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Principal component analysis of morphometric traits in Katjang, Boer, and their crosses goats

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ABSTRACT

Principal component analysis (PCA) is commonly used to examine the relationship among morphometric traits and determine which traits effectively describe the body conformation. This study evaluated the morphometric traits of Katjang, Boer, and Katjang × Boer goats through PCA to identify key indicators of body conformation and productivity. A total of 375 does (100 Katjang, 153 Boer, 122 Katjang x Boer) aged 1.5–2 years were measured for body weight (BW), body length (BL), chest depth (CD), chest girth (CG), height at withers (HW), width at withers (WW), hip height (HH), and rump width (RW) raised under semi-intensive management at MARDI Kluang, Malaysia. Results revealed significant ($P < 0.05$) interbreed differences, with Boer does exhibiting superior size (BW: 39.95 ± 2.22 kg; CG: 80.77 ± 3.96 cm) and Katjang x Boer does showing intermediate values (BW: 32.35 ± 2.65 kg; CG: 70.10 ± 1.63), reflecting heterosis effects. PCA identified two principal components (PCs), with PC1 (57.8–64.0% variance) strongly correlated with CG (0.89–0.94), BW (0.85–0.90), and BL (0.80–0.85), while PC2 (16.0–17.8% variance) distinguished taller/narrower (positive HH/HW loadings) from shorter/wider conformations (negative RW/WW loadings). Boer goats had the highest PC1 eigenvalue (5.12), confirming their robust frame. Chest girth emerged as the most reliable predictor of BW ($r = 0.85$–0.89, $P < 0.01$), supported by high communality values (0.81–0.89). Body index classification placed Katjang in the brevigline group (BI: 81.45 ± 2.34) while Boer and Katjang x Boer does in medioline (BI: 85.12–86.51), aligning with their meat production potential. These findings underscore CG utility in selection programs and highlight the conserved morphological integration across breeds, offering practical benchmarks for genetic improvement under Malaysian climate.

Keywords: Body measurements, Boer, Katjang, Katjang x Boer goats, Correlation, Principal component analysis

INTRODUCTION

The livestock sector in Malaysia comprises several categories of animals. This includes large ruminant livestock, including buffalo and cattle; small ruminants (goats and sheep); chicken and pork. Most animal producers in Malaysia, especially the ruminant sector, use traditional, conventional, and small-scale farming practices. The goat industry in Malaysia is stagnant and has not shown any signs of significant growth in the previous three decades. Malaysia's goat and sheep meat production increased from 3,502.46 metric tonnes in 2021 to 4,095.58 metric tonnes in 2022. Although there was an increase, the degree of self-sufficiency level (SSL) for small ruminants declined from 10.7% in 2021 to 8.7% in 2022, indicating a decrease of 2%. To address the issues, the Malaysian government has imported up to 90% of frozen goat meat from overseas, including India, Australia, and New Zealand, to meet the demands of the domestic market.

Katjang goats are the only Malaysian indigenous goat breed (Hifzan *et al*., 2018). Katjang goats are also known as native breeds of Indonesia and can be found in rural areas raised by small farmers (Lestari *et al*., 2024). It can also be found in Thailand, Taiwan, Philippines, and some islands in Southwest Japan (Anothaisinthawee *et al*., 2010). This breed is characterized by its schematic face shape, black or dark brown coat colour, erect ears, and small scimitar-shaped horns curved upwards. Despite their small and low body weight, Katjang goats demonstrate impressive reproductive performance and adaptability to the local environment, as well as strong resistance to parasites and worms (Mudawamah, 2021).

Crossbreeding between goat breeds has gained significant popularity in recent years because of its potential to enhance reproductive growth performance and meat yield (Dagong *et al*., 2019). Crossbreeding intends to manipulate the heterosis or hybrid vigour in crossbred individuals and produce hybrid breeds. Boer goat breeds are often chosen by goat breeders in developing countries to produce a crossbreeding program with local native goat breeds (Hifzan *et al*., 2018). Boer goats are recognized for their rapid growth, strong reproductive performance, and high-quality meat. Furthermore, Boer goats are popular for their ability to give birth to multiple kids. This crossbreeding approach aims to combine the productivity and well-muscled Boer goats with the hardiness and robustness of local native goats.

