Research Article

Body Morphometric Characterization in Conjunction with Reproductive Performance of Bali and Bali Cross Cattle in Indonesia

Endang Baliarti[1*], Muh Auliya Rozzaq[2], Adi Tiya Warman[2], Sigit Bintara[3], Tri Satya Mastuti Widi[1], Diah Tri Widayati[3], Bayu Andri Atmoko[4], Tristianto Nugroho[1]

[1]Department of Animal Production, Faculty of Animal Science, Universitas Gadjah Mada, Yogyakarta, Indonesia 55281; [2]Postgraduate Program, Faculty of Animal Science, Universitas Gadjah Mada, Yogyakarta, Indonesia 55281; [3]Department of Animal Breeding and Reproduction, Faculty of Animal Science, Universitas Gadjah Mada, Yogyakarta, Indonesia 55281; [4]Research Center for Animal Husbandry, National Research and Innovation Agency (BRIN), Indonesia.

Abstract | Crossbreeding between Bali Cattle (*Bos javanicus*) with *Bos taurus* is applied to improve productivity, however, it may impact the body morphometric characteristics and reproductive performance. This paper aimed to investigate body morphometric characterization in conjunction with the reproductive performance of Bali and Bali Cross Cattle in Indonesia. A total of 110 cattle consisting of 59 Bali, 27 Limousin × Bali (Limbal) and 24 Simmental × Bali (Simbal) were measured for body morphometric data collection. Reproductive performance data were collected based on information from farmers. Data were analyzed by analysis of variance followed by Duncan's Multiple Range Test, Pearson's correlation, principal component analysis (PCA), canonical discriminant analysis (CDA), and canonical correlation analysis (CCA). Results showed that Bali Cross (Limbal and Simbal) have higher body morphometric ($P<0.05$) but lower reproductive performance ($P<0.05$) compared to Bali Cattle. The first three principal components were able to explain 66.36%, 67.45%, and 78.97% variance of body morphometric on Bali, Limbal and Simbal, respectively. Body length, head length, wither height, rump width, and chest depth were selected as discriminant variables. Based on those variables, 98.30% of Bali cattle were predicted as members of its origin. However, Simbal cattle are classified as Simbal (62.50%) and Limbal (33.30%) while Limbal are classified as Limbal (66.70%) and Simbal (29.60%). The set of body morphometric and reproductive performance variables on Bali Cross have a high canonical correlation. It is concluded that Simbal and Limbal have a high similarity in body morphometrics and a high correlation to reproductive performances.

Keywords | Bali cattle, Body morphometric, Multivariate analysis, Reproductive performance.

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***Correspondence** | Endang Baliarti, Department of Animal Production, Faculty of Animal Science, Universitas Gadjah Mada, Yogyakarta, Indonesia 55281; **Email:** bali_arti@ugm.a.id
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INTRODUCTION

Bali Cattle (*Bos javanicus*) is Indonesian indigenous cattle originated from Bali Island, Indonesia but spread over the archipelago. They are small-sized meat-type cattle that are known to be highly adaptable to harsh conditions and low quality feed resources (Mohamad et al., 2012; Sutarno and Setyawan, 2016). However, a previous study found that Bali Cattle reared outside Bali Island mostly have smaller body weights than those reared in Bali (Widyas et al., 2017). To improve the production performance, in several areas outside Bali, crossbreeding is applied to Bali Cattle by artificial insemination using semen from Limousin, Simmental (Sutarno and Setyawan, 2015), Angus (Putra et al., 2021), or Brahman (Irwansyah et al., 2021).

Simbal (Simmental × Bali) and Limbal (Limousin × Bali) as crossbred cattle prove to have higher body weights and body morphometrics compared to Bali Cattle. Nevertheless, the increase in phenotypic characteristics was followed by the lack of uniformity indicated by the deviation of the data (Almakmum et al., 2021; Depison, 2010; Kocu et al., 2019). High variation of cattle in a population will challenge the production system such as feed requirements which will impact the performance of the cattle itself and also adaptation constraints (Leroy et al., 2016). Moreover, it is well known that Crossbreds produced by Bali Cattle face reproductive problems. Extremely, several studies mention that male crossbred between *Bos taurus* and Bali Cattle are infertile (Diwyanto and Inounu, 2009; Kocu et al., 2019). In the case of the smallholder farming system, those two problems may be paid for by the increase in body weight which impacts the price of the cattle. However, reproduction is one of the cores of crossbreeding, which was the process to produce a calf. Thus, in terms of a sustainable crossbreeding system, both body morphometric characteristics and reproduction traits should receive a great concern.

