https://doi.org/10.17576/serangga-2025-3003-18

MORPHOMETRIC ANALYSIS OF *Coptotermes curvignathus* IN AN OIL PALM PEAT PLANTATION

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Received: 18 July 2025; Accepted: 12 November 2025; Published: 15 December 2025

ABSTRACT

Coptotermes curvignathus Holmgren is a major subterranean termite pest in Southeast Asia oil palm (*Elaeis guineensis* Jacq.) plantations on peat soils, yet little is known about its morphological variation across different field populations. This study assessed 400 soldier termites from four sites in a peat-based oil palm plantation in Sarawak, Malaysia. Using detailed morphometric measurements including head width at mandible base, maximum head width, left mandible length, and head length, we explored inter-site differences using MANOVA, ANOVA, and Principal Component Analysis (PCA). Significant variation was found in head width, maximum head width, and head length, across sites ($P<0.05$), while mandible length remained consistent ($P>0.05$). PCA confirmed that most morphological variation was size-related and site-specific, with some sites showing broader internal variability and others forming compact clusters. Comparisons with data from previous studies revealed in agreement with reference values although some with reduced trait sizes, likely reflecting environmental constraints, colony age, or local adaptation. These findings highlight the role of phenotypic plasticity in termite morphology and suggest that local ecological factors shape soldier traits, with implications for termite management in plantation systems.

Keywords: *Coptotermes curvignathus;* termite morphology; oil palm; phenotypic plasticity; peat soil; morphometric analysis

ABSTRAK

Coptotermes curvignathus Holmgren merupakan perosak anai-anai bawah tanah utama di ladang sawit (*Elaeis guineensis* Jacq.) di Asia Tenggara yang berasaskan tanah gambut. Namun, variasi morfologi spesies ini di antara populasi lapangan masih kurang diketahui. Kajian ini menilai 400 sampel anai-anai kasta askar dari empat tapak berbeza dalam ladang sawit tanah gambut di Sarawak, Malaysia. Kajian ini menggunakan ukuran morfometrik terperinci iaitu lebar kepala di pangkal mandibula, lebar maksimum kepala, panjang mandibula kiri, dan panjang kepala untuk menilai perbezaan antara tapak. Analisis statistik seperti MANOVA, ANOVA, dan Analisis Komponen Utama (PCA) telah digunakan. Variasi signifikan ditemui bagi lebar kepala, lebar maksimum kepala, dan panjang kepala di antara tapak, manakala panjang mandibula kekal konsisten. PCA mengesahkan bahawa kebanyakan variasi morfologi berkait rapat dengan saiz dan spesifik mengikut tapak, dengan sesetengah tapak menunjukkan variasi dalaman yang tinggi manakala yang lain membentuk kelompok padat. Perbandingan dengan data kajian terdahulu menunjukkan keselarasan dengan nilai rujukan, meskipun terdapat pengecilan saiz bagi beberapa ciri, yang berkemungkinan mencerminkan kekangan persekitaran, usia koloni, atau penyesuaian tempatan. Penemuan ini menonjolkan peranan kepelbagaian fenotipik dalam morfologi anai-anai dan mencadangkan bahawa faktor ekologi setempat membentuk ciri-ciri askar, dengan implikasi penting dalam pengurusan anai-anai di sistem perladangan.

Kata kunci: *Coptotermes curvignathus;* morfologi anai-anai; kelapa sawit; keplastikan fenotip; tanah gambut; analisis morfometrik

INTRODUCTION

The oil palm (*Elaeis guineensis* Jacq.) industry plays a critical role in the global economy, driven largely by the rising demand for palm oil in food, cosmetic, and biofuel industries (Chin et al. 2013; Keng et al. 2009; Mba et al. 2015). In many tropical regions, oil palm cultivation has expanded into peatland areas (Koh et al. 2011). Oil palm peat plantations, however, are often subject to a range of biotic stresses, among which termite infestations, specifically *Coptotermes curvignathus* Holmgren*,* are particularly problematic (Kon et al. 2012).

