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The Markers of Body Size and Shape of Bali Cattle and its Crosses with Exotic Bulls

Muh. Rusdin[1]*, La Ode Nafiu[1], Achmad Selamet Aku[1], La Ode Sahaba[1]

[1] Faculty of Animal Science, Universitas Halu Oleo, Kendari, Southeast Sulawesi, Indonesia.

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Corresponding Author:
Muh. Rusdin
mrusdin05@uho.ac.id

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Abstract: One of the genetic improvement efforts to improve the performance of Bali cattle offspring production is crossbreeding Bali cattle with exotic bulls. This study aimed to identify markers of body size and shape of Bali cattle and its crosses with exotic bulls using principal component analysis. The materials used in this study were 91 heads of Bali, Simbal, Brahmbal, Limbal, and Pobal cattle, consisting of 34 males and 57 females. The variables observed were body measurements (morphometrics) consisting of shoulder height, body length, chest circumference, chest depth, chest width, hip height, and hip width. Data analysis used Principal Component Analysis in the Minitab Release 19 statistical application. The results showed that Bali, Simbal, Brahmbal, Limbal, and Pobal male cattle had the same body size markers, namely chest circumference. The body shape markers of male cattle are hip height for Bali cattle, chest length for Simbal and Pobal cattle, chest depth for Brahmbal cattle, and hip width for Limbal cattle. The body shape markers in female cattle are body length for Bali, Simbal, Brahmbal, and Pobal cattle, and hip height for Limbal cattle. These body size and shape markers have a strong correlation with the first principal component and the second principal component, so they can be used as selection criteria to improve the production performance of Bali and Bali crossbred cattle.

Keywords: Bali cattle; body shape; Body size; Exotic cattle; Marker.

Introduction

Bali cattle is a native Indonesian cattle breed known to be adaptive to hot and humid climates in tropical environments, resistant to disease, and able to utilize feed efficiently. According to (Sahaba et al., 2024), Bali cattle can adapt to new environments, have a carcass content above 50%, have rapid growth, and have good reproduction and fertility rates. Bali cattle is one of the ruminant livestock meat producers that spread in almost all regions of Indonesia, including Southeast Sulawesi. However, the development of Bali cattle in Indonesia is still directed at community livestock farming (Hasan et al., 2022). The characteristics of community livestock farming are that the business scale is relatively small (1-5 heads), a household business, rearing traditionally, animals as a source of labor and producer of manure, and savings for farmers (Matondang & Rusdiana, 2014).

One of the problems in the community livestock business is that livestock sales often do not apply to sell price standards, where the livestock sold are the livestock with the best performances, as a cause of negative selection that affects decreased livestock productivity in community livestock farmers (Sari et al., 2020). The negative selection has a significant impact on the decline in the genetic quality of Bali cattle (Rumbesiano et al., 2020). On the other hand, the demand for Bali cattle in the community is high. Still, it has not been balanced by breeding efforts or things related to improving the genetic quality of livestock. The

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low quality of seeds is a main problem in the development of Bali cattle, including matting between close relatives (inbreeding) and inappropriate rearing management (Sukanteri et al., 2022). The effect of inbreeding can increase the frequency of recessive homozygous genes. It's closely related to decreased vitality (Nascimento et al., 2023), and then every 1% increase in the inbreeding coefficient will reduce 4% of body weight in cattle (García-Ruiz et al., 2021).

One of the genetic improvement efforts to improve the performance of Bali cattle offspring production is through crossbreeding Bali cattle with exotic bulls from Bos taurus cattle, for example, Simmental and Limousine cattle, and also Bos indicus cattle, such as Brahman and Peranakan Ongole cattle using artificial insemination technology (Sutarno & Setyawan, 2015; Yulianto et al., 2021; Irwansyah et al., 2021). The main reason for crossbreeding between Bali cattle and exotic cattle is that the daily weight gain of Bali cattle is relatively low. Meanwhile, exotic cattle are known to have the advantage of high daily weight gain but are not resistant to hot weather in tropical climates and low feed quality. Through the crossbreeding method, it's hoped that offspring can result that have the characteristics of both parents, namely being able to survive in poor environmental conditions but producing high daily body weight (Rumbeisano et al., 2019; Yulianto et al., 2021).