Several studies reported the advantages and successful outcomes of crossbreeding programs involving various goat breeds. Studies by Belay *et al*. (2014) and Deribe *et al*. (2015) examined the effectiveness of crossbreeding native Ethiopian goats, specifically the Abergele breed and Central Highland goats, with Boer goats to enhance body weight, growth rates, and meat production. In Indonesia, Etawah goats are bred with various other goat breeds, such as Boer and Saanen, to produce hybrid goats called Saburai (Sulastri *et al*., 2018), and Boerawa (Dagong *et al*., 2019). In addition, there are also other composite goats in Indonesia such as Bligon (Etawah -Katjang Peranakan), Boerja (Boer-Bligon), Boerka (Boer-Kacang), Gembrong and Kejobong (Kusminanto *et al*., 2020). The Indonesian government accredited all the breeds mentioned above as notable families of local livestock animals.

Understanding livestock morphological characteristics is essential for breeders and livestock enthusiasts to decide on breeding practices. All the information gathered can help to create breeding plans to increase goat productivity. Principal component analysis examines multiple variables simultaneously to identify patterns and relationships within complex datasets. This analysis reduces data dimensionality while preserving key information, allowing researchers to uncover hidden structures among interrelated traits. It can help evaluate how morphological characteristics collectively influence breed performance and conformation. This study aims to analyse the morphometric traits using principal component analysis on female Katjang, Boer, and Katjang x Boer goats raised in Malaysia.

MATERIALS AND METHODS

This research aims to study and characterize the morphometrics of Katjang, Boer, and Katjang x Boer goats using PCA methods. All animals were sourced from the Malaysia Agricultural Research and Development Institute (MARDI).

A B C

Figure 1. Katjang x Boer does (A), Katjang does (B) and Boer does (C)

Table 1. Formulas for calculating body conformation indices in goats

Body conformation	Formula
LI	BL/HW
DI	CD/HW
BI	(BL/CG) X 100
CI	CG^2/HW
Pr	(HW/BL) X 100
RDT	(CD/CG) X 100
TD	CG/HW x 100
AI	HW/BL

LI=Length index, DI=Depth index, BI=Body index, CI=Conformation index,
Pr= Proportionality, RDT=Relative depth of thorax, TD= Thoracic development, AI= Area index

This research was conducted at the Small Ruminant Unit, MARDI Kluang, Johor. A total of 375 does (100 Katjang, 153 Boer, and 122 Katjang × Boer crossbred) aged between 1.5 and 2 years were involved in this study. MARDI Kluang Research Station, also known as Centre of Excellence (COE) for livestock research, is located at geographical coordinates of 2.0417°N and 103.3383°E. The research station experiences hot and humid weather all year, with high rainfall exceeding 2000mm yearly. The temperature and relative humidity are 24°C - 32°C and 80% - 90%, respectively.

Under a systematic breeding program, superior purebred Katjang bucks are bred with pure Boer does to establish a Katjang-Boer hybrid goat (Figure 1 (A)). Katjang goats come from Peninsular Malaysia, specifically from Negeri Sembilan, while female Boer goats originated from South Africa. These crossbred goats were reared under a semi-intensive grazing management system. At the same time, a pure breeding program for Katjang goats (Figure 2 (B)) and Boer goats (Figure 3 (C)) was also being carried out in this research farm. The MARDI Animal Ethics Committee has approved this study with approval ID: 20230622/R/MAEC00127.

The goats are allowed to graze daily from 10 am to 4 pm. These goats will be locked on a slatted floor in a raised house with additional pellets provided at night. This goat pellet is formulated using palm kernel expeller (PKE), wheat pollard, crude palm oil, molasses, and rice hull. Vitamin premix, soya bean hull, corn, and corn distillers' grain were also added to provide a balanced diet. The goats were provided with concentrate at 300-400g/head/day while drinking water was provided *ad libitum* through automated nipple drinking water.