Characterizing the body morphometrics between Bali and Bali Cross cattle is important. This is because Bali Cross cattle are crossbred by two parents that have highly distinctive characteristics. It is also hypothesized that body morphometrics may impact the reproductive performance of cattle (de Melo et al., 2020; Tramonte et al., 2019). Multivariate analysis is a reliable method to assess multiple variables of morphometric characteristics among livestock as well as the relationship between two sets of multiple variables simultaneously. There are various types of multivariate analysis, such as principal component analysis (PCA), canonical discriminant analysis (CDA), and canonical correlation analysis (CCA) (Mittal and Kumar, 2022). PCA is used to transform the variables and eliminate redundant variables to construct the principal components. Thus, dependencies among variables or individuals can be interpreted. CDA can classify each individual into a predicted population by obtaining a discriminator variable to locate subsets of the variable and associated function that lead to maximum separation of the groups. Whereas, CCA is used to investigate the relationship between two sets of variables (Timm, 2007). Multivariate analysis in Bali Cattle body measurement has been done by previous studies using PCA (Wilastra et al., 2021) and CDA (Depison et al., 2022). However, no study has addressed the relationship between the body morphometrics of Bali and Bali Cross with their reproductive trait simultaneously.

Hence, this study aimed to fill the gap by investigating body morphometric characterization in conjunction with the reproduction performance of Bali and Bali Cross Cattle in Indonesia.

MATERIALS AND METHODS

Ethical approval

The design of this research has been approved by the Research Ethics Commission, The Faculty of Veterinary Science, Universitas Gadjah Mada, Yogyakarta (00018/EC-FKH/EKs/2021).

Study area and animals

This research was conducted in the district of Lombok Tengah, West Nusa Tenggara Province, Indonesia. The area is part of Lombok Island and is located between 116°05' until 116°24' East Longitude and 8°24' until 8°57' South Latitude. Lombok Tengah has a tropical climate with a dry summer. The air temperature is between 22°C to 31.3°C, the humidity level is 67% to 95%, and the precipitation is of 170 mm per year (BPS, 2022). Cattle are reared in this area by smallholder farmers in an intensive production system. Body morphometric data were collected from 110 cattle (59 Bali, 27, Limbal, and 24 Simbal). Cattle were chosen by purposive sampling that required the female ones as the product of insemination and have calved twice or calved once but currently pregnant in the first semester and the pregnancy age were recorded to calculate the calving intervals.

Data collections

Body morphometric data were collected from the direct measurement using measurement tape and measuring sticks. Nine body measurements were collected including body length (BL), wither height (WH), rump height (RH), rump width (RW), chest girth (CG), chest depth (CD), chest width (CW), head length (HL) and head width (HW). Body weight (BW) data was not collected directly due to the technical problem caused by the field conditions. Thus, BW was estimated by schoorl methods (Widyas et al., 2021). Reproduction performance of each cattle was collected from the farmers' information. The data include puberty age, first mating age, first calving age, postpartum estrus (PPE), postpartum mating (PPM), and services per conception (S/C). Calving intervals (CI) were calculated by the information of PPM, gestation length, and S/C.

Data analysis

Data analyses were done by several types of analysis methods including analysis of variances followed by Duncan's

Multiple Range Test (DMRT), Pearson's Correlation, PCA, CDA, and CCA. All of them were done using SPSS version 25 software (IBM Corp, 2017). Dendrogram was built by Agglomerative Hierarchical Clustering using Euclidean method in R Programming Language (R Core Team, 2022). Analysis of variance and DMRT was used to figure out the difference of each body morphometric and reproductive trait between Bali and Bali Cross. Pearson's correlation matrix was used to define the correlation between each variable. Pearson's Correlation between CG and BW was not because BW estimation used a formula that involved CG.

