Phenotypic Characterization of Indonesian Jambi Buffalo in the Highland and Lowland Areas using Multivariate Analysis

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ABSTRAK

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Kerbau Jambi dipelihara secara ekstensif dengan sistem tertutup oleh peternak kecil. Studi ini bertujuan menganalisis karakteristik fenotipik kerbau di Provinsi Jambi pada dataran tinggi dan rendah. Sebanyak 160 ekor kerbau digunakan, terdiri dari 53 ekor di dataran tinggi dan 107 ekor di dataran rendah. Analisis deskriptif diterapkan pada data kualitatif, sedangkan analisis varians, Uji Rentang Berganda Duncan, korelasi Pearson, analisis komponen utama (PCA), analisis diskriminan, dan analisis klaster hierarkis (HCA) digunakan untuk data kuantitatif. Hasil menunjukkan keragaman sifat kualitatif pada kedua populasi. Morfometri tubuh kerbau dataran tinggi secara signifikan (P<0,05) lebih besar dibandingkan kerbau dataran rendah. Korelasi Pearson antara morfometri tubuh dan indeks morfometrik berkisar dari rendah hingga tinggi. Kerbau dataran tinggi menunjukkan tiga komponen utama (PC) berdasarkan morfometri tubuh, sedangkan kerbau dataran rendah menunjukkan dua PC. Pada kedua populasi, indeks morfometrik menghasilkan empat komponen utama. Analisis diskriminan mengkarakterisasi sekitar 48,09% kerbau dataran tinggi dan 51,92% dataran rendah berdasarkan morfometri tubuh, serta 57,69% dan 42,31% berdasarkan indeks morfometrik. HCA mengelompokkan kerbau Jambi ke dalam tiga klaster: Merangin (klaster pertama), Kerinci (klaster kedua), dan Tanjung Jabung Barat, Tebo, serta Batanghari (klaster ketiga). Kesimpulan, kerbau Jambi di dataran tinggi dan rendah menunjukkan perbedaan fenotipik signifikan dengan morfometri tubuh lebih besar pada populasi dataran tinggi, serta variasi genetik dan adaptasi lokal yang tercermin dalam pola klasterisasi, memberikan dasar ilmiah penting untuk pengembangan program pemuliaan dan konservasi sesuai kondisi ekosistem.

Kata Kunci: Kerbau, Morfometrik, Multivariat Analisis, Fenotipik

ABSTRACT

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Jambi buffaloes are extensively reared under a closed system by smallholder farmers. This study aimed to analyze the phenotypic characteristics of buffaloes in Jambi Province, Indonesia, across the Highland and lowland areas. A total of 160 buffaloes were sampled, comprising 53 from the highlands and 107 from the lowlands. Descriptive analysis was applied to qualitative data, while analysis of variance, Duncan's Multiple Range Test, Pearson correlation, principal component analysis (PCA), discriminant analysis, and hierarchical cluster analysis (HCA) were used for quantitative data. Results revealed considerable diversity in qualitative traits across both populations. Highland buffaloes exhibited significantly larger body morphometrics (P<0.05) than their lowland counterparts. Pearson correlations between body morphometrics and morphometric indices ranged from low to high. PCA identified three principal components (PCs) for highland buffaloes and two PCs for lowland buffaloes based on body morphometrics, while four PCs were extracted from morphometric indices in both groups. Discriminant analysis characterized approximately 48.09% of Highland and 51.92% of lowland buffaloes based on body morphometrics, and 57.69% and 42.31%, respectively, based on morphometric indices. HCA classified Jambi buffaloes into three clusters: Merangin (first cluster), Kerinci (second cluster), and Tanjung Jabung Barat, Tebo, and Batanghari (third cluster). In conclusion, buffaloes from Highland and lowland areas exhibit significant phenotypic differences, characterized by larger body size in highland populations, alongside genetic variation and local adaptations reflected in clustering patterns. These findings provide a scientific foundation for breeding and conservation programs tailored to the specific conditions of each ecosystem.

Key Words: Buffalo; Body Morphometric; Multivariate Analysis; Phenotypic

INTRODUCTION

Indonesia has mega biodiversity, including the genetic resources of livestock. Buffalo is one of Indonesia's livestock species. Buffaloes play a significant role in contributing to meat and milk (Prihandini et al. 2023), are integral to traditional and religious activities (Kurniadi & Putri 2021), and exhibit excellent adaptability (Saputraa et al. 2020). Based on their phenotype and genotype, we can categorize buffaloes into two types: river buffaloes and swamp buffaloes. River buffaloes are characterized by black body color and curved horns, while swamp buffaloes are dark gray with one to two chevron lines (Curaudeau et al. 2021). Based on the number of chromosomes, river buffaloes have 50 pairs of chromosomes, while mud buffaloes have 48 pairs (Barker et al. 1997).

Differences in geographical conditions or the isolation of areas by natural features such as rivers, mountains, and forests can result in livestock species with distinct characteristics. The information provided by characterization studies is essential for planning the management of (Animal genetic resources) AnGR at local, national, regional, and global levels (FAO 2012). Characterization of livestock phenotypes and body biometry measures, particularly for lesser-known livestock groups, is essential to provide information on their genetic diversity (Vohra et al. 2015).

Jambi Province has a large buffalo population of 46,106 (Badan Pusat Statistik Provinsi Jambi 2024), which is spread across several districts. Smallholder farmers typically keep buffaloes in extensive systems. Compared to other livestock, including those in Jambi Province, buffalo characterization activities in Indonesia remain limited. There is no report comparing the phenotypic diversity of qualitative and quantitative traits based on multivariate analysis of buffaloes from the Highland and lowland areas in Jambi province. Phenotypic data, like morphometric data, can be analyzed using multivariate analysis. Multivariate analysis is a standard statistical approach used in analyzing compound data with multiple variables (Rezende et al. 2017). Multivariate analyses included PCA, Pearson correlation, discriminant analysis, and hierarchical cluster analysis (HCA). In addition to assessing genetic diversity, morphometric analysis can also be used to estimate genetic distance within and between livestock populations (Yunusa et al. 2013).

Based on these reasons, this study aims to analyze the phenotypic diversity of Jambi buffaloes in the highlands and lowlands. The study's results can inform the conservation and breeding strategies of Jambi buffalo.