Coptotermes curvignathus is a highly destructive subterranean termite species recognised as a major pest in agricultural and urban environments (Kalshoven 1963; Kirton et al. 1999; Lee 2002). In Malaysia, it poses a significant threat to plantation crops, particularly oil palms, rubber trees, and various hardwoods (Kalshoven 1963; Lee 2002), leading to extensive economic losses due to structural damage (Ghaly & Edwards 2011) and reduced crop yields (Lenz et al. 2000). This species is known for its aggressive foraging behaviour and large colony size, primarily attacking living trees by feeding on inner tissues and compromising their structural integrity (Masijan et al. 2012). In oil palm ecosystems, their feeding behaviour can lead to significant damage by disrupting the apical meristem at the base of the spear of a young palm or damage the trunk of a mature palm (Cheng et al. 2008). Despite the economic and ecological implications of termite infestations, there remains a notable gap in the reports concerning the morphometric analysis of the species of termites infesting plantation estates.

Morphological analysis has traditionally served as a cornerstone in insect taxonomy, offering a cost-effective and reliable method for species identification through the examination of external traits such as body size, mandible configuration, and wing structures (Snodgrass 1935). In the context of oil palm peat plantations, morphological methods provide an accessible means to distinguish among termite species that may appear similar at first glance. By applying detailed morphometric analysis, researchers cannot only accurately identify the predominant termite species but also monitor potential variations that may arise among different colonies such as polymorphism and phenotypic plasticity. For example, a morphometric study of four *Coptotermes* species from western Sarawak showed that key soldier traits still overlapped among species and explicitly recommended the use of Principal Component Analysis to identify the most informative diagnostic characters for reliable separation (Norsyarizan & Wan Nurainie 2016).

The primary aim of this study was to investigate the morphometric variations of *C. curvignathus* collected from several different sites in an oil palm peat plantation. By analysing the morphological characteristics of this economically important termite species, the study enhanced termite identification and support more precise targeting of pest control measures. Improved identification of *C. curvignathus* can help reduce the economic losses associated with termite damage while promoting the sustainable management of oil palm plantations. Moreover, this study will contribute to the broader scientific understanding of *C. curvignathus* ecology in peatland environments, an area that has received relatively little attention compared to other agricultural landscape.

MATERIALS AND METHODS

Study Site

The study was carried out at Palmcol 1 Estate, Palmgroup Holdings Sdn Bhd, Sibu, Sarawak (2°49'30.50" N, 112°37'28.44" E) (Figure 1). Palmcol 1 Estate is entirely covered by deep peat soils of the Anderson 3 series, with peat depths exceeding 250 cm. It is a first-generation oil palm plantation established on land converted from a logged-over peat swamp forest (Palmcol 1 EIA 2006). The annual rainfall recorded in the estate was 2,915.25 mm in 2022 and 2,718.37 mm in 2023, classifying the area as wet. The plantation, situated on deep peat, maintains a water table approximately 50–75 cm below the peat surface, although it can rise during periods of heavy rainfall. The plantation is managed in five phases, covering a total area of 4,732.55 hectares of oil palm. This study was conducted in Phase 4, Block E7 of Palmcol 1 Estate, which comprised of mature 14-year-old palms. Owing to the inherent characteristics of peat soil, termite infestations have been reported throughout the plantation since its establishment.