Next, data were analyzed by PCA with the Varimax rotation method to maximize the sum of the variance of the squared loadings within each column of the loading matrix. Principal components (PC), Extraction Communalities (EC), Eigenvalue, Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy, and Bartlett's Test P Value were extracted from the analysis. CDA was performed to classify each cattle into its predicted origin population due to the body measurement characteristics. Stepwise discriminant analysis was applied to select the best-entered variables. Last, CCA was applied to set the variable of body morphometric and reproductive performance. HL and HW were excluded from the analysis due to their correlation with reproduction traits that may not be biologically explainable. The data analysis and extracted value from the PCA, DCA and CCA were based on the several previous study (Acciaro et al., 2020; de Melo et al., 2020; Destefanis et al., 2000; Ibrahim et al., 2022). Reproduction performances in the analysis that only included at puberty age, PPE, SC, and CI due to other traits were the decision of the farmer. Although CI is influenced by biological and farmer decisions, it is still included in the analysis due to the importance of the trait. The same data analysis methods were applied to Bali or Bali Cross to compare the cattle characteristics, although the preliminary assumption was not adequate.

RESULTS

Body morphometrics and reproduction performance

All body morphometrics of Bali Cross cattle were significantly higher ($P<0.05$) than Bali Cattle. Moreover, Simbal produces higher BL, CD, and HL compared to Limbal (Table 1). Pearson's correlation between CG and BW was not mentioned in all analyses because BW was calculated using the formula that involved CG. Pearson's correlation among body measurements varies from no correlation to medium in Bali Cattle. There are only four combinations which have correlation value more than 0.5 (Table 2). Similarly, Pearson's correlation in Limbal Cattle also is diverse from no correlation to high with only 5 correlation which has a value of more than 0.5 (Table 3). In contrast, the correlation was dominated by medium to high in Simbal Cattle with the highest value being 0.77 as a correlation between BL and RH (Table 4). Limbal and Simbal Cattle showed their first estrous as an indication of puberty at an older age than Bali Cattle which impact the longer first mating and first calving age. Despite no different performance in PPE and PPM among cattle, nonetheless Limbal has a higher S/C value which impacts to be the longest CI (Table 5).

Principal component and canonical discriminant analysis
Three principal components (PCs) were extracted and reveals explained cumulative variance of 66.36%, 67.45%, and 78.97% of the total variance for Bali, Limbal, and Simbal, respectively. 53.04% of variance has been explained by PC1 for Simbal, whilst only 38.54% and 32.88% for Bali and Limbal, respectively. KMO sampling adequacy was adequate for Bali and Simbal but not for Limbal for the value was only 0.37. The highest PC1 for all cattle was CG, whereas the highest PC2 was CG for Bali and Limbal, while Simbal was CW (Table 6). Rotated component matrix plot of the PC1 and PC2 were presented in Figure 1. Five variables consisting of BL, HL, WH, RW and CD were selected by stepwise discriminant analysis to characterize Bali and Bali Cross Cattle (Table 7). The discriminant functions were built by the canonical discriminant function coefficient presented in Table 8. The Canonical discriminant plot presented in Figure 2 shows that Function 1 and Function 2 of Simbal and Limbal located in a close area, whereas Bali separated in the different area. As a result, individual classification per breed based on discriminant analysis showed that 98% of Bali Cattle were classified as their origin. On the other hand, Simbal cattle are classified as Simbal (62.50%) and Limbal (33.30%) while Limbal are classified as Limbal (66.70%) and Simbal (29.60%) (Table 9). The dendrogram distances of Bali and Bali Cross cattle were presented in Figure 3.