MATERIALS AND METHODS

Ethical approval

The methods in this study were approved by the Animal Ethics Commission of the Faculty of Medicine, Andalas University, Indonesia, with permit number 588/UN.16.2/KEP-FK/2023.

Research area and animals

This study was conducted in highland areas (>500-1000 m above sea level), including the Merangin and Kerinci districts, and in lowland areas (0-100 m above sea level), including the Batanghari, Tebo, and Tanjung Jabung Barat districts (Figure 1). Climatic conditions in the research areas are presented in Table 1. Jambi Province is located at a latitude of 0°45′–2°45′ S and a longitude of 101°10′–104°55′ E. A total of 52 buffaloes were collected from highland areas, with a proportion of (male, 21 and female, 31), and 107 buffaloes were collected from lowland areas, with a proportion of (male, 36 and female, 71). To avoid sex effects, only adult buffaloes (3 to 6 years old) were observed; age determination was based on birth records and also on changes in fixed incisors (Badan Standarisasi Nasional, Bibit kerbau - Bagian 1: Lumpur 2011).

Livestock rearing management

The observed livestock were reared using semi-intensive methods, where they were released in the morning and penned in the afternoon without being provided with forage or concentrates. The housing system was colony-based, and the mating system was natural.

Data collection

The data collected include qualitative traits such as 1) skin color, 2) hair color, 3) horn shape, 4) chevron, 5) stocking, 6) back line, 7) hoof shape, 8) whorls on the head, 9) whorls on the back, and 10) whorls on the waist (Suhardi et al. 2020; Abdullah et al. 2024).

The quantitative trait of body measurements is measured based on (Vohra et al. 2015; Maleo et al. 2018). Quantitative properties of body measurements were measured based on Vohra et al. (2015) and Maleo et al. (2018) were 1) Shoulder height (SH), the highest distance of the shoulder through the back of the shoulder blade perpendicular to the ground (cm); 2) Hip height (HH), the highest distance of the hip perpendicular to the ground (cm); 3) Hip width (HW), the vast distance between the two hip joints (cm); 4) Body length (BL), the straight-line distance from the edge of the processus spinosus bone to the protrusion of the tapis bone (Os ischium) (cm); 5) Chest circumference (CC), measured right around the chest cavity, behind the shoulder joint (os scapula), using a tape measure (cm); 6) Deep chest (DC), the distance between the highest point of the shoulder and the base of the sternum (cm); 7) Chest width (CW), the distance between the left and right shoulder joints (between the humeral tuberosity and the dextral tuberosity) (cm); 8) Buttock length (RL), measured from the groin to the hip (cm); 9) Rump width

Table 1. Cinematic condition of the research area

Description	Highland		Lowland		
	Kerinci	Merangin	Batanghari	Tebo	Tanjung Jabung Barat
Temperature (^{0}C)	23.24	23.24	27.58	27.58	27.27
Humidity (%)	80.10	80.10	82.68	82.68	87.62
Rainfall (mm/year)	1,996	1,996.50	2,091.20	2,091.20	-
Regional Height (asl)	1000	501	36	43	37

Source: Badan Pusat Statistik Provinsi Jambi (2024)

Table 2. Calculations for body index

No.	Variables	Formula
1.	Height index (HI)	Shoulder Height/Body length
2.	Rump length index (RLI)	Rump Length/Body Length*100
3.	Over increase index (OI)	Hip Height/Shoulder Height*100
4.	Height slope (HS)	Hip Height-Shoulder Height
5.	Length index (1) (LI1)	Body Length/Shoulder Height
6.	Width slope (WS)	Hip Width/Chest Width
7.	Body weight index (BWI)	Body weight/Hip Height
8.	Length index (2) LI2)	Body Length/Chest Deep
9.	Balance: (Ba)	(Rump Width*Rump Length)/(Chest deep*Chest Circumference)
10.	Depth index: (DI)	Chest deep/Hip Height
11.	Foreleg length: (FL)	Hip Height-Chest deep
12.	Body index[a] (Bia)	Body Length*100/Chest Width
13.	Body ratio[e] (Bre)	Hip Height/Shoulder Height
14.	Transverse pelvic (Tp)	Rump Width*100/Shoulder Height