Previous studies have reported that crossbreed Bali cattle such as Simbal (Simmental x Bali) and Limbal (Limousine x Bali), as well as Brahmbal (Brahman x Bali) and Pobal (Peranakan Ongole x Bali) have been showed to have higher body weight, weight gain and body morphometrics than Bali cattle (Yulianto et al., 2021; (Zafitra et al., 2020; Almakmum et al., 2021; Baliarti et al., 2023). However, the crossbreeding of Bali cattle with exotic bulls has an impact on increasing the diversity of productivity traits of their offspring (Kocu et al., 2019; Baliarti et al., 2023). Therefore, it is necessary to carry out the selection and characterization of superior traits for the development of Bali crossbreed cattle.

One approach in the selection programs and characterization of superior traits in beef cattle breeds is based on body morphometrics. This characterization can be done through principal component analysis to identify markers of body size and shape of each breed of beef cattle. According to (Khanikar et al., 2024), principal components have proven helpful in breeding and selection programs to achieve coordinated livestock morphometrics using fewer measurements. Body morphometrics would be useful if grouped in a more meaningful way.

In the principal component analysis, the body size markers are influenced by environmental factors, and body shape markers are influenced by genetic factors (Mahmudi et al., 2019; Adelia et al., 2020; (Almakmum et al., 2021; Aminurrahman et al., 2021). The markers of the body size and shape of Bali cattle and its crosses with exotic bulls developed by breeders in various regions in Indonesia, such as in Amonggedo District, Konawe Regency, Southeast Sulawesi Province, need to be analyzed in depth as a basis for designing effective breeding strategies and determining the most appropriate crossbreeding scheme between Bali cattle and exotic bulls in increasing the productivity of Bali crossbreed cattle. This study aimed to identify markers of body size and shape of Bali cattle and its crosses with exotic bulls using principal component analysis.

Method

Time and Location of Study

This study was conducted for three months, starting October-December 2023 in Amonggedo District, Konawe Regency, Southeast Sulawesi Province. The determination of this study location used a purposive sampling method based on the availability of Bali cattle and its crosses with exotic bulls.

Study Procedures

This study began with a pra-survey to searching for information on the where abouts of Bali cattle and its crosses with exotic bulls (Simental, Brahman, Limousine, and Peranakan Ongole cattle) mated using the artificial insemination method. This information includes cattle breed names and the names and addresses of the owners obtained from inseminator officers in Amonggedo District, Konawe Regency, Southeast Sulawesi Province. Sampling using the purposive sampling method with the criteria that the Bali cattle and its crosses with exotic bulls from the results of mating using the artificial insemination method, raised intensively and semi-intensively, and the mother cows were not pregnant. Determining the ages of cattle was based on the growth of the incisors and information from the breeders. Next, measurements of the body morphometrics of Bali cattle and its crosses with exotic bulls were carried out directly in the field.

Materials and Equipment

The study material was Bali cattle and its crosses with exotic bulls. The total of cattle used was 91 heads consisting of 34 males aged 1 to > 2 years, and 57 females aged 1 to > 5 years. The total of samples based on the cattle breeds can be seen in Table 1.

Table 1. The total of samples based on the cattle breeds

Breeds	Male	Female
Bali (Bali x Bali)	9	11
Simbal (Simmental x Bali)	5	7
Brahmbal (Brahman x Bali)	5	15
Limbal (Limousine x Bali)	6	11
Pobal (Peranakan Ongole x Bali)	9	13
Total	34	57

The equipment includes measuring sticks, measured tapes, calipers (1 cm accuracy), clamp cages, stationery, data entry formats, and digital cameras.

Variables Observed

The variables observed in the study were body measurements (morphometrics), measured based on the cattle skeletal system (Figure 1), namely: (1) shoulder height, measured from the highest point between the shoulders (withers) to the ground using a measuring stick in cm, (2) Body length, measured from the shoulder crest (scapula) to the tip of the pelvis (processus spinous) in cm, (3) chest circumference, measured in a circle around the chest cavity through the back of the hump and behind the shoulder joint (Os scapula) using a measuring tape in cm, (4) chest depth, measured from the top of the gumba to the lower edge of the sternum using a measuring tape in cm, (5) chest width, measured from the protrusion of the left and right shoulder joints (Os scapula) using a measuring stick in cm (6) hip height, measured from the highest distance of the pelvis perpendicular to the ground using a measuring stick in cm, and (7) hip width, measured from the outer edge of the right and left hip joints (gluteus) using a measuring tape in cm.

