

Morphometric Analysis of Three *Draco* Lizard Species (*D. blanfordii*, *D. maculatus*, and *D. taeniopterus*) (Squamata: Agamidae) from Thailand

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ABSTRACT

Two hundred sixty-seven preserved specimens of three *Draco* lizard species from Thailand consisting of *D. blanfordii* (17 females and 70 males), *D. maculatus* (58 females and 79 males) and *D. taeniopterus* (13 females and 30 males) were examined using 21 morphometric characters and 25 character ratios to assess morphometric differences. The results of univariate analysis showed that there were 12 morphometric characters and 2 character ratios that can be used for discrimination of the three *Draco* species regardless of sexual differences. Among these three species, it was found that 13 morphometric characters and 7 character ratios and 15 morphometric characters and 8 character ratios can be used to discriminate female and male lizards, respectively. The results of cluster analysis produced a dendrogram of the relationships among the three species and revealed that the three *Draco* species were divided into two morphometric clusters at a level of 0% of information remaining in which the *D. blanfordii* cluster was distinctly different from the *D. maculatus* and *D. taeniopterus* cluster.

Keywords: morphometric analysis, *Draco*, *D. blanfordii*, *D. maculatus*, *D. taeniopterus*

INTRODUCTION

The agamid lizard genus *Draco* is the most remarkable and successful of gliding vertebrates. It is well-known as a flying lizard or flying dragon due to its ability to glide long distances between trees using its wing-like patagial membrane, supported by elongated ribs or rib-like dermal structures (McGuire, 1998; McGuire and Dudley, 2011). The habitats of *Draco* lizards are large, tall and thick forest with climbing sites, open areas for gliding and sheltered areas for hiding (Mori and Hikida, 1994). In Thailand,

Musters (1983) and Nabhitabhata *et al.* (2000) reported there are nine species of *Draco* lizards consisting of: *D. blanfordii*, *D. fimbriatus*, *D. haematopogon*, *D. maculatus*, *D. melanopogon*, *D. obscurus*, *D. quinquefasciatus*, *D. taeniopterus* and *D. volans*. The three commonly found *Draco* lizard species—*D. blanfordii*, *D. maculatus* and *D. taeniopterus*—are distributed in many regions of Thailand, with *Draco blanfordii* distributed from Northern to Southern Thailand, whereas, *D. maculatus* and *D. taeniopterus* are distributed in all regions (Musters, 1983).

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Morphometric analysis is the quantitative analysis of form and is commonly used in research to characterize the pattern of morphological variation of organisms (Rohlf, 1990; Ljubicavljec *et al.*, 2010). In *Draco* lizards, morphometric analysis has been used for the identification and description of organisms as well as being used to study morphological variation in the population (Inger, 1983; Musters, 1983). However, there is no reported usage of morphometric analysis to discriminate *Draco* lizard species in Thailand. Therefore, the objective of this study was to analyze the morphometric difference among the three *Draco* lizard species—*D. blanfordii*, *D. maculatus* and *D. taeniopterus*. Furthermore, the differences in the morphometric characters of males and females among the three *Draco* species were also analyzed. The results from this study

may be used as a diagnostic tool to discriminate among the three *Draco* species.

MATERIALS AND METHODS

In total, 267 specimens were inspected that had been preserved in 70% ethanol and were housed in the collections of the Thailand Natural History Museum and the National Science Museum, Pathum Thani, Thailand. Specimens were collected from 1967 to 2012. Eighty seven individuals of *D. blanfordii* (*DBI*, 17 females and 70 males), 137 individuals of *D. maculatus* (*DMA*, 58 females and 79 males) and 43 individuals of *D. taeniopterus* (*DTa*, 13 females and 30 males) were measured for 21 morphometric characters to the nearest 0.05 mm using a set of vernier calipers (Figure 1). The measurements were modified

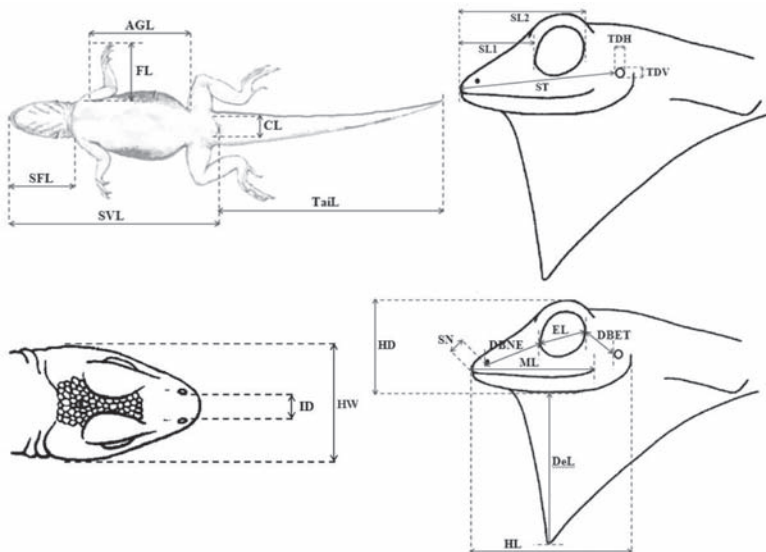


Figure 1 Snout-vent length (SVL), snout-forelimb length (SFL), forelimb length (FL), axilla-groin length (AGL), tail length (Tail), cloacal length (CL), head width (HW), internarial distance (ID), head length (HL), head depth (HD), mouth length (ML), dewlap length (DeL), snout to nostril (SN), distance between nostril to anterior edge of eye (DBNE), distance between posterior edge of eye to anterior edge of tympanum (DBET), eye length (EL), snout to anterior edge of eye (snout length 1 (SL1)), snout to posterior edge of eye (snout length 2 (SL2)), snout to anterior edge of tympanum (ST), tympanum diameter (vertical) (TDV), and tympanum diameter (horizontal) (TDH). The figure is modified from Musters (1983) and Stebbins (2003).

from Taylor (1963), Inger (1983), and Musters (1983). There were three sets of characters in this study: external morphology, head characters, and the ratio of characters (Table 1). Morphological differences among females and among males of the three *Draco* species were measured according to the characters described above.

All morphometric characters and character ratios of the three *Draco* lizard species and the morphological difference of females and males were analyzed using univariate analysis which consisted of the mean, the 95% confidence intervals for the mean and one-way analysis of variance followed by Duncan's post-hoc test

Table 1 External morphology, head characters and character ratios examined in 267 specimens of three *Draco* lizard species from Thailand.