Canonical correlation analysis

Limbal and Simbal have a higher canonical correlation between body morphometric and reproductive performance compared to Bali Cattle. Correlation in the first canonical function was higher for Simbal compared to Limbal, while otherwise for canonical function numbers 2-4. On the other hand, the canonical loading and canonical cross-loading were diverse among variables. Extracted variance for the first canonical function was between 0.02-0.14 for body morphometric and between 0.21-0.35 for reproductive performance (Table 10). On Bali Cattle, CG, CW, BW, and puberty were highly contributed as canonical loadings. RW, S/C, and CI were highly contributed as canonical loadings for Limbal cattle. However, there was no high canonical load ing from body measurement, but it was high

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Table 1: Mean ± SD of age and body morphometrics of Bali and Bali Cross Cattle

Variables	Bali	Limbal	Simbal
N	59	27	24
Age	3.68 ± 0.84	3.63 ± 0.97	3.98 ± 0.87
BL	110.95 ± 5.89[a]	132.48 ± 6.39[b]	136.25 ± 10.73[c]
WH	110.54 ± 5.01[a]	122.96 ± 3.64[b]	123.54 ± 5.32[b]
RH	108.69 ± 3.98[a]	121 ± 4.23[b]	120.92 ± 5.53[b]
RW	33.59 ± 2.54[a]	41.33 ± 2.34[b]	41.79 ± 4.06[b]
CG	152.37 ± 9.4[a]	172.85 ± 9.61[b]	176.88 ± 15.79[b]
CD	59.8 ± 3.02[a]	66.11 ± 4.15[b]	68.83 ± 4.02[c]
CW	35.15 ± 3.49[a]	41.44 ± 4.94[b]	41.25 ± 4.2[b]
HL	35.42 ± 2.88[a]	42.07 ± 3.68[b]	43.92 ± 1.86[c]
HW	19.46 ± 2.22[a]	22.63 ± 2.63[b]	23.33 ± 2.76[b]
BW	304.93 ± 32.46[a]	380.56 ± 37.72[b]	397.9 ± 62.45[b]

N: Number of observations; SD: Standard Deviation; [abc] Different superscripts in the similar row differ significantly ($P<0.05$); BL: Body length, WH: Wither height, RH: Rump height, RW: Rump weight, CG: Chest girth, CD: Chest depth, CW: Chest width, HL: Head length, HW: Head width, BW: Body weight

Table 2: Pearson's correlation among body measurements in Bali Cattle

	BL	WH	RH	RW	CG	CD	CW	HL	HW	BW
BL	-									
WH	0.33	-								
RH	0.39	0.63	-							
RW	0.53	0.41	0.26	-						
CG	0.47	0.13	0.17	0.41	-					
CD	0.37	0.33	0.27	0.40	0.67	-				
CW	0.30	-0.09	-0.06	0.43	0.34	0.32	-			
HL	0.11	-0.00	-0.01	-0.01	0.08	0.13	0.06	-		
HW	0.27	0.33	0.41	0.26	0.21	0.16	0.05	0.06	-	
BW	0.46	0.13	0.17	0.41	NA	0.67	0.35	0.08	0.21	-

NA: Not available; BL: Body length, WH: Wither height, RH: Rump height, RW: Rump weight, CG: Chest girth, CD: Chest depth, CW: Chest width, HL: Head length, HW: Head width, BW: Body weight

Table 3: Pearson's correlation among body measurements in Limbal Cattle

	BL	WH	RH	RW	CG	CD	CW	HL	HW	BW
BL	-									
WH	0.11	-								
RH	0.42	0.80	-							
RW	0.60	0.05	0.15	-						
CG	0.52	0.29	0.20	0.19	-					
CD	0.16	0.47	0.52	0.11	0.35	-				
CW	-0.02	0.08	0.06	-0.30	0.34	0.04	-			
HL	0.20	0.38	0.30	0.04	-0.04	-0.12	-0.02	-		
HW	0.30	0.05	0.01	0.15	0.03	-0.19	0.10	0.43	-	
BW	0.51	0.27	0.18	0.19	NA	0.35	0.34	-0.05	0.036	-

NA: Not available; BL: Body length, WH: Wither height, RH: Rump height, RW: Rump weight, CG: Chest girth, CD: Chest depth, CW: Chest width, HL: Head length, HW: Head width, BW: Body weight

