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MORPHOLOGICAL VARIATION OF SELECTED SPECIES OF *COPTOTERMES* (ISOPTERA: RHINOTERMITIDAE) IN WESTERN SARAWAK

Norsyarizan, J. and Wan Nurainie, W. I.
Department of Zoology, Faculty of Resource Science and Technology,
Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak
Corresponding author: wiwnurainie@unimas.my

ABSTRACT

The termite genus of *Coptotermes* from the family of Rhinotermitidae is an invasive pest in suburban and urban areas and commonly known as metropolitan pest. Previous studies and data indicated that the genus lacks robust diagnostic characters for morphological species identification and causes many named *Coptotermes* species remain unclear. This has resulted in additional junior synonyms which involves a few species of the most destructive pest of wood. The morphology variation between internest and intranest of soldier also complicates the species identification. The purpose of the study was to assess the morphological variation of *Coptotermes* particularly in soldier caste at species level. A total of 123 soldier's individuals from four selected species of this genus were appropriately measured and recorded, in which 17 morphometric measurements were used. The data were later subjected to unweighted pair-group method average (UPGMA) cluster analysis using Minitab version 16.1.1. The cluster

analysis shows that the genus *Coptotermes* examined is divided into two major clusters where each species was distinctly separated. The morphometric variation for respective species was observed and presented in this paper. From this study, it is suggested that cluster analysis is reliable to assist in species identification among *Coptotermes.*

Keywords: cluster analysis, *Coptotermes*, morphometric, morphological variation, termite

ABSTRAK

Genus anai-anai, *Coptotermes* daripada keluarga Rhinotermitidae adalah perosak invasif di kawasan pinggir bandar dan luar bandar dan biasanya dikenali sebagai perosak metropolitan. Kajian dan data sebelumnya menunjukkan bahawa genus ini tidak mempunyai ciri-ciri diagnostik yang mantap untuk mengenal pasti spesies melalui morfologi dan menyebabkan banyak nama spesies *Coptotermes* kekal tidak jelas. Ini telah menyebabkan sinonim junior tambahan yang melibatkan beberapa spesies perosak yang paling merosakkan kayu. Perubahan morfologi antara dan sesama askar juga merumitkan pengenalan spesies. Tujuan kajian ini adalah untuk menilai variasi morfologi *Coptotermes* terutamanya dalam kasta askar di peringkat spesies. Seramai 123 individu askar daripada empat spesies dipilih daripada genus ini telah diukur dan direkodkandengan sewajarnya, di mana 17 ukuran morphometric telah digunakan. Data yang kemudiannya telah dianalisis dengan kaedah "unweighted pair-group method average" (UPGMA) menggunakan Minitab versi 16.1.1. Analisis kelompok menunjukkan bahawa *Coptotermes* genus yang diperiksa dibahagikan kepada dua kelompok utama di mana setiap spesies ini telah jelas dipisahkan. Perubahan morfometrik untuk spesies masing-masing diperhatikan dan dibentangkan dalam kertas ini. Daripada kajian ini, analisis

kelompok boleh dipercayai bagi membantu mengenal pasti spesies dalam kalangan *Coptotermes*.

Kata kunci: analisis kelompok, *Coptotermes,* morfometrik, variasi morfologi, anai-anai

INTRODUCTION

The termite genus of *Coptotermes* from the family of Rhinotermitidae is an invasive pest in urban and suburban areas. The genus is very destructive to wood and wooden material in the world (Takematsu *et al*., 2000) and has wide distribution throughout Asia, Australia, Africa, and the New World. Research on this destroying pest is comprehensively studied in many countries because it can threaten infrastructure and food security and thus will affecting the human well-being and the potential of economic growth. In Peninsular Malaysia, infestation of the termite was reported on the rubber trees (*Hevea brasilliensis)* before it is considered as serious pest in early 1900. However, the species was recently reported to become an important pest to building and premises, agricultural pests such as oil palm plantation, garden landscapes (Lee, 2002) and bring damages to any cellulose materials such as books, papers, blanket, windows frame and furniture (Oshima, 1912, Yi, 1954, Chao *et al.*, 1989).

Termite taxonomy especially *Coptotermes* species is very challenging as the morphological identification of this species cannot provide robust taxonomic status. The overdependence on the soldier morphology presenting a major challenge to species identification because of the intraspecific variation in morphological characters in soldiers (Emerson, 1971; Hussender & Grace,2 001) and lack of distinguishing diagnostic features among the species of *Coptotermes* (Li *et al*, 2010) but the identification based on soldier morphology considered as a best option so far compared to alates due to

seasonal occurrences that prevent simultaneous collection and description of this caste (Jones *et al.,* 2005; Yang & Li, 2012).

Recently, the identification of the species is not solely depending on the morphology diagnostic features. Normal classical identification procedure as practised by experienced zoologist in the field, may still encounter some misidentification problem (Sazali *et al.,* 2008). Therefore, by using statistical analysis which combined with morphological data, rapid assessment and evaluation of the species can be done in more reliable and convincing way.

The morphological variation of selected *Coptotermes* species presented in this paper aim to assess the morphological variation between species of the genus particularly in soldier caste aided with cluster analysis. Morphological analysis is very important for identification of the species and assessing genetic variability (Manzoor and Akhtar., 2006, Manzoor, 2009; Noor and Nashir Uddin, 2010, Singham *et al,* 2016). The study will provide a baseline information to taxonomic of this species in terms of intercolonial variation in the soldier caste.

MATERIALS AND METHOD

Morphology

The photographs of the soldiers were taken using a Motic SMZ-16B Series stereomicroscope attached to a Moticam 2000 camera and then the image sequences were combined with Helicon Focus 6 software. Calibrated measurements were taken by using Motic Image Plus 2.0 software.

Total of 123 individuals of soldiers from four *Coptotermes* species namely, *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* (Table 1) from selected areas in western part of Sarawak were microscopically examined and identified. The following 17 morphometric characters were

measured; (1) total length (TL) (2) total length without head (TLH) (3) length of head at base of mandibles (TLM) (4) length to fontanelle (LF) (5) maximum width of head (WH) (6) width of head at base of mandibles (WHM) (7) length of antennae, segment 1 (AL1) (8) width of antennae, segment 1 (WA1) (9) length of antennae, segment 2 (AL2) (10) width of antennae, segment 2 (AW2) (11) length of labrum (LLb) (12) width of labrum (WLb) (13) width of pronotum (WPr) (14) length of pronotum (LPr) (15) maximum width of postmentum (MWPt) (16) minimum width of postmentum (MWPt) (17) length of postmentum (LPt). Indices: (1) Body index (WH/TL) (2) head index (WH/WHM) (3) pronotum index (WPr/LPr)

Statistical Analysis

The data recorded were subjected to statistical analysis for mean, standard deviation, coefficient of variability and analysis of variance (Model I ANOVA). The Turker Kramer analysis and cluster analysis was made latter by using Euclidean distance of unweighted pair-group method average (UPGMA) method in Minitab version 16.0. A probability of $p < 0.015$ was considered significant in all analysis.