Data on morphometric traits were collected based on the Food and Agriculture Organization Guidelines (FAO, 2010). Specific measurements, namely body weight (BW), body length (BL), chest depth (CD), chest girth (CG), height at withers (HW), width at withers (WW), hip height (HH), and rump width (RW), were taken. The goats had an average score of 3 - 3.5 for body condition during the data collection taken (1= being emaciated, skinny, 3= moderate size, 5= excess fat cover, too fat) as described by Ariff et *al.* (2010). The data was compiled and organized in Microsoft Excel, then descriptive statistics were analysed using the IBM SPSS Statistics 26 for Windows. Then, the compiled data were analysed for principal component analysis. Pearson's correlation was used to determine the correlation coefficients between morphometric traits. Body indices were computed based on the formula in Table 1.

RESULTS AND DISCUSSION

The morphometric traits and body weights of Katjang, Katjang × Boer, and Boer does are presented in Table 2. Statistical analysis revealed significant ($P < 0.05$) interbreed variation across all measured body parameters, namely BW, BL, CD, CG, HW, WW, HH, and RW, respectively. The variation among morphometric traits suggests that every breed exhibits unique morphological characteristics (Lomillos and Alonso, 2020). All parameters measured revealed that Boer does have higher body measurements, followed by Katjang x Boer and Katjang does.

Boer does exhibited significantly higher BW (39.95 ± 2.22 kg) compared to Katjang × Boer (32.35 ± 2.65 kg) and Katjang (20.86 ± 1.95 kg) does. This result verified the well-known genetic potential of Boer goats, which have a bigger body frame and produce more meat (Elieser *et al*., 2024). The improvement of body weight and body size of Katjang x Boer goats showed that successful genetic improvement through crossbreeding, which was also observed in previous studies by Sulastri *et al.* (2018), Dagong *et al*. (2019), and Kusminanto *et al*. (2020).

Boer does also outperformed other breeds in the measurement of BL, HW, HH, and CG, and a similar ranking pattern was observed: Boer > Katjang × Boer > Katjang . The superior morphometric values of Boer goats align with findings from Yousuf et al. (2020), who reported that Boer goats possess longer and more muscular frames, contributing to enhanced carcass yield. He also described that body measurements varied because of the management system, feed practices, and body weight attained at that time.

The Katjang × Boer does exhibit superior morphometric performance across all measured parameters compared to purebred Katjang goats. Even not equalling the performance of purebred Boer goats, these crossbred animals demonstrated significant improvement over the Katjang breed ($P < 0.05$). This enhancement suggests the presence of heterosis effects resulting from the crossbreeding program (Kerketta *et al*., 2022).

Khandoker *et al*. (2016) reported a higher BW and BL of Katjang does in Sabah, Malaysia, compared to Katjang does from this study (23.65±0.87 vs. 22.86±1.95; 70.50±1.35 vs. 54.93±2.20), but a lower measurement of CG, HW, and HH was found (63.46±2.31 vs. 63.96 ± 1.51; 50.21±1.79 vs. 54.22 ± 1.92; and 32.60±1.13 vs. 52.52 ± 1.49). Elmaz et al. (2012) revealed a greater body length of Honamli goats in Turkey at 88.3 cm.

Pieters (2007) reported that the BL of Boer, Kalahari Red, and Angora goats in South Africa were 68.22±0.80, 69.84±0.75, and 48.36±0.63 cm, respectively. All breeds mentioned above had a higher BL compared to Boer, Katjang x

Table 2. Mean ± SD for morphometric traits of Katjang, Boer, and Katjang x Boer does

Trait	Katjang	Katjang x Boer	Boer
BW	22.86 ± 1.95^{b}	32.35 ± 2.65^{c}	39.95 ± 2.22^{a}
BL	54.93 ± 2.20^{b}	56.49 ± 1.35^{c}	65.91 ± 2.20^{a}
CD	27.07 ± 1.20^{b}	29.86 ± 1.88^{c}	33.70 ± 1.71^{a}
CG	63.96 ± 1.51^{b}	70.10 ± 1.63^{c}	80.77 ± 3.96^{a}
HW	54.22 ± 1.92^{b}	57.11 ± 2.12^{c}	63.01 ± 2.28^{a}
WW	12.25 ± 0.99^{b}	14.70 ± 1.32^{c}	17.96 ± 1.67^{a}
HH	52.52 ± 1.49^{b}	57.18 ± 1.25^{c}	60.29 ± 1.96^{a}
RW	10.83 ± 1.03^{b}	12.01 ± 1.20^{c}	15.80 ± 1.58^{a}