Table 4: Pearson's correlation among body measurements in Simbal Cattle

	BL	WH	RH	RW	CG	CD	CW	HL	HW	BW
BL	-									
WH	0.67	-								
RH	0.77	0.70	-							
RW	0.66	0.25	0.38	-						
CG	0.60	0.69	0.60	0.26	-					
CD	0.69	0.78	0.71	0.47	0.57	-				
CW	0.32	0.11	0.16	0.50	0.12	0.31	-			
HL	0.43	0.43	0.45	0.24	0.13	0.24	0.17	-		
HW	0.46	0.60	0.55	0.23	0.54	0.49	-0.16	0.23	-	
BW	0.60	0.69	0.60	0.26	NA	0.57	0.12	0.13	0.55	-

NA: Not available; BL: Body length, WH: Wither height, RH: Rump height, RW: Rump weight, CG: Chest girth, CD: Chest depth, CW: Chest width, HL: Head length, HW: Head width, BW: Body weight

Table 5: Mean ± SD of reproduction performance of Bali and Bali Cross cattle

Variables	Bali	Limbal	Simbal
N	59	27	24
Puberty age (months)	21.73 ± 2.75[a]	24.22 ± 4.64[b]	23.83 ± 3.96[b]
First mating age (month)	21.90 ± 2.73[a]	24.26 ± 4.60[b]	23.83 ± 3.96[b]
First calving age (month)	30.92 ± 2.72[a]	33.30 ± 4.65[b]	32.88 ± 4.04[b]
Postpartum estrus (PPE) (days)	70.12 ± 26.52	86.00 ± 38.15	79.75 ± 33.55
Postpartum mating (PPM) (days)	75.05 ± 27.22	91.56 ± 37.42	84 ± 37.23
Services per conception (S/C)	1.64 ± 1.09[a]	2.30 ± 1.03[b]	2.08 ± 0.93[ab]
Calving interval (CI, days)	368.05 ± 34[a]	396.81 ± 49.96[b]	386.71 ± 36.53[ab]

N = Number of observations; SD = Standard Deviation; [abc] Different superscripts in the similar row differ significantly (P<0.05)

Table 6: Rotated component matrix, communalities, eigenvalues, variance, cumulative, Kaiser-Meyer-Olkin (KMO) measure adequacy, and Bartlett's test probability of body morphometric on Bali and Bali Cross Cattle

Parameter	Bali				Limbal				Simbal			
	PC1	PC2	PC3	EC	PC1	PC2	PC3	EC	PC1	PC2	PC3	EC
BL	0.56	0.46	-0.08	0.53	0.49	0.15	0.69	0.82	0.62	0.50	0.43	0.82
WH	0.06	0.85	-0.06	0.73	0.11	0.90	-0.07	0.87	0.78	0.09	0.43	0.81
RH	0.06	0.86	0.01	0.73	0.08	0.91	0.14	0.87	0.68	0.22	0.52	0.77
RW	0.59	0.39	-0.37	0.64	0.18	0.03	0.88	0.80	0.22	0.78	0.22	0.71
CG	0.90	0.10	0.16	0.85	0.94	0.17	0.13	0.93	0.94	0.13	-0.08	0.90
CD	0.73	0.26	0.17	0.63	0.26	0.69	0.10	0.70	0.69	0.39	0.28	0.71
CW	0.64	-0.19	-0.31	0.55	0.58	-0.01	-0.60	0.73	-0.03	0.89	-0.01	0.79
HL	0.19	0.02	0.83	0.71	-0.13	0.32	0.01	0.76	0.06	0.13	0.90	0.82
HW	0.14	0.61	0.09	0.40	0.11	-0.12	0.12	0.72	0.71	-0.19	0.33	0.65
Eigenvalues	3.85	1.75	1.02		3.29	1.80	1.67		5.30	1.56	1.04	
Variance (%)	38.54	17.58	10.24		32.88	17.96	16.60		53.04	15.58	10.36	
Cumulative (%)	38.54	56.12	66.36		32.88	50.85	67.45		53.04	68.62	78.97	
KMO	0.71				0.37				0.75			
Bartlett's test P value	<0.05				<0.05				<0.05			

PC: Principal Component; EC: Extraction Communalities; KMO: Kaiser-Meyer-Olkin; BL: Body length; WH: Wither height; RH: Rump height; RW: Rump weight; CG: Chest girth; CD: Chest depth; CW: Chest width; HL: Head length; HW: Head width