External morphology
- Snout-vent length (SVL): the tip of the snout to the vent
- Snout-forelimb length (SFL): the tip of the snout to the shoulder
- Forelimb length (FL): the left side from the axilla to the tip of the fourth finger when extended at right angles
- Axilla-groin length (AGL): the axilla to the anterior edge of hindlimb at its insertion into the body
- Tail length (Tail): the vent to the tip of the tail
- Cloacal length (CL): the broadest part at the level of the cloacal opening
Head characters
- Head width (HW): the widest part of the head
- Internarial distance (ID): across the nostrils at the snout
- Head length (HL): the tip of the snout to the posterior margin of the jaw
- Head depth (HD): the deepest part of the head
- Mouth length (ML): the tip of the snout to the mouth corner
- Dewlap length (DeL): maximally extended, from the ventral edge of the lower jaw to the tip of the dewlap
- Snout to nostril (SN): the tip of the snout to the anterior edge of the nostril
- Distance between nostril to anterior edge of eye (DBNE): the anterior edge of the nostril to the anterior edge of the eye
- Distance between posterior edge of eye to anterior edge of tympanum (DBET): the posterior edge of the eye to the anterior edge of the tympanum
- Eye length (EL): the anterior edge of the orbit to the posterior edge of the orbit
- Snout to anterior edge of eye (snout length 1(SL1)): the tip of the snout to the anterior edge of the eye
- Snout to posterior edge of eye (snout length 2 (SL2)): the tip of the snout to the posterior edge of the eye
- Snout to anterior edge of tympanum (ST): the tip of the snout to the anterior edge of the tympanum
- Tympanum diameter (vertical) (TDV): the dorsal edge of the tympanum to the ventral edge of the tympanum
- Tympanum diameter (horizontal) (TDH): the anterior edge of the tympanum to the posterior edge of the tympanum
Character ratios
- SFL/SVL, FL/SVL, AGL/SVL, Tail/SVL, CL/SVL, HW/SVL, ID/SVL, HL/SVL, HD/SVL, ML/SVL, DeL/SVL, SN/SVL, DBNE/SVL, DBET/SVL, EL/SVL, SL1/SVL, SL2/SVL, ST/SVL, TDV/SVL, TDH/SVL, FL/AGL, HW/HL, HD/HW, HD/HL and DeL/HL

using the software SPSS (version 16; SPSS Inc.; Chicago, IL, USA). The relationships among the three *Draco* lizard species and for the females and males were determined on the basis of morphometric characters and character ratios using cluster analysis according to Jaccard and Ward's method in the software program PC-ORD (version 5.10; MJM Software Design; Gleneden Beach, OR, USA) in the form of a dendrogram.

RESULTS AND DISCUSSION

Univariate analysis

The mean values, 95% confidence intervals for the mean and significance levels ($P < 0.05$) of the morphometric characters and character ratios are shown in Tables 2 and 3. The results showed significant differences in 21 morphometric characters as well as in the character ratios which also showed significant differences in most characters except for the ratio of DeL/HL. Most of the morphometric characters showed *DBI* having the highest values, followed by the values of *DMA* and *DTa*.

There is no previous report on the use of morphometric characters to separate the three *Draco* species in Thailand. However, on the basis of this study, there are 12 morphometric characters and 2 character ratios—FL, TaiL, HW, HL, HD, ML, SN, DBET, SL1, SL2, ST, TDH, HD/SVL and SL2/SVL—that can be used to distinguish species as shown in Table 4.

The 95% confidence interval for the mean were narrow for most of the morphometric characters and character ratios except for the TaiL character (Table 4).

Discrimination of females among the three *Draco* species is shown by the values of morphometric characters and character ratios in Tables 5 and 6. There was a significant difference in 13 morphometric characters—FL, TaiL, HW, HL, HD, ML, DeL, SN, DBET, SL1, SL2, ST and TDH—and 7 character ratios—HW/SVL, HD/SVL, DeL/SVL, SL2/SVL, ST/SVL, HD/HW and

DeL/HL.

Discrimination of males among the three *Draco* species is shown by the values of morphometric characters and character ratios in Tables 7 and 8. There was a significant difference in 15 morphometric characters—SFL, FL, TaiL, HW, ID, HL, HD, ML, SN, DBNE, DBET, SL1, SL2, ST and TDH—and 8 character ratios—FL/AGL, CL/SVL, HD/SVL, DeL/SVL, SL1/SVL, SL2/SVL, TDH/SVL and DeL/HL.

Therefore, to discriminate the three *Draco* species regardless of sexual differences, there are 12 suitable morphometric characters—FL, TaiL, HW, HL, HD, ML, SN, DBET, SL1, SL2, ST and TDH—and 2 character ratios—HD/SVL and SL2/SVL (Table 4). Furthermore, 12 of the morphometric characters and 2 character ratios mentioned above can be used to discriminate females among the three *Draco* species in addition to another 6 characters—DeL, HW/SVL, DeL/SVL, ST/SVL, HD/HW and DeL/HL (Table 5 and 6). Similarly, the males among three *Draco* species can be discriminated using another 9 characters—SFL, ID, DBNE, FL/AGL, CL/SVL, DeL/SVL, SL1/SVL, TDH/SVL and DeL/HL (Tables 7 and 8).

In practical use, the morphometric characters may not be appropriate for the identification of the three *Draco* species. However, they can be used as an additional or diagnostic tool to support the qualitative characters in the three *Draco* lizard species. Furthermore, the morphometric characters can be used to describe the size of the three *Draco* species. The present study showed that *DBI* is the largest species and this is consistent with Taylor (1963), Inger (1983), and Musters (1983) while *DMA* and *DTa* were classified as moderate and small species, respectively (Taylor, 1963).

The 95% confidence interval for the mean showed the TaiL character had a wide confidence interval. Therefore, it would not be a good character to use for determining the differences among the three *Draco* species.

Table 2 Mean, 95% Confidence interval for means and one-way analysis of variance of external morphology in three *Draco* species: *D. blanfordii* (*DBI*), *D. maculatus* (*DMa*) and *D. taeniopterus* (*DTa*) from Thailand.

Morphometric Character	DBI (n = 87)			DMa (n = 137)			DTa (n = 43)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
SVL	101.11 ^a	98.17	104.05	73.19 ^b	72.05	74.32	71.30 ^b	70.10	72.50	0.000
SFL	32.49 ^a	31.56	33.42	24.19 ^b	23.82	24.56	23.42 ^b	22.95	23.90	0.000
FL	41.65 ^a	40.59	42.72	30.40 ^c	29.90	30.90	34.13 ^b	33.56	34.70	0.000
AGL	56.92 ^a	55.01	58.84	40.52 ^b	39.84	41.21	39.10 ^b	38.32	39.89	0.000
TailL	187.90 ^a	182.99	192.82	109.25 ^c	106.90	111.60	133.92 ^b	131.11	136.73	0.000
CL	5.48 ^a	5.30	5.65	5.15 ^b	5.02	5.27	4.44 ^c	4.23	4.64	0.000
SFL/SVL	0.32 ^b	0.32	0.33	0.33 ^a	0.33	0.33	0.33 ^a	0.32	0.33	0.000
FL/SVL	0.41 ^b	0.41	0.42	0.42 ^b	0.41	0.42	0.48 ^a	0.47	0.49	0.000
AGL/SVL	0.56 ^a	0.56	0.57	0.55 ^b	0.55	0.56	0.55 ^b	0.54	0.56	0.004
FL/AGL	0.74 ^b	0.72	0.75	0.75 ^b	0.74	0.76	0.87 ^a	0.86	0.89	0.000
TailL/SVL	1.87 ^a	1.84	1.89	1.49 ^b	1.47	1.52	1.88 ^a	1.85	1.91	0.000
CL/SVL	0.05 ^c	0.05	0.06	0.07 ^a	0.07	0.07	0.06 ^b	0.06	0.07	0.000

SVL = Snout-vent length; SFL = Snout-forelimb length; FL = Forelimb length; AGL = Axilla-groin length; TailL = Tail length; CL = Cloacal length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 3 Means, 95% confidence intervals for means and one-way analysis of variance of head characters in three *Draco* species: *D. blanfordii* (DBI), *D. maculatus* (DMA) and *D. taeniopterus* (DTa) from Thailand.

