Research Article

Canonical Correlation Analysis to Estimate the Relationship Between Body Measurements at Post-Weaning and Yearling Ages in Bali Cattle

Graciano Lucky Scovier[1], Veronica Margareta Ani Nurgiartiningsih[1*], Marjuki Marjuki[1], Yuli Arif Tribudi[2], Gatot Ciptadi[1], Mashudi Mashudi[1], Muhammad Pramujo[1], Ahmad Furqon[3]

[1]Faculty of Animal Science, Universitas Brawijaya, Malang 65145, Indonesia; [2]Animal Science Study Program, Faculty of Agriculture, Universitas Tanjungpura, Pontianak 78124, Indonesia; [3]Research Center for Applied Zoology, National Research and Innovation Agency (BRIN), Bogor 16911, West Java, Indonesia.

Abstract | This study aimed to estimate the multivariate relationships between morphometric traits at post-weaning (205 days) and yearling (365 days) ages using Canonical Correlation Analysis (CCA). Data on body weight (BW), body length (BL), withers height (WH), and chest girth (CG) were collected from male and female Bali cattle (n = 210). Analysis revealed sexual dimorphism. CCA was performed on the combined dataset using sex-adjusted values. The first canonical function (CV1) demonstrated a highly significant correlation ($R_c = 0.733$; $P < 0.001$), indicating a strong association between the linear combinations of traits across growth stages. However, redundancy analysis showed that post-weaning traits explained only 33.7% of the total variance in yearling traits, indicating that the shared multivariate structure represents only part of the overall variability. Canonical loadings and standardized coefficients revealed that BW was the primary contributor to the canonical relationship, while other morphometric traits provided limited additional information.

Keywords | Bali cattle, Canonical correlation, Early selection, Morphometrics, Weaning weight

Received | February 15, 2026; **Accepted** | April 25, 2026; **Published** | July 18, 2026
***Correspondence** | Veronica Margareta Ani Nurgiartiningsih, Faculty of Animal Science, Universitas Brawijaya, Malang 65145, Indonesia; **Email:** vm_ani@ub.ac.id
Citation | Scovier GL, Nurgiartiningsih VMA, Marjuki M, Tribudi YA, Ciptadi G, Mashudi M, Pramujo M, Furqon A (2026). Canonical correlation analysis to estimate the relationship between body measurements at post-weaning and yearling ages in Bali cattle. Adv. Anim. Vet. Sci., 14(7):1496-1501.
DOI | https://dx.doi.org/10.17582/journal.aavs/2026/14.7.1496.1501
ISSN (Online) | 2307-8316

INTRODUCTION

Bali cattle (*B. javanicus domesticus*) are the most significant local cattle breed in Indonesia. Bali cattle exhibit heat stress tolerance, parasite resistance, and efficient utilization of low-quality feed resources (Anwar *et al*., 2025; Nurgiartiningsih *et al*., 2025). The designation of Bali cattle based on the Decree of the Minister of Agriculture of the Republic of Indonesia No. 325/KPTS/OT.140/1/2010, positions it as a genetic asset and plays an important role in national meat production.

Body weight (BW) and morphometric traits are selection criteria in the beef cattle industry. BW is used to assess health status, determine nutritional needs, and develop marketing strategies (Guo *et al*., 2012). In recent years, studies have examined the relationship between morphometric traits and BW, particularly to improve meat production efficiency (Faraz *et al*., 2021). In tropical cattle, morphometric traits such as chest girth (CG) are frequently associated with BW and carcass-related traits (Azis *et al*., 2023; Adinata *et al*., 2021). Relevant studies on morphometric measurements at various growth stages have been conducted; for example, Suhendro *et al*. (2024) reported a relationship between weaning age morphometric traits and subsequent growth performance in Bali cattle.

Canonical correlation analysis (CCA) is a multivariate technique designed to evaluate the relationship between two sets of variables by identifying linear combinations that maximize their correlation (Bilgin *et al*., 2003). Although Pearson correlation, multiple regression, and CCA share the commonality of being based on linear relationships, there are differences among the three. In multiple regression, several predictors are combined to explain a single response variable, whereas in CCA, both sets of variables are treated as composite linear combinations (Koskan *et al*., 2011). Morphometric traits are biologically interrelated and often exhibit multicollinearity, so analyzes based on separate correlation and regression may lead to fragmented interpretations of growth relationships.