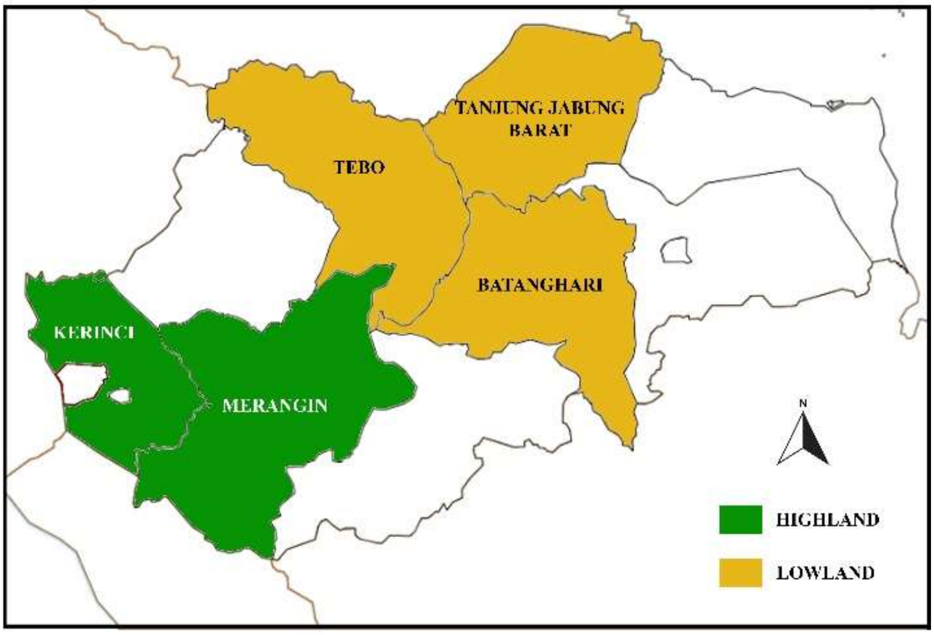

Figure 1. Research location in Jambi Province, Sumatra Island

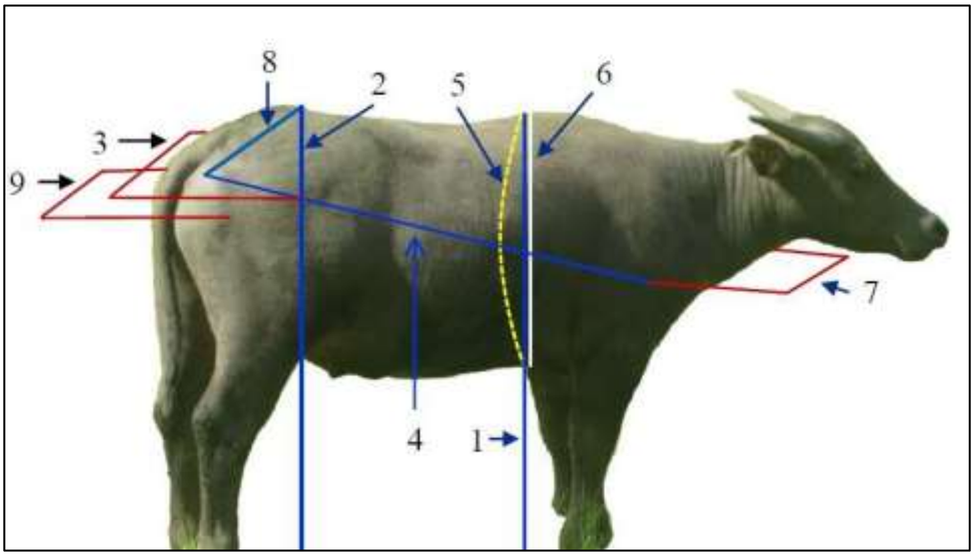

Figure 2. Illustration of buffalo body measurements. 1= Shoulder height, 2= Hip height, 3= Hip width, 4= Body length. 5= Chest circumference, 6= Deep , 7= Chest width , 8= Buttock length, 9= Rump width

