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MORPHOMETRIC ANALYSIS AND INTERRELATIONSHIP OF SEVEN INDONESIAN HORNBILL SPECIES (AVES, BUCEROTIDAE) UTILIZING PRINCIPAL COMPONENT AND CLUSTER ANALYSIS

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Morphometric Analysis and Interrelationship of Seven Indonesian Hornbill Species (Aves, Bucerotidae) Utilizing Principal Component and Cluster Analysis. Jarulis, Solihin, D. D., Mardiastuti, A., Prasetyo, L. B. & Novarino, W. — In this comprehensive study, we examined 15 distinct morphometric characteristics within seven Indonesian hornbill species. Precise measurements of these morphometric traits were obtained using 0.1 mm calipers and a 1000 mm measuring tape. Our analysis encompassed a total of 85 individuals representing seven hornbill species: *Anthracoceros albirostris* (18 individuals), *A. malayanus* (4 individuals), *Aceros cassidix* (3 individuals), *Rhyticeros plicatus* (7 individuals), *R. undulatus* (36 individuals), *Buceros bicornis* (1 individual), and *B. rhinoceros* (16 individuals). To elucidate the morphometric ratio data, we employed a robust analytical approach involving the Principal Component Analysis (PCA), Discriminant Analysis, and Cluster Analysis. Our findings underscored a clear separation between hornbill genera, primarily attributed to a combination of PC1

(pertaining to body length) and PC3 (associated with beak morphology). Key morphometric traits that delineated these genera on PC1 included tail length, beak length, horn length, total length, and wing length. Meanwhile, on PC3 (characterizing beak morphology), the distinguishing features encompassed beak width, horn width, and tarsus length. Additionally, our analysis unveiled the characteristics that distinguish species within the genera *Anthracoceros* and *Rhyticeros* to be a composite of tail length and head length. This discerning morphometric data facilitated the clustering of seven hornbill species into two distinct groups: Group I comprised *A. albirostris* and *A. malayanus*, while Group II included *R. plicatus, R. undulatus, A. cassidix, B. rhinoceros,* and *B. bicornis*. Notably, these groups exhibited a 31.93% degree of similarity. This dataset holds immense potential for facilitating genetic classification and comparative studies of Indonesian hornbills.

Key words: classification, hornbills, morphometric, principal component analysis, similarity.

Introduction

Hornbills, belonging to the avian family Bucerotidae, are notable for their large size and long-distance flying capabilities from their nest. Their diet primarily consists of fruits and insects (MacKinnon et al., 2010), rendering them crucial agents in seed plant dispersal within forest ecosystems (Kinnaird, 1998; Kitamura et al., 2008; Balasubramanian et al., 2011). Indonesia is home to all 13 hornbill species, including those designated as protected species (Sukmantoro et al., 2007).

Morphological characters continue to be a fundamental tool for ascertaining the taxonomic classification of birds. These characters offer particular advantages when dealing with species possessing distinct morphological traits, such as unique coloration or patterns on specific body parts. Species with well-defined morphological characteristics tend to perceive more certain identification. However, this is not always the case for species lacking distinctive traits. Consequently, hornbill species are still primarily identified based on morphological features, often revolving around variations in body coloration and patterns. For instance, the Oriental Pied Hornbill (*Anthracoceros albirostris*) includes two subspecies, the northern Oriental Pied Hornbill (*A. albirostris*) and the southern Oriental Pied Hornbill (*A. convexus*) (MacKinnon et al., 2010). Consequently, disparities in species nomenclature still persist among bird researchers.

Apart from coloration variations and patterns, morphometric characters are frequently employed for species identification within the animal kingdom. In the class Aves, common morphometric characters used for species differentiation encompass beak length, wing length, tail length, tarsus length, and total length (Pettingil, 1984; Lua and Nakkuntod, 1998; Novarino et al., 2008). Some studies, such as that by Ricklefs and Ravis (1980), focus on a subset of these characters, including beak length, beak width, beak depth, wing length, and tarsus length. Smith et al. (2012) expanded the list to encompass eight morphometric characters: beak length, beak depth, beak width, head length, tarsus length, wing length, tail length, and weight.

Morphometric characters employed for hornbill identification closely resemble those used for other bird species. For instance, Frith and Frith (1983) examined wing length, tail length, tarsus length, beak length and casque (horn) characteristics when describing the taxonomic status of six Anthracoceros species. Kemp (1988) constructed a cladogram for the Bucerotidae family in the Oriental and Australasian regions, employing three morphometric characters: beak length, wing length, and tail length. Lua and Nakkuntod (1998) measured 13 morphological characters of hornbills within Singapore's zoological reference collection (ZRC). Eeden (2004) analyzed wing length, body length, tarsus length, beak length, tail length, head length, and weight to determine the sex of *Tockus leucomelas*. However, these studies generally do not highlight specific morphometric characteristics that serve as distinguishing features between species.