The CCA method has been successfully applied in various contexts, such as estimating the relationship between body measurements and performance in Etawah crossbred goats (Husen *et al*., 2025), analyzing udder characteristics and body morphometry in Holstein cows (Ural and Baritci, 2013), and estimating body size relationships in crossbred goats (Çankaya and Kayaalp, 2007). Studies investigating the multivariate relationship between growth stages in Bali cattle are still limited. The objective of this study is to evaluate the relationship between morphometric traits at weaning and performance in later stages of age using canonical correlation.

MATERIALS AND METHODS

Animals and data collection

Data were collected from the Breeding Center (BPTU-HPT) Denpasar, a primary site for the genetic improvement of Bali cattle in Indonesia. A total of 210 Bali cattle (105 males and 105 females) with complete morphometric records were utilized in this study. Cattle were maintained under a herd management system, with the population divided according to age, sex, and health status. Feeding is done twice a day, consisting of forage in the morning and concentrate feed in the afternoon, as well as ad libitum drinking water. Measurements were recorded at two distinct growth stages: weaning age (205 days) and yearling age (365 days). Body weight (BW) and three linear body measurements: chest girth (CG), body length (BL), and withers height (WH) were recorded for each animal. BW was measured using a calibrated ID3000 digital scale (True-Test Limited, New Zealand) with 1% accuracy; the scale was calibrated bi-annually to ensure precision. Linear body measurements were taken while the animals were restrained in a cattle crush to minimize movement. A standard measuring tape was used for CG and BL, while a measuring stick was employed for WH. Body measurements were recorded in centimeters (cm) and body weight in kilograms (kg). Measurement followed standardized protocol performed by a trained operator.

Statistical analysis

All statistical analyses were performed using R Studio software (version 4.4.3). Descriptive statistics, including mean and standard deviation, were calculated for all traits. The t-test is used to explain sex differences, with significance determined at the threshold of $P < 0.01$. The Levene's test was applied to assess the homogeneity of variances between male and female groups for each morphometric trait. The residual values from the linear model (trait ~ sex) are used to control for potential sex bias in correlation and canonical correlation analyzes. Pearson correlation coefficients were calculated to evaluate bivariate linear relationships. The Variance Inflation Factor (VIF) was additionally calculated to quantify the degree of multicollinearity among morphometric predictors (post-weaning age). Univariate normality was assessed using the Shapiro–Wilk test. Box's M test is used for multivariate homogeneity. Multivariate outliers were assessed using Mahalanobis distance at a 97.5% confidence level. Canonical Correlation Analysis (CCA) was subsequently applied to determine the magnitude of relationships between the two multivariate sets: morphometric traits at post-weaning age (set X) and morphometric traits at yearling age (set Y). The multivariate analysis utilized the 'CCA' package to compute canonical correlations and coefficients, while the 'CCP' package was used to assess the statistical significance of the canonical roots using Wilks' Lambda test. The canonical variates for the first pair are defined as:

$$U_1 = -0.914\ BW_{205} + 0.033\ BL_{205} - 0.133\ WH_{205} - 0.022\ CG_{205}$$
$$V_1 = -0.945\ BW_{365} + 0.008\ BL_{365} + 0.048\ WH_{365} - 0.108\ CG_{365}$$

Limitations

Although this study provides important insights into the multivariate relationships among morphometric traits in Bali cattle, several limitations should be acknowledged. The data were obtained from a single breeding center (BPTU-HPT), and therefore the findings may reflect specific management, environmental conditions, and genetic backgrounds, which may not fully represent the broader Bali cattle population. CCA applied in this study is exploratory and descriptive in nature; thus, the results require further validation using independent datasets. Future studies are expected to include more diverse populations from multiple locations, as well as integrate genetic and environmental factors. Nevertheless, this study provides an important initial foundation for understanding the role of morphometric traits in explaining early growth patterns in Bali cattle.

