Optimizing Body Weight Prediction in Bali Cattle Using Morphometric Traits and Principal Component Regression

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Abstract. This study aims to predict the body weight of Bali cattle using morphometric measurements through correlation analysis, multiple regression, and principal component analysis (PCA). A total of 54 female Bali cattle, consisting of 24 two-year-old and 30 three-year-old cows, were measured for body weight (BW), body length (BL), body height (BH), chest circumference (CC), chest width (CW), and chest depth (CD). Correlation analysis showed that BW had the strongest positive relationship with CC in both age groups (r = 0.87 and r = 0.91, respectively). Stepwise multiple regression produced accurate prediction models with high coefficients of determination (R^2 = 0.823 for two-year-old and R^2 = 0.891 for three-year-old). PCA identified CC, BL, and BH as the main contributors to body size variation, with PC1 explaining 61.97% of the total variance. Principal component regression (PCR) using PC1 and PC2 produced a robust predictive model (R^2 = 0.80). These results indicate that the BW of Bali cattle can be accurately estimated using simple morphometric measurements, and PCA provides an effective approach to reduce multicollinearity and improve prediction stability in field conditions.
Keywords: Bali cattle, body weight prediction, correlation, regression.

1 Introduction

Bali cattle are one of Indonesia's indigenous livestock genetic resources, originating from the domestication of banteng (*Bos javanicus*) approximately 3,500 years ago. Bali cattle have a distinct phenotype from *Bos taurus*, which is believed to be related to differences in genetic background and chromosome shape and structure that affect the regulation and expression of growth and adaptation traits [1]. These cattle are known for adapting well to tropical environments, resilience to heat stress and efficient utilisation of low-quality feed [2]. Because of these traits, small-scale farmers in rural areas often raise Bali cattle under semi-intensive and extensive systems.

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Measuring body weight (BW) is important in managing beef cattle, especially to determine nutritional needs, reproductive status, and health condition [3]. Ideally, BW is measured with a weighing scale. However, many traditional farms in rural areas do not have access to such equipment. As a result, farmers estimate BW using body size measurements.

Linear regression models that use predictors such as body length (BL), chest circumference (CC), body height (BH), and chest width (CW) have been widely applied to estimate BW. However, the strength of the relationship between BW and these measurements can vary with breed, age, sex, and body condition. Therefore, a model designed specifically for Bali cattle is needed. Previous studies have proposed such models [4-7]. However, linear regression can be less effective when predictors are highly correlated. This multicollinearity may cause redundant information, larger variation in the regression coefficients, and lower predictive reliability [8].

Principal Component Analysis (PCA) can address this issue by transforming correlated measurements into a smaller set of independent components while retaining most of the original variation. However, the use of PCA to estimate BW in Indonesian local cattle is still limited. Therefore, this study aims to identify the main components of Bali cattle using PCA and to develop a model that estimates BW from those components. The study also evaluates the performance of this PCA-based model compared to standard linear regression.

2 Materials and methods

2.1 Ethical Approval

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

2.2 Animals and Data Collection

This research was conducted at the UPTD-PTHPT (Plantation and Livestock Development Unit) in Penajam Paser Utara Regency, East Kalimantan Province (coordinates: 1°25'04.3"S 116°34'23.8"E). This area is a centre for Bali cattle breeding in Indonesia. A total of 54 female Bali cattle were collected and grouped by age (two years and three years). Data collection lasted two weeks in September 2025. Two- and three-year-old cattle were selected because they represent a stable adult phenotype and are commonly used as breeding stock, making them relevant for body weight prediction and selection purposes. The management system implemented is flock management. The cattle population is divided by age, mating group, and health status. Each flock receives unlimited access to drinking water. Feed is provided twice daily: *Pennisetum purpureum* forage in the morning and concentrate feed in the afternoon.

The morphometric traits recorded included body weight (BW), body length (BL), body height (BH), chest circumference (CC), chest width (CW), and chest depth (CD). Body weight was measured using a livestock scale, while morphometric traits were measured using a measuring stick and tape.

Table 1. Body morphometric measurements in Bali cattle.

No	Variable	Measurement Scale
1	Body weight (BW)	Measured using a calibrated digital scale; the animal is placed in a weighing cage.
2	Body length (BL)	Measured from the humeral tubercle to the ischial tubercle.
3	Body height (BH)	Measured directly behind the scapula, from the dorsal point to the ground.
4	Chest circumference (CC)	Measured directly behind the scapula, with the measuring tape wrapped tightly around the body.
5	Chest width (CW)	Measured from the left humeral tubercle to the right humeral tubercle.
6	Chest depth (CD)	Measured directly behind the scapula, from the dorsal point to the ventral point.