The primary objective of this study is to elucidate how and which morphometric characters can be employed to differentiate among seven species of Indonesian hornbills and their respective genera. Our dataset encompasses 15 morphometric characters, with the standard length (PSd) character serving as a reference point to derive morphometric ratio values.

Material and Methods

The morphometry data were collected from living specimens housed within esteemed institutions, including Taman Safari Indonesia (TSI), Ragunan Wildlife Park (TMR), Taman Mini Indonesia Indah (TMII), and Tegal Alur PPS (PPSTA) Jakarta. Birds were caught from cages and handled by keepers. Morphometric character measurements were carried out outside the cage by researchers to avoid stress to other birds inside. The data collection process transpired over a meticulous period, spanning from October 2015 to August 2016.

The assessment of hornbill morphometry was undertaken with methodological modifications drawn from Pettingil (1984), Lua and Nakkuntod (1998), and Novarino et al. (2008). Morphological characters were meticulously quantified employing calipers calibrated with a precision of 0.1 millimeters, and for those parameters beyond the calipers' range, a measuring tape with a length of 1000 mm was utilized. The sampled dataset consisted of individuals from seven distinct hornbill species, namely *Anthracoceros albirostris* (n = 18 individuals), *A. malayanus* (n = 4 individuals), *Aceros cassidix* (n = 3 individuals), *Rhyticeros plicatus* (n = 7 individuals), *R. undulatus* (n = 36 individuals), *Buceros bicornis* (n = 1 individuals), and *B. rhinoceros* (n = 16 individuals) (see table 1).

Each specimen underwent a rigorous measurement regimen, wherein a single individual, specifically the first author, conducted three measurements for each individual, subsequently computing an averaged value to ensure precision and reliability. The quantitative morphological characteristics (morphometry) assessed encompassed the following parameters:

1. Wing length (PS): Defined as the distance from the carpal joint to the wing tip.
2. Beak length (PP): Denoting the measurement from the base of the beak to its terminal end.
3. Beak height (TP): Representing the distance from the upper half of the beak's highest point to its lower half.
4. Half width (LP): Measuring the span between the right and left sides of the beak.
5. Length of the casque (PC): Quantifying the distance from the horn's base to its tip.
6. Width of the horn (LC): Signifying the measurement between the right and left sides of the horn.
7. Head length (PK): The distance extending from the posterior of the skull to the beak's tip.
8. Head width (LK): Indicating the measurement between the right and left sides of the head.
9. Body length (standard length) (PSd): The distance from the beak's tip to the uropygial length at the posterior of the body.
10. Total length (PT): Encompassing the measurement from the beak's tip to the tail's extremity.
11. Diameter of the tarsus (DTs): Measured on the section of the tarsus above the joint of the feet's soles.
12. Tarsus length (PTs): Denoting the distance from the tarsus joints to the soles of the feet.
13. Tail length (PE): The measurement extending from the base of the tail to its tip.
14. Length of the first finger (PJ1): The distance from the base of the first finger to its tip.
15. Length of the middle finger/third finger (PJ3): Representing the measurement from the base of the finger to the tip of the middle finger.

The morphometry measurement data for each character, when normalized by standard length (PSd), is herein referred to as morphometric ratio data, as delineated in table 2. To ensure data normalization, the morphometric ratio results are subsequently subjected to a log transformation (log (x+1)). The analysis of these morphometric ratio data was conducted employing the Principal Component Analysis (PCA) method through Minitab 16 software to determine the distinguishing characteristics between genera and species. The fundamental premise underlying PCA is the dimensionality reduction of measurements by identifying the principal component values. This multivariate analysis technique distinguishes the same or different groups based on the characters measured. The outcome of the PCA yields a phenetic grouping, commonly referred to as a phenogram (Doherty & McCarthy, 2004). These results are also presented graphically. Further discrimination between genera and species was achieved through Discriminant Analysis, wherein discriminant functions were computed using IBM SPSS 22 software. Additionally, cluster analysis, employing the average linkage model, was employed for the morphometric classification of each species.

Table 1. Enumeration of hornbill species assessed at Taman Mini Indonesia Indah, Taman Margasatwa Ragunan, Taman Safari Indonesia, and Pusat Penyelamatan Satwa Tegal Alur

No	Species	English Name	TMII		TMR		TSI		PPSTA		Amount	
			M	F	M	F	M	F	M	F	M	F
1.	*Anthracoceros albirostris*	Oriental Pied Hornbill	2	1	1	0	9	5	0	0	12	6
2.	*Anthracoceros malayanus*	Asian Black Hornbill	0	1	2	0	0	1	0	0	2	2
3.	*Aceros cassidix*	Knobbed Hornbill	0	0	0	1	1	1	0	0	1	2
4.	*Rhyticeros plicatus*	Blyth's Hornbill	2	0	1	0	2	2	0	0	5	2
5.	*Rhyticeros undulatus*	Wreathed Hornbill	5	4	0	6	8	11	0	2	13	23
6.	*Buceros bicornis*	Great Hornbill	0	0	0	1	0	0	0	0	0	1
7.	*Buceros rhinoceros*	Rhinoceros Hornbill	1	1	0	1	6	7	0	0	7	9
	Total		10	7	4	9	26	27	0	2	40	45

Note. M (male) and F (female).