RESULTS AND DISCUSSION

Morphometric measurements of Bali cattle

Descriptive statistics for morphometric traits at post-weaning (205 days) and yearling (365 days) ages are presented in Table 1. The increase in BW in males (+ 63.63 kg) than in females (+ 61.41 kg). Similarly, males showed greater gains in BL and CG. The most notable difference was observed in male WH, which experienced a higher increase (+ 13.47 cm) compared to females (+ 4.92 cm), indicating a faster skeletal growth rate.

Male calves showed greater increases in body weight and body dimensions than females; however, only BL and WH were statistically significant (P < 0.01). Sex and age significantly affect the development of body size in Bali cattle (Rachma *et al*., 2011). Recently, Setiaji *et al*. (2025) showed that Bali cattle have specific growth patterns based on gender, where males tend to reach a higher adult body weight, while females experience faster growth in the early phase but reach a smaller final size. This difference may be related to females reaching skeletal maturity earlier than males (Sampurna *et al*., 2014). Several studies link sexual dimorphism to hormonal roles, including androgens, to stimulate height growth in males (Chacur *et al*., 2018; Kholghi *et al*., 2020; Brito, 2021; Doyle *et al*., 2021). Nevertheless, the patterns of development and growth are generally influenced by various factors such as genetic growth potential, sex, hormones, environment, rearing conditions, and management systems, but the level of feed nutrition is the main factor.

Pearson correlation among morphometric traits

The Pearson correlation analysis revealed that all morphometric trait pairs exhibited positive and significant correlations (P < 0.05), with coefficients ranging from low (r = 0.28) to very high (r = 0.86) (Figure 1). A distinct pattern was observed within age groups. At the post-weaning age, a remarkably strong correlation was found between skeletal dimensions, specifically between BL-WH (r= 0.86). Meanwhile, the relationship between BW-CG remained consistently strong at both post-weaning (r= 0.76) and yearling (r= 0.84) ages. These findings align with recent studies on tropical cattle (Hlokoe *et al*., 2022; Misrianti *et al*., 2023; Nurgiartiningsih *et al*., 2026), reaffirming CG as a single morphometric indicator that is sufficiently predictive for estimating BW in field conditions.

In terms of predictive potential across growth stages, weaning weight demonstrated a strong linear correlation with yearling weight (r= 0.73). This suggests that calves heavier at weaning have a high probability of maintaining their weight advantage at yearling age, supporting the efficacy of early selection based on mass. However, a different trend was observed for linear skeletal traits. The correlations between weaning and yearling dimensions for BL (r= 0.31) and WH (r= 0.34) were weak. This low correlation implies that skeletal frame size at weaning is not a definitive predictor of frame size at the yearling age. This discrepancy may be attributed to individual variations in skeletal maturity rates or non-linear growth spurts during the post-weaning transition. Furthermore, the presence of very strong correlations (r > 0.70) among independent variables (e.g., between BL and WH at post-weaning) confirms the existence of multicollinearity.

Canonical correlation analysis (CCA) between age groups

The multivariate relationship between body dimensions at the post-weaning age (Set X) and yearling age (Set Y) was evaluated using CCA. The multivariate significance test (Table 3) revealed that among the four canonical functions constructed, only the first canonical variate (CV1) was statistically significant (P < 0.001). The interpretation focuses on CV1. Multicollinearity in the predictor variables (post-weaning age) was assessed using the variance inflation factor (VIF). As presented in Table 2, the level of collinearity remained within acceptable limits (VIF < 5), thus being considered reliable for inclusion in the multivariate model without causing instability in parameter estimates.

Table 1: Descriptive statistics of morphometric traits in Bali cattle.

Variable	Weaning			Yearling		
	Male	Female	Levene's test (P-value)	Male	Female	Levene's test (P-value)
BW	92.36±16.51	90.31±17.11	0.713	155.99±26.59	151.72±24.07	0.264
BL	87.56±6.91[a]	90.37±6.49[b]	0.206	101.85±5.44[a]	103.82±5.09[b]	0.336
WH	93.00±6.31[a]	95.43±5.86[b]	0.105	106.47±5.96[a]	100.35±5.88[b]	0.690
CG	110.27±9.22	109.61±8.61	0.672	133.48±9.88	131.96±7.31	0.049

Notes: Values are presented as mean ± standard deviation. Different superscripts (a,b) within the same age group indicate significant differences between sexes (P < 0.01).