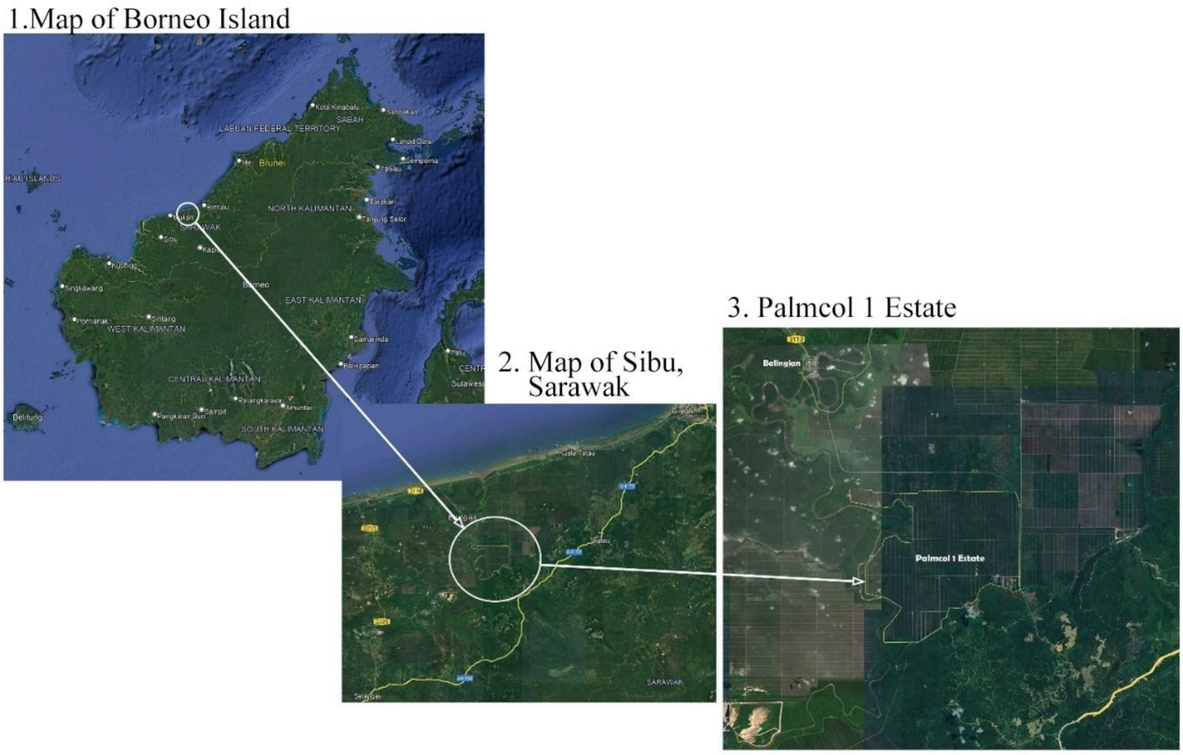

Figure 1. Palmcol 1 Estate location in Sibu, Sarawak, Malaysia

The sampling for this study was conducted in four distinct sites. The distance between sampling site ranges from 100m (Site 1 & Site 2) to 400m (Site 1 & Site 4). Each site consists of 134 planting rows, with each row containing 14 oil palms, resulting in a total of 1,876 palms per site. Figure 2 shows the aerial view of the sites. The GPS coordinates for each site are as follows: Site 1 (S1) at 2°49'31.6"N, 112°35'28.1"E; Site 2 (S2) at 2°49'31.3"N, 112°35'24.2"E; Site 3 (S3) at 2°49'31.6"N, 112°35'19.0"E; and Site 4 (S4) at 2°49'31.4"N, 112°35'08.2"E.