2.3 Data Analysis

Statistical analysis was performed using R Studio software. Descriptive statistics (mean, standard deviation, coefficient of variation, minimum, and maximum) were calculated for each trait in both age groups. The Pearson correlation coefficient (a measure of linear association between two variables) was used to determine the strength of the relationship between body weight (BW) and body size. Stepwise multiple regression analysis was conducted separately for each age group to develop a BW prediction equation. The R^2 value (coefficient of determination), model correlation coefficient (R), standard error of estimate (SEM; an indicator of prediction accuracy), and root mean square error (RMSE; a measure of the average magnitude of prediction errors) were used to assess model accuracy.
The Pearson correlation model can be expressed as follows:

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2}\sqrt{\sum(y_i-\bar{y})^2}} \quad (1)$$

Where
r = Pearson correlation coefficient
xi,yi = Observed values of variables X and Y
x̄, ȳ = Mean of variables X and Y
n = Number of observations

The multiple regression model for BW prediction can be expressed as follows:

$$BW = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon \quad (2)$$

Where
BW = Body weight (dependent variable)
β0 = Intercept (constant term)
β1, β2, …, βk = Regression coefficients for each predictor variable
X1, X2, …, Xk = Predictor variables (body size traits)
k = Number of predictor variables in the model
ε (epsilon) = Error term (unexplained variation/residuals)

Principal Component Analysis (PCA) was performed on body size variables after standardization (z-score normalization) to eliminate the influence of unit differences. Principal components were selected based on eigenvalues >1 and proportion of variance. Standard deviation, eigenvalue, and contribution to total variance were calculated for each component. A loading matrix was used to identify the body variables that contributed most to PC1 and PC2. Visualization was performed using biplots and individual plots to examine morphometric distribution patterns across age groups. In Principal Component Regression (PCR), significant principal components (PC1 and PC2) were used as predictors in a BW regression model. The performance of the PCR model was evaluated using R^2, r, SEM, and RMSE values and compared with a conventional regression model.
The PCR model can be expressed as:

$$BW = \alpha_0 + \alpha_1 PC_1 + \alpha_2 PC_2 + \varepsilon \quad (3)$$

Where
BW = Body weight (dependent variable)
α0 = Intercept
α1, α2 = Regression coefficients of principal components
PC1, PC2 = Significant principal components used as predictors
ε = Error term

3 Results and discussion

3.1 Descriptive Statistics

Body size (BL, BH, CC, CW, CD) increased with age in Bali cattle (Table 2). The average BW of two-year-old cattle was 173.62 kg, increasing to 229.00 kg at three years of age. CC exhibited substantial growth, rising from 136.40 cm to 148.93 cm. This suggests that CC growth is influenced by feed provision and cattle age. Variation analysis showed that CW had the highest CV in the entire population (15.24%), indicating considerable diversity in chest shape among individuals. BH had the lowest CV (4.34%).

Table 2. Descriptive Statistics of Overall Population

	Variable	n	Mean	SD	CV	Min	Max
Overall Population	BW (kg)	54	204.38	41.77	20.43	127	317
	BL (cm)	54	108.43	7.66	7.06	92	123
	BH (cm)	54	107.98	4.69	4.34	99	117
	CC (cm)	54	143.36	9.80	6.84	125	165
	CW (cm)	54	21.62	3.29	15.24	10	28
	CD (cm)	54	55.38	5	9.04	45	66
2 years old	BW (kg)	24	173.62	24.55	14.14	127	228
	BL (cm)	24	103.67	6.64	6.40	92	117
	BH (cm)	24	105.49	4.48	4.25	99	117
	CC (cm)	24	136.40	7.13	5.23	125	152
	CW (cm)	24	20.46	3.50	17.11	10	26
	CD (cm)	24	53.96	3.71	6.88	47	62
3 years old	BW (kg)	30	229.00	36.08	15.75	163	317

	BL (cm)	30	112.25	6.20	5.52	99	123
	BH (cm)	30	109.98	3.89	3.53	103	117
	CC (cm)	30	148.93	7.95	5.34	132	165
	CW (cm)	30	22.57	2.85	12.62	17	28
	CD (cm)	30	56.53	5.64	9.98	45	66