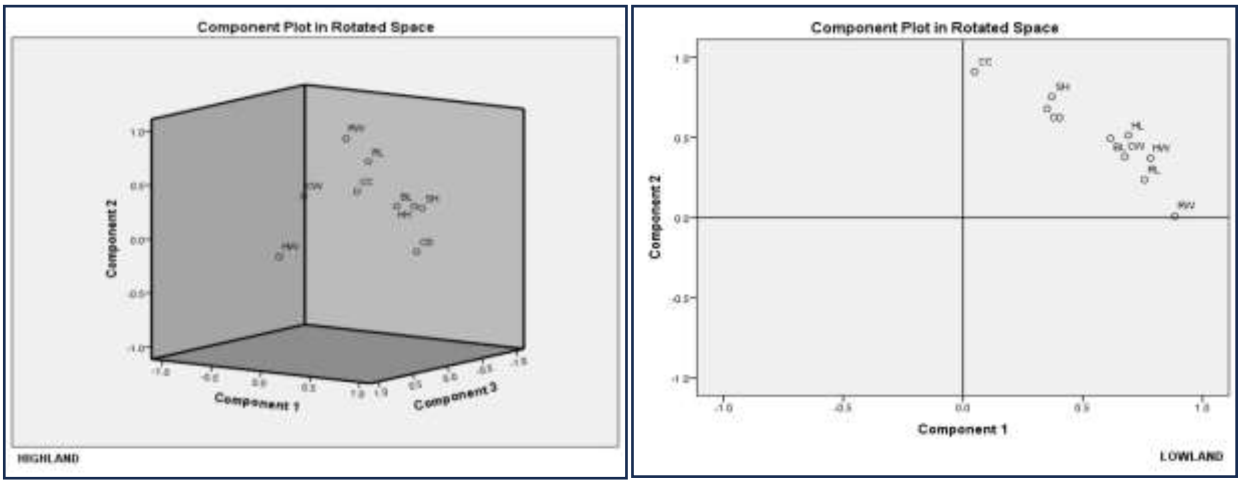

Figure 3. Component plot in rotated space for body morphometric

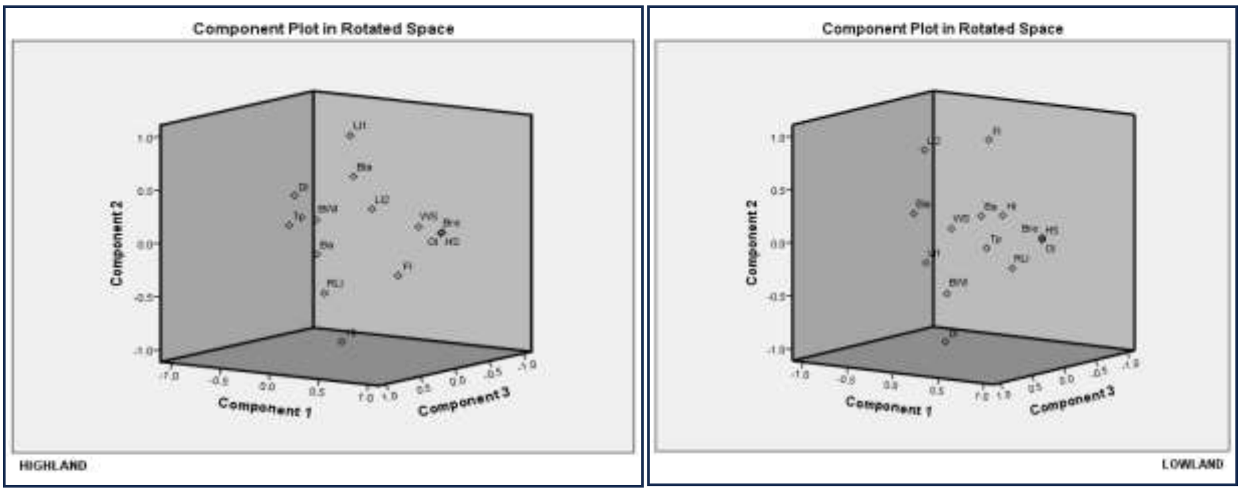

Figure 4. Component plot in rotated space for morphometric index

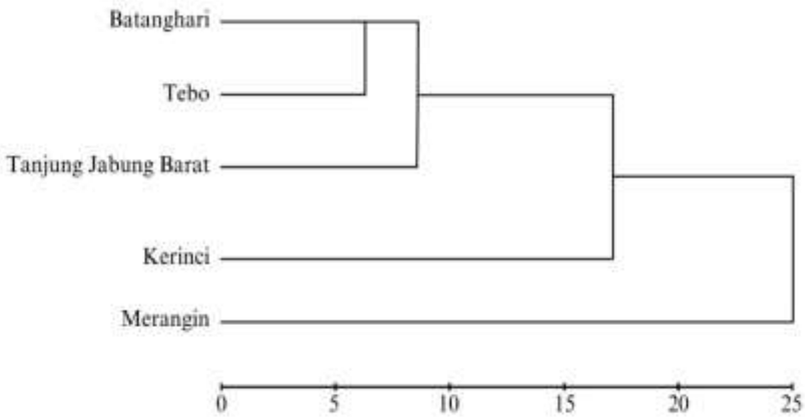

Figure 5. Dendrogram of genetic distances between five populations of Jambi buffalo

(RW), the distance between the left and right tuber femoris (cm) (Figure 2). SH, HH, HW, BL, and DC were measured using a yardstick. CW, RL, and RW were measured using callipers, and CC was measured using a tape measure. The body index in this study was analyzed based on the equation in Table 2, according to (Alderson 1999; Benerjee et al. 2014).

Statistical analysis

Qualitative trait data were analyzed by percentage and discussed descriptively using Microsoft Excel 21 version software. Body size and body index data were calculated as means and standard deviations. Pearson correlation, principal component analysis (PCA), discriminant analysis, and hierarchical cluster analysis (HCA) were analysed using SPSS 25 version software (IBM Corp, 2017). The Kaiser-Meyer-Olkin (KMO) sample adequacy test and Bartlett (1950) test were used in PCA to see if the data set was valid at a 1% significance level. This number, known as the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA), indicates the extent to which variation in certain biometric traits can be attributed to underlying factors (Kaiser 1958). Rotation of principal components: We used Varimax rotation through component transformation to simplify the interpretation of factor analysis. HCA is used to group buffalo from different populations. We performed HCA using combined data (body size and body index), the nearest neighbor method, the Euclidean distance measure, and the Z-score transformation value.

RESULTS AND DISCUSSION

Qualitative and quantitative traits

Table 3 presents observations of qualitative traits of highland and lowland buffaloes. The skin color of buffaloes (both male and female) in both populations is generally dark gray to black. Observations of coat color also showed a similar trend, although in the lowland population, the black coat color was more dominant. The results revealed that the skin color and coat color in this study were in agreement with the Paraguas et al. (2018) on swamp buffalo in Calayan Island, Philippines; Suhardi et al. (2020) on Kalimantan, Indonesia, and Thailand buffaloes; and buffaloes from East Java, Indonesia (Putri et al. 2022). Others reported buffaloes in Bali, Indonesia (Adebowale et al. 2022), India (Vandre et al. 2022), and in Bangladesh (Yeasmin et al., 2016), which are predominantly black. In general, swamp buffalo have a characteristic dark gray to black coat color (Yusnizar et al. 2015; Liang et al. 2021). Under extreme environmental conditions, differences in phenotypes, such as coat color, can be observed, as reported by Khan et al. (2013), who found that the majority of Azikheli buffaloes in the mountainous areas of Pakistan have a brown coat color. This variation is strongly suspected to be related to adaptation to the environment, as the area lacks swamps for bathing, making it difficult for buffalo to reduce heat stress.

The Tranga horn shape dominates the horn shape in both populations; however, in the lowland male population, the Sikki horn shape is more prevalent. Maulana et al. (2023). The Taranga horn shape (horns grow upwards to form a half circle) was also found in Toraya buffalo populations, Musi Rawas Utara Setiawan (2022), Bangladesh Rahman et al. (2015), and buffalo in Konawe (Nafiu et al. 2023), while in the Indian state, buffalo have a backward curved horn shape (Khatke et al. 2023).

Double strip chevrons dominate the number of chevrons in both populations. One of the characteristics of the swamp buffalo is the presence of chevrons on the neck, typically one or two in white color (Zhang et al. 2020). The Chevron lines of swamp buffaloes in Jepara are predominantly single-line Chevron (Nur et al. 2018). The results of the study, Suhardi et al. (2020), report that double strip chevrons dominated buffaloes from East Kalimantan and South Kalimantan, while single chevrons dominated Thale Noi Buffaloes from Thailand. Meanwhile, light gray and white dominate the stocking colors of both populations. Nur et al. (2018) reported that white stockings were found on the majority of buffaloes in Jepara, Indonesia, and the Nagpuri buffalo of the Purnathadi strain in India (Thalkar et al. 2018). In contrast, buffaloes in Konawe, Indonesia, have light gray legs (Karabu et al. 2021).

The backline shape of highland buffaloes is predominantly curved, while in lowland populations, the more common shape is flat. Buffaloes have a dorsal line that can be used to characterize meat proportions; a straight dorsal line indicates a high proportion of fat in the body (Rusdin et al. 2022). Krisnandi et al (2013) reported that buffaloes in Garut, Indonesia, have curved (56.67%) and flat (43.33%) backlines, while Suhardi et al. (2020) reported that buffalo populations in Kalimantan, Indonesia, are dominated by buffaloes with flat backlines.

The hoof shapes of the two regions also show similarities, with the bowl-type hoof shape dominating. Erdiansyah and Anggraeni (2008) reported that swamp buffaloes in Dompu, Indonesia, have a bowl hoof type. Buffaloes with a bowl hoof type are suitable for use as farming livestock. Buffaloes with bowl hoof types can be a selection criterion for labor buffaloes (Dudi et al. 2011).

The number of whorls on the head in both populations is one, while the number of whorls on the shoulder and hips is two. Yulianty et al. (2016) found that whorls on buffaloes in Jembrana, Indonesia, varied, such as on the face, left and right shoulders, and left and right gluteal regions. The variation of whorls in buffaloes in Bombana Island, Indonesia, was dominated by the face and waist (Nafiu & Asminaya 2023). Whorls are a parameter that can be used for the selection of temperament traits in animals. Aierqing et al. (2020) reported the results of a study on the relationship between whorls and temperament traits in Chinese cattle and horses (Encina et al. 2023).