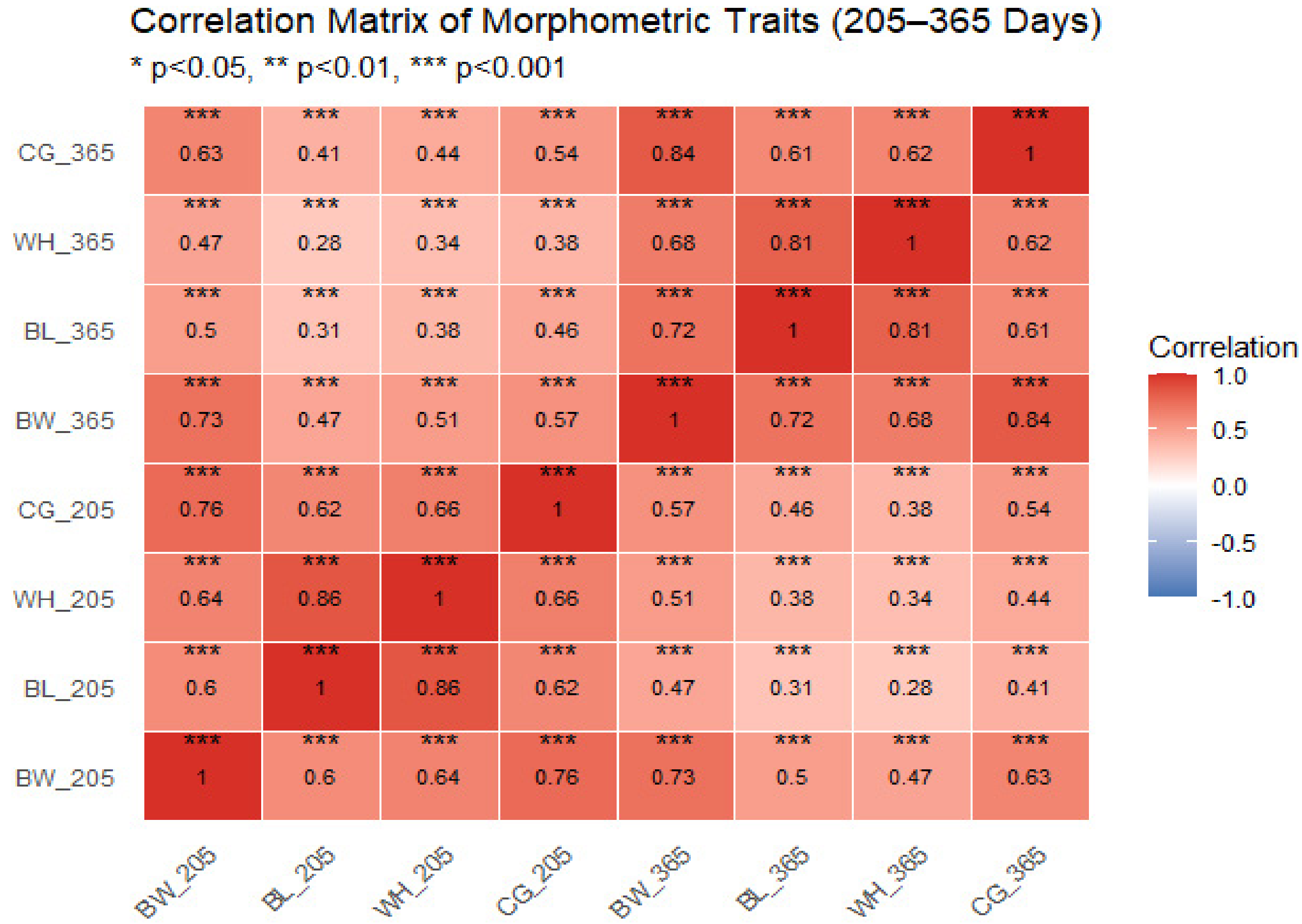

Figure 1: Pearson correlation matrix among morphometric traits in Bali cattle. Values represent correlation coefficients, while color gradients indicate the strength and direction of relationships (red = positive, blue = negative).