3.2 Correlation and Regression Analysis

Tables 3 and 4 show that BW has a very strong positive correlation with CC, both in two-year-old (r = 0.87) and three-year-old cattle (r = 0.91). A very strong positive correlation between BW and CC was also found in Bali [1], Kuantan [9] and Nguni cattle [10]. CC is closely related to meat production and can therefore be used as an index of cattle production performance [11]. Changes in CC size are usually influenced by the addition of muscle tissue, fat accumulation, foetal growth, and body growth. BH showed a low correlation with BW, especially in the three-year-old age group (r = 0.26). This finding can be attributed to the growth pattern of Bali cattle, which follows a sigmoid curve. In a sigmoid growth curve, BH tends to reach the adult phase earlier than other parameters, such as CC and CW. As age increases, BH growth slows down, making its contribution to BW variation relatively small [12].

The multiple linear regression model involving several body measurements (BL, BH, CW, CC, CD) provides a higher prediction accuracy value compared to the single-variable model. In three-year-old cattle, the multivariable model yielded an R^2 value of 0.89 with an RMSE of 11.69. This indicates that the multivariate approach is capable of providing a more comprehensive picture of body size.

Table 3. Regression equation for predicting body weight from body size of two-year-old Bali cattle

Model	P-value	RMSE	SEM	r	R^2
BW= -79,595+2,442BL	0,000	18,04	18,43	0.66	0,44
BW= -119,037+2,774BH	0,011	20,73	21,17	0.51	0,26
BW= 77,004+4,722CW	0,000	17,76	18,14	0.67	0,45
BW= -235,570+3,000CC	0,000	11,79	12,05	0.87	0,76
BW= -39,571+3,951CD	0,002	19,27	19,68	0.60	0,36
BW= -235,212+2,091CC+0,320CD+1,382CW+0,725BL+0,026BH	0,000	10,11	10,33	0,91	0,82

Table 4. Regression equation for predicting body weight from body size of three-year-old Bali cattle.

Model	P-value	RMSE	SEM	r	R^2
BW= -181.314+3.655BL	0,000	27.60	28.07	0.63	0.39
BW= -32.687+2.379BH	0.171	34.28	34.87	0.26	0.07
BW= 41.326+8.316CW	0,000	26.75	27.21	0.66	0.43
BW= -385.966+4.129CC	0,000	14,72	14,97	0.91	0,83
BW= 64,248+2,914CD	0,011	31.57	32.11	0.46	0,21
BW= -534.351+3.560CC+-0.675CD+1.229CW+1.266BL+0.921BH	0,000	11.69	11.89	0,94	0.89

3.3 Principal Component Analyses (PCA)

Body measurements such as BH, CW, and CC have a strong correlation with BW. Figure 2 shows that the principal components (PCs) are evenly distributed across the three-year age group and exhibit high variation in the two-year age group. The high variation in the two-year age group is due to the fact that Bali cattle are still in an active growth phase. The PC scores for Bali cattle body measurements, along with their cumulative proportions, variance proportions, and eigenvalues, can be seen in Table 5.