Table 2. Morphometric ratios of hornbill morphological characters in Indonesia

No.	Code	Ratio	Explanation
1.	PS	PS/PSd	wing length/standard length
2.	PP	PP/PSd	half-length/standard length
3.	TP	TP/PSd	standard half-length/length
4.	LP	LP/PSd	standard half-length/length
5.	PC	PC/PSd	horn length/standard length
6.	LC	LC/PSd	horn width/standard length
7.	PK	PK/PSd	head length/standard length
8.	LK	LK/PSd	standard head width/length
9.	PT	PT/PSd	total length/standard length
10.	DTs	DTs/PSd	Tarsus diameter/standard length
11.	PTs	PTs/PSd	tarsus length/standard length
12.	PE	PE/PSd	tail length/standard length
13.	PJ1	PJ1/PSd	finger length one/standard length
14.	PJ3	PJ3/PSd	third finger length/standard length

Results

The measurement results of 14 morphometric characters displayed variations in the size of each character across different hornbill species refer to table 3. Specifically, data concerning the average total length character (PT) indicated that among the seven hornbill species, *Anthracoceros albirostris* possessed the smallest body size. Conversely, *Buceros rhinoceros* exhibited the

Table 3. Mean and standard deviation values of the 14 morphometric characters measured in hornbills

Character	Value Category	Measurement Value, mm						
		A. albirostris (n = 18)	*A. malayanus* (*n = 4*)	*R. plicatus* (*n = 7*)	*R. undulatus* (*n = 33*)	*A. cassidix* (*n = 3*)	*B. bicornis* (*n = 1*)	*B. rhinoceros* (*n = 16*)
PS	Min	288.00	306.00	414.00	432.00	448.00	449.00	488.00
	Max	310.00	310.00	420.00	457.00	466.00	449.00	510.00
	Ave	297.72	308.25	417.57	442.94	457.67	449.00	497.50
	SD	6.56	1.71	2.07	7.47	9.07	(–)	7.06
PP	Min	140.58	153.00	164.00	164.00	178.00	251.00	243.00
	Max	153.00	155.00	170.00	178.00	182.00	251.00	257.00
	Ave	146.95	154.00	167.29	169.15	179.67	251.00	248.13
	SD	3.42	0.82	1.89	4.40	2.08	(–)	3.93
LP	Min	32.11	35.22	45.82	40.15	44.30	48.94	52.20
	Max	38.00	36.46	50.13	51.30	46.53	48.94	61.24
	Ave	34.75	35.67	47.68	44.28	45.33	48.94	55.92
	SD	1.58	0.56	1.32	3.79	1.12	(–)	2.64
TP	Min	40.03	48.43	55.97	49.13	55.42	61.13	54.35
	Max	47.62	53.52	61.79	61.10	58.31	61.13	75.44
	Ave	43.55	51.10	58.50	54.74	56.88	61.13	60.69
	SD	2.22	2.52	2.17	3.74	1.45	(–)	5.35
PK	Min	159.00	154.00	228.00	197.00	197.00	254.00	232.00
	Max	173.00	161.00	237.00	226.00	208.00	254.00	278.00
	Ave	166.16	157.00	231.57	211.45	203.33	254.00	249.00
	SD	4.62	2.94	3.26	8.79	5.69	(–)	14.30
LK	Min	35.69	39.42	49.32	47.30	48.39	44.88	45.70
	Max	41.81	42.42	56.80	55.69	54.41	44.88	58.55
	Ave	38.42	40.82	52.06	50.92	50.88	44.80	51.00
	SD	2.01	1.24	2.86	2.63	3.14	(–)	3.43
PC	Min	102.52	114.54	98.40	77.88	95.71	168.00	150.10
	Max	122.02	120.07	107.00	98.00	99.67	168.00	207.00
	Ave	111.76	117.54	102.19	88.04	97.16	168.00	173.44
	SD	5.63	2.43	3.89	5.48	2.18	(–)	17.75