Morphometric character	DBI (n = 87)			DMA (n = 137)			DTa (n = 43)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HW	10.76 ^a	10.47	11.05	8.79 ^b	8.66	8.92	7.58 ^c	7.39	7.76	0.000
ID	2.59 ^b	2.49	2.69	2.77 ^a	2.72	2.82	1.90 ^c	1.82	1.98	0.000
HL	19.39 ^a	18.90	19.88	15.17 ^b	14.98	15.36	13.51 ^c	13.24	13.78	0.000
HD	8.93 ^a	8.75	9.12	7.41 ^b	7.32	7.50	6.74 ^c	6.61	6.88	0.000
ML	14.35 ^a	14.00	14.69	11.61 ^b	11.46	11.76	10.40 ^c	10.17	10.62	0.000
DeL	25.86 ^a	24.35	27.38	21.33 ^b	19.96	22.70	18.80 ^c	16.69	20.91	0.000
SN	2.17 ^a	2.10	2.25	1.78 ^b	1.74	1.83	1.41 ^c	1.36	1.47	0.000
DBNE	5.26 ^a	5.10	5.42	3.72 ^b	3.65	3.78	3.54 ^c	3.45	3.64	0.000
DBET	4.03 ^a	3.92	4.13	3.29 ^b	3.24	3.35	2.73 ^c	2.64	2.81	0.000
EL	7.31 ^a	7.18	7.43	5.88 ^b	5.82	5.94	5.87 ^b	5.77	5.98	0.000
SL1	7.42 ^a	7.20	7.63	5.68 ^b	5.59	5.77	4.92 ^c	4.80	5.05	0.000
SL2	13.26 ^a	12.97	13.55	10.83 ^b	10.70	10.97	10.05 ^c	9.84	10.26	0.000
ST	16.76 ^a	16.36	17.17	13.04 ^b	12.89	13.2	11.67 ^c	11.41	11.93	0.000
TDV	1.94 ^a	1.86	2.02	1.92 ^a	1.87	1.97	1.66 ^b	1.58	1.73	0.000
TDH	1.78 ^a	1.70	1.86	1.57 ^b	1.54	1.61	1.35 ^c	1.29	1.41	0.000
HW/SVL	0.11 ^b	0.11	0.11	0.12 ^a	0.12	0.12	0.11 ^b	0.10	0.11	0.000
ID/SVL	0.03 ^b	0.02	0.03	0.04 ^a	0.04	0.04	0.03 ^b	0.03	0.03	0.000
HL/SVL	0.19 ^b	0.19	0.19	0.21 ^a	0.21	0.21	0.19 ^b	0.19	0.19	0.000

Table 3 (Continued)

Morphometric character	DBI (n = 87)			DMa (n = 137)			DTa (n = 43)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HD/SVL	0.09 ^c	0.09	0.09	0.10 ^a	0.10	0.10	0.09 ^b	0.09	0.10	0.000
ML/SVL	0.14 ^b	0.14	0.14	0.16 ^a	0.16	0.16	0.15 ^b	0.14	0.15	0.000
DeL/SVL	0.26 ^b	0.24	0.27	0.29 ^a	0.27	0.31	0.26 ^{ab}	0.23	0.29	0.019
SN/SVL	0.02 ^b	0.02	0.02	0.02 ^a	0.02	0.02	0.02 ^b	0.02	0.02	0.000
DBNE/SVL	0.05 ^a	0.05	0.05	0.05 ^{ab}	0.05	0.05	0.05 ^b	0.05	0.05	0.009
DBET/SVL	0.04 ^b	0.04	0.04	0.05 ^a	0.04	0.05	0.04 ^b	0.04	0.04	0.000
EL/SVL	0.07 ^b	0.07	0.07	0.08 ^a	0.08	0.08	0.08 ^a	0.08	0.08	0.000
SL1/SVL	0.07 ^b	0.07	0.07	0.08 ^a	0.08	0.08	0.07 ^c	0.07	0.07	0.000
SL2/SVL	0.13 ^c	0.13	0.13	0.15 ^a	0.15	0.15	0.14 ^b	0.14	0.14	0.000
ST/SVL	0.17 ^b	0.16	0.17	0.18 ^a	0.18	0.18	0.16 ^b	0.16	0.17	0.000
TDV/SVL	0.02 ^c	0.02	0.02	0.03 ^a	0.03	0.03	0.02 ^b	0.02	0.02	0.000
TDH/SVL	0.02 ^c	0.02	0.02	0.02 ^a	0.02	0.02	0.02 ^b	0.02	0.02	0.000
HW/HL	0.56 ^b	0.55	0.56	0.58 ^a	0.57	0.59	0.56 ^b	0.55	0.57	0.000
HD/HW	0.84 ^b	0.82	0.85	0.85 ^b	0.84	0.86	0.89 ^a	0.88	0.91	0.000
HD/HL	0.46 ^c	0.46	0.47	0.49 ^b	0.48	0.49	0.50 ^a	0.49	0.51	0.000
DeL/HL	1.33	1.26	1.40	1.40	1.31	1.48	1.39	1.24	1.55	0.575

HW = Head width; ID = Internarial distance; HL = Head length; HD = Head depth; ML = Mouth length; DeL = Dewlap length; SN = Snout to nostril; DBNE = Distance between nostril to anterior edge of eye; DBET = Distance between posterior edge of eye to anterior edge of tympanum; EL = Eye length; SL1 = Snout to anterior edge of eye (snout length 1); SL2 = Snout to posterior edge of eye (snout length 2); ST = Snout to anterior edge of tympanum; TDV = Tympanum diameter (vertical); TDH = Tympanum diameter (horizontal); SVL = Snout-vent length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 4 Morphometric characters used to discriminate three *Draco* species: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand regardless of sexual difference.