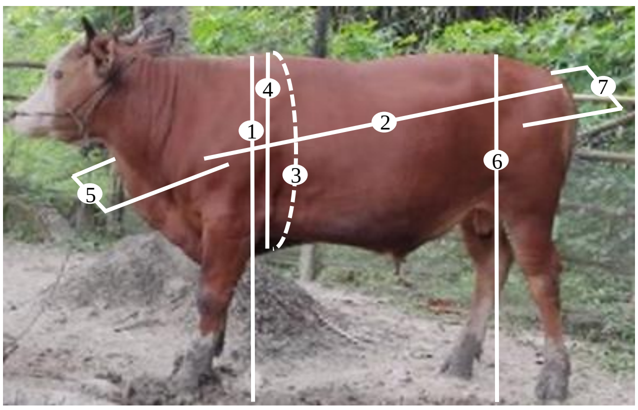

Figure 1. Methods of morphometric measurement of Bali and Bali crossbreed cattle. 1: Shoulder height; 2: body length; 3: chest girth; 4: chest depth; 5: chest width; 6: hip height; 7: hip width.

Data Analysis

Morphometric data of Bali cattle and its crosses with exotic bulls in this study was corrected to the most age, namely 1-2 years for males and 3-5 years for females with the formula (Salamena, 2006):

$$\overline{X}_{\text{i-corrected}} = \frac{\overline{X}_{\text{standard age}}}{\overline{X}_{\text{observation age}}} \text{ x } \overline{X}_{\text{observatin to-i}} \quad (1)$$

Note:
$X_{\text{i-corrected}}$ = average corrected size to-i
$X_{\text{standard age}}$ = average age of the most
$X_{\text{observation age}}$ = average observation age
$X_{\text{observation to-i}}$ = average size of observation to-i

Furthermore, the body morphometrics data were analyzed using Principal Component Analysis (PCA) to provide discrimination of markers of body size and shape of Bali cattle and their crosses with exotic bulls based on the equation of body size and shape derived from the covariance matrix Gaspersz (Gaspersz, 1992). The principal component scores are presented in the form of a crowd diagram. The X-axis is the principal component 1 (size vector), and the Y-axis is the principal component 2 (shape vector).

The mathematical model of PCA (Garpersz 1992) is as follows:

$$Y_1 = a_{11}X_1+a_{21}X_2+a_{31}X_3+\ldots+a_nX_n \quad (2)$$

Note:
Y_1 = first principal component (PC1)
X_1-X_n = variable to 1,2,3…n
a_{11}-a_n = eigen vector to 1,2,3…n
n = total of variable

$$Y_2 = a_{12}X_1+a_{22}X_2+a_{32}X_3+\ldots+a_nX_n \quad (3)$$

Note:
Y_2 = second principal component (PC2)
X_1-X_n = variable to 1,2,3…n
a_{12}-a_n = eigen vector to 1,2,3…n

Principal component analysis using the Minitab Release 21 application. In addition, principal component correlation analysis was used to determine the closeness of the relationship between body measurements with the first principal component (PC1) and second principal component (PC2) using the Gaspersz (1992) formula as follows:

$$r_{XiYj} = \frac{\alpha_{ij}\sqrt{\lambda_j}}{s_i} \quad (4)$$

Note:
r_{XiYj} = correlation between variable X to-i and principal component Y to-j
α_{ij} = eigenvector

λ_j = eigenvalue
S_i = deviate standard

The flow chart of study methods and data analysis is presented in Figure 2.