LC	Min	23.83	21.20	43.22	38.07	36.82	68.62	46.69
	Max	28.71	23.94	50.11	49.55	38.72	68.62	69.17
	Ave	25.88	22.23	45.88	42.80	37.64	68.62	55.74
	SD	1.53	1.24	2.11	3.49	0.98	(–)	6.50
PE	Min	257.00	285.00	241.00	255.00	297.00	388.00	384.00
	Max	276.00	289.00	253.00	284.00	304.00	388.00	415.00
	Ave	264.94	286.50	247.24	265.91	299.67	388.00	393.56
	SD	6.96	1.91	4.50	8.08	3.79	(–)	8.89
PTs	Min	46.05	42.23	54.50	58.70	63.36	65.24	68.20
	Max	52.89	45.94	58.43	68.84	66.29	65.24	77.00
	Ave	48.94	44.26	55.65	62.99	64.63	65.24	72.63
	SD	2.24	1.53	1.45	2.71	1.50	(–)	3.18
DTs	Min	7.39	6.69	11.15	13.06	12.81	14.73	11.85
	Max	9.58	9.34	13.70	14.91	14.18	14.73	16.10
	Ave	8.75	8.39	12.59	14.04	13.47	14.73	13.83
	SD	0.58	1.17	0.86	0.60	0.69	(–)	1.23
PT	Min	714.00	748.00	830.00	867.00	938.00	1064.00	1105.00
	Max	769.00	765.00	876.00	939.00	947.00	1064.00	1176.00
	Ave	745.78	755.00	847.60	899.97	943.67	1064.00	1135.86
	SD	16.14	7.26	16.50	23.33	4.93	(–)	23.61
PJ1	Min	20.19	28.48	31.40	33.13	28.84	37.13	34.19
	Max	24.45	32.07	35.31	40.77	30.24	37.13	38.17
	Ave	26.20	30.38	33.76	36.43	29.74	37.13	36.11
	SD	1.34	1.48	1.56	1.94	0.78	(–)	1.43
PJ3	Min	30.13	31.63	42.00	40.00	48.11	43.08	46.87
	Max	37.12	34.38	52.55	50.84	50.72	43.08	58.10
	Ave	33.77	33.09	47.26	46.14	49.14	43.08	52.52
	SD	1.82	1.45	3.52	3.63	1.39	(–)	3.33

largest body size among the hornbills, with an average PT of 1135.86 ± 23.61 mm. The PT measurements for all species fell within the range of 745.78 to 1135.86 mm.

The cumulative total value of 74.90 % on PC3 (characterizing half-life) from the Eigen analysis results indicates its eligibility to proceed to the subsequent PCA analysis stage refer to table 4. However, it's worth noting that in PC2 (representing head character), the cumu-

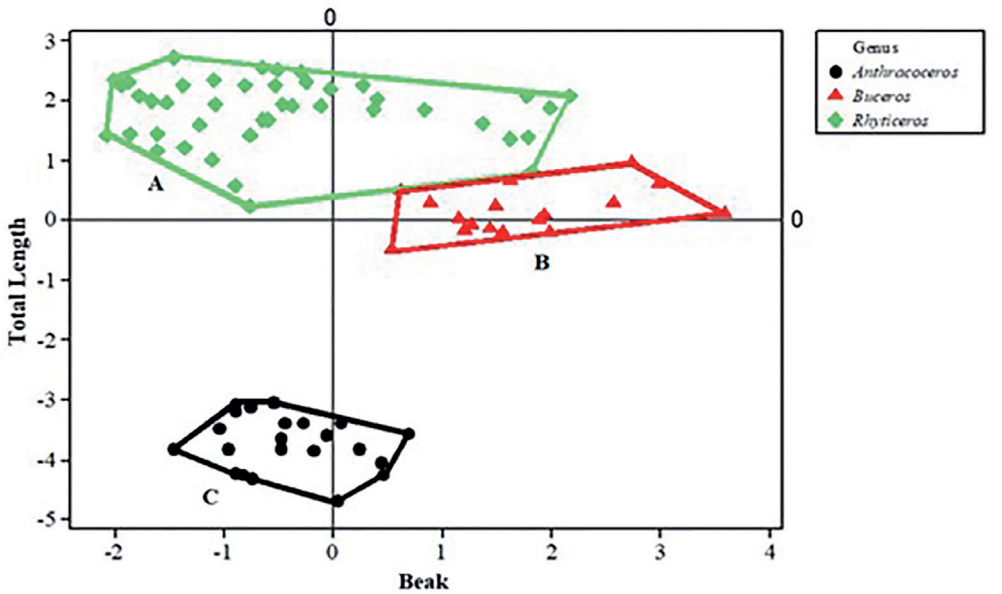

Fig. 1. Hornbill genus grouping based on a combination of body length characters (PC1) and beak characters (PC3): A — genus *Rhyticeros*; B — genus *Buceros*; C — genus *Anthracoceros*.