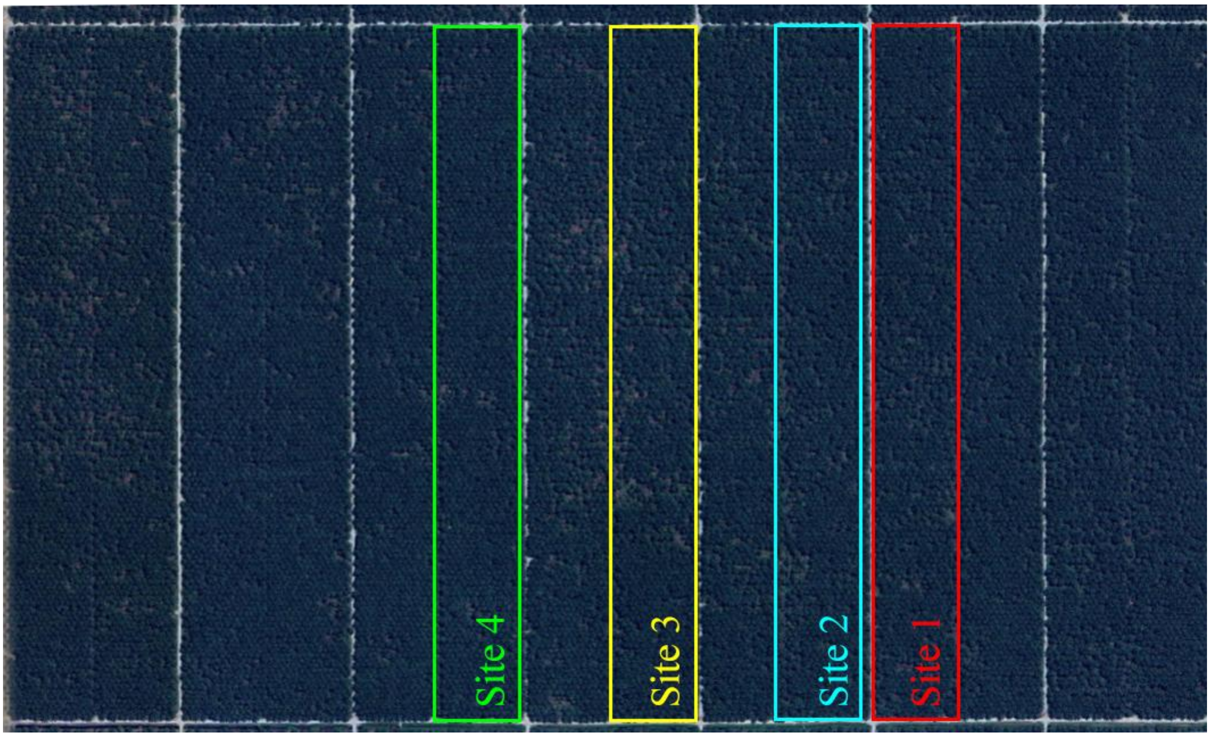

Figure 2. Aerial view of termite sampling location according to sub-blocks

Sampling Procedure

In the field, every palm in each site was thoroughly inspected for termite activity using a metal bar, a tool for effective scraping of the oil palm frond bud. This method ensured that termites were detected on each individual palm. When termite activity was observed, soldier termites were collected from that palm, with a minimum of 10 soldier specimens obtained per occurrence. A total of 10 colonies from infested palms were selected per site. The collected termites were immediately preserved in universal bottles (28ml) containing 95% ethanol. While all palms were inspected and those with termite infestations were identified and sampled, 10 bottle samples per site were randomly selected for further morphological analysis in the Microscopy Laboratory at Universiti Sains Malaysia (USM). A total of 400 soldier termites (10 termites per sample × 10 samples per site × 4 sites) were analysed.

Identification and Morphological Analysis of Termites

Morphological identification was carried out using the identification key developed by Lee (2003). The process began by examining soldier termites for the presence of mandibles which is a critical diagnostic trait. Next, the soldier's head was evaluated, with an oval-shaped head emerging as a key characteristic in this study. In addition, when disturbed, the soldiers were observed to produce latex, a secretion unique to *Coptotermes* species soldiers as indicated by the key. Additionally, a subset of specimens was sent to a private laboratory for molecular identification of the species. This molecular analysis focused on sequencing the partial 16S ribosomal RNA gene, a reliable marker for species-level identification in termites.

A systematic protocol was implemented based on the methodology outlined by Tho and Kirton (Tho 1992). Measurements were taken for the termite head capsule and mandible as they are primarily used for species identification because it is heavily sclerotised (Bourguignon & Roisin 2011) and morphologically stable. In contrast, other soft body part, such as the thorax and abdomen is more prone to change with nutrition and preservation shrinkage (Marquina et al. 2021). A total of 400 termite specimens were measured (10 termites per sample x 10 samples per site x 4 sites). The head of each termite was carefully excised using a sterilised razor blade to ensure a clean cut for accurate measurement. The isolated heads were then arranged in a petri dish and examined under a motorised stereo microscope (Olympus SZX16). Under the microscope, detailed measurements were taken for each specimen, such as (1) the head width at the base of the mandibles, (2) the length of the left mandible, (3) the maximum width of the head, and (4) the head length to the base of the mandibles (Figure 3).