Morphometric character	DBI (n = 87)			DMa (n = 137)			DTa (n = 43)			P-value
	Mean	95% Confidence interval for		Mean	95% Confidence interval for		Mean	95% Confidence interval for		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
FL	41.65 ^a	40.59	42.72	30.40 ^c	29.90	30.90	34.13 ^b	33.56	34.70	0.000
Tail	187.90 ^a	182.99	192.82	109.25 ^c	106.90	111.60	133.92 ^b	131.11	136.73	0.000
HW	10.76 ^a	10.47	11.05	8.79 ^b	8.66	8.92	7.58 ^c	7.39	7.76	0.000
HL	19.39 ^a	18.90	19.88	15.17 ^b	14.98	15.36	13.51 ^c	13.24	13.78	0.000
HD	8.93 ^a	8.75	9.12	7.41 ^b	7.32	7.50	6.74 ^c	6.61	6.88	0.000
ML	14.35 ^a	14.00	14.69	11.61 ^b	11.46	11.76	10.40 ^c	10.17	10.62	0.000
SN	2.17 ^a	2.10	2.25	1.78 ^b	1.74	1.83	1.41 ^c	1.36	1.47	0.000
DBET	4.03 ^a	3.92	4.13	3.29 ^b	3.24	3.35	2.73 ^c	2.64	2.81	0.000
SL1	7.42 ^a	7.20	7.63	5.68 ^b	5.59	5.77	4.92 ^c	4.80	5.05	0.000
SL2	13.26 ^a	12.97	13.55	10.83 ^b	10.70	10.97	10.05 ^c	9.84	10.26	0.000
ST	16.76 ^a	16.36	17.17	13.04 ^b	12.89	13.20	11.67 ^c	11.41	11.93	0.000
TDH	1.78 ^a	1.70	1.86	1.57 ^b	1.54	1.61	1.35 ^c	1.29	1.41	0.000
HD/SVL	0.09 ^c	0.09	0.09	0.10 ^a	0.10	0.10	0.09 ^b	0.09	0.10	0.000
SL2/SVL	0.13 ^c	0.13	0.13	0.15 ^a	0.15	0.15	0.14 ^b	0.14	0.14	0.000

FL = Forelimb length; TailL = Tail length; HW = Head width; HL = Head length; HD = Head depth; ML = Mouth length; SN = Snout to nostril; DBET = Distance between posterior edge of eye to anterior edge of tympanum; SL1 = Snout to anterior edge of eye (snout length 1); SL2 = Snout to posterior edge of eye (snout length 2); ST = Snout to anterior edge of tympanum; TDH = Tympanum diameter (horizontal); SVL = Snout-vent length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 5 Means, 95% confidence intervals for means and one-way analysis of variance of external morphology in females among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand.

Morphometric character	DBI (n = 17)			DMa (n = 58)			DTa (n = 13)			P-value
	Mean	95% Confidence interval for		Mean	95% Confidence interval for		Mean	95% Confidence interval for		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
SVL	99.43 ^a	93.18	105.68	71.11 ^b	69.60	72.61	70.55 ^b	68.10	73.00	0.000
SFL	32.79 ^a	30.61	34.96	23.45 ^b	22.95	23.96	23.40 ^b	22.39	24.41	0.000
FL	41.68 ^a	39.54	43.82	29.59 ^c	28.92	30.26	34.05 ^b	33.07	35.04	0.000
AGL	56.53 ^a	52.26	60.80	40.05 ^b	39.12	40.97	39.77 ^b	38.05	41.49	0.000
Tail	184.99 ^a	173.80	196.18	104.44 ^c	101.87	107.02	132.83 ^b	127.67	137.99	0.000
CL	5.47 ^a	4.93	6.02	5.06 ^{ab}	4.84	5.29	4.60 ^b	4.24	4.96	0.027
SFL/SVL	0.33	0.32	0.34	0.33	0.33	0.33	0.33	0.32	0.34	0.677
FL/SVL	0.42 ^b	0.41	0.43	0.42 ^b	0.41	0.42	0.48 ^a	0.47	0.49	0.000
AGL/SVL	0.57	0.55	0.58	0.56	0.56	0.57	0.56	0.55	0.58	0.699
FL/AGL	0.74 ^b	0.71	0.77	0.74 ^b	0.73	0.75	0.86 ^a	0.83	0.89	0.000
Tail/SVL	1.86 ^a	1.82	1.91	1.47 ^b	1.44	1.50	1.89 ^a	1.83	1.94	0.000
CL/SVL	0.05 ^b	0.05	0.06	0.07 ^a	0.07	0.07	0.07 ^a	0.06	0.07	0.000

SVL = Snout-vent length; SFL = Snout-forelimb length; FL = Forelimb length; AGL = Axilla-groin length; Tail_L = Tail length; CL = Cloacal length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 6 Means, 95% confidence intervals for means and one-way analysis of variance of head characters in females among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMA) and *D. taeniopterus* (DTA) from Thailand.

Morphometric characters	DBI (n = 17)			DMA (n = 58)			DTA (n = 13)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HW	11.24 ^a	10.59	11.89	8.75 ^b	8.54	8.97	7.72 ^c	7.31	8.13	0.000
ID	2.77 ^a	2.54	3.00	2.77 ^a	2.69	2.84	1.95 ^b	1.79	2.12	0.000
HL	19.61 ^a	18.39	20.83	14.94 ^b	14.63	15.24	13.62 ^c	13.00	14.24	0.000
HD	8.78 ^a	8.40	9.16	7.27 ^b	7.11	7.42	6.81 ^c	6.50	7.12	0.000
ML	14.54 ^a	13.69	15.40	11.45 ^b	11.21	11.69	10.43 ^c	9.89	10.96	0.000
DeL	14.68 ^a	13.58	15.78	12.69 ^b	12.18	13.20	9.03 ^c	8.30	9.76	0.000
SN	2.14 ^a	1.93	2.34	1.73 ^b	1.67	1.79	1.38 ^c	1.28	1.48	0.000
DBNE	5.22 ^a	4.82	5.62	3.63 ^b	3.51	3.74	3.52 ^b	3.30	3.73	0.000
DBET	3.99 ^a	3.71	4.27	3.21 ^b	3.14	3.28	2.72 ^c	2.57	2.86	0.000
EL	7.34 ^a	7.05	7.63	5.86 ^b	5.77	5.96	5.91 ^b	5.67	6.16	0.000
SL1	7.36 ^a	6.84	7.88	5.56 ^b	5.42	5.70	4.97 ^c	4.69	5.24	0.000
SL2	13.26 ^a	12.60	13.92	10.70 ^b	10.47	10.92	10.05 ^c	9.53	10.57	0.000
ST	16.85 ^a	15.86	17.85	12.86 ^b	12.61	13.12	11.57 ^c	10.99	12.16	0.000
TDV	2.09 ^a	1.91	2.28	1.91 ^{ab}	1.84	1.99	1.77 ^b	1.58	1.96	0.016
TDH	1.98 ^a	1.76	2.20	1.57 ^b	1.52	1.63	1.34 ^c	1.19	1.48	0.000
HW/SVL	0.11 ^b	0.11	0.12	0.12 ^a	0.12	0.13	0.11 ^c	0.10	0.11	0.000
ID/SVL	0.03 ^b	0.03	0.03	0.04 ^a	0.04	0.04	0.03 ^b	0.03	0.03	0.000
HL/SVL	0.20 ^b	0.19	0.20	0.21 ^a	0.21	0.21	0.19 ^b	0.19	0.20	0.000