Table 4 presents observations of body morphometrics for highland and lowland buffaloes. Body morphometric parameters such as SH, HH, BL, DC, and RW of highland buffaloes were significantly higher ($P<0.05$) than those of lowland buffaloes; all body morphometric parameters of highland buffaloes were higher than those of lowland buffaloes. Komariah et al. (2015) reported that swamp buffaloes in West Java, Indonesia, at high altitudes had greater body weight than those at low altitudes. Similar results were reported (Depison et al. 2022) in Balinese cattle research at different altitude locations. Many studies have found that the body size of buffaloes in Jambi province is the same as that of the Simeulue buffalo (Eriani et al. 2019), Serang Banten buffalo (Murni et al. 2020), Kuntu buffalo Yendraliza et al. 2021), and Kalimantan buffalo (Suhardi et al. 2022). However, they are smaller than buffaloes in Calayan, Philippines (Villamor et al. 2024), Murrah buffalo (Yadav & Vijh, 2022), and buffaloes in North India (Vohra et al. 2015). Different morphometric sizes in the two populations are likely due to the nutrient content of the available forage. Depison et al. (2021) reported that the crude protein and ether extract content of the highlands were better than those in lowland areas at the exact location. The content of minerals such as potassium and manganese in the highlands is relatively higher than in the lowlands, while the content of P, Fe, and Zn is comparatively lower and affects livestock performance (Komariah et al. 2015; Kumar et al. 2022).

Table 5 presents the morphometric indices of highland and lowland buffaloes. Analysis of morphometric indices revealed that only WS was significantly different ($P<0.05$), with higher values in highland buffaloes. In contrast, lowland buffaloes showed higher mean values in OI, HS, LI1, LI2, and BWI. HI, DI, FI, Bia, and Tp were higher in highland buffaloes. The morphometric indices of buffaloes showed that LI was not different from Kalimantan and Patalung buffaloes of Thailand (Suhardi et al. 2022), while HS, WS, FL, and Ba values were lower than those of these populations. In addition, HS, LI1, and DI were also not different from those of buffaloes in Sulawesi (Rusdin et al. 2022), but WS and Ba were recorded as lower than those populations. Body size is crucial because it can describe the productivity level of livestock (Kocu et al. 2017). Differences in body size can be influenced by sex, breed, and environmental factors (Syaiful & Maulida 2020; Wilastra et al. 2021; Lan et al.2022).

Phenotypic correlation

Pearson correlation between body morphometrics of highland and lowland buffaloes had low, medium ($P<0.05$), and high ($P<0.001$) correlation values Table 6. Highland buffalo had the lowest correlation (HW-SH) and the highest correlation (HH-SH), while the highland population had the lowest correlation (CC-RW) and the highest correlation (HH-SH). Murni et al. (2020) reported a similar finding, indicating that SH and HH had the highest correlation in swamp buffaloes in Banten, Indonesia. Singh et al. (2022) conducted a study on Indian dairy buffaloes. This report demonstrated a linear relationship between the SH and HH of buffaloes. Ağyar et al. (2022) reported that body weight had a significant correlation with SH, WH, and BL in Anatolian buffaloes. The highest correlation in this study was also found between HW and HH, as reported by Khan et al. (2022), who also noted a high correlation between (HW-HH) and (thigh width-chest width); this suggests that we can use Height and rump width as selection criteria for

Table 3. Percentage of qualitative traits in male and female buffalo

No	Qualitative traits		Highland		Lowland	
			Male (21)	Female (31)	Male (36)	Female (71)
1.	Skin color	a. Black	33.33	16.13	41.03	19.72
		b. Dark gray	52.38	51.61	41.03	56.34
		c. Light gray	14.29	32.26	12.82	16.90
		d. Albino	0.00	0.00	5.12	7.04
2.	Hair color	a. Black	9.52	16.13	30.77	30.99
		b. Dark gray	80.95	51.61	46.15	42.25
		c. Blonde	9.52	32.26	23.08	19.72
		d. White	0.00	0.00	0.00	7.04
3.	Horn shape	a. Tranga	57.14	51.61	28.21	57.75
		b. Pampang	0.00	0.00	23.08	7.04
		c. Siki	23.81	19.35	35.90	30.99
		d. Soko	4.76	6.45	7.69	2.82
		e. Langi	14.29	22.58	7.69	5.63
4.	Chevrons	a. Single	38.10	45.16	35.90	33.80
		b. Double	61.90	54.84	64.10	66.20
5.	Stocking color	a. Dark gray	33.33	25.81	0.00	11.27
		b. Light gray	38.10	58.06	53.85	43.66
		c. White	28.57	16.13	43.59	45.07
6.	Backline	a. Curved	66.67	58.06	41.03	47.89
		b. Flat	33.33	41.94	58.97	52.11
7.	Hoof Shape	a. Scissor type	14.29	45.16	41.03	30.99
		b. Bowl type	85.71	54.84	58.97	69.01
8.	Whorls on the head	a.1	38.10	41.94	61.54	53.52
		b.2	33.33	48.39	35.90	36.62
		c.>2	28.57	9.68	2.56	14.08
9.	Whorls on shoulders	a.1	4.76	9.68	25.64	29.58
		b.2	52.38	64.52	66.67	59.15
		c.>2	42.86	25.81	7.69	11.27
10.	Whorls on hips	a.1	19.05	16.13	23.08	16.90
		b.2	61.90	70.97	64.10	67.61
		c.>2	19.05	12.90	12.82	14.08

Taranga (horns grow upwards to form a half circle), Pampang (horns that grow sideways and tend to be very long, this pattern is usually observed from a castrated male buffalo), Sikki (horn growth is similar to Tarangga with points almost meeting), Sokko (horns grow downward with points under the neck), Langi (horns grow in opposite directions) (Suhardi et al. 2020).