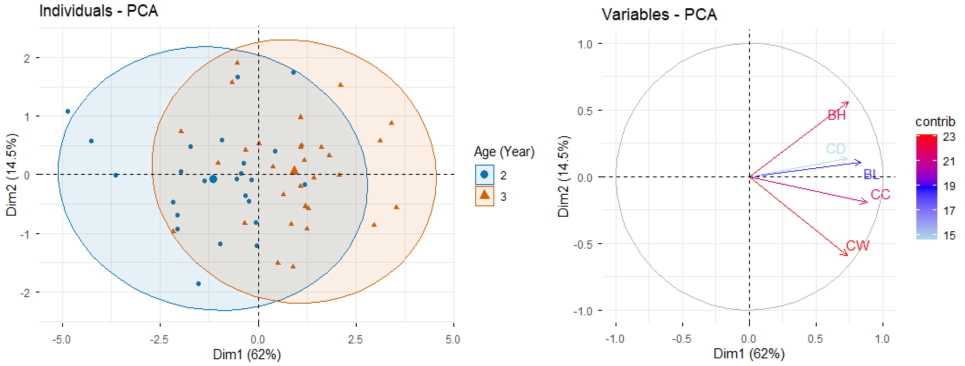

Figure 1. Individual PCA of body measurements in Bali cattle

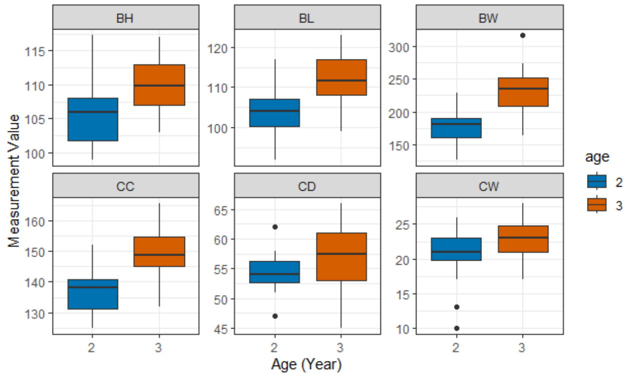

Figure 2. Boxplot of morphometrics and body weight based on age

PCA produced four main components (PC1, PC2, PC3, and PC4), with PC1 explaining 61.97% of the total variation in body morphometry of Bali cattle. This indicates that most of the information on body size in Bali cattle is concentrated in PC1. There are variations in PC1 values across different types of cattle, including [13] reporting 38.54% for Bali cattle, 85.71% for OG cattle [8], and 47.89% for Pasundan cattle [14]. Adding PC2 increased the cumulative proportion to 76.51%, making these two components considered sufficiently representative to describe the structure of morphometric variation in Bali cattle in this study. Furthermore, the PC1 eigenvalue of 3.098 (>1) indicates that a regression model using only one PC is sufficient for predicting the BW of Bali cattle.

Table 5. The Principal components scores, cumulative proportion, proportion of total variance, and eigenvalues for Bali cattle.

	PC1	PC2	PC3	PC4
Standard deviation	1.760	0.852	0.763	0.588
Proportion of variance (%)	61.97	14.53	11.66	6.92
Cumulative proportion (%)	61.97	76.51	88.17	95.09
Eigen value	3.098	0.726	0.583	0.346

The correlation between body size variables and PCs is presented in Table 6. On PC1, all morphometric variables showed strong positive correlation values, especially CC at 0.882, BL at 0.834, BH at 0.741, CW at 0.732, and CD at 0.73. These findings support previous studies reporting that CC is the best indicator for estimating BW in various cattle breeds because it is related to chest cavity capacity and tissue deposition. PC2 shows a different correlation pattern, namely BH is positively correlated at 0.557 and CW is negatively correlated at –0.592. This contrasting pattern illustrates body conformation.

Table 6. Correlation table of body size variables with principal components

	PC1	PC2	PC3	PC4
BL	0.834	0.110	-0.384	-0.270
BH	0.741	0.557	-0.121	0.342
CW	0.732	-0.592	-0.023	0.318
CD	0.736	0.132	0.646	-0.103
CC	0.882	-0.191	-0.056	-0.211

3.4 PCA-Based Weight Prediction Model (PCR)

The PCA-based BW prediction model is presented in Table 7. The resulting regression model is BW = 204.387 + 20.747(PC1) - 7.789(PC2). For biological interpretation, the model was transformed back to the original morphometric variables, resulting in BW = 204.387 + 16.447BL + 11.040BH + 19.789CW + 14.234CD + 19.780CC. The largest coefficients are found in CW and CC, indicating that chest width and circumference are the main predictors of BW. The VIF values for all variables are < 3 (see Table 8), indicating no significant multicollinearity in the Bali cattle population sample.

Table 7. PCA based weight prediction model (PCR)

Model	p-value	RMSE	SEM	r	R^2
BW= 204.387+20.747(PC1) –7.789(PC2)	0.000	18.30	2.51	0.79	0.80
Transformation from PCA to original data					
BW= 204.387+16.447BL+11.040BH+19.789CW+14.234CD+19.780CC					

Table 8. Variance inflation factor (VIF)

Variable	VIF
BL	2.34
BH	1.79
CW	1.78
CD	1.63
CC	2.84

From a practical perspective, the PCA-based prediction model developed in this study is suitable for field conditions where weighing facilities are unavailable. The use of easily measured traits such as chest circumference and chest width allows farmers and breeding centers to estimate body weight more accurately, supporting feed management, health monitoring, and selection of breeding stock in Bali cattle production systems.

4 Conclusion

CC was the best predictor of BW across all age groups of Bali cattle. Multicollinearity among morphometric variables was within acceptable limits, and PCA effectively stabilized the regression model. The PCA-based prediction model provides high accuracy in estimating BW. Future research should include larger populations and explore integrating body condition or genetic markers to further improve prediction precision and selection efficiency.