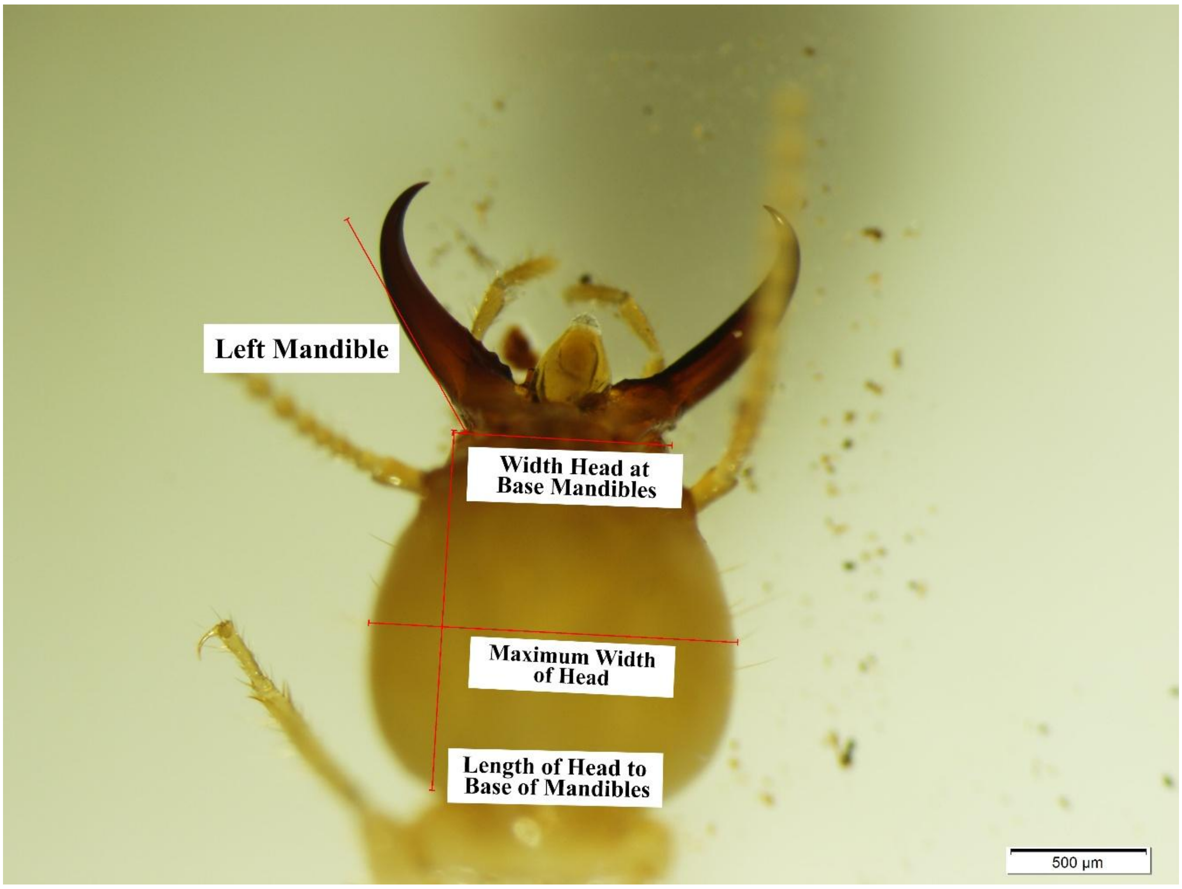

Figure 3. Head of *Coptotermes curvignathus* with labelled morphology

Data Analysis

The morphometric data collected from termite soldiers were statistically analysed using IBM Statistical Package for Social Sciences (SPSS) for Windows, Version 28.0. To evaluate overall morphological differences among termite soldier populations from the four sites (Site 1 to Site 4), a Multivariate Analysis of Variance (MANOVA) including Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root were performed. Subsequently, univariate Analyses of Variance (ANOVA) were conducted for each morphological trait individually to determine their specific contribution to the observed overall variation. In cases where significant differences were detected (*P<0.05*), Tukey post-hoc test was applied to identify statistically significant pairwise differences between site groups.