Table 6 (Continued)

Morphometric character	DBI (n = 17)			DMA (n = 58)			DIA (n = 13)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HD/SVL	0.09 ^c	0.09	0.10	0.10 ^a	0.10	0.10	0.10 ^b	0.09	0.10	0.000
ML/SVL	0.15 ^b	0.14	0.15	0.16 ^a	0.16	0.16	0.15 ^b	0.14	0.15	0.000
DeL/SVL	0.15 ^b	0.14	0.16	0.18 ^a	0.17	0.18	0.13 ^c	0.12	0.14	0.000
SN/SVL	0.02 ^b	0.02	0.02	0.02 ^a	0.02	0.02	0.02 ^b	0.02	0.02	0.005
DBNE/SVL	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.447
DBET/SVL	0.04 ^b	0.04	0.04	0.04 ^a	0.04	0.05	0.04 ^b	0.04	0.04	0.000
EL/SVL	0.07 ^b	0.07	0.08	0.08 ^a	0.08	0.08	0.08 ^a	0.08	0.09	0.000
SL1/SVL	0.07 ^b	0.07	0.08	0.08 ^a	0.08	0.08	0.07 ^b	0.07	0.07	0.000
SL2/SVL	0.13 ^c	0.13	0.14	0.15 ^a	0.15	0.15	0.14 ^b	0.14	0.15	0.000
ST/SVL	0.17 ^b	0.17	0.17	0.18 ^a	0.18	0.18	0.16 ^c	0.16	0.17	0.000
TDV/SVL	0.02 ^b	0.02	0.02	0.03 ^a	0.03	0.03	0.02 ^a	0.02	0.03	0.000
TDH/SVL	0.02 ^{ab}	0.02	0.02	0.02 ^a	0.02	0.02	0.02 ^b	0.02	0.02	0.040
HW/HL	0.57	0.56	0.59	0.59	0.58	0.59	0.57	0.55	0.58	0.101
HD/HW	0.79 ^c	0.75	0.82	0.83 ^b	0.82	0.85	0.88 ^a	0.86	0.91	0.000
HD/HL	0.45 ^b	0.43	0.47	0.49 ^a	0.48	0.49	0.50 ^a	0.49	0.51	0.000
DeL/HL	0.75 ^b	0.70	0.80	0.85 ^a	0.82	0.88	0.66 ^c	0.62	0.71	0.000

HW = Head width; ID = Internarial distance; HL = Head length; HD = Head depth; ML = Mouth length; DeL = Dewlap length; SN = Snout to nostril; DBNE = Distance between nostril to anterior edge of eye; DBET = Distance between posterior edge of eye to anterior edge of tympanum; EL = Eye length; SL1 = Snout to anterior edge of eye (snout length 1); SL2 = Snout to posterior edge of eye (snout length 2); ST = Snout to anterior edge of tympanum; TDV = Tympanum diameter (vertical); TDH = Tympanum diameter (horizontal); SVL = Snout-vent length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 7 Means, 95% confidence intervals for means and one-way analysis of variance of external morphology in males among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand.

Morphometric character	DBI (n = 70)			DMa (n = 79)			DTa (n = 30)			P-value
	Mean	95% Confidence interval for		Mean	95% Confidence interval for		Mean	95% Confidence interval for		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
SVL	101.52 ^a	98.13	104.91	74.71 ^b	73.14	76.29	71.62 ^b	70.18	73.07	0.000
SFL	32.41 ^a	31.36	33.47	24.72 ^b	24.22	25.23	23.44 ^c	22.88	23.99	0.000
FL	41.65 ^a	40.41	42.89	30.99 ^c	30.30	31.69	34.16 ^b	33.42	34.89	0.000
AGL	57.02 ^a	54.83	59.21	40.88 ^b	39.89	41.86	38.81 ^b	37.92	39.71	0.000
TaiL	188.61 ^a	183.01	194.21	112.78 ^c	109.33	116.22	134.39 ^b	130.85	137.94	0.000
CL	5.48 ^a	5.30	5.66	5.21 ^a	5.06	5.36	4.37 ^b	4.10	4.63	0.000
SFL/SVL	0.32 ^b	0.32	0.32	0.33 ^a	0.33	0.34	0.33 ^a	0.32	0.33	0.000
FL/SVL	0.41 ^b	0.41	0.42	0.42 ^b	0.41	0.42	0.48 ^a	0.47	0.49	0.000
AGL/SVL	0.56 ^a	0.55	0.57	0.55 ^b	0.54	0.55	0.54 ^b	0.54	0.55	0.000
FL/AGL	0.74 ^c	0.72	0.75	0.76 ^b	0.75	0.77	0.88 ^a	0.86	0.90	0.000
TaiL/SVL	1.87 ^a	1.83	1.90	1.51 ^b	1.47	1.55	1.88 ^a	1.84	1.91	0.000
CL/SVL	0.05 ^c	0.05	0.06	0.07 ^a	0.07	0.07	0.06 ^b	0.06	0.07	0.000

SVL = Snout-vent length; SFL = Snout-forelimb length; FL = Forelimb length; AGL = Axilla-groin length; TaiL = Tail length; CL = Cloacal length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Table 8 Means 95% confidence intervals for means and one-way analysis of variance of head characters in males among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMA) and *D. taeniopterus* (DTA) from Thailand.