Table 4. The average and standard deviation of buffalo body morphometric

Variables (cm)	Highland			Lowland		
	Male (21)	Female (31)	Total (52)	Male (36)	Female (71)	Total (107)
Shoulder Height	124.73±7.43	122.30±5.10	123.27±6.13*	121.19±3.83	118.76±4.34	119.57±4.29*
Hip Height	125.05±7.74	122.42±5.65	123.48±6.57*	121.24±5.20	119.77±4.07	120.26±4.49*
Body Length	130.34±7.42	123.52±7.68	126.27±8.15*	126.47±5.83	121.95±5.86	123.47±6.18*
Chest deep	77.68±5.67	76.91±4.96	77.22±5.17*	74.20±5.82	74.55±5.27	74.43±5.41*
Rump Length	45.75±4.03	41.28±1.78	43.08±3.59	43.23±5.01	42.28±3.43	42.6±4.01
Rump Width	31.78±1.92	28.84±2.08	30.02±2.45*	28.92±4.22	28.09±2.82	28.37±3.35*
Hip Width	46.33±5.72	47.83±3.94	47.22±4.70	48.09±8.14	45.29±5.70	46.23±6.68
Chest Width	49.76±5.21	46.74±4.71	47.95±5.04	45.49±6.52	44.26±5.10	44.67±5.59
Chest Circumference	180.96±7.71	174.28±6.05	176.97±7.40	176.55±7.27	175.10±7.15	175.58±7.15

*=Significant (P<0.001)

Table 5. The average and standard deviation of buffalo body morphometric indices

Variables	Highland			Lowland		
	Male (21)	Female (31)	Total (57)	Male (36)	Female (71)	Total (107)
Height index	95.72±2.96	99.23±4.92	97.81±4.51	95.94±3.43	97.51±4.05	96.98±3.89
Rump length index	35.10±2.45	33.52±2.06	34.15±2.32	34.17±3.42	34.69±2.56	34.51±2.86
Over-increase index	100.27±2.27	100.09±1.52	100.16±1.82	100.04±2.85	100.88±2.41	100.59±2.57
Height slope	0.33±2.78	0.12±1.85	0.20±2.23	0.05±3.43	1.00±2.81	0.68±3.04
Length index (1)	1.05±0.03	1.01±0.05	1.02±0.05	1.04±0.04	1.03±0.04	1.03±0.04
Width slope	0.93±0.10	1.03±0.12	0.99±0.12*	1.06±0.14	1.03±0.12	1.04±0.13*
Body weight index	327.35±18.07	315.29±24.29	320.15±22.39	323.85±19.46	325.23±22.79	324.76±21.55
Length index (2)	1.68±0.10	1.61±0.09	1.63±0.10	1.71±0.13	1.64±0.10	1.66±0.11
Balance:	0.10±0.01	0.08±0.01	0.09±0.01	0.09±0.018	0.09±0.01	0.09±0.02
Depth index:	0.62±0.05	0.63±0.04	0.62±0.04	0.61±0.04	0.62±0.04	0.61±0.04
Foreleg length:	47.37±7.38	45.50±5.40	46.25±6.21	47.04±5.23	45.22±5.19	45.82±5.22
Body index[a]	72.05±3.16	70.93±4.69	71.38±4.10	71.68±3.12	69.72±3.51	70.37±3.48
Body ratio	1.00±0.02	1.00±0.02	1.00±0.02	1.00±0.03	1.01±0.02	1.00±0.03
Transverse pelvis	25.53±1.58	23.60±1.73	24.38±1.89	23.84±3.20	23.66±2.31	23.72±2.62

*=Significant (P<0.001)

economically valuable livestock. The correlation between variables occurs due to the phenomenon of pleiotropy.

The highest correlation values were found between morphometric indices in highland buffaloes (OI-HS, Bre-HS, and Bre-OI) and those in lowland buffaloes (OI-HS, Bre-HS, and Bre-OI), as shown in Table 7. The correlation values between the morphometric indices match the body morphometry. The height slope value in livestock evaluation is an indication of excellent body posture quality (Sakar et al. 2023). Unfortunately, there have been no reports on the correlation of morphometric indices in buffaloes. Several reports on the correlation of morphometric indices were reported in Pasundan cattle (Putra et al., 2020), the highest correlation values (WS and Tp), Kacang goats (Depison et al., 2020), body weight, with the Dactyl thorax index, the Relative cannon index, and area index for Kacang goats in the lowland area. Body weight with a conformation index, area index, and index of body weight for Kacang goats in the highland area and thin-tailed sheep. The highest correlation between body weight and body index for thin-tailed sheep in the lowland area and body weight and area index for thin-tailed sheep in the highland area (Depison et al. 2021).

Principal component analysis

PCA of body morphometrics in buffaloes showed that highland buffaloes had three PCs and buffaloes in lowland areas had two PCs (Table 8). PCA of body morphometrics showed that 74.16% of the differences in highland buffaloes and 69.45% in lowland buffaloes can be explained, with the difference in the number of PCs suggesting that highland buffaloes have more complex body shapes and greater variation than lowland buffaloes. Several previous studies reported four PCs that explained 59.52% of the total variation in Murrah buffalo (Dahiya et al. 2021). Raut et al. (2023) identified five PCs that explained 61.90% of the total variation in Marathwadi buffaloes. Vohra et al. (2015) identified four PCs that explain 70.86% of the total variation of the lesser-known buffalo. Vohra et al. (2017) identified five PCs that accounted for 70.13% of the total variation in Chhattisgarhi buffalo. Five PCs were able to explain 67.4% of the total variation in Murrah females, while four PCs were obtained in Murrah bulls and explained 62% of the total variation (Vohra et al. 2017).

Meanwhile, the PCA of morphometrics indices in highland and lowland buffaloes had four PCs (Table 9). The extracted morphometrics index (PCA) accounted for 84.17% of the total variance of animal morphometrics indices in highland buffaloes and 84.02% in lowland buffaloes. However, there is currently no reported research on PCA for buffalo morphometric indices. Putra et al. (2020) found 4 PCs in Pasundan cattle based on 13 observed morphometric indices. The PCs could explain 89.38% of the total variation. Depison et al. (2021) found four PCs of thin-tailed sheep in the lowlands with a total variance of 78.23% and five PCs in the highlands with a total variance of 84.99%. Kacang goats have 4 PCs with a total variance of 85.82% in the lowlands and 86.19% in the highlands (Depison et al. 2020). In addition to genetic factors, this study shows that environmental factors also play a strong role in livestock performance. These environmental factors include disease, adaptability, and the nutritional quality of feed. Plots of morphometric components and morphometric indices of buffaloes are illustrated in Figures 3 and 4.