Table 7: Entered variable selected by stepwise discriminant analysis to characterize Bali and Bali Cross Cattle

Variable	Tolerance	Sig. of F to Remove	Wilks' Lambda
BL	0.548	0.075	0.177
HL	0.949	0.000	0.210
WH	0.717	0.016	0.182
RW	0.626	0.030	0.180
CD	0.699	0.044	0.178

Note: BL: Body length; WH: Wither height; RW: Rump weight; CD: Chest depth; HL: Head length

Table 8: Canonical discriminant function coefficients

Parameter	Function 1	Function 2
(Constant)	-24.871	1.118
BL	0.045	0.026
WH	0.058	-0.158
RW	0.108	-0.193
CD	0.033	0.268
HL	0.170	0.110

Note: BL: Body length; WH: Wither height; RW: Rump weight; CD: Chest depth; HL: Head length

Table 9: Individual classification per breed based on discriminant analysis

Actual population	% Predicted Group Membership (N)			
	Bali	Simbal	Limbal	Total
Bali	98.30 (58)	0.00 (0)	1.70 (1)	100.00 (59)
Simbal	4.20 (1)	62.50 (15)	33.30 (8)	100.00 (24)
Limbal	3.70 (1)	29.60 (8)	66.70 (18)	100.00 (27)

Table 10: Canonical functions (CF), correlation and eigenvalue from body morphometric and reproduction trait of Bali and Bali Cross

CF	Bali		Limbal		Simbal	
	Correlation	Eigenvalue	Correlation	Eigenvalue	Correlation	Eigenvalue
1	0.536	0.403	0.764	1.402	0.839	2.368
2	0.365	0.154	0.590	0.534	0.537	0.404
3	0.270	0.078	0.493	0.321	0.360	0.149
4	0.206	0.044	0.313	0.109	0.309	0.105

Table 11: Canonical loading and cross loading between body morphometrics and reproduction trait of Bali and Bali Cross

Parameter	Bali		Limbal		Simbal	
	Canonical Loading	Cross Loading	Canonical Loading	Cross Loading	Canonical Loading	Cross Loading
BL	-0.013	-0.007	0.344	0.263	-0.287	-0.241
WH	0.074	0.040	0.108	0.082	0.035	0.029
RH	-0.297	-0.159	0.149	0.114	0.079	0.066
RW	0.069	0.037	0.775	0.592	-0.065	-0.054
CG	-0.611	-0.328	0.274	0.209	-0.161	-0.135
CD	-0.259	-0.139	0.162	0.124	0.075	0.063
CW	-0.418	-0.224	0.192	0.147	-0.043	-0.036
BW	-0.625	-0.335	0.285	0.218	-0.133	-0.112
Extracted variance	0.14		0.12		0.02	

Puberty	0.873	0.468	-0.090	-0.069	-0.548	-0.459
PPE	0.201	0.108	-0.285	-0.218	-0.475	-0.398
S/C	-0.154	-0.082	-0.959	-0.733	-0.276	-0.232
CI	-0.085	-0.046	-0.628	-0.480	-0.792	-0.664
Extracted variance	0.21		0.35		0.31	

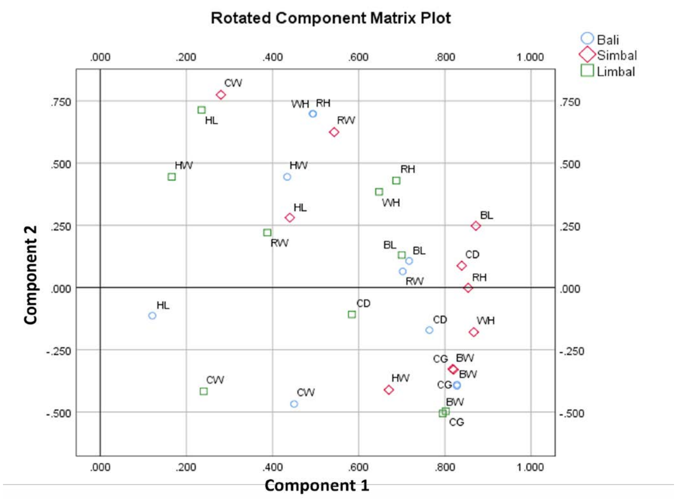

Figure 1: Rotated component matrix of Principal component analysis (PCA) on Bali and Bali Cross Cattle body measurement