RESULTS

A total of four *Coptotermes* species, *C. curvignathus* (40 individuals), *C. sepangensis* (47 individuals), *C. kalshoveni* (20 individuals) and *C. borneensis* (16 indviduals) were found in different locations as summarised in Table 1. Ten individuals were collected and measured as a representative from each location.

Table 1 List of *Coptotermes* species collected and examined

Sample Id#	Species Name	Localities	Number of soldiers collected
CS01UNS	*C. sepangensis* (Krishna)	Secondary forest, UNIMAS	10
CC02UNS	*C. curvignathus* (Holmgren)	Secondary forest, UNIMAS	10
CK03UNS	*C. kalshoveni* (Kemner)	Secondary forest, UNIMAS	10
CK04UNS	*C. kalshoveni* (Kemner)	Secondary forest, UNIMAS	10
CS01SWS	*C. sepangensis* (Krishna)	Primary forest, Samunsam Wildlife Sanctuary	10
CS02SWS	*C. sepangensis* (Krishna)	Primary forest, Samunsam Wildlife Sanctuary	10
CS03SWS	*C. sepangensis* (Krishna)	Primary forest, Samunsam Wildlife Sanctuary	10
CB01SNP	*C. borneensis* (Oshima)	Primary forest, Santubong National Park	10
CB01KNP	*C. borneensis* (Oshima)	Primary forest, Kubah National Park	6
CS02KNP	*C. sepangensis* (Krishna)	Primary forest, Kubah National Park	7
CC01TB	*C. curvignathus* (Holmgren)	Secondary forest, Tanjung Bijat, Sri Aman	10
CC02SKA	*C. curvignathus* (Holmgren)	Sekolah Kebangsaan Abg Aing, Sri Aman	10
CC03SKA	*C. curvignathus* (Holmgren)	Sekolah Kebangsaan Abg Aing, Sri Aman	10
		Total	123

Diagnostic features examination

Comparison was made between the *Coptotermes* species based on the diagnostic features such as head capsule (Figure 1), shape of the mandibles (Figure 2), shape of pronotum (Figure 3), shape of postmentum (Figure 4) and their fontanelle (Figure 5) under various magnification.

Head capsule: As shown in Figure 1, the head capsule of *C. curvignathus* was observed to have very rounded to broadly rounded lateral margin, and most of the colour of collected specimens were generally yellow. *C. curvignathus* was noted to be distinctively different from other three *Coptotermes* species based on the head capsule. *C. sepangensis* and *C. kalshoveni* was noted to have pear-shaped head capsule and both of the species were difficult to be distinguished based on the head capsule shaped alone. *C. borneensis* was differed from *C. sepangensis* and *C. kalshoveni* where the head of soldiers is ovoid, much longer than wide.

Shape of mandibles: As shown in Figure 2, *C. curvignathus* and *C. sepangensis* have strongly curved, slender mandibles and the curvature begins at the middle of its length. The soldier's mandibles of *C. curvignathus* are distinctive in being large compared to the other mandibles of *Coptotermes* species. *C. kalshoveni* and *C. borneensis* have less curved mandibles and the curvature begins at the anterior thirds of its length.

Pronotum: As shown in Figure 3, it was difficult to distinguish between *C. kalshoveni*, *C. sepangensis* and *C. borneensis* based on the pronotum shape. The pronotum shape between *C. borneensis* and *C. kalshoveni* almost similar; lateral margin weakly convex and anterolateral corners narrowly rounded, compared to *C. sepangensis* which have strongly convex lateral margin and appeared in small pronotum size.

Postmentum: As shown in Figure 4, *C. borneensis* was noted to have different shape postmentum compared to other *Coptotermes* species; long postmentum with more than twice as long as its maximum width; posterior waist slightly less wide compared to anterior waist. *C. kalshoveni, C. sepangensis* and *C. curvignathus* was observed to have almost similar shape of pronotum yet *C. curviganthus* was the largest compared to other two *Coptotermes* species.

Fontanelle: As shown in Figure 5, *C. borneensis* observed to have distinctively small in fontanelle size compared to other three *Coptotermes* species with ovoid shape. *C. curviganthus, C. sepangensis* and *C. kalshoveni* have rounded fontanelle shape yet *C. curviganthus* have the largest size of fontanelle compared to other *Coptotermes* species.

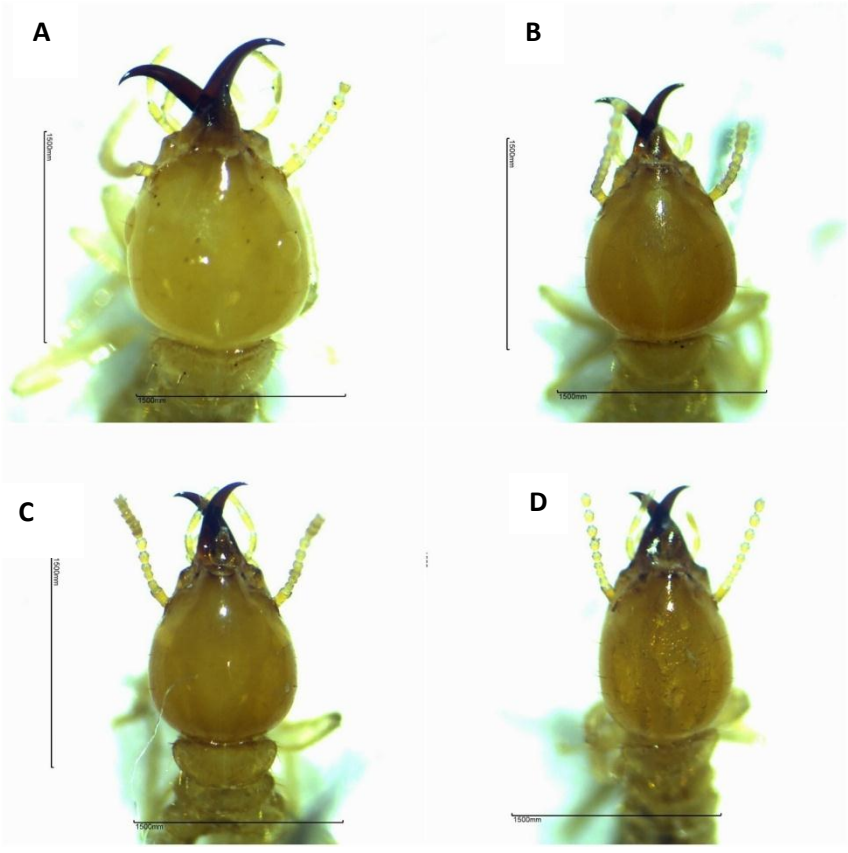

Figure 1 Dorsal view of soldier head of *Coptotermes* under 30x magnification. A. *C. curvignathus;* B. *C. sepangensis;* C. *C. kalshoveni;* D. *C. borneensis*