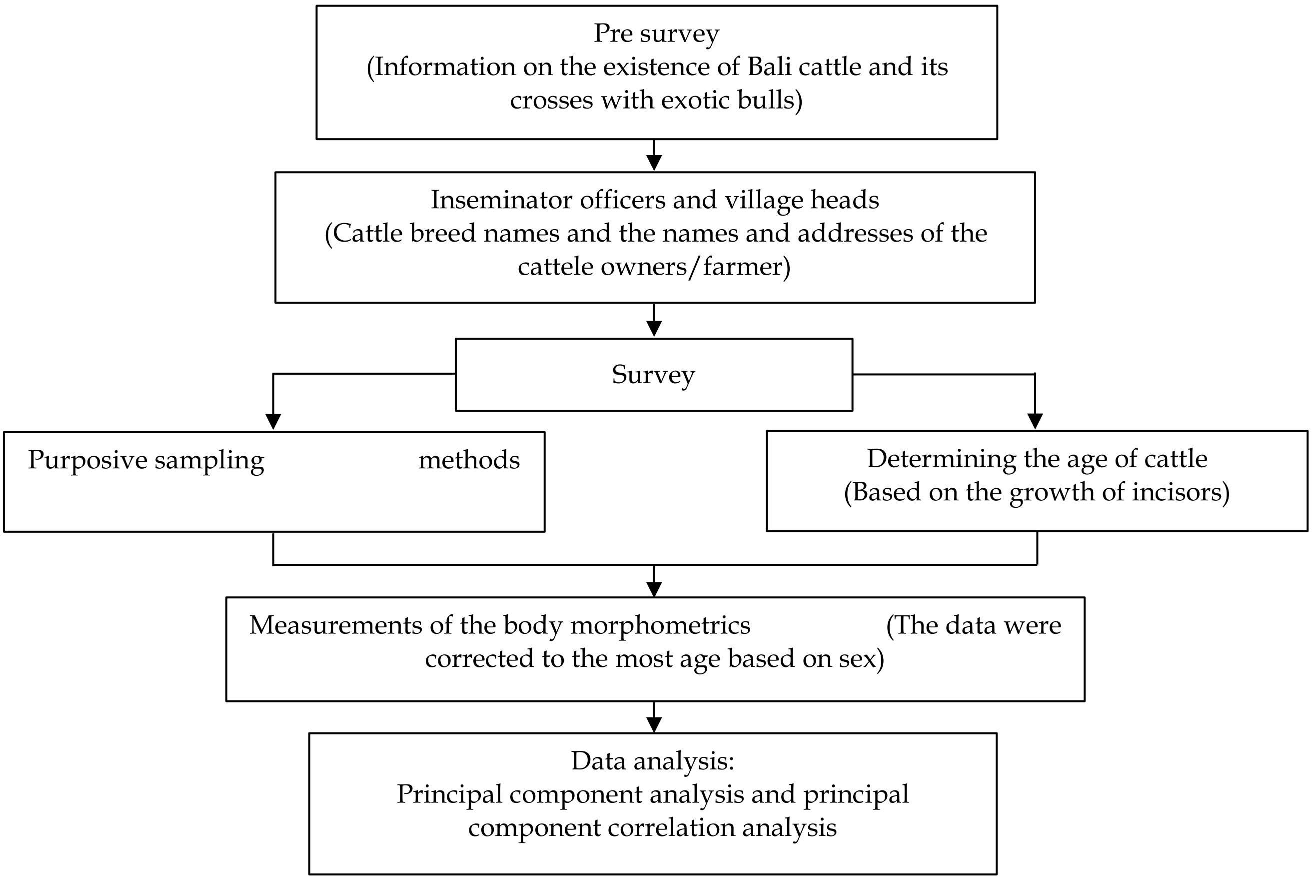

Figure 2. Flow chart of study methods and data analysis

Result and Discussion

Principal Component Analysis

The results of the PCA of the size and body shape of Bali cattle and its crosses with exotic bulls in males and females are presented in Table 2 and 3. The results in Table 2 and 3 show that of the seven body morphometric variables analyzed, the variation in size and body shape of cattle can be explained by two principal components, namely PC1 and PC2. It can be seen from the high percentage of cumulative variance in PC1 and PC2 for all cattle breeds observed, both males and females. Cumulative variance in males ranges from 90.75% (Simbal cattle) to 98.1% (Brahmbal cattle), while in females it ranges from 76.60% (Brahmbal cattle) to 93.30% (Limbal cattle).

Table 2. Eigenvector, eigen value, proportion, and cumulative body morphometric of Bali and Bali crossbreed cattle in males

Breeds	PC	Eigenvector	Eigen Value	Proportion (%)	CV (%)
Bali	1	$0{,}132X_1+0{,}472X_2+\mathbf{0{,}729X_3}+0{,}395X_4+0{,}020X_5+0{,}087X_6+0{,}253X_7$	200.85	84.8	91.8
(n = 9)	2	$0{,}141X_1-0{,}382X_2+0{,}080X_3+0{,}142X_4-0{,}327X_5+\mathbf{0{,}834X_6}-0{,}076X_7$	16.62	7.0	
Simbal	1	$0{,}263X_1+0{,}343X_2+\mathbf{0{,}652X_3}+0{,}542X_4+0{,}061X_5+0{,}259X_6+0{,}149X_7$	182.01	63.7	90.7
(n = 5)	2	$0{,}246X_1+\mathbf{0{,}817X_2}-0{,}138X_3-0{,}459X_4+0{,}112X_5-0{,}121X_6+0{,}125X_7$	76,81	26.9	
Brahmbal	1	$0{,}274X_1+0{,}374X_2+\mathbf{0{,}717X_3}+0{,}254X_4+0{,}294X_5+0{,}256X_6+0{,}235X_7$	693.88	89.6	98.1
(n = 5)	2	$0{,}358X_1+0{,}548X_2-0{,}397X_3-\mathbf{0{,}557X_4}+0{,}046X_5+0{,}256X_6+0{,}191X_7$	66.40	8.6	
Limbal	1	$0{,}322X_1+0{,}469X_2+\mathbf{0{,}660X_3}+0{,}365X_4+0{,}088X_5+0{,}285X_6+0{,}138X_7$	347.45	85.0	93.4
(n = 6)	2	$0{,}271X_1-0{,}312X_2-0{,}030X_3-0{,}328X_4+0{,}426X_5+0{,}227X_6+\mathbf{0{,}699X_7}$	34.22	8.4	
Pobal	1	$0{,}296X_1+0{,}523X_2+\mathbf{0{,}567X_3}+0{,}303X_4+0{,}195X_5+0{,}382X_6+0{,}203X_7$	443.06	91.0	95.9
(n = 9)	2	$0{,}201X_1-\mathbf{0{,}831X_2}+0{,}427X_3+0{,}255X_4+0{,}061X_5+0{,}129X_6-0{,}026X_7$	23.94	4.9	