Table 4. Cumulative values of morphometric characters based on PCA analysis

Parameter	PC1	PC2	PC3
Eigen Value	5.7724	2.9312	1.1014
Proportion	0.4120	0.2090	0.1280
Cumulative	0.4120	0.6220	0.7490

Table 5. Eigenvalues of canonical correlation between hornbill species

Func-tion	Eigen-value	Percentage of Variance	Cumulative, %	Canonical Correlation
1	116.332[a]	81.9	81.9	0.996
2	14.867[a]	10.5	92.3	0.968
3	5.491[a]	3.9	96.2	0.920
4	3.010[a]	2.1	98.3	0.866
5	1.802[a]	1.3	99.6	0.802
6	0.609[a]	0.4	100.0	0.615

Note: a — first 6 canonical discriminant functions were used in the analysis.

lative value of 62.2 % falls below the minimum requirements typically employed for PCA analysis. The separation of distinct hornbill genera is clear based on their grouping in both the PCA analysis (fig. 1) and discriminant analysis (fig. 2). This separation between hornbill genera is best observed in the combination of PC1 (body length character) and PC3 (beak character). In the results of the discriminant analysis, the separation of hornbill genera is portrayed through function 1 (F1) and function 2 (F2) (Eigen values F1 and F2 account for 92.3 % collectively) with a canonical correlation of 0.968 refer to table 5.

Analysis of the coefficient factor values reveals specific morphological characters that differentiate between the genera within the *Bucerotidae* family (table 6). In the context of PC1 (representing body length character), the characters responsible for

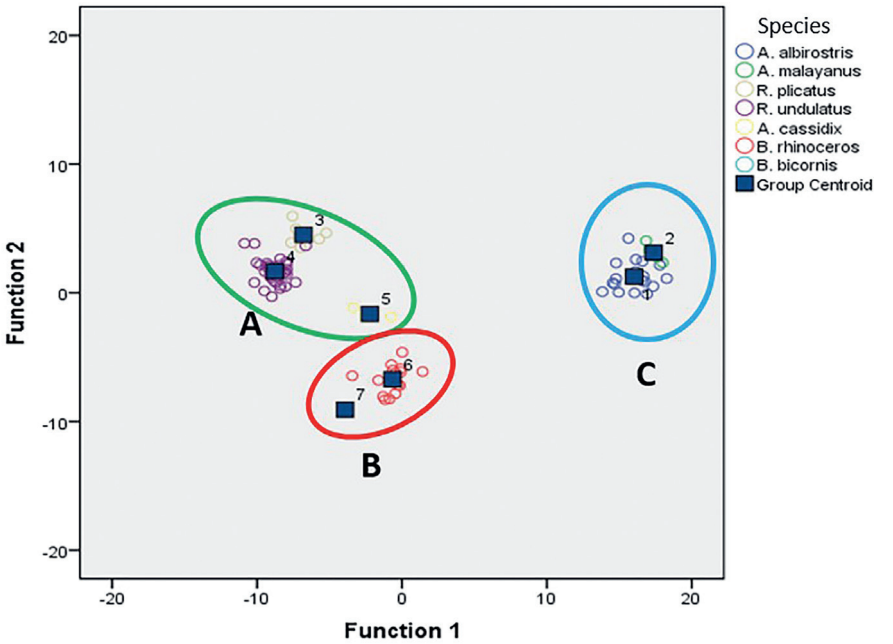

Fig. 2. Discriminant function graph of seven hornbill species based on the enter independents together model: A — genus *Rhyticeros*; B — genus *Buceros*; C — genus *Anthracoceros*.

Table 6. Coefficient factor values PC1, PC2, and PC3 of the genera *Rhyticeros, Buceros* and *Anthracoceros*

Character	Body Length (PC1)	Head (PC2)	Bill (PC3)
Wing span (PS)	0.357	–0.102	0.172
Bill length (PP)	–0.393	0.069	0.086
Bill width (LP)	–0.023	0.330	0.480
Bill height (TP)	–0.132	0.472	–0.039
Head length (PK)	0.014	0.430	0.299
Head width (LK)	0.008	0.481	–0.307
Casque length (PC)	–0.384	0.084	0.178
Casque width (LC)	0.289	0.042	0.458
Tail length (PE)	–0.404	–0.021	0.007
Tarsus length (PTs)	–0.022	0.024	–0.421
Tarsus diameter (DTs)	0.316	0.173	–0.247
Total length (PT)	–0.379	0.068	–0.096
1st finger length (PJ1)	0.193	0.297	–0.236
3rd finger length (PJ3)	0.155	0.324	–0.044

separating the genera *Rhyticeros, Buceros*, and *Anthracoceros* include tail length, half length, horn length, total length, and wing length. Meanwhile, in PC2 (head characters), the distinctive characters distinguishing between these genera are head width, beak height, and head length. On PC3 (beak characters), the separating factors encompass beak width, horn width, and tarsus length.