In addition to inferential statistics, exploratory data visualisation was employed to assess trait distribution and variability using box plots. Box plots were generated for each trait across the four site groups to visually present the median, interquartile range (IQR), and potential outliers. In order to explore the structure of the variation and reveal patterns of morphological clustering, Principal Component Analysis (PCA) was performed. PCA score plots, loading biplots and convex hull plots were generated to visualize the clustering of sites and the contributions of individual traits to the principal components. All data visualizations, including box plots and PCA outputs were constructed using Python programming language with the support from scientific libraries such as Matplotlib, Seaborn, and Scikit-learn (Garreta & Moncecchi 2013; Hunter 2007; Jolliffe 2002; Mckinney 2010; Virtanen et al. 2020; Waskom 2021).

RESULTS AND DISCUSSION

Morphological Variation Across Sampling Sites

Morphological analysis of the soldier caste specimens revealed key diagnostic traits consistent with the genus *Coptotermes*, based on presence of mandibles, an oval-shaped head, and secretion of white latex from the frontal gland. These features are characteristic identifiers of *Coptotermes* soldiers. To complement the morphological assessment, molecular identification through sequencing of a partial mitochondrial 16S ribosomal RNA gene, validated the identification and confirmed the species as *C. curvignathus*. This species is a dominant and economically significant subterranean termite in oil palm plantations on peat soils in Southeast Asia (Lim & Silek 2001; Sudharto et al. 1991; Tho 1992).

A total of 400 soldier termites of *C. curvignathus* were analysed from four distinct sites (Site 1 – Site 4), with 100 individuals per location (site), representing 10 infested palms per site. Four morphological traits were measured: (1) head width at the base of the mandibles, (2) left mandible length, (3) maximum head width, and (4) length from the head to the mandible base. The summarised mean and range for those traits across all four sites, with overall mean and reference values from Tho (1992) are presented in Table 1. Comparison was generally in agreement with the reference values reported by Tho (1992), although with several notable differences.–While head width measurements from the current study populations (mean: 0.73 mm) were comparable to the reference value (0.71 mm), and maximum head width (1.24 mm), which was slightly lower than Tho's mean of 1.34 mm. However, traits such as the length of the head to the base of the mandibles (mean: 1.39 mm vs. 1.68 mm) were markedly reduced. These reductions are unlikely to indicate taxonomic distinctions, but rather reflect potential environmental constraints, colony developmental stages, or localised adaptations to varying ecological conditions (Deligne 1999; Eggleton 2011; Miura 2005). Length of the left mandible was not compared to Tho (1992) despite being used to compare cross species between *Coptotermes* species especially on size and curvature (Loong et al. 2020; Wikantyoso et al. 2021). Due to its diagnostic relevance, it was included as a variable in this study.

Multivariate analysis (MANOVA) offered mixed outcomes. Roy's Largest Root identified a significant multivariate effect of site, while other statistics such as Wilks' Lambda, Hotelling-Lawley's Trace and Pillai's Trace were non-significant (*P>0.05*). Follow-up univariate ANOVAs provided clarity by indicating significant differences in traits like head width at the mandible base, maximum head width, and head-to-mandible length. Notably, left mandible length did not differ significantly across sites, suggesting that this trait may be conserved under stabilizing selection, maintaining its functional role in soldier defense regardless of environmental variability (Eggleton 2011).