PC: Principal Component; CV: Cumulative Variance; 1: Size vector; 2: Shape vector; X_1: Shoulder height; X_2: Body length; X_3: Chest girth; X_4: Chest depth; X_5: Chest width; X_6: Hip height; X_7: Hip width.

Table 3. Eigenvector, eigen value, proportion, and cumulative body morphometric of Bali and Bali crossbreed cattle in females

Breeds	PC	Eigenvector	Eigen Value	Proportion (%)	CV (%)
Bali	1	$0{,}1562X_1+0{,}227X_2\mathbf{+0{,}880X_3}+0{,}277X_4+0{,}101X_5+0{,}210X_6+0{,}135X_7$	511.01	79.5	89.6
(n = 11)	2	$0{,}323X_1\mathbf{-0{,}503X_2}-0{,}295X_3-0{,}306X_4+0{,}324X_5+0{,}439X_6+0{,}405X_7$	64.97	10.1	
Simbal	1	$0{,}159X_1+0{,}372X_2\mathbf{+0{,}756X_3}+0{,}482X_4+0{,}002X_5+0{,}157X_6+0{,}085X_7$	400.00	76.4	91.5
(n = 7)	2	$0{,}036X_1\mathbf{-0{,}781X_2}+0{,}385X_3-0{,}029X_4+0{,}428X_5-0{,}077X_6+0{,}225X_7$	79.41	15.2	
Brahmbal	1	$0{,}005X_1+0{,}165X_2\mathbf{+0{,}879X_3}+0{,}307X_4+0{,}189X_5-0{,}059X_6+0{,}258X_7$	225.03	57.1	76.6
(n = 15)	2	$-0{,}006X_1\mathbf{-0{,}764X_2}+0{,}108X_3-0{,}224X_4+0{,}055X_5+0{,}590X_6-0{,}051X_7$	76.98	19.5	
Limbal	1	$0{,}238X_1+0{,}563X_2\mathbf{+0{,}609X_3}+0{,}297X_4+0{,}261X_5+0{,}178X_6+0{,}262X_7$	641.12	78.6	93.3
(n = 11)	2	$-0{,}329X_1+0{,}176X_2+0{,}137X_3+0{,}139X_4+0{,}051X_5\mathbf{-0{,}905X_6}+0{,}009X_7$	120.04	14.7	
Pobal	1	$0{,}232X_1+0{,}326X_2\mathbf{+0{,}694X_3}+0{,}235X_4+0{,}325X_5+0{,}237X_6+0{,}374X_7$	199.79	84.4	91.6
(n = 13)	2	$-0{,}279X_1\mathbf{+0{,}784X_2}-0{,}370X_3+0{,}028X_4+0{,}185X_5-0{,}312X_6+0{,}196X_7$	17.07	7.2	

PC: Principal Component; CV: Cumulative Variance; 1: Size vector; 2: Shape vector; X_1: Shoulder height; X_2: Body length; X_3: Chest girth; X_4: Chest depth; X_5: Chest width; X_6: Hip height; X_7: Hip width.

The two principal components found in Bali and crossbred Bali cattle are the same as the report of Bila et al. (2023) that the PCA results of 13 body measurements in male and female South African Sussex cattle, only extracted two principal components, but the cumulative variance obtained was lower than our findings. The two principal components in male South African Sussex cattle contributed 74% of the variance, wich PC1 contributing 64% of the total variance, and PC2 contributed 10% of the total variance. The two principal components in female South African Sussex cattle contributed 70% of the variance, wich PC1 contributed 61% of the total variance, and PC2 contributed 9% of the total variance.