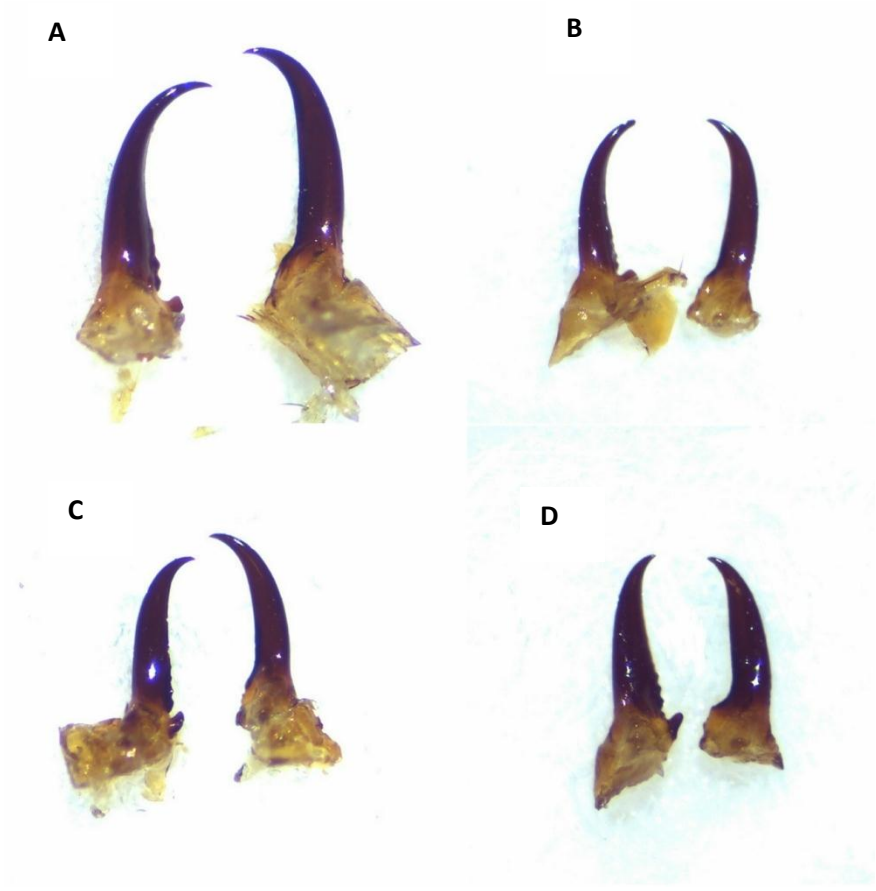

Figure 2 The shape of mandibles of *Coptotermes* under 50x magnification. A. *C. curvignathus;* B. *C. sepangensis;* C. *C. kalshoveni;* D. *C. borneensis*

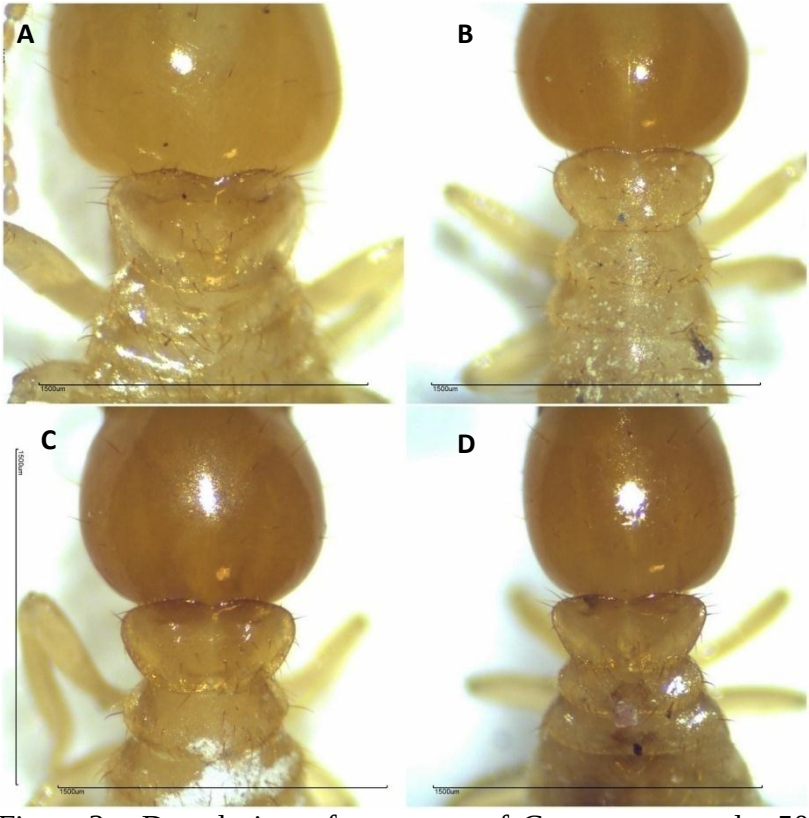

Figure 3 Dorsal view of pronotum of *Coptotermes* under 50x magnification. A. *C. curvignathus;* B. *C. sepangensis;* C. *C. kalshoveni;* D. *C. borneensis*