These statistical trends were visually reinforced by the boxplots in Figure 4, which provide an intuitive overview of variation and distribution across the four sites. Termites from Site 1 and Site 4 consistently exhibited the highest median values for all measured traits, with narrow interquartile ranges (IQRs), indicating morphological uniformity possibly reflective of mature colonies. Site 2, in contrast, showed the smallest medians and wider IQRs in some traits, highlighting smaller, more variable individuals which suggesting either early developmental stage or nutritional limitations. For instance, head width in Site 1 had a median of 0.82 mm (tight IQR), while Site 2 had the lowest at 0.67 mm and showed broader spread. Similarly, maximum head width and head-to-mandible length patterns echoed this gradient, where S1 > S4 > S3 > S2 in terms of median values. Interestingly, although minor differences were observed in left mandible length, the narrow range of medians across all sites and overlapping IQRs were in agreement with the ANOVA result showing no significant inter-site difference.

The boxplot data complement the descriptive summary in Table 1, wherein Site 1 soldiers also showed the largest trait means followed by Site 4, and Site 2 the smallest. Tukey's HSD post hoc tests confirmed statistically distinct groupings among sites, particularly for head width and head length, aligning with the visual dispersion seen in the boxplots. Moreover, Site 3 consistently displayed the widest IQRs and more outliers across traits, pointing to heightened intra-site variation. This suggests potential colony heterogeneity, perhaps due to mixed-age cohorts or polymorphic soldier morphotypes (Chouvenc & Su 2014).

In summary, both statistical and visual analyses converge to show clear geographic structuring in soldier morphology, with Site 1 and Site 4 likely harbouring more mature or better-nourished colonies due to their larger median trait, and Site 2 representing smaller and more uniform individuals. These patterns are likely shaped by interacting factors such as colony age, resource availability, and local environmental pressures like soil and microclimate (Miura 2005; Zukowski & Su 2020). Such variation may have adaptive implications for defence strategies and ecological resilience in *C. curvignathus* populations.

Table 1 Mean and range of soldier morphological measurements (mm) in *Coptotermes curvignathus* across four sites, with overall mean and reference values from Tho (1992)

Site	**Width Head Base Mandibles (mm)±SE**		**Length of Left Mandibles (mm)±SE**		**Maximum Width of Head (mm)±SE**		**Length of Head to Base of Mandible (mm)±SE**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Site 1 (n =100; 10 colonies)	0.78±0.03a	0.59-0.84	0.97±0.03a	0.75-1.07	1.36±0.05a	1.05-1.48	1.47±0.05a	1.12-1.60
Site 2 (n = 100; 10 colonies)	0.66±0.03b	0.53-0.80	0.83±0.03a	0.69-1.00	1.11±0.05b	0.99-1.46	1.26±0.05b	1.05-1.54
Site 3 (n = 100; 10 colonies)	0.73±0.02ab	0.65-0.82	0.89±0.03a	0.80-1.02	1.21±0.06ab	1.00-1.41	1.38±0.04ab	1.21-1.53
Site 4 (n = 100; 10 colonies)	0.76±0.02a	0.57-0.81	0.94±0.06a	0.42-1.06	1.30±0.06 ab	0.93-1.42	1.43±0.06ab	1.04-1.58
F value	4.315	-	2.325	-	3.985	-	3.496	-
P value	0.011		0.091		0.015		0.025	
Mean of four sites	0.73±0.03	0.53-0.84	0.91±0.03	0.42-1.07	1.24±0.05	0.93-1.48	1.39±0.05	1.04-1.60
Tho (1992)	0.71	0.65-0.82	-	-	1.34	1.28-1.57	1.68	1.51-1.85

Means in columns with same letter are not significantly different ($P>0.05$) according to Tukey's test.