Discriminant analysis

Discriminant analysis was used to characterise the buffalo population based on body morphometrics and morphometric indices. In addition, about 48.09% of highland buffaloes and 51.92% in the lowlands can be characterised based on body morphometrics. Meanwhile, about 57.69% of highland buffaloes and 42.31% in the lowlands can be characterised based on morphometric indices (Table 10).. Previous studies have reported that breed characterization based on body size can distinguish buffaloes in three populations. Ali et al. (2024) Purnathadi (71.7%), Marathwadi (79.6%) and Ngapuri (61.7%); Anggraeni et al. (2011); West Nusa Tenggara buffalo (95.0%); North Sumatra (74.51%); South Sulawesi (74.9%); Central Java (67.33%); and NAD (66.0%). Salamena & Papilaja (2010) characterized the western (67.4%), central (53.6%), and eastern (50.8%) subpopulations of Moa buffaloes. Suhardi et al. (2022) North Kalimantan (100%), East Kalimantan (66%), and South Kalimantan (70%).

Hierarchical cluster analysis (HCA) based on body size and body index revealed three clusters. The first cluster was Merangin; Kerinci was in the second cluster, and Tanjung Jabung Barat, Tebo, and Batanghari were in the third cluster (Figure 5). The lowest Euclidean distance was Batanghari-Tebo (4.92), while the highest was Batanghari-Merangin (36.34) (Table 11). The highland buffalo populations (Merangin and Kerinci) are in close clusters, and the lowland buffalo populations are also in the same cluster. This evidence suggests that geographical and environmental factors play a significant role in shaping buffalo subpopulations. Clustering based on body size has also been reported for buffaloes in Banten (Murni et al. 2020), Indonesian local buffaloes (Anggraeni et al. 2011), and river buffaloes in India (Ali et al. 2024).

Table 6. Coefficient Correlation among body morphometrics of buffaloes in the Highland (below diagonal) and the lowland (above diagonal)

Traits	SH	HH	BL	CD	RL	RW	HW	CW	CC
SH	0	0.76**	0.64**	0.44**	0.40**	0.34*	0.54**	0.43**	0.60**
HH	0.94**	0	0.65**	0.46**	0.58**	0.61**	0.69**	0.55**	0.45**
BL	0.73**	0.74**	0	0.46**	0.45**	0.52**	0.64**	0.55**	0.40**
CD	0.59**	0.46	0.58**	0	0.51**	0.32	0.52**	0.51**	0.59**
RL	0.53**	0.56**	0.58**	0.25	0	0.54**	0.65**	0.57**	0.28
RW	0.38	0.37	0.42	0.11	0.54**	0	0.63**	0.56**	0.14
HW	0.07	0.15	0.24	0.01	0.14	-0.01	0	0.59**	0.38**
CW	0.30	0.26	0.39	0.19	0.31	0.43	0.39	0	0.42**
CC	0.47*	0.45	0.49	0.33	0.60**	0.35	0.25	0.31	0

*=Significant (P<0.005), **=Significant (P<0.001). SH= Shoulder height, HH= Hip height, HW= Hip width, BL= Body length, CC= Chest circumference, DC= Deep chest, CW= Chest width, RL= Buttock length, RW= Rump width

Table 7. Coefficient Correlation among body morphometrics index of buffaloes in the Highland (below diagonal) and the lowland (above diagonal)

Traits	HS	WS	RLI	HI	OI	LI1	LI2	BWI	DI	FL	Bia	Bre	Tp	Ba
HS	0	0.04	0.28	-0.37	0.99**	0.36*	-0.03	-0.43**	-0.17	0.30	0.21	0.99**	0.56**	0.48**
WS	0.26	0	0.07	-0.02	0.03	0.02	0.03	-0.12	-0.05	0.10	0.13	0.03	0.06	0.12
RLI	0.06	-0.07	0	0.17	0.26	-0.18	-0.42**	-0.05	0.18	-0.09	-0.16	0.26	0.28	0.52**
HI	-0.21	-0.07	0.32	0	-0.36	-0.99**	-0.33	0.14	-0.13	0.07	-0.73**	-0.36	-0.41**	-0.31
OI	0.99**	0.26	0.06	-0.21	0	0.35	-0.03	-0.43**	-0.18	0.30	0.20	1.00**	0.55**	0.47**
LI1	0.21	0.06	-0.32	-1.00**	0.21	0	0.32	-0.13	0.14	-0.08	0.72**	0.35	0.41**	0.30
LI2	0.48*	0.05	-0.01	-0.49*	0.47*	0.49*	0	-0.38**	-0.81**	0.74**	0.52**	-0.03	0.04	0.26
BWI	-0.27	0.02	0.24	-0.17	-0.26	0.17	-0.07	0	0.51**	-0.50**	-0.64**	-0.43**	-0.30	-0.52**
DI	-0.59**	-0.07	-0.23	-0.17	-0.59**	0.17	-0.74**	0.27	0	-0.95**	-0.18	-0.18	-0.03	-0.30
FL	0.60**	0.00	0.18	0.13	0.60**	-0.13	0.69**	-0.35	-0.93**	0	0.26	0.30	0.15	0.42**
Bia	0.16	-0.09	-0.47*	-0.59**	0.16	0.58**	0.36	-0.60**	0.01	0.19	0	0.20	0.37**	0.50**
Bre	0.99**	0.26	0.06	-0.21	1.00**	0.21	0.47*	-0.26	-0.59**	0.60**	0.16	0	0.55**	0.47**
Tp	0.04	-0.28	0.27	-0.21	0.04	0.23	0.27	0.20	-0.10	0.00	-0.08	0.04	0	0.84**
Ba	0.27	-0.22	0.58**	-0.10	0.27	0.11	0.59**	-0.09	-0.56**	0.53**	0.10	0.27	0.73**	0

*=Significant (p<0.005), **=Significant (P<0.001). HS= Heigh slope, WS= Width slope, RLI= Rump length index, HI= Height index, OI= Over increase index, LI1= Length index (1), LI2= Length index (2), BWI= Body weight index, DI= Depth index, FL=Foreleg length, Tp= Transverse pelvic, Bia= Body index[a], Bre= Body ratio[e]