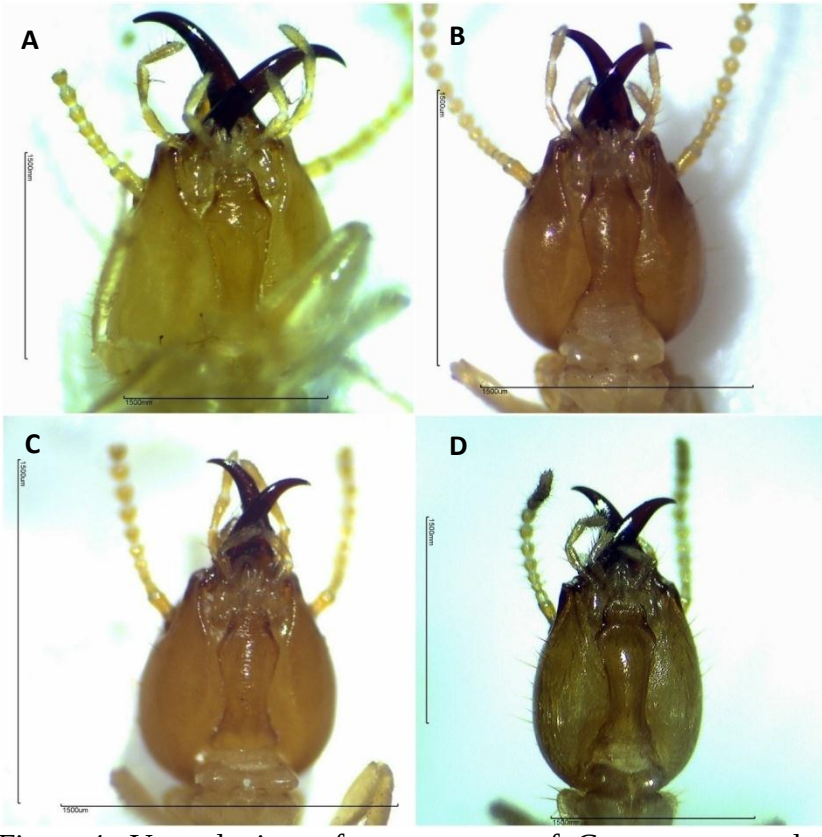

Figure 4 Ventral view of postmentum of *Coptotermes* under 40x magnification. A. *C. curvignathus;* B. *C. sepangensis;* C. *C. kalshoveni;* D. *C. borneensis*

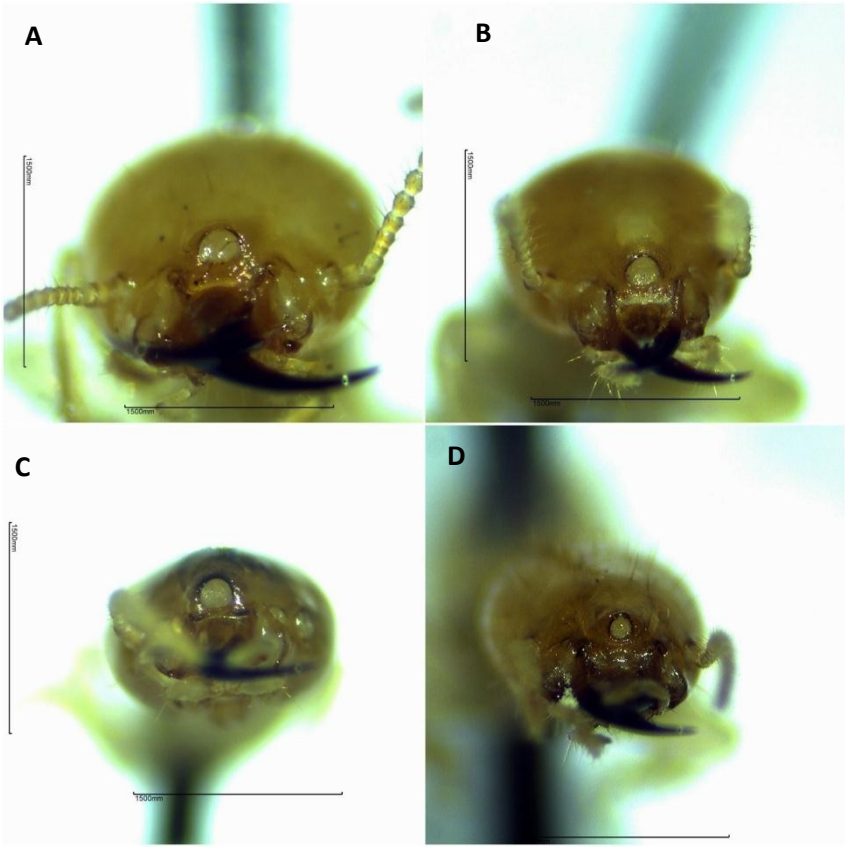

Figure 5 Anterior view of fontanelle of *Coptotermes* under 50x magnification. A. *C. curvignathus;* B. *C. sepangensis;* C. *C. kalshoveni;* D. *C. borneensis*

Morphometric variation

An overview of variation of all characteristics measured in the study was established (Table 2) with ANOVA F-statistics indicating the presence of significant difference between at least two populations. For 17 morphometric characteristics measured, statistical differences between populations were indicated. Tukey-Kramer testing of individual characteristics provided

groupings that indicate significant pairwise population differences (Table 4).

Total length: Total length varied from 2.71 to 6.45 mm. Four *Coptotermes* species, *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 5.20, 3.58, 4.18 and 3.97 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 7.51 to 11.66. Analysis of variance revealed there were significant (F: 100.9; $p<0.05$) differences among the *Coptotermes* species (Table 2). As regards to Turkey Kramer Analysis, *C. curvignathus* significantly different with *C. sepangensis, C. kalshoveni* and *C. borneensis. C. sepangensis* was non-significant with *C. kalshoveni* but significantly different with *C. borneensis*(Table 4).

Length of body without head: It varied from 1.54 to 4.10 mm. Four *Coptotermes* species, *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 3.06, 2.06, 2.67 and 2.23 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 12.46 to 16.43. Analysis of variance revealed that there were significantly differences (F=60.26; $p<0.05$) between *Coptotermes* species collected (Table 2). The Turkey Kramer Analysis showed that *C. curvignathus* was significantly different with *C. kalshoveni, C. borneensis* and *C. sepangensis. C. borneensis* was non-significant with *C. sepangensis* but significantly different with *C. kalshoveni*(Table 4).

Length of head at base of mandibles: Length of head at side base of mandibles varied from 0.79 to 1.21 mm. Four *Coptotermes* species, *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 1.50, 1.09, 1.06 and 1.18 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 4.97 to 11.46. Analysis of variance revealed that there were significantly differences

(F=147.07; $p<0.05$) between *Coptotermes* species collected (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with other three *Coptotermes* species. *C. sepangensis* was non-significant with *C. kalshoveni* but significantly different with *C. borneensis*(Table 4).

Head, length to fontanelle: Head, length to fontanelle varied from 0.96 to 1.21 mm. Four *Coptotermes* species, *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 1.34, 1.09, 1.11 and 1.16 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 3.99 to 6.82. Analysis of variance revealed that there were significantly differences (F = 107.15; $p<0.05$) between *Coptotermes* species collected (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with other three *Coptotermes* species. *C. kalshoveni* was non-significant with *C. borneensis* and *C. sepangensis* while *C. borneensis* was significantly different with *C. sepangensis*(Table 4).