Table 2: Variance inflation factor (VIF) at post-weaning age.

Variable	VIF
BL	3.82
WH	4.17
CG	1.81

Table 3: Summary result for the CCA.

Canonical function	R_c	R_c^2	Redundancy (X→Y)	Redundancy (Y→X)	P value
CV1	0.733	0.537	0.337	0.357	0.000
CV2	0.209	0.044	0.004	0.004	0.273
CV3	0.094	0.009	0.0003	0.001	0.746
CV4	0.025	0.001	0.0002	0.00006	0.716

The canonical correlation (R_c) for CV1 was 0.733, indicating a strong association between body measurements at weaning and yearling ages. The squared canonical correlation (R_c^2) of 0.537 suggests that the canonical variate of the post-weaning trait set explains 53.7% of the variance in the canonical variate of the yearling trait set. In practical terms, the redundancy index provides a more informative measure: post-weaning traits explain 33.7% of the total variance in yearling traits. This indicates that while the multivariate pattern of early growth traits is strongly associated with later growth patterns, its ability to explain the overall variation in individual yearling traits remains moderate.

Canonical structure and key growth determinants

The interpretation of the relationship structure is based on canonical loadings and cross-loadings, while standardized canonical coefficients are used to assess the unique contribution of each variable (Table 4). The canonical loadings revealed that BW at post-weaning (r_s = -0.996) overwhelmingly dominated the first canonical variate, indicating that this dimension is primarily driven by BW. CG showed a relatively high loading (rs = -0.785), its contribution appears to be largely redundant due to its strong correlation with BW. This pattern is further supported by the standardized canonical coefficients, where BW exhibited a substantial coefficient (−0.914), while BL, WH, and CG had coefficients close to zero. Therefore, CV1 interpreted as a body mass-related dimension.

Table 4: Standardized Coefficients, Canonical Loadings, and Cross-Loadings for the first canonical variate pair (CV1).

Set	Variable	Std. Canonical Coeff.	Canonical loading (r_s)	Cross-loading (r_c)
X (Weaning)	BW	-0.914	-0.996	-0.730
	BL	0.033	-0.640	-0.469
	WH	-0.133	-0.702	-0.515
	CG	-0.022	-0.785	-0.575
Y (Yearling)	BW	-0.945	-0.998	-0.731
	BL	0.008	-0.698	-0.511
	WH	0.048	-0.653	-0.478
	CG	-0.108	-0.866	-0.635

Notes: Std. canonical coefficients represent the unique contribution of each variable to the canonical variate after accounting for multicollinearity. Canonical loadings (rs) indicate the correlation between each variable and its own canonical variate. Cross-loadings (rc) represent the correlation between each variable and the canonical variate of the opposite set. Negative signs reflect the direction of the relationship and do not affect the magnitude of interpretation.

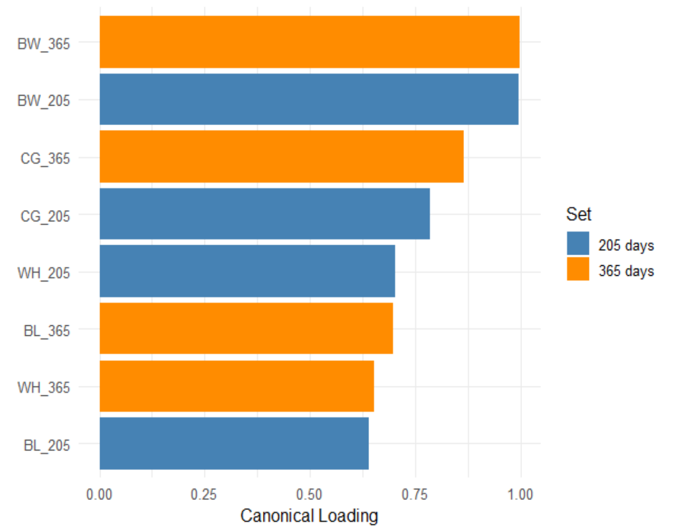

Figure 2: Canonical loadings of morphometric traits on CV1 in Bali cattle.