Distinct separation of species within the genera *Anthracoceros* and *Rhyticeros* is evident in figures 3 and 4. The characters responsible for this separation primarily consist of a combination of tail length and head length. When examining the measurements, it becomes apparent that the mean values for tail length and head length of *Anthracoceros malayanus* species are 286.50 ± 1.91 and 157.00 ± 2.94 mm, respectively. In comparison, species *A. albirostris* exhibits mean tail length and head length

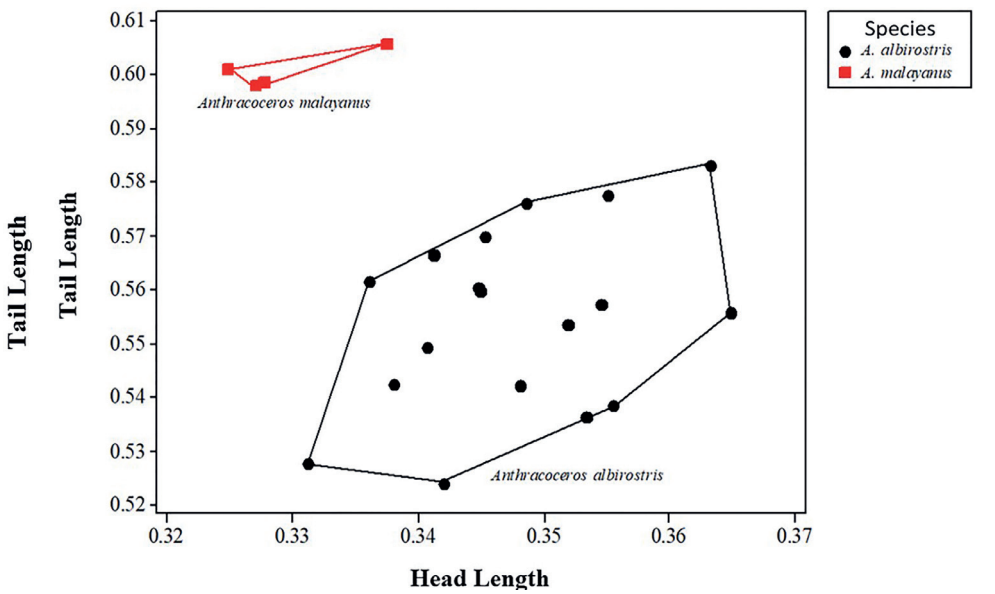

Fig. 3. The combination of tail length and head length of two hornbill species within the genus *Anthracoceros*.

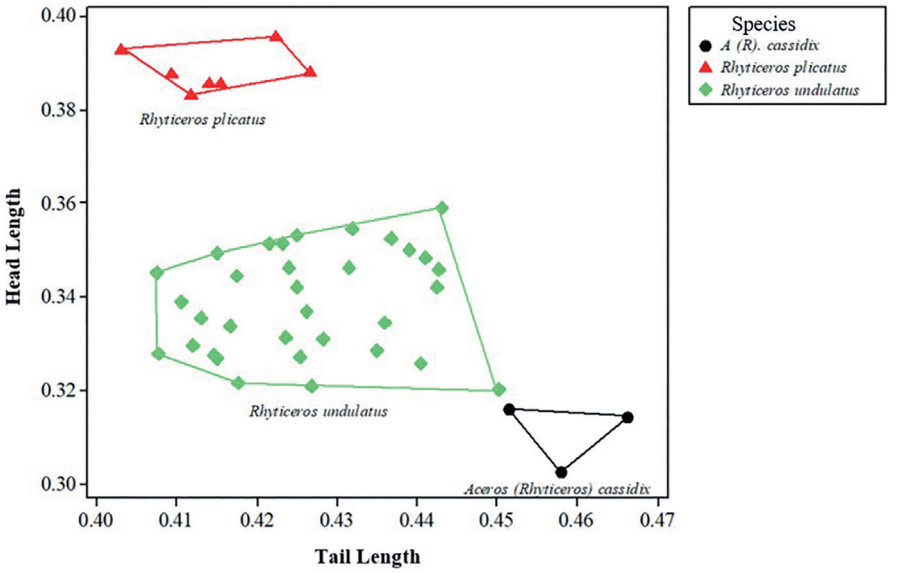

Fig. 4. The combination of head length and tail length of three hornbill species within the genus *Rhyticeros*.