Maximum width of head: Maximum width of head varied from 0.91 to 1.44 mm. *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 1.35, 1.00, 1.00, 0.95 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 2.53 to 5.62. Analysis of variance revealed that there were significantly differences (F=504.08; $p<0.05$) between the *Coptotermes* species (Table 2). The Turker Kramer Analysis revealed *C. curvignathus* significantly different with *C. sepangensis, C. kalshoveni* and *C. borneensis. C. sepangensis* was non-significant with *C. kalshoveni* but significantly different with *C. borneensis* (Table 4).

Width of head at base of mandibles: It varied from 0.22 to 0.65 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* were 0.52, 0.32, 0.32, 0.46 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 8.0 to 19.60, and was recorded the highest in *C. sepangensis*. Analysis of variance revealed that there were significantly differences ($F=86.04$; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with others *Coptotermes* species. *C. sepangensis* was non-significant with *C. kalshoveni* but significantly different with *C. borneensis* (Table 4).

Postmentum, minimum width: Minimum width of postmentum varied from 0.16 to 0.30 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* were 0.24, 0.20, 0.21 and 0.19 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 6.30 to 9.01, and was recorded highest in *C. sepangensis*. The analysis of variance revealed that there were significantly differences ($F=43.13$; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* was significantly different with *C. kalshoveni, C. sepangensis* and *C. borneensis, C. kalshoveni* was non-significant with *C. sepangensis* but significantly different with *C. borneensis* (Table 4).

Postmentum, maximum width: Maximum width of postmentum varied from 0.23 to 0.46 mm. *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* had mean values of 0.41, 0.30, 0.31 and 0.34 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 3.79 to 7.17, and was recorded highest in *C. sepangensis.* The analysis of variance showed that there were significantly differences ($F=230.1$; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus, C.*

sepangensis, C. borneensis, C. kalshoveni and *C. sepangensis* were significantly different among each other (Table 4).

Postmentum, length: Length of postmentum varied from 0.39 to 1.12 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* were 0.93, 0.63, 0.67 and 0.76 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 9.08 to 17.40, and was recorded highest in *C. kalshoveni*. The analysis of variance showed that there were significantly differences ($F=60.15$; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with *C. sepangensis, C. kalshoveni* and *C. borneensis. C. kalshoveni* was non-significant with *C. sepangensis* but significantly different with *C. borneensis* (Table 4).

Pronotum, length: Length of pronotum varied from 0.23 to 0.55 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.50, 0.34, 0.34, 0.30 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 8.8 to 11.4 and was recorded highest in *C. sepangensis.* The analysis of variance showed that there were significantly differences ($F= 189.68$; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with *C. kalshoveni, C. sepangensis* and *C. borneensis. C. kalshoveni* was non-significant with *C. sepangensis* but significantly different with *C. borneensis* (Table 4).

Pronotum, width: Width of pronotum varied from 0.46 to 1.02 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.94, 0.05, 0.07, 0.04 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 5.24 to 9.41 and was recorded highest in *C. kalshoveni.* The analysis of variance showed that there were significantly differences ($F= 233.66$; $p<0.05$) between the

Coptotermes species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with *C. kalshoveni, C. sepangensis* and *C. borneensis. C. kalshoveni*, *C. sepangensis* and *C. borneensis*was non-significant between each other (Table 4).

Labrum, width: Width of labrum varied from 0.10 to 0.48 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.05, 0.05, 0.07 and 0.03 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 14.2 to 32.4 and was recorded highest in *C. kalshoveni.* The analysis of variance showed that there were significantly differences (F= 33.93; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with *C. kalshoveni, C. sepangensis* and *C. borneensis. C. kalshoveni*, *C. sepangensis* and *C. borneensis* was non-significant between each other (Table 4).

Labrum, length: Length of labrum varied from 0.10 to 0.50 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.07, 0.05, 0.06 and 0.04 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 14.9 to 33.5 and was recorded highest in *C. kalshoveni.* The analysis of variance showed that there were significantly differences (F=65.78; $p<0.05$) between the *Coptotermes* species (Table 2). The Turkey Kramer Analysis revealed *C. curvignathus* significantly different with *C. kalshoveni, C. sepangensis* and *C. borneensis. C. kalshoveni* was non-significantwith C. *sepangensis* but significantly different with *C. borneensis* (Table 4).

Body index: Body index varied from 0.203 to 0.365 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.261, 0.284, 0.240 and 0.241 mm respectively. The coefficient of variability of four *Coptotermes*

species varied from 7.13 to 10.2 and was recorded highest in *C. sepangensis.* The analysis of variance showed that there were significantly differences (F=21.63; $p<0.05$) between the *Coptotermes* species (Table 3). The Turkey Kramer Analysis revealed *C. sepangensis* significantly different with *C. curvignathus, C. kalshoveni* and *C. borneensis*. *C. borneensis* was non-significant with *C. kalshoveni* but significantly different with *C. curvignathus* (Table 4).

Head index: Head index varied from 0.785 to 1.279 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 0.903, 0.925, 0.952 and 0.809 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 3.19 to 9.98 and was recorded highest in *C. kalshoveni.* The analysis of variance showed that there were significantly differences (F=13.22; $p<0.05$) between the *Coptotermes* species (Table 3). The Turkey Kramer Analysis revealed *C. borneensis* significantly different with *C. curvignathus, C. kalshoveni* and *C. sepangensis*. *C. curvignathus, C. kalshoveni* and *C. sepangensis* was non-significant with each other (Table 4).

Pronotum index: Pronotum index varied from 1.438 to 2.618 mm. The mean values of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis* was 1.907, 2.021, 2.036 and 2.273 mm respectively. The coefficient of variability of four *Coptotermes* species varied from 6.42 to 11.17 and was recorded highest in *C. sepangensis.* The analysis of variance showed that there were significantly differences (F=13.89; $p<0.05$) between the *Coptotermes* species (Table 3). The Turkey Kramer Analysis revealed *C. borneensis* significantly different with *C. curvignathus, C. kalshoveni* and *C. sepangensis*. *C. curvignathus, C. kalshoveni* and *C. sepangensis* was non-significant with each other (Table 4).

Table 2 Morphometric variation in taxonomic parameters of the soldier caste of *Coptotermes* species.