Cross-loadings analysis highlighted the relative contribution of post-weaning traits to the multivariate structure of yearling performance. Weaning weight (BW_{205}) showed the highest cross-loading (-0.730), indicating that it is the most strongly associated individual trait with the canonical variate of yearling measurements. Cross-loadings reflect how well variables in one set predict the canonical variate of the opposite set. Consequently, BW can be considered a practical proxy trait for summarizing overall morphometric growth in this population.

Although the canonical correlation is strong (R_c = 0.733), the post-weaning trait set explains only 33.7% of the total variance in the yearling trait set. This indicates that the shared multivariate structure captured by the canonical variates represents only a portion of the overall variability in individual yearling traits. In practical terms, this suggests that post-weaning measurements provide moderate but incomplete information about subsequent growth performance. While early body weight captures an important component of growth continuity, a substantial proportion of variation remains unexplained.

CONCLUSION

This study demonstrates that weaning body weight is the primary factor underlying growth continuity from weaning to the yearling stage in Bali cattle. While post-weaning morphometric traits provide moderate information of 33.7% on subsequent growth, a substantial proportion of the variation remains unexplained. Most of the variation in yearling performance is influenced by other factors.

ACKNOWLEDGEMENTS

The authors are grateful to the Beasiswa Unggulan Program of the Ministry of Research and Technology of the Republic of Indonesia for supporting both the educational program and the implementation of this research. The authors also express their sincere appreciation to the Head and staff of the Breeding Center (BPTU-HPT) Denpasar, Indonesia, for their assistance during field data collection.

NOVELTY STATEMENT

This study applies Canonical Correlation Analysis (CCA) to evaluate the complex relationship structure between body measurement traits at the post-weaning (205 days) and yearling (365 days) stages. The findings demonstrate that weaning body weight is the primary factor underlying growth continuity in Bali cattle from the weaning to the yearling stage.

This study applies Canonical Correlation Analysis (CCA) to evaluate the complex relationship structure between body measurement traits at the post-weaning (205 days) and yearling (365 days) stages. The findings demonstrate that weaning body weight is the primary factor underlying growth continuity in Bali cattle from the weaning to the yearling stage.

AUTHOR'S CONTRIBUTION

All authors participated in the design of the methodology, data analysis, and writing of the protocol. GLS wrote the first draft of the manuscript. VMAN, MM, AF, GC, MM, and MP supervised and reviewed the manuscript. YAT

Links Researchers

collected data and reviewed the manuscript.

Ethics approval

The design of this study has been approved by the Research Ethics Commission, Universitas Brawijaya (No. 126/EC/KEPK/05/2025).

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Adinata Y, Noor RR, Priyanto R, Cyrilla L, Sudrajad P (2023). Morphometric and physical characteristics of Indonesian beef cattle. Arch. Anim. Breed., 66(2): 153-161. https://doi.org/10.5194/aab-66-153-2023

Anwar S, Shidiq F, Noor RR, Semiadi G, Dharmayanthi AB, Furqon A, Jakaria J (2025). The complete mitochondrial genome assembly of Bali cattle (*Bos javanicus*) using Oxford nanopore long-read sequencing technology. Gene, 149706. https://doi.org/10.1016/j.gene.2025.149706

Azis R, Ciptadi G, Wahjuningsih S, Hariyono DNH, Tribudi YA, Nurgiatiningsih VMA (2023). Prediction of body weight from body measurements in Bali cattle of Indonesia using regression analysis. Adv. Anim. Vet. Sci., 11(9): 1486-1491. https://doi.org/10.17582/journal.aavs/2023/11.9.1486.1491

Bilgin OC, Emsen E, Davis ME (2003). An application of canonical correlation analysis to relationships between the head and scrotum measurements in Awassi fat tailed lambs.

Brito LF (2021). Sexual development and puberty in bulls. Bovine reproduction, pp. 58-78. https://doi.org/10.1002/9781119602484.ch6

Çankaya S, Kayaalp GT (2007). Estimation of relationship between live weights and some body measurements in German farm x hair crossbred by canonical correlation analysis. J. Anim. Prod., 48(2).