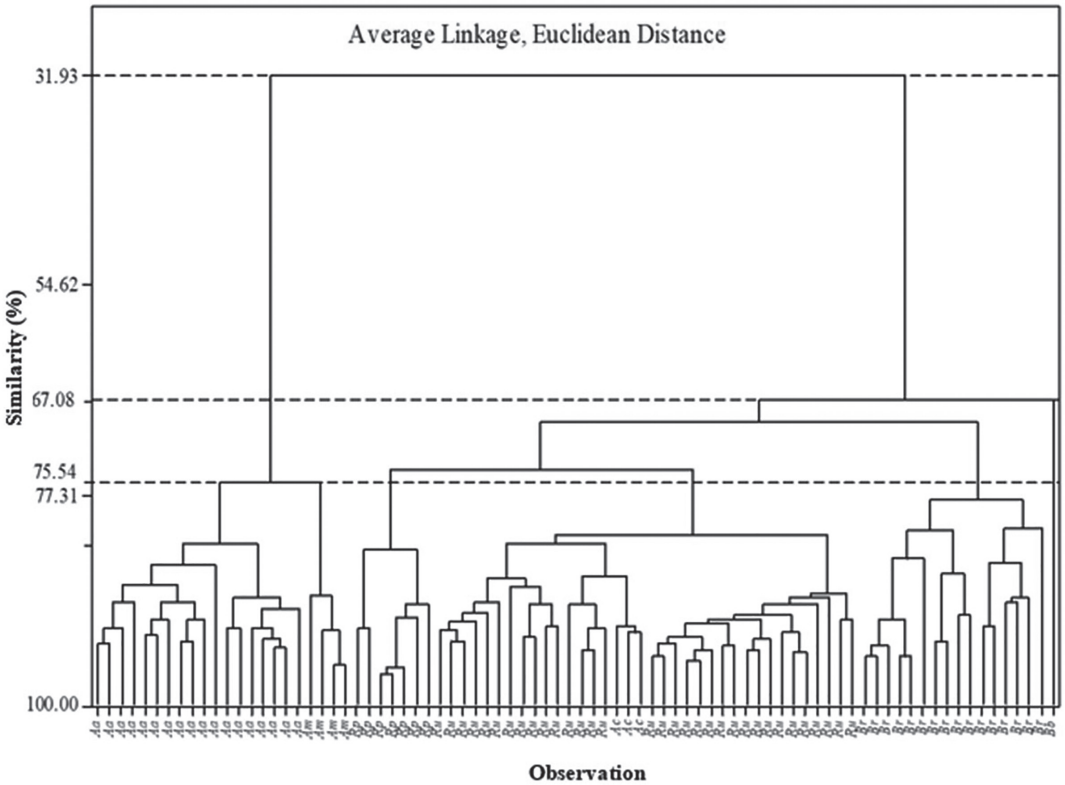

Fig. 5. A dendrogram illustrating the relationships among the seven Indonesian hornbill species based on 14 morphometric characters, constructed using the Average Linkage model. Legend: *Aa = Anthracoceros albirostris, Am = Anthracoceros malayanus, Ru = Rhyticeros undulatus, Rp = Rhyticeros plicatus, Ac = Aceros cassidix, Br = Buceros rhinoceros,* dan *Bb = Buceros bicornis.*

measurements of 264.94 ± 6.96 and 166.16 ± 4.6 mm, respectively. As for *Rhyticeros plicatus*, its mean tail length and head length are 247.24 ± 4.50 and 231.57 ± 3.26 mm, while *R. undulatus* species display measurements of 265.91 ± 8.08 and 211.45 ± 8.79 mm, respectively. Lastly, *Aceros (Rhyticeros) cassidix* species show mean tail length and head length measurements of 299.67 ± 3.79 and 203.33 ± 5.69 mm (as detailed in table 3).

The cluster analysis results revealed the segregation of the seven hornbill species into two primary groups, with a similarity value of 31.93 % (as depicted in fig. 5). The first group comprises *Anthracoceros albirostris* and *Anthracoceros malayanus*, while the second group encompasses *Rhyticeros undulatus*, *Rhyticeros plicatus*, *Aceros cassidix, Buceros rhinoceros*, and *Buceros bicornis*. Each of these two main groups further subdivided into additional subgroups when the similarity value reached 67.08 %.

Discussion

Differences between genera

Our comprehensive analysis, encompassing the PCA and discriminant analysis, has revealed discernible morphometric distinctions among the three genera of Bucerotidae: *Anthracoceros, Rhyticeros,* and *Buceros*. These genera exhibit clear demarcations when scrutinized through a combination of PC1 and PC3, resulting in a cumulative eigenvalue of 74.90 %. The character that predominantly delineates these genera in PC1 encompasses several cranial and bodily features, including beak length (PP), casque length (PC), wing length (PS), tail length (PE), tarsus diameter (DTs), and total length (PT). In PC2, the dominant characters that separate the genus are beak height (TP), head length, head width (LK), and third toe length (PJ3). PC3 highlights the significant influence of beak width (LP), casque width (LC), and tarsus length (PTs) in discerning genus classification. Importantly, the loading factor for all these influential characters, as separators exceeds the threshold of > 0.3. The findings of our discriminant analysis affirm the presence of distinct groupings within each Bucerotidae genus (fig. 2). Genus *Anthracoceros*, for instance, is categorized into group C, featuring two centroid groups. Meanwhile, the *Rhyticeros* genus aligns with group A demonstrating the existence of three distinct group centroids. Nevertheless, *Aceros cassidix* appears relatively distant from the two members of group A, namely *R. undulatus* and *R. plicatus*. In contrast, group B is predominantly represented by the genus *Buceros* with two centroid groups. Notably, the morphometric characteristics shared between genera *Buceros* and *Rhyticeros* are closer in proximity than their respective resemblances to the *Anthracoceros* genus.