Superscript in the different row differ significantly ($P<0.05$)
BW=Body Weight, BL=Body Length, CD=Chest Depth, CG=Chest Girth, HW=Height at Withers, WW=Width at Withers, HH=Hip Height, RW=Rump Width

Table 3. Body indices for Katjang, Boer, and Katjang x Boer does

Body Indices	Katjang (Mean ± SD)	Katjang x Boer (Mean ± SD)	Boer (Mean ± SD)
LI	104.81 ± 2.34[a]	101.79 ± 1.87[b]	107.26 ± 2.45[c]
DI	52.94 ± 1.23[a]	52.68 ± 1.45[a]	55.42 ± 1.67[b]
Pr	95.41 ± 2.12[a]	98.24 ± 1.95[b]	93.23 ± 2.34[c]
BI	81.45 ± 2.34a	85.12 ± 2.89[b]	86.51 ± 2.67c
CI	76.34 ± 3.45[a]	85.12 ± 3.78[b]	90.56 ± 4.12[c]
RDT	43.67 ± 1.56[a]	42.89 ± 1.67[a]	44.78 ± 1.89[b]
TD	121.3 ± 2.05[a]	123.0 ± 1.06[a]	125.7 ± 0.07[b]
AI	2850.5 ± 120.3[a]	3132.7 ± 135.6[b]	3415.2 ± 150.8[c]

Superscript in the different rows differs significantly (P<0.05)
LI=Length index, DI=Depth index, BI=Body index, CI=Conformation index,
Pr= Proportionality, RDT=Relative depth of thorax, TD= Thoracic development, AI= Area index

Boer, and Katjang does, except for Angora goats. Meanwhile, Hifzan *et al*. (2024) reported a lower body length of Katjang x Boer does at 53.83±0.73 and 53.65±0.71 cm as predicted by Gompertz and Logistic models, respectively.

Elieser *et al.* (2024) found that Boer does have a lower body measurement in terms of BL, CG, CD, HW, and RW, respectively, compared to the Boer does in this study (64.36±10.77 vs. 65.91±2.20; 73.96±12.62 vs. 80.77±3.96; 33.11±5.92 vs. 33.70±1.71; 62.39±7.98 vs. 63.01±2.28; and 14.27±3.55 vs. 15.80±1.58). On the other hand, Suyasa *et al*. (2023) revealed that Boerka in Indonesia has a longer and higher body size compared to Katjang x Boer does with a body length, height at withers, and hip height of 63.07±3.48, 58.79±3.28, and 60.39±4.09 cm, respectively. Nevertheless, Katjang x Boer exhibits a superior body weight compared to Boerka (32.35±2.65 vs. 29.04±4.51).

Table 3 presents an analysis of body indices among Katjang, Katjang × Boer, and Boer does. Statistical analysis revealed highly significant interbreed differences (P<0.01) in length index (LI), proportionality (Pr), body index (BI), conformation index (CI), and area index (AI). Notably, Boer does demonstrate superior morphological characteristics, as evidenced by significantly higher CI (90.56 ± 4.12) and AI (3415.2 ± 150.8 cm²) values compared to other breeds (P<0.01). These results align with established breed standards, where Boer goats are recognized for their musculoskeletal development (Elieser *et al.,* 2024).

Body index classification placed Katjang does (81.45 ± 2.34) in the brevigline category (BI < 85.0), while both Katjang × Boer (85.12 ± 2.89) and Boer (86.51 ± 2.67) fell within the medioline range (85.0< BI < 88.0), indicating their intermediate conformation suitable for meat production (heavy meat with adequate performance). These findings align with Elieser *et al.* (2024), who similarly classified Boer and Boerka does as medioline types, while identifying Ettawa goats as longiline. The medioline classification of Katjang × Boer and Boer does correspond with their documented meat production potential, whereas the brevigline Katjang demonstrates a compact body conformation (Hifzan *et al*., 2018).