Morphometric character	DBI (n = 70)			DMA (n = 79)			DTA (n = 30)			P-value
	Mean	95% Confidence interval for		Mean	95% Confidence interval for		Mean	95% Confidence interval for		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HW	10.65 ^a	10.32	10.97	8.82 ^b	8.66	8.97	7.51 ^c	7.30	7.72	0.000
ID	2.55 ^b	2.43	2.66	2.78 ^a	2.72	2.84	1.87 ^c	1.78	1.97	0.000
HL	19.34 ^a	18.79	19.88	15.34 ^b	15.11	15.57	13.46 ^c	13.15	13.77	0.000
HD	8.97 ^a	8.75	9.19	7.51 ^b	7.40	7.63	6.72 ^c	6.56	6.87	0.000
ML	14.30 ^a	13.91	14.69	11.73 ^b	11.55	11.91	10.39 ^c	10.14	10.64	0.000
DeL	28.58 ^a	27.42	29.74	27.68 ^a	26.80	28.55	23.03 ^b	22.10	23.96	0.000
SN	2.18 ^a	2.10	2.27	1.82 ^b	1.76	1.89	1.43 ^c	1.36	1.50	0.000
DBNE	5.27 ^a	5.09	5.45	3.79 ^b	3.70	3.87	3.56 ^c	3.45	3.66	0.000
DBET	4.04 ^a	3.92	4.15	3.36 ^b	3.29	3.42	2.73 ^c	2.62	2.84	0.000
EL	7.30 ^a	7.15	7.44	5.89 ^b	5.81	5.97	5.86 ^b	5.75	5.97	0.000
SL1	7.43 ^a	7.19	7.68	5.77 ^b	5.65	5.88	4.91 ^c	4.76	5.05	0.000
SL2	13.26 ^a	12.92	13.60	10.93 ^b	10.76	11.11	10.05 ^c	9.82	10.28	0.000
ST	16.74 ^a	16.28	17.20	13.17 ^b	12.98	13.36	11.72 ^c	11.41	12.02	0.000
TDV	1.90 ^a	1.81	1.99	1.93 ^a	1.86	2.00	1.61 ^b	1.54	1.68	0.000
TDH	1.73 ^a	1.64	1.82	1.57 ^b	1.52	1.62	1.36 ^c	1.29	1.42	0.000
HW/SVL	0.11 ^b	0.10	0.11	0.12 ^a	0.12	0.12	0.11 ^b	0.10	0.11	0.000
ID/SVL	0.03 ^b	0.02	0.03	0.04 ^a	0.04	0.04	0.03 ^b	0.02	0.03	0.000
HL/SVL	0.19 ^b	0.19	0.19	0.21 ^a	0.20	0.21	0.19 ^b	0.18	0.19	0.000

Table 8 (Continued)

Morphometric character	DBI (n = 70)			DMA (n = 79)			DTa (n = 30)			P-value
	Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		Mean	95% Confidence interval for mean		
		Lower bound	Upper bound		Lower bound	Upper bound		Lower bound	Upper bound	
HD/SVL	0.09 ^c	0.09	0.09	0.10 ^a	0.10	0.10	0.09 ^b	0.09	0.10	0.000
ML/SVL	0.14 ^b	0.14	0.14	0.16 ^a	0.15	0.16	0.14 ^b	0.14	0.15	0.000
DeL/SVL	0.28 ^c	0.27	0.29	0.37 ^a	0.36	0.38	0.32 ^b	0.31	0.33	0.000
SN/SVL	0.02 ^b	0.02	0.02	0.02 ^a	0.02	0.03	0.02 ^b	0.02	0.02	0.000
DBNE/SVL	0.05 ^a	0.05	0.05	0.05 ^{ab}	0.05	0.05	0.05 ^b	0.05	0.05	0.011
DBET/SVL	0.04 ^b	0.04	0.04	0.05 ^a	0.04	0.05	0.04 ^b	0.04	0.04	0.000
EL/SVL	0.07 ^b	0.07	0.07	0.08 ^a	0.08	0.08	0.08 ^a	0.08	0.08	0.000
SL1/SVL	0.07 ^b	0.07	0.07	0.08 ^a	0.08	0.08	0.07 ^c	0.07	0.07	0.000
SL2/SVL	0.13 ^c	0.13	0.13	0.15 ^a	0.14	0.15	0.14 ^b	0.14	0.14	0.000
ST/SVL	0.17 ^b	0.16	0.17	0.18 ^a	0.17	0.18	0.16 ^b	0.16	0.17	0.000
TDV/SVL	0.02 ^b	0.02	0.02	0.03 ^a	0.02	0.03	0.02 ^b	0.02	0.02	0.000
TDH/SVL	0.02 ^c	0.02	0.02	0.02 ^a	0.02	0.02	0.02 ^b	0.02	0.02	0.000
HW/HL	0.55 ^b	0.54	0.56	0.58 ^a	0.57	0.59	0.56 ^b	0.55	0.57	0.000
HD/HW	0.85 ^b	0.83	0.87	0.86 ^b	0.84	0.87	0.90 ^a	0.88	0.91	0.002
HD/HL	0.47 ^b	0.46	0.47	0.49 ^a	0.48	0.50	0.50 ^a	0.49	0.51	0.000
DeL/HL	1.48 ^c	1.44	1.51	1.80 ^a	1.76	1.84	1.71 ^b	1.66	1.76	0.000

HW = Head width; ID = Internarial distance; HL = Head length; HD = Head depth; ML = Mouth length; DeL = Dewlap length; SN = Snout to nostril; DBNE = Distance between nostril to anterior edge of eye; DBET = Distance between posterior edge of eye to anterior edge of tympanum; EL = Eye length; SL1 = Snout to anterior edge of eye (snout length 1); SL2 = Snout to posterior edge of eye (snout length 2); ST = Snout to anterior edge of tympanum; TDV = Tympanum diameter (vertical); TDH = Tympanum diameter (horizontal); SVL = Snout-vent length. Values with different superscripts in the same row indicate a significant difference ($P < 0.05$).

Multivariate analysis

The mean values of 21 morphometric characters and 25 character ratios were subjected to multivariate analysis using cluster analysis. The results of clustering produced a dendrogram which depicted a level of dissimilarity (difference). This study produced three dendrograms of the three *Draco* species: 1) regardless of sexual differences; 2) females; and 3) males shown in Figures 2, 3, and 4, respectively.

All three dendrograms showed two main distinguishable clusters. The *DBI* cluster was easily distinguishable from the cluster of *DMA* and *DTa* on the basis of morphometric characters and character ratios at a level of 0% of information remaining.

In the dendrogram of the three *Draco* species without regard to sexual differences, the *DBI* cluster was distinctly different from the cluster of *DMA* and *DTa* and this difference was supported by 18 morphometric characters—SVL, SFL, DBNE, AGL, HL, ST, SL1, HW, DBET, SN, TaiL, FL, EL, HD, SL2, ML, DeL and TDH. On the other hand, the cluster of *DMA* and *DTa* was different from the *DBI* cluster based on three morphometric characters—ID, CL and TDV; and 25 character ratios—HL/SVL, HD/SVL, DeL/SVL, HW/SVL, ST/SVL, ML/SVL, SL2/SVL, SL1/SVL, SFL/SVL, DeL/HL, HW/HL, SN/SVL, DBNE/SVL, TDH/SVL, AGL/SVL, EL/SVL, HD/HL, HD/HW, FL/SVL, FL/AGL, TaiL/SVL, ID/SVL, DBET/SVL, CL/SVL and TDV/SVL (Figure 2).

The dendrogram for females among the three *Draco* lizard species showed a clearly separate *DBI* cluster from *DMA* and *DTa* based on 18 morphometric characters—SVL, SFL, AGL, DBNE, FL, TaiL, HL, ST, HW, SL1, ML, SN, DBET, TDH, DeL, HD, SL2 and EL. The cluster of *DMA* and *DTa* was different from the *DBI* cluster based on three morphometric characters—ID, CL, and TDV and 25 character ratios—HL/SVL, ST/SVL, HW/SVL, ML/SVL, SL1/SVL, SL2/SVL,

SFL/SVL, SN/SVL, DBNE/SVL, TDH/SVL, AGL/SVL, HW/HL, TaiL/SVL, FL/SVL, FL/AGL, HD/SVL, HD/HL, HD/HW, CL/SVL, EL/SVL, TDV/SVL, ID/SVL, DBET/SVL, DeL/SVL and DeL/HL (Figure 3).