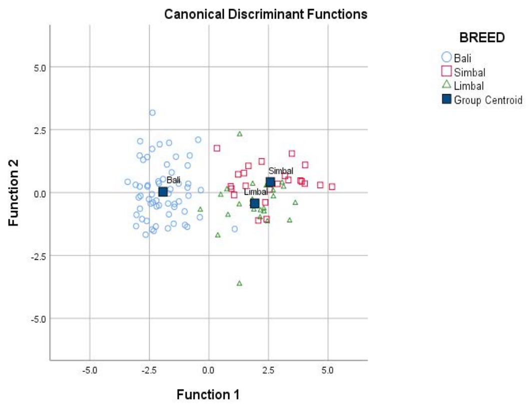

Figure 2: Canonical Discriminant Plot of Bali and Bali Cross Cattle

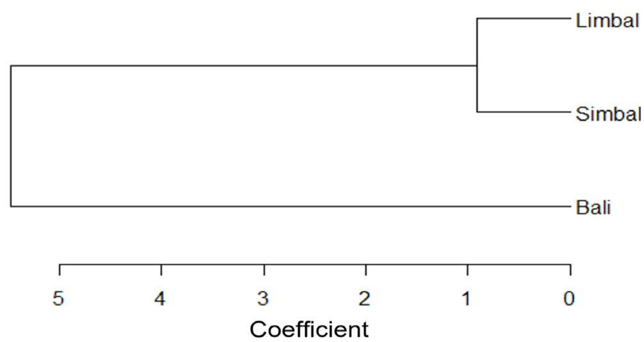

Figure 3: The dendrogram of Bali and Bali Cross cattle based on body measurement

but it was high for puberty and CI for reproductive canonical loading (Table 11).

DISCUSSION

Body morphometrics and reproduction performance

The high body morphometrics of Bali Cross was common because it was the aim of this crossbreeding. This result is in agreement with the previous study which found that the body morphometrics of Bali Cross was higher compared to the Bali Cattle (Kocu et al., 2019) and Simbal was higher than Limbal (Depison, 2010). The high body morphometrics and its impact on body weight is one of the goals of crossbreeding between local cattle and exotic cattle. The previous studies reported that Simbal has higher useful heterosis compared to Limbal on weaning weight and yearling weight (Prastowo et al., 2017), however, in the present study, the impact only increased significantly to the BL, CF, and HL but not significantly for body weight.

Most of the correlations in Bali dan Limbal Cattle are below 0.4 in which it is a weak correlation and indicates that the body measurements are very diverse or not consistent with each other. This result is in contrast with the previous study which reported that almost all body morphometrics of Bali Cattle have a high correlation (Depison et al., 2022). However, it is in agreement with the previous study reported that Bali Cattle body measurements have a low correlation (Khasanah et al., 2020) and Simbal has a high correlation (Almakmum et al., 2021). Correlations of Simbal Cattle body measurements are quite strong and positive between BL, WH, and RH to another measurement. This indicates that the change in those three measurements will be followed by a change of another measurement, positively. Despite Simbal being crossbred cattle that is able to have diverse body measurements among individuals, it still has a consistent change for every body measurement type. The increase of Bali Cross' body morphometrics, unfortunately, followed by a decrease in reproduction performances. A previous study also reported that Bali cattle have better reproductive performance compared to their cross (Kocu et al., 2019). Bali cattle are known to have excellent fertility rates because they can produce offspring every year and the life percentage is 80% (Sutarno and Setyawan, 2016). On the other hand, the low reproduction performance of Bali Cross is typical of most crossbreeding where generally the greatest heterosis is achieved in traits with the lowest heritabilities such as reproductive performance. Moreover, the reproductive problem of the crossbreed may be affected by the lack of feed input. It is because farmers feed the big crossbreed with the same amount of feed given to Bali Cattle (Widyas et al., 2022).