Application of morphometrics in principal component analysis, two principal components with the highest cumulative diversity values are used as the size and shape equations. PC1 is a marker of body size, and PC2 is a marker of body shape (Verma et al., 2015; (Heryani et al., 2018). **T**he present study, the two principal components in males contributed 90,7% (Simbal cattle) to 98.1% (Brahmbal cattle) of the variance, while females contributed 76.6% (Brahmbal cattle) to 93,3% (Limbal cattle) of the variance. It can be interpreted as that of the seven initial morphometric variables analyzed, 90.75 - 98.1% of the total variation of size and body shape of males can be explained by PC1 and PC2, and 76.6 - 93.3% of the total variation of size and body shape of females can be explained by PC1 and PC2 (Buzanskas et al., 2013).

The cumulative variance of the two principal components in Bali cattle and crossbred Bali cattle found in this study was higher compared to the report by Baliarti et al. (2023) that the cumulative variance of the two principal components in Bali, Limbal, and Simbal cattle were 56.12, 50.85, and 68.62%, respectively. Variations in the rearing environment and genetic traits of the breed can influence these differences. In Pasundan cattle, the cumulative variance of the two principal components (PC1 and PC2) was 89.38% (Putra et al., 2020), meanwhile in female Bali cattle in Central Lombok Regency was 67.47% (Warman et al., 2023).

The morphometric variable that has the highest eigenvector value (characteristic vector) in the PC1 can be used as the marker of body size, while the morphometric variable with the highest eigenvector value in the PC1 can be used as the marker of body shape (Adelia et al., 2020; Mahmudi et al., 2019; Zafitrah et al., 2020). The results in Table 1 show that the morphometric variable with the highest eigenvector value in PC1 for bulls that can be claimed as a marker of body size from all cattle breeds observed is chest circumference (X3), with eigenvector values ranging from 0.567 (Pobal cattle) to 0.729 (Bali cattle). The PC2 shows the variation of eigenvector values between Bali cattle and crossbred Bali cattle. The morphometric variable that has the highest eigenvector value on the PC2 as a marker of the body shape of Bali cattle is hip height (0.834), while in Simbal and Pobal cattle are body length (0.817 and -0.831, respectively), while in Brahmbal cattle is chest depth, and Limbal cattle is hip width (0.699). In female cattle, chest circumference (X3) can be used as a body size marker in Bali, Simbal, Brahmbal, Limbal, and PO cattle because it has the highest eigenvector value in the PC1. The eigenvector value ranges from 0.609 (Limbal cattle) to 0.880 (Bali cattle).

The PC2 shows differences in the body shape marker. The highest eigenvector value in the shape vector in Limbal cattle is the hip height (-0.905). In contrast to Limbal cattle, in Bali, Simbal, Brahmbal, and Pobal cattle have the same body shape marker, namely body length (X2) with eigenvector values ranging from -0.503 (Bali cattle) to 0.784 (Pobal cattle). The PC1 eigenvector values in Bali cattle and Bali crossbred cattle are all positive in both males and females. It indicates that the principal components can be accepted as body size markers (Mulyono et al., 2009). Meanwhile, the PC2 eigenvector values are positive and negative. High positive eigenvector values describe a more compact body shape, while negative eigenvector values describe a looser body shape (Brown et al., 1973).

The summary of the marker variables of the size and shape of Bali and Bali crossbreed cattle in males and females presented in Table 4.

Table 4. Summary of the markers of body size and shape of Bali and Bali crossbreed cattle

Breeds	Males		Females	
	PC1	PC2	PC1	PC2
Bali	Chest Girth (+)	Hip Height (+)	Chest Girth (+)	Body Length (-)
Simbal	Chest Girth (+)	Body Length (+)	Chest Girth (+)	Body Length (-)
Brahmbal	Chest Girth (+)	Chest Depth (-)	Chest Girth (+)	Body Length (-)
Limbal	Chest Girth (+)	Hip Width (+)	Chest Girth (+)	Hip Height (-)
Pobal	Chest Girth (+)	Body Length (-)	Chest Girth (+)	Body Length (+)

PC: Principal Component; 1: Size vector; 2: Shape vector.

The findings in Table 4 show that the body size marker (PC1) of Bali cattle and all crossbred Bali cattle in both males and females is chest girth. The similarity of this marker's body size is likely due to the similarity in environment and rearing management applied by breeders. In addition, the similarity in body size markers among Bali cattle and all crossbred Bali cattle can also caused by genetic similarities inherited from pure Bali cows. Previous studies have found the same thing that the character of body size of male and female Bali, Limbal, and Simbal cattle are chest circumference (Mahmudi et al., 2019; Zafitra et al., 2020; Adelia et al., 2020; Alkamun et al., 2021; Baliarti et al., 2023).

