape. Recorded in centimeters (cm) immediately after milking.

Data Analysis. Statistical analyses were performed using R Studio software. Descriptive statistics, including mean and standard deviation were calculated for all variables in the dataset. A T-test analysis was conducted to determine the effect of lactation age patterns on morphometric data. A single-factor analysis of variance (ANOVA) was employed to examine the impact of birth types. In cases where ANOVA results showed significant differences, a post-hoc Duncan's test was performed. The ANOVA model can be expressed as follows:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \quad (1)$$

Where:

Y_{ij} = observed value of the dependent variable

μ = overall mean

α_i = effect of the i -th treatment (birth type)

ε_{ij} = random error

Pearson's correlation analysis was conducted to evaluate the linear associations among morphometric variables. The correlation coefficient (r) was computed to quantify the strength and direction of these relationships, with values ranging from -1 to +1. Coefficients approximating ± 1 indicate strong linear relationships, while those near 0 suggest weak or absent linear associations. Statistical significance was determined at $P < 0.05$

3 Result and Discussion

3.1 Descriptive Statistics of Lactation Age

Analysis of lactation age influence revealed significant production declines ($P < 0.01$) as lactation progressed, from 616.53 ± 243.86 mL in early lactation (<90 days) to 438.33 ± 187.37 mL in late lactation (>90 days). This trajectory aligns with contemporary lactation curve models. Geldsetzer-Mendoza et al. [10] recently documented peak production occurring 4-8 weeks post-partum, followed by systematic decline reflecting secretory cell activity modifications.

Udder morphology demonstrated dynamic adaptation throughout lactation stages. Teat length increased from 11.80 ± 2.77 cm to 13.00 ± 3.69 cm ($P < 0.05$), indicating tissue response to repeated milking stimulus. Current research by Vrdoljak [15] links dimensional modifications to physiological adaptations in supporting tissues and vasculature responding to mechanical milking pressures.

Pre-milking udder parameters showed substantial modifications between early and late lactation phases. Length decreased from 12.47 ± 2.21 cm to 11.30 ± 2.30 cm ($P < 0.05$), while width reduced from 38.31 ± 5.93 cm to 34.10 ± 5.81 cm. Contemporary findings by Lérias et al. [16] associate these phenomena with mammary tissue reorganisation and declining milk synthesis capacity during extended lactation.

Pre-milking circumference showed reduction from 38.31 ± 5.93 cm to 34.10 ± 5.81 cm in late lactation. Recent studies by Kouri et al. [17] demonstrate strong correlations between udder volume changes and milk storage capacity, reflecting alveolar cell activity in milk component synthesis. Tissue response to milking showed temporal variations, with early lactation length reduction of 19.7% post-milking (12.47 ± 2.21 cm to 10.01 ± 1.82 cm) compared to 21.2% in late lactation (11.30 ± 2.30 cm to 8.93 ± 1.41 cm). Contemporary research by Ziadi et al. [24] identifies that lateral udder dimensional changes serve as indicators of milking efficiency and alveolar function.

3.2 Descriptive Statistics of Lactation Age

The investigation of milk production patterns across different birth types revealed intriguing variations in daily milk yield. Dams with singleton births demonstrated superior production (592.11 ± 144.26 mL/day) compared to their twin (557.05 ± 229.67 mL/day) and triplet (568.75 ± 346.24 mL/day) counterparts. This pattern aligns with contemporary findings by Raza et al. [19], suggesting that singleton-bearing dams maintain more consistent production patterns due to reduced gestational physiological demands.

Pre-milking udder morphological assessments exhibited distinct variations across birth types. Teat dimensions showed gradual increases from singleton (11.95 ± 3.14 cm) through twin (12.08 ± 3.03 cm) to triplet births (12.55 ± 3.38 cm). Contemporary research by Rezaei et al. [19] attributes such variations to mammary tissue adaptations responding to differential lactation requirements. Pre-milking udder length measurements displayed comparable trends (12.34 ± 1.74 cm vs 12.03 ± 2.43 cm vs 12.28 ± 2.33 cm).

Post-milking dimensional modifications revealed crucial insights into tissue elasticity patterns. Notably, post-milking udder length demonstrated significant variations between singleton (9.03 ± 1.25 cm) and triplet births (10.53 ± 2.20 cm). Recent investigations by Safayi et al. [20] suggest these variations reflect differences in mammary tissue architecture and milk storage capacity.

Post-milking udder width measurements followed similar patterns (9.89 ± 1.22 cm vs 11.45 ± 2.68 cm). Udder circumference measurements, both pre- and post-milking, provided comprehensive insights into production capacity. In singleton births, circumference reduced from 37.34 ± 4.17 cm to 29.97 ± 4.45 cm post-milking, while triplet births showed a reduction from 37.08 ± 6.95 cm to 32.20 ± 5.52 cm. Recent work by Sam et al. [21] correlates these dimensional changes with milk production volume and milking efficiency.

Table 2. The influence of the fixed effects of lactation age and birth type on milk production and the morphometrics of the udder-teat in PE goats.