Table 8. Eigenvalues, total variance, cumulative, communalities, Kaiser-Meiyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity in the body morphometrics of buffalo

Body Measurement	Highland				Low land		
	PC1	PC2	PC3	EC	PC1	PC2	EC
Shoulder Height	0.82*	0.35	0.07	0.81	0.37	0.75*	0.71
Hip Height	0.76*	0.37	0.23	0.78	0.69*	0.51*	0.74
Body Length	0.82*	-0.07	0.03	0.68	0.61*	0.49	0.62
Chest deep	0.39	0.72*	0.11	0.70	0.35	0.67*	0.58
Rump Length	0.09	0.89*	0.00	0.81	0.75*	0.23	0.63
Rump Width	0.05	-0.07	0.92*	0.87	0.88*	0.00	0.78
Hip Width	0.10	0.45	0.64*	0.63	0.78*	0.37	0.75
Chest Width	0.41	0.48	0.31	0.51	0.67*	0.37	0.60
Chest Circumference	0.87*	0.33	0.03	0.88	0.04	0.91*	0.83
Eigenvalues	4.34	1.29	1.03	-	5.12	1.12	-
Variance (%)	48.24	14.42	11.49	-	56.93	12.51	-
Cumulative (%)	48.24	62.67	74.16	-	56.93	69.45	-
KMO		0.72				0.86	
Barlett's test		*				*	

a = main component, *=Significant (P<0.005). PC=Principal component, EC= Eigenvalue contribution

Table 9. Eigenvalues, total variance, cumulative, communalities, Kaiser-Meiyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity in the morphometrics indices of buffalo

Variables	Highland					Lowland				
	PC1	PC2	PC3	PC4	EC	PC1	PC2	PC3	PC4	EC
Height index	-0.09	-0.99	-0.06	-0.01	0.98	-0.24	0.05	-0.95	0.00	0.96
Rump length index	0.15	-0.42	0.53*	0.47	0.70	0.30	-0.31	-0.34	0.69*	0.77
Over-increase index	0.94*	0.15	-0.05	-0.04	0.91	0.97*	0.10	0.14	0.08	0.99
Height slope	0.94*	0.15	-0.05	-0.01	0.91	0.97*	0.10	0.15	0.10	0.99
Length index (1)	0.09	0.99*	0.07	0.00	0.98	0.25	-0.07	0.95*	0.00	0.97
Width slope	0.37	0.07	-0.52	0.31	0.51	-0.11	0.07	0.03	0.40	0.18
Body weight index	-0.24	0.16	0.09	0.84*	0.80	-0.31	-0.59	-0.18	-0.34	0.59
Length index (2)	0.59*	0.40	0.47	-0.19	0.77	-0.16	0.87*	0.39	-0.06	0.93
Balance:	0.33	0.02	0.90*	0.01	0.92	0.37	0.28	0.25	0.80*	0.87
Depth index:	-0.78*	0.27	-0.37	0.21	0.86	-0.11	-0.97	0.14	-0.01	0.97
Foreleg length:	0.76*	-0.22	0.33	-0.35	0.87	0.21	0.93*	-0.1	0.11	0.93
Body index[a]	0.07	0.59	0.00	-0.75	0.92	0.02	0.35	0.81	0.30	0.91
Body ratio	0.95*	0.14	-0.02	-0.01	0.92	0.97*	0.12	0.15	0.08	0.99
Transverse pelvic	-0.04	0.23	0.78*	0.24	0.72	0.50	0.00	0.35	0.58	0.71

Variables	Highland					Lowland				
	PC1	PC2	PC3	PC4	EC	PC1	PC2	PC3	PC4	EC
Eigenvalues	5.08	2.89	2.26	1.56	-	5.34	2.82	2.32	1.28	-
Variance (%)	36.27	20.62	16.12	11.16	-	38.12	20.14	16.59	9.18	-
Cumulative (%)	36.27	56.88	73.01	84.17	-	38.12	58.26	74.84	84.02	-
KMO			0.5					0.61		
Barlett's test			*					*		

a = main component, *=Significant (P<0.005). PC=Principal component, EC= Eigenvalue contribution

Table 10. Percentage (%) of individual classification per breed based on discriminant analysis

Factor	Prediction group membership (N)			
	Population	Highland (%)	Lowland (%)	Total
Morphometric	Highland	48.09 (25)	51.92 (27)	100 (52)
	Lowland	13.08 (14)	86.92 (93)	100 (107)
Morphometric index	Highland	57.69 (30)	42.31 (22)	100 (52)
	Lowland	16.82 (18)	83.18 (89)	100 (107)

Table 11. Euclidean morphometric distance matrix between five populations of Jambi buffalo based on body morphometry

Population	Batanghari	Kerinci	Merangin	Tanjabar	Tebo
Batanghari	0.00	77.65	90.82	133.71	89.63
Kerinci		0.00	83.86	65.22	48.96
Merangin			0.00	107.96	78.13
Tanjabar				0.00	51.96
Tebo					0.00

CONCLUSION

This study is the first report to characterise Jambi buffaloes in two different locations based on altitude using multivariate analysis. Buffaloes in both populations have high diversity in qualitative traits. Body morphometrics of highland buffaloes are larger than those of lowland buffaloes. There was a high correlation between the parameters observed in both populations. Highland buffaloes showed three principal components (PCs) based on body morphometrics, while lowland buffaloes showed two PCs. The four principal components are based on morphometric indices in both populations. We characterized about 48.09% of buffaloes in the highlands and 51.92% of those in the lowlands using body morphometrics.

Meanwhile, 57.69% of highland buffaloes and 42.31% of lowland buffaloes could be characterized based on morphometric indices. Hierarchical cluster analysis (HCA) based on body size and body index revealed three clusters. The first cluster was Merangin; Kerinci was in the second cluster, and Tanjung Jabung Barat, Tebo, and Batanghari were in the third cluster. The government and breeders must collaborate to conserve the genetic resources of Jambi's local buffaloes and enhance their productivity through ecosystem-appropriate breeding programs that support population sustainability.

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