Chacur M, Arikawa A, Oba E, Souza C, Gabriel FLR (2018). Influence of testosterone on body and testicular development in Zebu cattle in the tropical climate. Adv. Testost. Action, pp. 91-108. https://doi.org/10.5772/intechopen.76706

Doyle JL, Purfield DC, Moore T, Carthy TR, Walsh SW, Veerkamp RF, Berry DP (2021). Identification of genomic regions that exhibit sexual dimorphism for size and muscularity in cattle. J. Anim. Sci., 99(5): skab070. https://doi.org/10.1093/jas/skab070

Faraz A, Tirink C, Eyduran E, Waheed A, Tauqir NA, Nabeel MS, Tariq MM (2021). Prediction of live body weight based on body measurements in Thalli sheep under tropical conditions of Pakistan using CART and MARS. Trop. Anim. Health Prod., 53(2): 301. https://doi.org/10.1007/s11250-021-02748-6

Guo J, Jorjani H, Carlborg Ö (2012). A genome-wide association study using international breeding-evaluation data identifies major loci affecting production traits and stature in the Brown Swiss cattle breed. BMC Genet., 13(1): 82. https://doi.org/10.1186/1471-2156-13-82

Hlokoe VR, Tyasi TL (2022). Nguni cattle body weight estimation using regression analysis. J. Anim. Health Prod., 10(3): 375-380. https://doi.org/10.17582/journal.jahp/2022/10.3.375.380

Husen AF, Suyadi PY, Sairi M, Nurgiartiningsih VMA (2025). Phenotypic characterization and canonical correlation analysis at weaning and eight month period of Indonesian Etawah (PE) goats. Adv. Anim. Vet. Sci., 13(4): 798-808. https://doi.org/10.17582/journal.aavs/2025/13.4.798.808

Kholghi M, Rostamzadeh J, Razmkabir M, Heidari F (2020). Blood testosterone level affects sex ratio of bull semen. Concepts Dairy Vet. Sci., 4(1): 363-369.

Koşkan Ö, Önder EG, Şen N (2011). Değişken setleri arası ilişkinin tahmini için kanonik korelasyon analizinin kullanımı. J. Inst. Sci. Technol., 1(2): 117-123.

Misrianti R, Ali A, Fitra D, Djuliyanto E, Safira N, Aswan A (2023). Analysis of morphometric features and development of a regression model for predicting the body weight of Kuantan cattle. J. Ilmu-Ilmu Petern., 33(3). https://doi.org/10.21776/ub.jiip.2023.033.03.14

Nurgiartiningsih VMA, Rinaldi R, Husen AF, Pramujo M, Novianti I, Marjuki M, van der Werf J (2026). Morphometric traits increase genetics selection accuracy for body weight in Bali cattle. Ital. J. Anim. Sci., 25(1): 23-31. https://doi.org/10.1080/1828051X.2025.2606507

Rachma AS, Harada H, Ishida T (2011). The estimation of growth curve of Bali cattle at Bone and Barru districts, South Sulawesi, Indonesia using ten body measurements. J. Indones. Trop. Anim. Agric., 36(4): 228-236. https://doi.org/10.14710/jitaa.36.4.228-236

Sampurna IP, Saka IK, Oka GL, Putra S (2014). Patterns of growth of Bali cattle body dimensions. ARPN J. Sci. Technol., 4(1): 20-30.

Setiaji A, Lestari DA, Da'i MAM, Gariri PN, Sutopo S, Prahara PG, Kamila FT, Philco SV, Haris FZ (2025). The evaluation for recent growth performance of Bali cattle using non-linear models. Yuzuncu Yil Univ. J. Agric. Sci., 35(2): 299-308. https://doi.org/10.29133/yyutbd.1646048

Suhendro I, Jakaria J, Priyanto R, Manalu W, Hartono S, Noor RR (2024). Comparison of growth traits of male Bali cattle (*Bos javanicus*) with different adult coat colors. Trop. Anim. Sci. J., 47(1): 25. https://doi.org/10.5398/tasj.2024.47.1.25

Ural DA, Barıtcı İ (2013). Determination of relationship between some udder and body traits of Holstein cows by canonical correlation analysis. Kocatepe Vet. J., 6(1): 11-17. https://doi.org/10.5578/kvj.5476