Principal component and canonical discriminant analysis

The first three principal components explained 66.36-78.97% of variance which indicated that these principal components explained sufficient variance to visualize the correlations among explanatory variables in the data without losing much information. PC1 in Simbal showed the highest explained variances and Simbal has the highest cumulative variance. However, the value of each parameter's first principal component was diverse between Bali and Bali Cross Cattle. The high principal value can be selected as the main variable in the characterization tool. This selected parameter will simplify the variable without losing the power (Jollife and Cadima, 2016). KMO (Kaiser-Meyer-Olkin) sampling adequacy revealed the proportion of the variance in all parameters and different morphometric traits caused by the underlying factors (Valsalan et al., 2020). The recommended value of KMO is greater than 0.5, but in the present study, Limbal only has 0.37 which indicates that most of the variance was not able to be described by the principal component. Hence, only Bali and Simbal that are adequate to use the principal component to characterize the parameters. The use of the selected principal component allows constructing improvement simultaneously for several variables without losing much information (Amaya et al., 2021).

Five discriminant variables consisting of BL, WH, RW, CD, and HL were selected by stepwise selection. There are various studies that showed different discriminant variable. A study on Bali cattle obtained BL, CG, RH, and shoulder width as discriminant variables (Depison et al., 2022), meanwhile, in Pasundan and Ongole cattle CD, BL and CG were selected (Putra et al., 2020). Individual classification per breed based on discriminant analysis showed that 98% of Bali Cattle classified as their origin, which means that Bali Cattle have specific characteristics of their body morphometrics. However, there are high sharing predicted origins of the Simbal and Limbal cattle. This result can be interpreted as the high similarity body morphometrics between Simbal and Limbal. It is also supported by the dendrogram distances which showed that Simbal and Limbal were closely related, and they are far separated from Bali Cattle. The use of CDA and dendrogram can classify the cattle based on the signature. In this case, the interpretation of the canonical structure led to the identification of a large number of signatures (Sorbolini et al., 2016).

Body morphometric characteristics in conjunction with reproductive performance

The high of Bali Cross' body morphometrics followed by the decrease in reproductive performance. This result confirmed that Bali Cross which has a higher body weight will have worse reproductive performance since in this case, the higher value of reproduction performance such as S/C and CI is a poor value. Canonical loading indicates the contribution of correlation among variables with their canonical variate, whereas canonical cross-loading indicates the correlation among variables with the opposite canonical variate (Hidalgo et al., 2014). In the present study, only Limbal has all positive canonical loading and cross-loading for body morphometrics. In Simbal, the canonical loading and cross loading of body morphometric were low since all of them are below than 0.3 and the extracted were the lowest compared to Bali and Limbal. On the reproduction side, it is only Puberty and PPE on Bali cattle that have positive canonical loading and cross loading. This may correspond to the reproductive performance of Bali cattle that have the youngest puberty age (Table 4). The high canonical loading value can be considered as the most important variable to derive the linear combination between them. Moreover, the parameter combination also can be used as a simple parameter rather than using all variables (Çankaya and Kayaalp, 2007; Rachel Thomas and Chakravarty, 2000).

CONCLUSION

In conclusion, Bali Cross has higher body morphometrics compared to Bali Cattle but worse reproductive performance. Correlations among body morphometrics of Simbal were higher than Bali and Limbal. The principal components were able to explain the high variance of body morphometrics on all cattle. Body length, head length, wither height, rump width, and chest depth were selected as discriminant variables. Most Bali cattle were predicted as members of their origin. However, Simbal cattle are classified as Simbal and Limbal while Limbal is also classified as Limbal and Simbal. This is shown that Simbal and Limbal are closely related to each other, since they are crossbred from the group of Taurine cattle but different breeds. The set of body morphometric and reproductive performance variables on Bali Cross have a high canonical correlation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

NOVELTY STATEMENT

The novelty of this study lies in examining the relationship between the body morphometrics of Bali and Bali Cross cattle with their reproductive traits simultaneously.

AUTHORS CONTRIBUTIONS

EB conceptualization, designed research, writing manuscript; MAR and ATW data collection; SB, TSMW, DTW designed research and supervision; BAA data collection supervision, manuscript correction; TN data analysis and writing original manuscript. All authors have read and agreed to the current version of the manuscript.

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