The results in PC2 show that there are variations in the marker of body shape in bulls, where the marker of body shape in Bali cattle is hip height, Simbal is body length, Brahmbal is chest depth, and Pobal cattle is body length. Meanwhile, the body shape markers in female cattle do not vary much. The body shape marker of Limbal cattle is hip height, while Bali, Simbal, Brahmbal, and Pobal cattle have the same body shape markers, namely body length.

The body shape markers of male Bali cattle in this study (hip height) are different from previous findings, namely chest depth (Mahmudi et al. 2019) and shoulder height (Zafitra et al., 2020; Alkamun et al., 2021). Likewise, the body shape markers in female Bali cattle (Body Length) are different from previous findings, namely shoulder height (Zafitra et al., 2020; Alkamun et al., 2021) and Chest Girth (Baliarti et al., 2023). The variations in the markers of body size and shape in Bali and crossbred Bali cattle indicated differences in environmental conditions and genetic quality of Bali and Bali crossbreed cattle developed in various regions in Indonesia. Body size is a quantitative trait related to productivity traits influenced by environmental factors, while body shape is a qualitative trait influenced by genetic factors (Mahmudi et al., 2019).

Scatterplot of principal components score of Bali cattle and Bali cattle cross in this study were presented in Figure 3 for males, and in Figure 4 for females cattle.

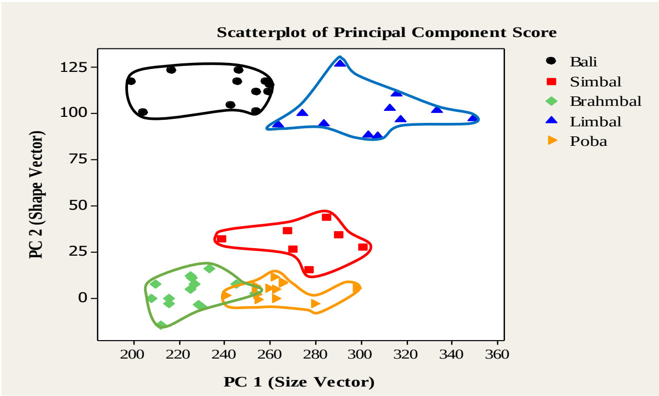

Figure 3. Scatterplot of principal components score in male cattle

Based on Figure 3, the X-axis is the first principal component (PC1), known as the size vector, and the Y-axis is the second principal component (PC2), known as the shape vector. In males, the crowd of principal component score data of Bali and crossbred Bali cattle separated and had no overlapping. The PC1 score in Simbal cattle is relatively higher than the other four cattle breeds. Thus, Simbal cattle have a higher body size than Bali cattle, Brahmbal, Limbal, and Pobal cattle. While the body sizes of Brahmbal and Pobal cattle are relatively the same, both cattle breeds have a higher size than Limbal and Bali cattle, while the body size of Limbal cattle is between Simbal and Bali cattle, and the lowest PC1 score is Bali cattle.

Figure 4 shows that the spread of principal component scores data in females is somewhat different from that in males. The distribution of principal component score data between Limbal, Bali, and Simbal cattle separated from each other. However, among Brahmbal and Pobal cattle, there is some overlapping principal component score data. The highest body size score was found in Limbal cattle, followed by Simbal and Pobal cattle, while Brahman and Bali cattle were not much different. Based on the spread of PC1 score data (size vector) in Figures 3 and 4, the highest body size in males is Simbal cattle, while in females is Limbal cattle. This finding proves that crossbreeding among Bali cattle and with exotic bulls (Simmental, Limousine, Brahman, and Peranakan Ongole cattle) can produce offspring of Bali crossbreed cattle that have larger body sizes than pure-line Bali cattle.