Morphological character	Number of		Sample measurements			Standard deviation	Coefficient of variation	ANOVA	
	Individuals	colonies	Minimum	Maximum	Mean			F statistics	P value
1. Total length									
C. curvignathus	40	4	4.07	6.45	5.203	0.508	9.760		
C. sepangensis	47	5	2.71	4.68	3.578	0.417	11.70		
C. kalshoveni	20	2	3.61	5.35	4.184	0.445	10.64	100.9	P<0.05
C. borneensis	16	2	3.44	4.66	3.971	0.298	7.510		
2. Length of body without head									
C. curvignathus	40	4	2.31	4.1	3.056	0.381	12.46		
C. sepangensis	47	5	1.54	2.84	2.064	0.317	15.35		
C. kalshoveni	20	2	2.05	3.61	2.666	0.438	16.43	60.26	P<0.05
C. borneensis	16	2	1.62	2.84	2.235	0.282	12.63		
3. Length of head at base of mandibles									
C. curvignathus	40	4	1.2	1.7	1.5	0.119	7.900		
C. sepangensis	47	5	0.79	1.21	1.091	0.083	7.630	147.07	P<0.05
C. kalshoveni	20	2	0.84	1.3	1.060	0.121	11.46		
C. borneensis	16	2	1.09	1.26	1.180	0.059	4.970		

4. Head, Length to fontanelle									
C. curvignathus	40	4	1.16	1.54	1.344	0.071	5.26		
C. sepangensis	47	5	0.98	1.5	1.094	0.075	6.82		
C. kalshoveni	20	2	0.96	1.21	1.115	0.064	5.71	107.15	P<0.05
C. borneensis	16	2	1.11	1.26	1.160	0.046	3.99		
5. Maximum width of head									
C. curvignathus	40	4	1.23	1.44	1.350	0.047	3.46		
C. sepangensis	47	5	0.93	1.13	1.004	0.051	5.07	504.08	P<0.05
C. kalshoveni	20	2	0.93	1.11	0.999	0.056	5.62		
C. borneensis	16	2	0.91	0.98	0.953	0.0241	2.53		
6. Width of head at base of mandibles									
C. curvignathus	40	4	0.29	0.65	0.519	0.073	14.05		
C. sepangensis	47	5	0.22	0.47	0.324	0.063	19.59		
C. kalshoveni	20	2	0.22	0.42	0.319	0.055	17.32	86.04	P<0.05
C. borneensis	16	2	0.37	0.5	0.463	0.037	7.99		
7. Segment I of antennae, length									
C. curvignathus	40	4	0.11	0.27	0.173	0.033	19.1		
C. sepangensis	47	5	0.07	0.2	0.142	0.027	19.26		

C. kalshoveni	20	2	0.1	0.18	0.133	0.019	14.03	13.58	P<0.05
C. borneensis	16	2	0.13	0.17	0.156	0.013	8.05		
8. Segment I of antennae, width									
C. curvignathus	40	4	0.07	0.14	0.102	0.013	12.23		
C. sepangensis	47	5	0.05	0.1	0.081	0.009	11.44		
C. kalshoveni	20	2	0.06	0.09	0.076	0.008	10.8	54.82	P<0.05
C. borneensis	16	2	0.06	0.08	0.072	0.006	9.11		
9. Segment II of antennae, length									
C. curvignathus	40	4	0.07	0.14	0.094	0.015	16.12		
C. sepangensis	47	5	0.05	0.1	0.069	0.011	15.79		
C. kalshoveni	20	2	0.04	0.09	0.072	0.011	15.35	32.88	P<0.05
C. borneensis	16	2	0.06	0.09	0.074	0.009	12.96		
10. segment II of antennae, width									
C. curvignathus	40	4	0.06	0.1	0.074	0.008	10.95		
C. sepangensis	47	5	0.04	0.09	0.056	0.010	18.32		
C. kalshoveni	20	2	0.05	0.06	0.058	0.004	7.73	43.65	P<0.05
C. borneensis	16	2	0.05	0.06	0.055	0.005	9.39		

11. Postmentum, minimum width									
C. curvignathus	40	4	0.2	0.3	0.241	0.021	8.79		
C. sepangensis	47	5	0.16	0.28	0.204	0.018	9.01		
C. kalshoveni	20	2	0.19	0.25	0.213	0.013	6.3	43.13	P<0.05
C. borneensis	16	2	0.16	0.21	0.188	0.016	8.51		
12. Postmentum, maximum width									
C. curvignathus	40	4	0.35	0.46	0.406	0.022	5.45		
C. sepangensis	47	5	0.23	0.39	0.299	0.021	7.17	230.1	P<0.05
C. kalshoveni	20	2	0.29	0.34	0.314	0.014	4.31		
C. borneensis	16	2	0.32	0.36	0.341	0.013	3.79		
13. Postmentum, length									
C. curvignathus	40	4	0.65	1.12	0.927	0.117	12.59		
C. sepangensis	47	5	0.39	0.82	0.631	0.088	13.87	60.15	P<0.05
C. kalshoveni	20	2	0.48	0.9	0.672	0.117	17.39		
C. borneensis	16	2	0.65	0.94	0.764	0.069	9.08		
14. Pronotum length									
C. curvignathus	40	4	0.34	0.55	0.495	0.044	8.8		
C. sepangensis	47	5	0.26	0.39	0.335	0.033	9.76		

C. kalshoveni	20	2	0.3	0.41	0.342	0.027	7.96	189.68	P<0.05
C. borneensis	16	2	0.23	0.35	0.304	0.035	11.4		
15. Pronotum width									
C. curvignathus	40	4	0.8	1.02	0.937	0.049	5.24		
C. sepangensis	47	5	0.46	0.76	0.672	0.047	7.06	233.66	P<0.05
C. kalshoveni	20	2	0.62	0.91	0.695	0.065	9.41		
C. borneensis	16	2	0.56	0.75	0.685	0.042	6.08		
16. Labrum, width									
C. curvignathus	40	4	0.14	0.48	0.318	0.052	16.49		
C. sepangensis	47	5	0.1	0.36	0.216	0.048	22.79	33.93	P<0.05
C. kalshoveni	20	2	0.12	0.33	0.217	0.070	32.43		
C. borneensis	16	2	0.17	0.29	0.220	0.031	14.18		
17. Labrum length									
C. curvignathus	40	4	0.24	0.5	0.363	0.069	19.09		
C. sepangensis	47	5	0.1	0.31	0.209	0.047	22.46	65.78	P<0.05
C. kalshoveni	20	2	0.11	0.33	0.190	0.064	33.48		
C. borneensis	16	2	0.22	0.38	0.288	0.043	14.89		

Table 3 Statistics for various indices used in this study for *Coptotermes* species.