Furthermore, the cluster analysis results (fig. 5) underscore the systematic delineation of each Bucerotidae genus. Genera *Buceros*, *Aceros*, and *Rhyticeros*, collectively forming Group 1, are notably segregated from the *Anthracoceros* genus within Group 2, achieving a similarity of 31.93 %. This distinction becomes further pronounced, resulting in the division of Groups 1 and 2 into two subgroups at a similarity of 67.08 %, and eventually culminating in the bifurcation of these subgroups at a similarity of 75.54 %. The observed body size of *Anthracoceros* genera, specifically *A. albirostris* and *A. malayanus*, is comparatively diminutive in contrast to the

Rhyticeros and *Buceros* genera, as reported in existing literature (MacKinnon et al., 2010; Poonswad et al., 2013; Eaton et al., 2016). Furthermore, an intriguing overlap in eight morphological characters has been observed among *Anthracoceros malayanus*, *Anorrhinus galeritus*, and *Berenicornis comatus* species (Laman et al., 2017). We suggest that these characters cannot be used to distinguish between the three species. However, the use of genetic data may help separate them.

Differences between species

The results of our PCA analysis clearly reveal distinct morphometric variations among species within the genera *Rhyticeros* and *Anthracoceros*, as depicted in figures 3 and 4. Among these variations, the most prominent differentiators for species, both within the *Rhyticeros* and *Anthracoceros* genera, are head length and tail length. Specifically, in the case of male *R. undulatus* (genus *Rhyticeros*), the beak length (head part) measures 202 mm (180–225 mm), while for females, it ranges from 162 mm (144–190 mm). Furthermore, the average tail length for male *R. undulatus* is 298 mm (270–333 mm), and for females, it averages at 267 mm (245–288 mm) (Kemp, 1988). Conversely, male *A. albirostris* (genus *Anthracoceros*) exhibits an average beak length ranging from 118.7 to 170 mm, whereas females span from 94.5 to 138.9 mm. The average tail length for male *A. albirostris* ranges between 253.9 and 299.4 mm, with females exhibiting a range of 249.0 to 280.4 mm (Frith and Frith, 1983). These data distinctly indicate that *R. undulatus* species possesses a longer tail than *A. albirostris*.

Additionally, the separation of species within the same genus across the three Bucerotidae genera is illustrated in figure 5. The discernible distinctions in morphometric characters between species in the genera *Anthracoceros* and *Buceros* are highlighted by the formation of distinct clusters for each species. A similar trend is also observed in the *Rhyticeros* genus, although *Rhyticeros undulatus* is bifurcated into two distinct groups, with the *Aceros cassidix* cluster positioned between them. Further analysis of the beak length (head part) in male *R. undulatus* (genus *Rhyticeros*) indicates measurements of 202 mm (180–225 mm), whereas for females, it spans 162 mm (144–190 mm) (Kemp, 1988). The body size of *Rhyticeros undulatus* is reported as 100 cm (MacKinnon et al., 2010), 100–117 cm (males) and 84-98 cm (females) (Poonswad et al., 2013), and 75–85 cm (Eaton et al., 2016). In contrast, *Aceros cassidix* exhibits a body size range of 70–80 cm (Poonswad et al., 2013; Eaton et al., 2016). These findings underscore the morphometric character similarity between *Aceros cassidix* (94.3 cm) and *Rhyticeros undulatus* species (89.9 cm). It is noteworthy to mention that Indonesia boasts a rich diversity of hornbill species, totaling 13 (MacKinnon et al., 2010; Poonswad et al., 2013; Eaton et al., 2016). However, our analysis exclusively encompasses seven species due to data limitations arising from zoological collections.

Summary

The differentiation between hornbill genera becomes evident when considering the combined influence of PC1, representing body length characteristics, and PC3, which encompasses beak characteristics. Specifically, the attributes that distinguish between the genera *Rhyticeros*, *Buceros,* and *Anthracoceros* within PC1

(body length character) encompass tail length, half length, horn length, total length, and wing length. In contrast, the distinguishing features on PC3 (beak character) include beak width, horn width, and tarsus length. Furthermore, the demarcation between species within the *Anthracoceros* and *Rhyticeros* genera primarily relies on a combination of tail length and head length.

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Conflicts of Interest

The authors declare that there are no conflicts of interest to disclose.

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