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References

1. Ashari, M., Busono, W., & Nurgiartiningsih, A. (2012). Analysis of chromosome and karyotype in Bali cattle and Simmental-Bali (Simbal) crossbreed cattle. *Pakistan journal of biological sciences: PJBS*, *15*(15), 736-741. Available from: https://doi.org/10.3923/pjbs.2012.736.741
2. Nurgiartiningsih, V. M. A., Rinaldi, R., Husen, A. F., Pramujo, M., Novianti, I., Marjuki, M., Septian, W. A., & van der Werf, J. (2026). Morphometric traits increase genetics selection accuracy for body weight in Bali cattle. Italian Journal of Animal Science, 25(1), 23–31. Available from: https://doi.org/10.1080/1828051X.2025.2606507
3. Cominotte, A., Fernandes, A. F. A., Dorea, J. R. R., Rosa, G. J. M., Ladeira, M. M., Van Cleef, E. H. C. B., Pereira, G. L., Baldassini, W. A., & Neto, O. R. M. (2020). Automated computer vision system to predict body weight and average daily gain in beef cattle

during growing and finishing phases. Livestock science, 232, 103904. Available from: https://doi.org/10.1016/j.livsci.2019.103904

4. Mohd. Hafiz, A.W., Izuan Bahtiar, A.J., Mohamad Hifzan, R., Ariff, O.M., & Faezal Ashraff, A.L. (2016). Body weight prediction of Brakmas and Bali cattle using body measurements. Mal. J. Anim. Sci, 19(1), 1-7.
5. Agung, P.P., Putra, W.P.B., Anwar, S., & Wulandari, A.S. (2018). Body Weight Estimation of Bali Cattle in Banyumulek Techno Park, West Nusa Tenggara using Several Morphometric Parameters. Buletin Peternakan, 42(1), 20–25.
6. Jakaria, J., Ulum, M. F., & Priyanto, R. (2019). Live Body Weight Assessment Based on Body Measurements in Bali cattle (*Bos javanicus*) at Extensive Rearing System. Pakistan Journal of Life & Social Sciences, 17(1), 17-23.
7. Azis, R., Ciptadi, G., Wahjuningsih, S., Hariyono, D.N.H., Tribudi, Y.A., & Nurgiatiningsih, V.M.A. (2023). Prediction of body weight from body measurements in bali cattle of indonesia using regression analysis. Adv. Anim. Vet. Sci, 11(9), 1486-1491. Available from: https://doi.org/10.17582/journal.aavs/2023/11.9.1486.1491
8. Dakhlan, A., Adhianto, K., Qisthon, A., & Husni, A. (2024). Optimizing Ongole Grade cattle weight prediction through principal component analysis. IOP Conference Series: Earth and Environmental Science, 1360(1), p. 012027. Available from: https://doi.org/10.1088/1755-1315/1360/1/012027
9. 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. Jurnal Ilmu-Ilmu Peternakan, 33(3). Available from: https://doi.org/10.21776/ub.jiip.2023.033.03.14
10. Hlokoe, V.R. & Tyasi, T.L. (2022). Nguni cattle body weight estimation using regression analysis. Journal of Animal Health and Production, 10(3), 375-380. Available from: http://dx.doi.org/10.17582/journal.jahp/2022/10.3.375.380
11. Adinata, Y., Noor, R. R., Priyanto, R., Cyrilla, L., & Sudrajad, P. (2023). Morphometric and physical characteristics of Indonesian beef cattle. Archives Animal Breeding, 66(2), 153-161. Available from: https://doi.org/10.5194/aab-66-153-2023
12. Sampurna, I.P., Saka, I.K., Oka, G.L., & Putra, S. (2014). Patterns of Growth of Bali Cattle Body Dimensions. ARPN Journal of Science and Technology, 4(1), 20-30.
13. Baliarti, E., Rozzaq, M.A., Warman, A.T., Bintara, S., Widi, T.S.M., Widayati, D.T., Atmoko, B.A., & Nugroho, T. (2023). Body morphometric characterization in conjunction with reproductive performance of bali and bali cross cattle in Indonesia. Advances in Animal and Veterinary Sciences, 11(6), 977-986. Available from: http://dx.doi.org/10.17582/journal.aavs/2023/11.6.977.986
14. Putra, W.P.B, Said, S., & Arifin, J. (2020). Principal component analysis (PCA) of body measurements and body indices in the Pasundan cows. Black Sea J. Agric, 3(1), 49–55.