Indices	Number of		Sample measurements			Standard deviation	Coefficient of variation	ANOVA	
	Individuals	colonies	Min	Max	Mean			F statistics	P value
1. Body index (BI=WH/TL)									
C. curvignathus	40	4	0.209	0.319	0.261	0.022	8.43		
C. sepangensis	47	5	0.231	0.365	0.284	0.029	10.2	21.63	P<0.05
C. kalshoveni	20	2	0.203	0.271	0.24	0.02	8.45		
C. borneensis	16	2	0.208	0.282	0.241	0.017	7.13		
2. Head index (HI=WH/WHM)									
C. curvignathus	40	4	0.826	1.083	0.903	0.056	6.23		
C. sepangensis	47	5	0.81	1.279	0.925	0.083	9.00	13.22	P<0.05
C. kalshoveni	20	2	0.785	1.128	0.952	0.095	9.98		
C. borneensis	16	2	0.77	0.853	0.809	0.026	3.19		
3. Pronotum index (PI=WPr/LPr)									
C. curvignathus	40	4	1.673	2.618	1.907	0.174	9.15		
C. sepangensis	47	5	1.438	2.615	2.021	0.226	11.17	13.89	P<0.05
C. kalshoveni	20	2	1.79	2.333	2.036	0.131	6.42		
C. borneensis	16	2	1.886	2.6	2.273	0.193	8.47		

Table 4 Turkey-Kramer multiple comparisons for morphological characteristics. Means followed by a different letter are significantly different (P<0.05; Tukey's HSD)

Morphometrical measurement	Species	N		Grouping
1. Total length	*C. curvignathus*	40	5.203	A
	C. sepangensis	47	3.577	B
	C. kalshoveni	20	4.184	B
	C. borneensis	16	3.971	C
2. Length of body without head	*C.curvigathus*	40	3.056	A
	C.kalshoveni	20	2.666	B
	C.borneensis	16	2.235	C
	C.sepangensis	47	2.064	C
3. Length of head at base of mandibles	*C. curvignathus*	40	1.5	A
	C. borneensis	16	1.179	B
	C.sepangensis	47	1.091	C
	C. kalshoveni	20	1.060	C
4. Head, Length to fontanelle	*C. curvignathus*	40	1.344	A
	C. borneensis	16	1.159	B
	C. kalshoveni	20	1.115	BC
	C.sepangensis	47	1.094	C

5. Maximum width of head	*C. curvignathus*	40	1.349	A
	C. sepangensis	47	1.004	B
	C. kalshoveni	20	0.999	B
	C. borneensis	16	0.953	C
6. Width of head at base of mandibles	*C. curvignathus*	40	0.519	A
	C. borneensis	16	0.463	B
	C.sepangensis	47	0.324	C
	C. kalshoveni	20	0.319	C
7. Segment I of antennae, length	*C. curvignathus*	40	0.173	A
	C. borneensis	16	0.156	AB
	C.sepangensis	47	0.142	B
	C. kalshoveni	20	0.133	B
8. Segment I of antennae, width	*C. curvignathus*	40	0.102	A
	C.sepangensis	37	0.081	B
	C. kalshoveni	20	0.076	BC
	C. borneensis	16	0.072	C
9. Segment II of antennae, length	*C. curvignathus*	40	0.094	A
	C. borneensis	16	0.074	B
	C. kalshoveni	20	0.072	B
	C.sepangensis	47	0.069	B

10. segment II of antennae, width	*C. curvignathus*	40	0.074	A		
	C. kalshoveni	20	0.058		B	
	C. sepangensis	47	0.056		B	
	C. borneensis	16	0.055		B	
11. Postmentum, minimum width	*C. curvignathus*	40	0.241	A		
	C. kalshoveni	20	0.213		B	
	C. sepangensis	47	0.204		B	
	C. borneensis	16	0.188			C
12. Postmentum, maximum width	*C. curvignathus*	40	0.406	A		
	C. borneensis	16	0.341		B	
	C. kalshoveni	20	0.315			C
	C.sepangensis	47	0.299			D
13. Postmentum, length	*C. curvignathus*	40	0.927	A		
	C. borneensis	16	0.764		B	
	C. kalshoveni	20	0.672			C
	C. sepangensis	37	0.631			C
14. Pronotum, length	*C. curvignathus*	40	0.044	A		
	C. kalshoveni	20	0.342		B	
	C. sepangensis	47	0.335		B	

	C. borneensis	16	0.304			C
15. Pronotum, width	*C. curvignathus*	40	0.937	A		
	C. kalshoveni	20	0.695		B	
	C. borneensis	16	0.685		B	
	C. sepangensis	47	0.672		B	
16. Labrum, width	*C. curvignathus*	40	0.318	A		
	C. borneensis	16	0.220		B	
	C. kalshoveni	20	0.217		B	
	C. sepangensis	47	0.216		B	
17. Labrum, length	*C. curvignathus*	40	0.363	A		
	C. borneensis	16	0.288		B	
	C. sepangensis	47	0.209			C
	C. kalshoveni	20	0.190			C
18. Body index (BI=WH/TL)	*C.sepangensis*	47	0.284	A		
	C. curvignathus	40	0.261		B	
	C. borneensis	16	0.241			C
	C. kalshoveni	20	0.240			C
19. Head index (HI=WH/WHM)	*C. kalshoveni*	20	0.952	A		
	C. sepangensis	47	0.925	A		
	C. curvignathus	40	0.903	A		

	C. borneensis	16	0.809	B
20. Pronotum index (PI=WPr/LPr)	*C. borneensis*	16	2.273	A
	C. kalshoveni	20	2.036	B
	C. sepangensis	47	2.021	B
	C. curvignathus	40	1.907	B

Cluster Analysis: Further comparison were made by considering all the parameters for unweighted pair-group method average (UPGMA) cluster analysis. The dendogram of two major clades were clearly separated (Figure 6). Clade1 represented all individual soldiers of *C. curvignathus.* Clade 2 represented individual soldiers of *C. curvignathus, C. sepangensis, C. kalshoveni* and *C. borneensis.*