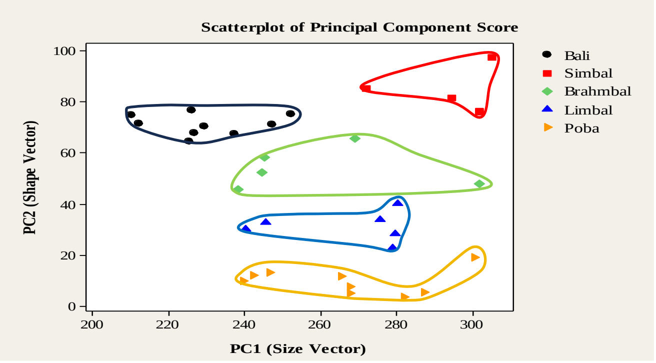

Figure 4. Scatterplot of principal components score in female cattle

The highest body shape score in male cattle is Simbal cattle, followed by Bali, Brahmbal, Limbal, and Pobal cattle. In contrast, in female cattle, the body shape scores of Limbal and Bali cattle are not much different and higher than Simbal, Brahmbal, and Pobal cattle. Meanwhile, Brahmbal and Pobal cattle show similarities in body shape (Figure 3). The similarity in body shape among Brahmbal and Pobal cattle is likely because they both inherit the traits of Indicus cattle from their father's lineage. Brahmbal cattle inherit the traits of Brahman cattle, while Pobal cattle inherit the traits of Ongole cattle. Body shape traits are qualitative traits in livestock, such as body shape, fat, thin, tall, and short. Body shape trait is a qualitative trait, such as body shape, fat, thin, tall, and short. Genetic factors have more influence on quantitative traits, while environmental factors have little or no influence at all (Martojo 1992; Warwick et al., 1995). Thus, the differences in body shape in male and female cattle of Bali cattle and crossbred Bali cattle are an expression of differences in their genetic traits.

Correlation of Principal Components

Principal components can be used as an index to evaluate animals based on several traits. The criteria for inclusion in the index selection, the correlation coefficient value of the principal components with PC1 or PC2 must be greater than 0.60 (Buzanskas et al., 2013). The correlation coefficients of PC1 and PC2 2 with morphometric variables of Bali cattle and its crosses with exotic bulls in males were presented in Table 5.

Table 5. The correlation coefficient of the marker variables of body size and shape with PC1 and PC2 of Bali and Bali crossbred cattle in males and females

Breeds	Males		Females	
	PC1	PC2	PC1	PC2
Bali	Chest Girth (+0.729)	Hip Height (+0.834)	Chest Girth (+0.880)	Body Length (+0.503)
Simbal	Chest Girth (+0.652)	Body Length (+0.817)	Chest Girth (+0.756)	Body Length (+0.781)
Brahmbal	Chest Girth (+0.717)	Chest Depth (+0.557)	Chest Girth (+0.879)	Body Length (+0.764)
Limbal	Chest Girth (+0.660)	Hip Width (+0.699)	Chest Girth (+0.609)	Hip Height (-0.905)
Pobal	Chest Girth (+0.567)	Body Length (-0.831)	Chest Girth (+0.694)	Body Length (+0.784)

PC1: Principal Component 1; PC2: Principal Component 2.

Table 5 shows that the correlation between the body size markers and PC1 in males and females in all observed cattle breeds is positively correlated. The correlation coefficient in males is moderate (+0.567) to strong (+0.729), while in females is strong (+0.694) to very strong (+0.880). Meanwhile, the correlation between the body shape markers and PC2 in males shows positive and negative correlations. The correlation coefficient in males is moderate to very strong, with correlation coefficients ranging from +0.557 to +0.834. The correlation coefficient in females ranges from +0.503 to -0.905. Thus, all the body size and shape markers found in Bali and Bali crossbred cattle, in males and females, can be used as selection criteria to improve production traits.

Conclusion

The findings concluded that Bali, Simbal, Brahmbal, Limbal, and Pobal male cattle have the same body size markers, namely chest girth. Meanwhile, body shape markers vary among cattle breeds, namely hip height for Bali cattle, body length for Simbal and Pobal cattle, chest depth for Brahmbal cattle, and hip width for Limbal cattle. The body shape markers in female cattle are body length for Bali, Simbal, Brahmbal, and Pobal cattle, while the body shape markers of Limbal cattle are hip height. The crossbreeding scheme between Bali cattle and exotic cattle that produces offspring with the highest (superior) body size score is the Simmental x Bali cross (Simbal cattle) in males and the Limousine x Bali cross (Limbal cattle) in females. These body size and shape markers have a strong correlation with the first principal component and the second principal component, so they can be used as selection criteria to improve the production performance of Bali and Bali crossbred cattle.

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Contribution of each author: Muh. Rusdin: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, funding acquisition. La Ode Nafiu: conceptualization, methodology, software, validation, resources, data curation, writing—review, funding acquisition. Achmad Selamet Aku: formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, supervision, and funding acquisition. La Ode Sahaba: investigation, resources, data curation, supervision, project administration, funding acquisition.

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Conflicts of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work described in this manuscript.

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