The dendrogram for males among the three *Draco* lizard species showed that the *DBI* cluster was distinctly different from the cluster of *DMA* and *DTa* and was characterized by 19 morphometric characters—SVL, SFL, HL, ST, SL1, DBNE, AGL, TaiL, FL, EL, HW, ML, HD, SL2, SN, DBET, DeL, CL and TDH. The cluster of *DMA* and *DTa* was different from the *DBI* cluster based on 1 morphometric character and 26 character ratios—ID, TDV/SVL, ID/SVL, DBET/SVL, DeL/SVL, CL/SVL, TDV, HW/SVL, HL/SVL, HD/SVL, ST/SVL, SL1/SVL, ML/SVL, SL2/SVL, DeL/HL, EL/SVL, SFL/SVL, SN/SVL, DBNE/SVL, TDH/SVL, AGL/SVL, HW/HL, HD/HL, HD/HW, FL/SVL, FL/AGL and TaiL/SVL (Figure 4).

The dendrograms produced by the current study were not consistent with the dendrogram of Musters (1983) as the current study revealed the cluster of *DBI* was distinctly different from the cluster of *DMA* and *DTa* as the current study used morphometrics only for clustering while Musters (1983) reported the cluster of *DMA* was distinctly different from the cluster of *DBI* and *DTa* based on morphological characters consisting of quantitative and qualitative characters and geographic ranges for clustering. However, the dendrogram in the current study was also not consistent with the study by Honda *et al.* (1999) due to their clustering being based on the 12S and 16S rRNA mitochondrial sequence (779 base pairs) which revealed the cluster of *DTa* was distinctly different from the cluster of *DBI* and *DMA*, while another clustering of Honda *et al.* (1999) based on allozymic data (20 presumptive loci) revealed the cluster of *DMA* was distinctly different from the cluster of *DBI* and *DTa* which was consistent with Musters (1983). Furthermore, the dendrogram of the current study

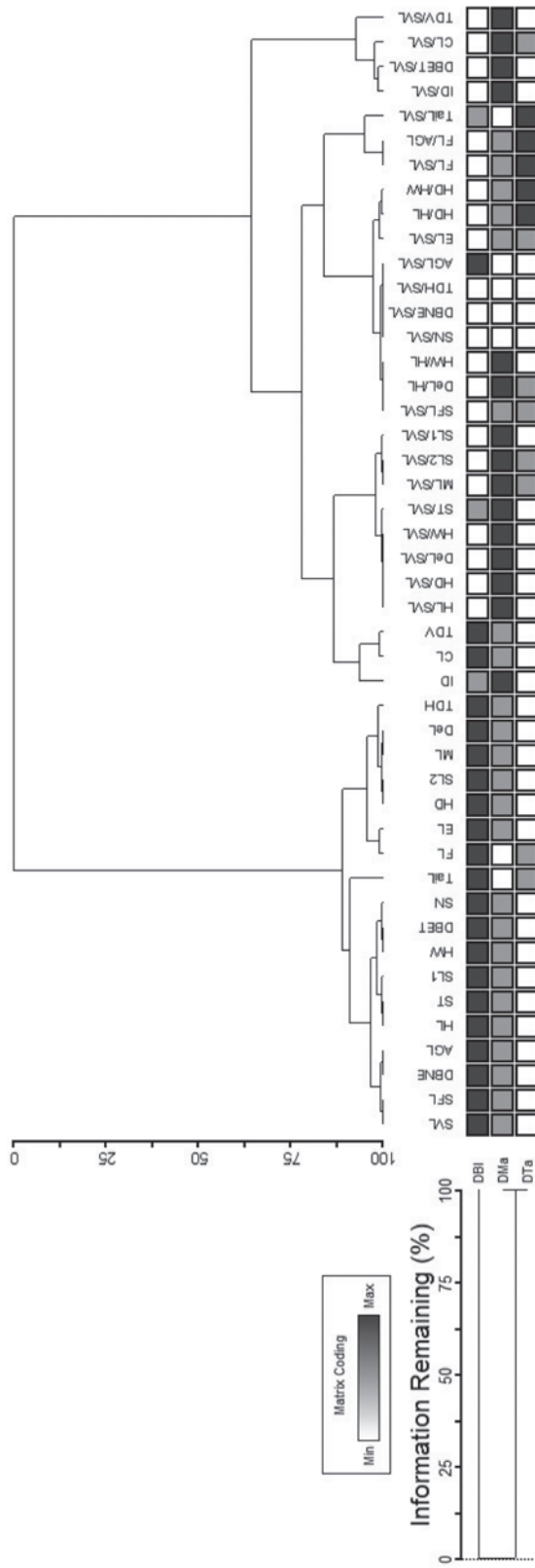


Figure 2 Dendrogram of three *Draco* lizard species regardless of sexual difference: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand. The vertical line indicates a level of 0% of information remaining. See Figure 1 for definitions of the morphometric terms used in this figure.