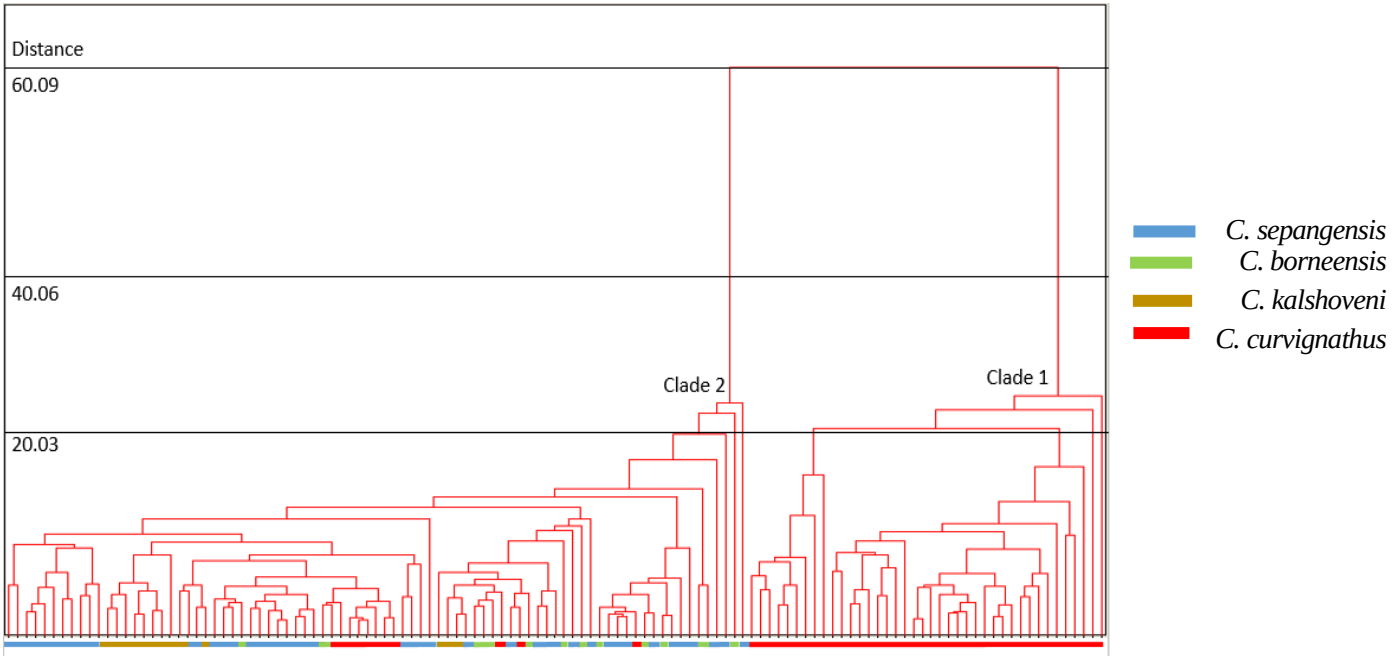

Figure 6. Dendogram of morphological relationships of *Coptotermes* species. Developed using 17 morphometric measurements and the UPGMA algorithm on standardized variables based on average linkage and squared Euclidean distances.

DISCUSSION

C. curvignathus (Holmgren) is a larger species compared to other three species of *C. sepangensis, C. kalshoveni* and *C. borneensis.C. curvignathus* can be easily distinguished from others by having the most incurved mandible, slender and saber shaped. In the dendogram (Figure 1), all the soldiers of *C. curvignathus* were fall under clade 1a with a distance of 60.09% with clade 2. It is supported by the distance value, *C. curvignathus* can be elucidate to be distinct from *C. sepangensis, C. kalshoveni* and *C. borneensis*with significant difference, $p<0.05$ based on morphological measurement and cluster analysis.The notable diagnostic features to differentiate *C. curvignathus* with other *Coptotermes* species besides the mandibles are the large and oval shaped head capsule, pronotum, postmentum and large fontanelle size.

Similarly, *C. sepangensis* (Krishna) has strong mandible with saber shaped and incurved mandible but the total body is much smaller than *C. curvignathus*. When comparison was made from three different species of *Coptotermes, C. borneensis, C. kalshoveni* and *C. sepangensis, C. sepangensis* closely resembled with *C. kalshoveni* in most of the morphological characters studied. However, when specimens of *C. borneensis* were compared, it was seen that the specimens differ from *C. sepangensis* and *C. kalshoveni* in having much longer than wide head capsule, less curved mandibles and small fontanelle.According to Thapa (1981) and Tho (1991), *C. kalshoveni* and *C. sepangensis* resemble likely each other and the only useful characters to differentiate them is the shape of mandibles where the *C. sepangensis* are strongly curved and the curvature begins at the halfway along their length, while *C. kalshoveni* curvature begins at the anterior third. These diagnostic features given by Thapa (1981) and Tho (1991) were noted from the comparison made between these two species as shown in Figure 3.

C. borneensis can be distinguish from *C. sepangensis* and *C. kalshoveni* based on the several characters. Based on the mandible features, *C. borneensis* have a nearly straight mandible and the curvature begins at the anterior third, which is almost similar with mandible of *C. kalshoveni*. The diagnostic characters which able to differentiate between *C. borneensis* and *C. kalshoveni* are the shape of head capsule, postmentum shape and the fontanelle size. As shown in Figure 2, *C. borneensis* head capsule are slightly longer than broad compared to *C. kalshoveni.* A distinct small size of fontanelle in *C. borneensis* as shown in Figure 6 may become useful distinguishing characters between *C. borneensis, C. sepangensis* and *C. kalshoveni.*The cluster analysis showed that *C. borneensis* individual's soldiers were distributed among the *C. sepangensis, C. kalshoveni* and *C. curvignathus* under clade 2 and thus make the cluster analysis of *C. borneensis* do not fully resolved. It was suggested that more extensive sampling of these specimens and more number of samples collection certainly needed to clarify these relationships.

From the Turkey Kramer analysis, *C. curvignathus* were tabulated to be significant difference with *C. sepangenis, C. kalshoveni* and *C. borneensis,* as 16 morphometric measurements were accepted to be significantly different with 94% dissimilarity between them. There were 11.8% dissimilarity equals to two morphometric measurements (length of body without head and maximum width of gula) were recorded between *C. kalshoveni* and *C. sepangensis*. *C. kalshoveni* and *C. borneensis* were observed to have 58.8% dissimilarity equals to 10 morphometric measurements which make *C. kalshoveni* are more related to *C. sepangensis. C. borneensis* are more related to *C. kalshoveni* compared to *C. sepangensis* with 64.7% dissimilarity between *C. borneensis* and *C. sepangensis.*

In terms of their morphological features, *Coptotermes* species revealed complex patterns of morphological variation especially in distinguishing *C. sepangensis*, *C. kalshoveni* and *C. borneensis*. For example, *C. borneensis*, *C. sepangensis* and *C. kalshoveni* were found in the same cluster, suggesting that they were phonetically similar. However, when the species were examined at their individual levels, they were observed to be morphologically variable. It was suggested that in terms of morphological features studied, there are some form of morphological heterogeneity which attributed to the phenotypic plasticity of the morphological characters studied and many overlapping measurements between the characters. The morphological features of *Coptotermes* species could be influenced by either ecological factors such as age and state of colony (Scheffrahn *et al.*, 2005) or by genetic differences.

CONCLUSION

From the morphometric analysis, the *Coptotermes* species particularly in soldier caste exhibited complex patterns of morphological variation. However, the cluster analysis of UPGMA constructed in this study could still reliable and convincing to use in distinguishing some species of *Coptotermes* such as *C. curvignathus*, *C. sepangensis* and *C. kalshoveni*. The great variation occurred between the *Coptotermes* species and some overlapping measurement occurred, thus required more detailed morphometric analysis such as by using Principal Component Analysis to determine which diagnostic character(s) that effectively contributes to the differentiation of these species. Furthermore, this study can be coupled with DNA sequencing analysis to provide more robust species identification.

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