Parameters	Lactation Age		Birth Type			Total Population (n = 105)
	< 90 Days (n = 75)	> 90 Days (n = 30)	Single (n = 19)	Twins (n = 66)	Triplets (n = 20)	
DMY (mL)	616.53±243.86^a	438.33±187.37^b	592.11±144.26	557.05±229.67	568.75±346.24	565.62±242.17
TLB (Cm)	11.80±2.77	13.00±3.69	11.95±3.14	12.08±3.03	12.55±3.38	12.14±3.09
UWB (Cm)	12.47±2.21^a	11.30±2.30^b	12.34±1.74	12.03±2.43	12.28±2.33	12.13±2.29
ULB (Cm)	12.44±2.57 ^a	11.80±2.70	12.13±1.73	12.09±2.61	12.93±3.27	12.26±2.61
UCB (Cm)	38.31±5.93^a	34.10±5.81^b	37.34±4.17	37.05±6.48	37.08±6.95	37.10±6.17
TLA (Cm)	10.27±1.90	11.30±2.66	10.13±1.85	10.61±2.24	10.80±2.30	10.56±2.18
UWA (Cm)	10.01±1.82^a	8.93±1.41^b	9.03±1.25^a	9.64±1.68^{ab}	10.53±2.20^b	9.70±1.77
ULA (Cm)	10.31±2.18	9.62±1.96	9.89±1.22^a	9.77±2.02^b	11.45±2.68^b	10.11±2.13
UCA (Cm)	31.83±4.98	29.90±4.07	29.97±4.45	31.38±4.66	32.20±5.52	31.28±4.80

Note: The bold numbers in each column of the variables indicate a highly significant difference (P < 0.01).

Table 3. Pearson correlation of milk production and udder-teat morphometrics in PE goats.

	DMY	TLB	UWB	ULB	UCB	TLA	UWA	ULA	UCA
DMY	1								
TLB	0.16	1							
UWB	0.31**	-0.28	1						
ULB	0.25**	-0.34	0.60**	1					
UCB	0.36**	-0.39	0.79**	0.57**	1				
TLA	0.11	0.88	-0.24	-0.24	-0.32	1			
UWA	0.14	-0.10	0.53**	0.41**	0.48**	-0.03	1		
ULA	0.15	-0.17	0.38	0.59**	0.28	-0.11	0.47	1	
UCA	0.12	-0.26	0.51**	0.34**	0.62**	-0.15	0.65**	0.39	1

Note: Bold values indicate significant correlations at the 0.01 level (2-tailed). ** denote highly significant (p < 0.01) correlations.

3.3 Pearson Correlation

The Pearson correlation analysis revealed significant relationships between daily milk yield (DMY) and several udder morphological parameters before milking, in Table 3. DMY demonstrated highly significant positive correlations (P<0.01) with udder width before milking (UWB; r=0.31), udder length before milking (ULB; r=0.25), and udder circumference before milking (UCB; r=0.36). These findings suggest that pre-milking udder dimensions could serve as potential predictors of milk production in PE goats. This observation aligns with research conducted by Can et al. [22] on Damascus goats, which reported positive correlations between udder size and milk production (r=0.42-0.68), highlighting the significance of udder morphological characteristics in production potential assessment.

The interrelationships amongst udder morphological parameters exhibited intriguing patterns. UWB showed particularly strong correlations with UCB ($r=0.79$) and ULB ($r=0.60$). This relationship reflects the proportionality of mammary tissue development, as elucidated by Torres-Vázquez et al. [23], who explained that udder dimensional development occurs in a coordinated manner to optimise milk storage capacity and production. Recent investigations by Ziadi et al. [24] further corroborated that proportional udder morphometry contributes to milk production efficiency.

Post-milking morphological parameters demonstrated weaker correlations with milk production compared to pre-milking measurements, suggesting that pre-milking udder capacity serves as a more reliable indicator of milk production potential. Nevertheless, strong positive correlations were observed between pre- and post-milking udder dimensions, as evidenced by the relationships between UWB and udder width after milking (UWA; $r=0.53$), and UCB with udder circumference after milking (UCA; $r=0.62$). Biffani et al. [25] emphasised that udder tissue elasticity, as reflected in dimensional changes during the milking cycle, plays a crucial role in maintaining optimal milk production.

Teat length before and after milking (TLB and TLA) exhibited relatively weak correlations with milk production parameters and other udder dimensions, indicating that teat characteristics may be more closely associated with milking functionality rather than milk production capacity. This finding is supported by Makamu et al. [14], who demonstrated that teat morphology has a greater influence on milking efficiency and udder health than milk volume production.

Overall, these correlation patterns affirm the importance of udder morphological characteristics, particularly pre-milking measurements, in evaluating the milk production potential of PE goats. Rupp et al. [26] suggested that understanding the relationship between udder morphology and milk production can facilitate the development of more effective selection programmes for enhancing milk productivity in dairy goat populations.

4 Conclusion

This study demonstrates that udder morphological characteristics in PE goats exhibit significant positive correlations with milk production, particularly in pre-milking measurements of udder width, length, and circumference. Milk production showed a significant decrease from early to late lactation periods, while birth type showed non-significant effects on daily milk yield. Post-milking measurements consistently showed reduction in udder dimensions across all birth types, with pre-milking measurements serving as more reliable indicators of milk production potential. These findings provide valuable insights for developing selection criteria in PE goat breeding programs, particularly for improving milk production traits in tropical regions.

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Ethical approval. The experimental procedure in this study was approved by the Institutional Animal Care and Use Committee (IACUC) of Universitas Brawijaya (Number: 003-KEP-UB-2024).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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