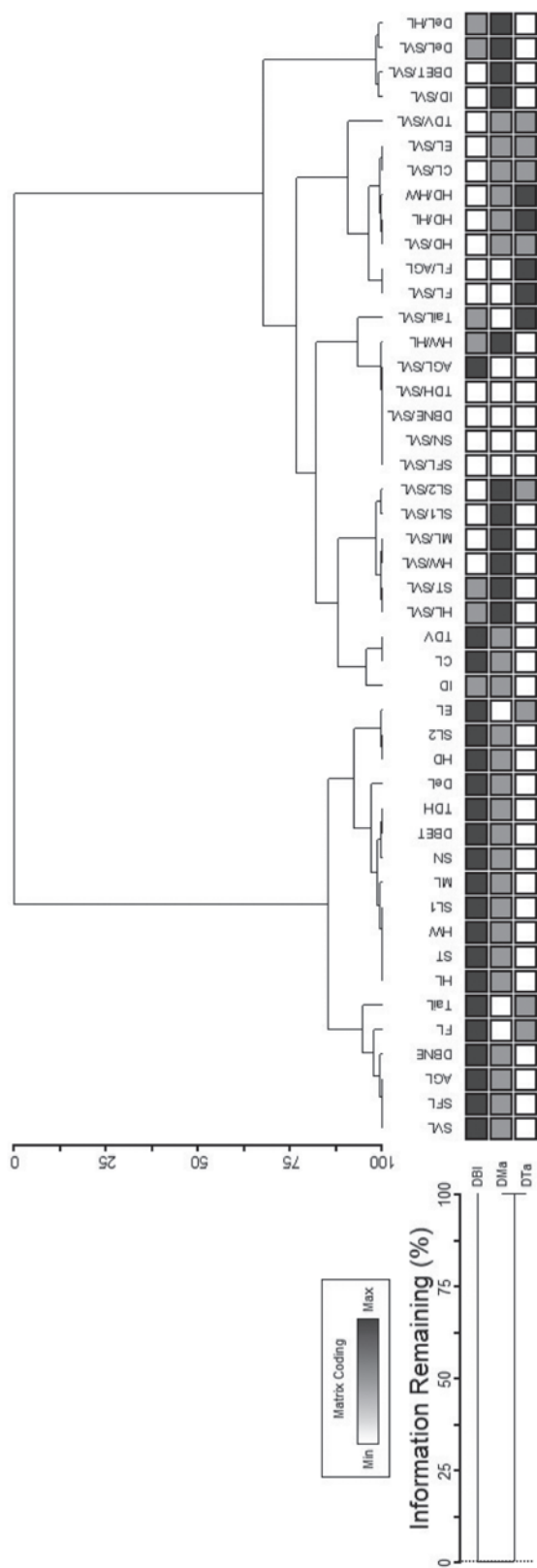


Figure 3 Dendrogram of females among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand. The vertical line indicates a level of 0% of information remaining. See Figure 1 for definitions of the morphometric terms used in this figure.

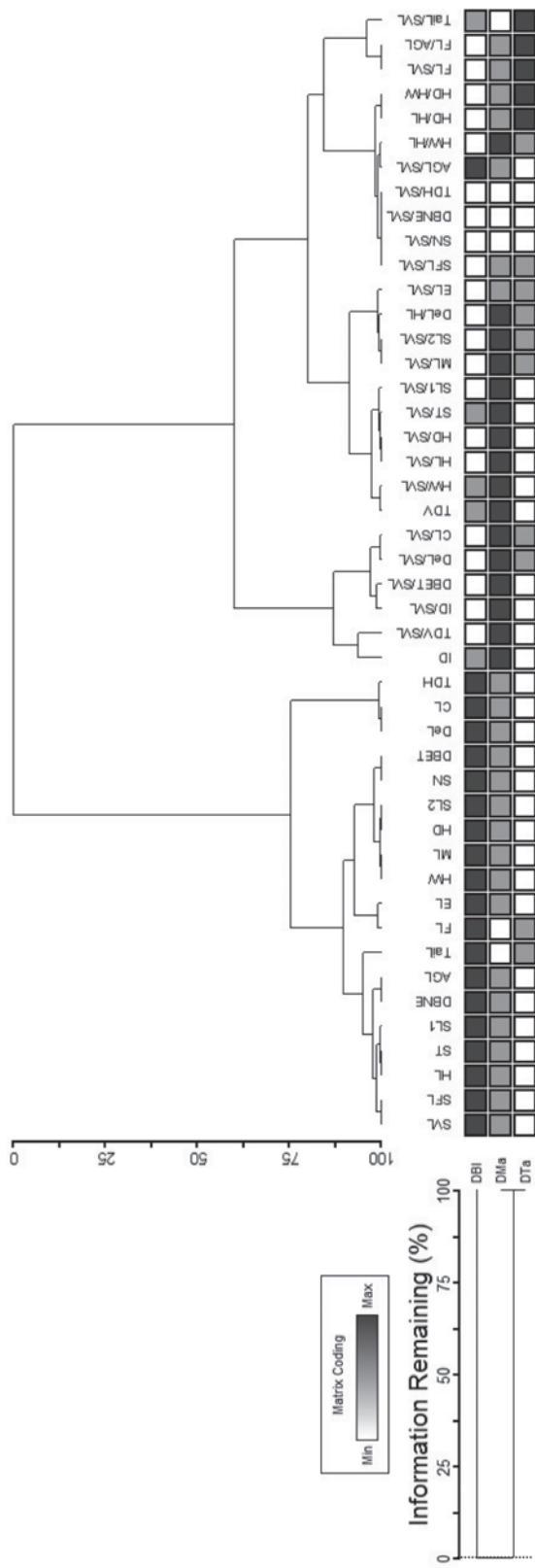


Figure 4 Dendrogram of males among three *Draco* lizard species: *D. blanfordii* (DBI), *D. maculatus* (DMa) and *D. taeniopterus* (DTa) from Thailand. The vertical line indicates a level of 0% of information remaining. See Figure 1 for definitions of the morphometric terms used in this figure.

was not consistent with the study of McGuire and Heang (2001) as their clustering was based on mitochondrial DNA sequence data (1,120 base positions) which revealed the cluster of *Dma* was distinctly different from the cluster of *DBI* and *DTa* which was consistent with the clustering based on morphological characters and geographic ranges of Musters (1983) and the clustering based on allozymic data of Honda *et al.* (1999).

From the dendrogram of the three *Draco* species regardless of sexual difference, the females and males among the three *Draco* lizard species were distinguishable based on the size of each species in clustering which in the current study indicated that most of the morphometric characters of *DBI* had higher values than those of *Dma* and *DTa*. However, the CL character in males among the three *Draco* species was not related to size (Figure 4) because during mating, this character of male lizards may not be a character for sexual selection during evolution (Andersson, 1994).

CONCLUSION

A sample of 267 preserved specimens of three *Draco* lizard species from Thailand consisting of 87 individuals of *D. blanfordii* (17 females and 70 males), 137 individuals of *D. maculatus* (58 females and 79 males), and 43 individuals of *D. taeniopterus* (13 females and 30 males) was examined based on 21 morphometric characters and 25 character ratios to assess morphometric differences. The results of univariate analysis showed that there were 12 morphometric characters and 2 character ratios that can be used for discrimination among the three *Draco* species regardless of sexual difference, being: FL, TaiL, HW, HL, HD, ML, SN, DBET, SL1, SL2, ST, TDH, HD/SVL and SL2/SVL. Among these three species, it was found that 13 morphometric characters and 7 character ratios (FL, TaiL, HW, HL, HD, ML, DeL, SN, DBET, SL1, SL2, ST, TDH, HW/

SVL, HD/SVL, DeL/SVL, SL2/SVL, ST/SVL, HD/HW and DeL/HL); and 15 morphometric characters and 8 character ratios (SFL, FL, TaiL, HW, ID, HL, HD, ML, SN, DBNE, DBET, SL1, SL2, ST, TDH, FL/AGL, CL/SVL, HD/SVL, DeL/SVL, SL1/SVL, SL2/SVL, TDH/SVL and DeL/HL) can be used to discriminate female and male lizards, respectively. The results of cluster analysis in all three dendrograms showed two main distinguishable clusters. The *D. blanfordii* cluster was distinguished from the cluster of *D. maculatus* and *D. taeniopterus* on the basis of morphometric characters and character ratios at a level of 0% of information remaining (100% dissimilarity).

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