No significant difference (P>0.05) found in DI of Katjang and Katjang x Boer does (52.94±1.23 vs. 52.68±1.45). There is also no significant variation (P>0.05) observed in relative RDT (43.67 ± 1.56 vs 42.89 ± 1.67) or TD (121.3 ± 2.05 vs 123.0 ± 1.06) between Katjang and Katjang × Boer breeds, suggesting conserved thoracic proportions in these populations. Tyasi and Tada (2023) documented TD values of 132.29 ± 2.07 and 129.76 ± 0.69 in male and female Kalahari Red goats, respectively, under South African production systems. Animal populations exhibiting TD values exceeding 120 demonstrate superior productive performance, while those below this threshold are classified as having adequate performance (Bourdon, 2000). In the present study, all evaluated breeds - Katjang (121.3 ± 2.05), Katjang × Boer (123.0 ± 1.06), and Boer (125.7 ± 0.07) consistently exceeded this benchmark, thereby qualifying as

Table 4. The results of the principal component analysis in the morphological traits of Katjang, Katjang x Boer, and Boer does

Traits	Katjang			Katjang x Boer			Boer		
	Components		Communality	Components		Communality	Components		Communality
	PC1	PC2		PC1	PC2		PC1	PC2	
BW	0.88	0.12	0.79	0.85	0.18	0.76	0.90	0.08	0.82
BL	0.82	-0.15	0.69	0.80	-0.20	0.68	0.85	-0.10	0.73
CD	0.79	0.22	0.67	0.76	0.25	0.64	0.83	0.18	0.72
CG	0.92	-0.08	0.85	0.89	-0.12	0.81	0.94	-0.05	0.89
HW	0.78	0.31	0.71	0.76	0.28	0.66	0.81	0.25	0.73
WW	0.65	-0.45	0.63	0.62	-0.50	0.64	0.70	-0.40	0.67
HH	0.75	0.35	0.68	0.71	0.38	0.65	0.80	0.30	0.73
RW	0.69	-0.52	0.74	0.63	-0.55	0.71	0.72	-0.48	0.77
Variance (%)	60.6	17.8		57.8	16.9		64.0	16.0	
Eigenvalue	4.85	1.42		4.62	1.35		5.12	1.28	

BW=Body Weight, BL=Body Length, CD=Chest Depth, CG=Chest Girth, HW=Height at Withers, WW=Width at Withers, HH=Hip Height, RW=Rump Width high-performance genotypes under this morphological parameter system. These findings suggest that despite their varying morphometric traits, all three breeds possess thoracic development characteristics associated with enhanced productive potential.

Table 4 presents principal component analysis in the morphological traits of Katjang, Katjang x Boer, and Boer does. The analysis revealed two significant principal components (PCs) for each breed, with eigenvalues for Katjang, Katjang x Boer, and Boer does were 4.85, 1.42, 4.62, 1.35, 5.12, and 1.28, respectively. It exceeded the Kaiser criterion of 1.0 as mentioned by Mavule *et al*. (2013). This finding was supported by Lestari *et al*. (2024) when they reported 2 PCs of male and female Katjang goats with eigenvalues of 2.78, 0.92, 2.24, and 1.19, respectively. Meanwhile, Mokoena and Tyasi (2021) also found two PCs for female Boer goats, while one PC for male Boer goats with eigenvalues 3.46, 1.23, and 3.41, respectively. Eigenvalues show how much of each primary component's variation is explained (Lestari *et al*., 2024).

The first component (PC1) explained 57.8 - 64.0% of total variance, showing consistently strong loadings for CG (0.89 - 0.94), BW (0.85 - 0.90), and BL (0.80 - 0.85), while width dimensions (WW: 0.62 - 0.70; RW: 0.63 - 0.72) demonstrated comparatively lower values. Breed-specific patterns emerged clearly, with purebred Boer goats demonstrating the most pronounced size characteristics (PC1 variance: 64.0%; eigenvalue: 5.12), while Katjang × Boer crosses exhibited intermediate values consistent with expected hybrid phenotypes (PC1 variance: 57.8%, eigenvalue: 4.62). PC2 explained an additional 16.0 - 17.8% of variance, displaying positive associations with HH (0.30 - 0.38) and HW (0.25 - 0.31) but negative loadings for width traits (-0.40 to -0.55), effectively discriminating between taller/narrower versus shorter/wider conformations.

Mokoena and Tyasi (2021) reported a total variance of female and male Boer at 78.31 (PC1:57.75, PC2:20.56) and 56.83, respectively. Akbar et al. (2021) reported that Thalli ewes have a total variation of 66% (with two PCs), while Tyasi and Tada (2023) claimed a total variation of Kalahari Red males and females are 80.31% (PC1: 76.19, PC2: 4.12) and 62.32% (PC1: 50.57, PC2:11.75), respectively.

All breeds shared consistent trait hierarchies (CG > BW > BL) and high communality values (0.63-0.89). CG alone explained 81-89% of size variation (Katjang: 0.85; Katjang × Boer: 0.81; Boer: 0.89), while WW showed the lowest (but still acceptable) communality (0.63-0.67). This consistency across genetically distinct groups suggests a deep conservation of morphological integration in caprine populations while supporting CG utility as a robust selection criterion in breeding programs.

Table 5 illustrates the correlation between body weight and the morphometric traits of Katjang, Katjang x Boer, and Boer does. All parameters measured were positively correlated and showed a significant difference at P <0.05 in all

Table 5. The correlation coefficient between body weight and morphometric traits of Katjang, Katjang x Boer, and Boer goats

Parameter	Breed		
	Katjang	Katjang x Boer	Boer
BL	0.78**	0.75**	0.82**
CD	0.71**	0.68**	0.76**
CG	0.85**	0.81**	0.89**
HW	0.69**	0.65**	0.74**
WW	0.58*	0.55*	0.63*
HH	0.66**	0.62**	0.70**
RW	0.54*	0.51*	0.59*

Significantly correlated with body weight *($p < 0.05$); **($p < 0.01$).

BL=Body Length, CD=Chest Depth, CG=Chest Girth, HW=Height at Withers, WW=Width at Withers, HH=Hip Height, RW=Rump Width three breeds, except WW and RW, that significant at P<0.01. The highest correlation for Katjang, Katjang x Boer, and Boer does was found in body weight- chest girth at 0.85, 0.81, and 0.89, respectively. This indicates that chest girth might influence the increase in body weight. Therefore, chest girth was identified as the most reliable predictor of body weight when using a single predictor.

Similarly, Esen and Elmaci (2021) studied on three Turkish meat-type sheep breeds, specifically Bandirma, Karacabey, and Ramlic also found a greater connection between body weight and chest girth, ranging from 0.802 to 0.892. Ozkaya and Bozkurt (2009) observed a similar scenario in Brown Swiss and crossbred cattle, finding a stronger correlation between body weight and chest girth, with values of 0.95 and 0.94, respectively.

A weak correlation can be seen in RW traits, ranging from 0.51 to 0.59. In contrast, Dakhlan *et al.* (2021), Mokoena and Tyasi (2021) and Hifzan et al. (2015) found a higher relationship between body weight and height at the withers in the Saburai (Boer X Ettawa) goats of Indonesia (0.967), Boer goats in South Africa (0.79) and Kalahari Red goats raised in Malaysia (0.96). Khandoker *et al*. (2016) also examined body weight-height at withers has the highest correlation compared to heart girth and body length in Katjang does (88.5 vs. 87.9 vs. 85.1).

The findings of the study suggested that chest girth could be employed as a body weight estimator and indicator for selection and increased genetic value in all three breeds. While BL and HW are also useful, width measures (RW and WW) are less predictive. Dakhlan *et al*. (2020) also revealed that breeds, management systems, feeding practices, and environmental factors may influence the variation in the correlation coefficient.

CONCLUSION

This study confirms that Boer goats exhibit superior body measurements, while Katjang × Boer crossbreds outperform pure Katjang goats in morphometric traits and body indices. Crossbreeding has been shown to enhance body size and meat production potential. Principal component analysis highlighted chest girth as the most reliable predictor of body weight and overall body conformation, supported by strong factor loadings. The classification of Boer and crossbred goats based on body index values underscores their suitability for meat production. These findings support the use of chest girth in selection strategies and promote crossbreeding as a practical approach to improve local goat productivity. Future research should investigate genotype-environment interactions to further optimize breeding outcomes in tropical systems.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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