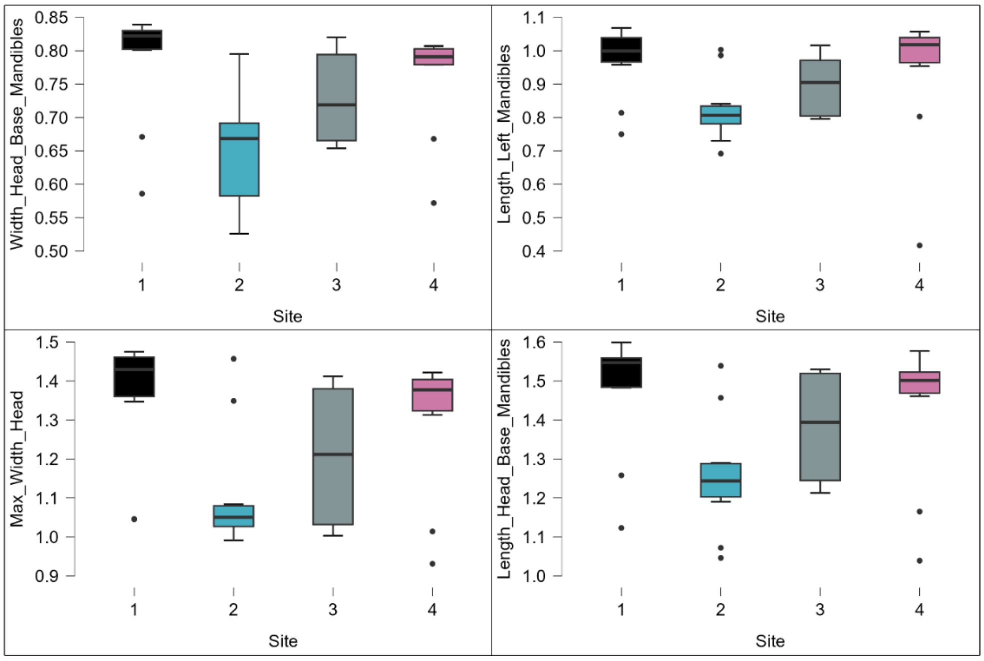

Figure 4. Box plot of morphological trait variations in *Coptotermes curvignathus* soldiers across site

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was conducted to explore the main patterns of morphological variation among *C. curvignathus*. The analysis aimed to reduce dimensionality and highlight the traits contributing most to inter-site differentiation. PC1 accounted for a dominant 94.86% of the total variance, while PC2 explained 2.57%, cumulatively capturing 97.43% of overall morphological variation (Figures 4–6). This confirms that the bulk of trait variability is concentrated along PC1, reflecting strong structuring within the dataset (Figure 5).

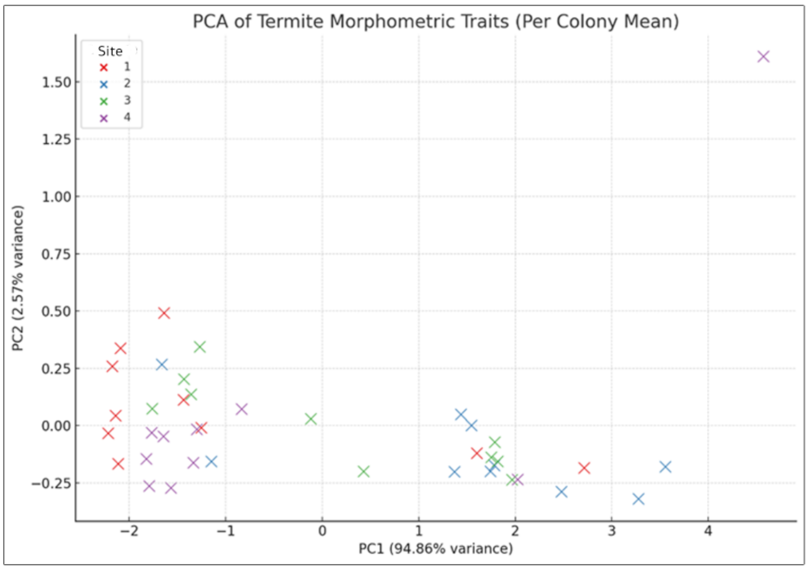

Figure 5. PCA score plot of termite soldier morphometric data across four sites

Loading vectors indicated that PC1 was primarily driven by size-related head traits, including head width and head length, whereas left mandible length contributed minimally aligning with ANOVA and Tukey's HSD results that found no significant inter-site difference for this trait (Table 1). This suggests that mandible length is likely under stabilizing selection, while head traits are more responsive to ecological variation (Figure 6).

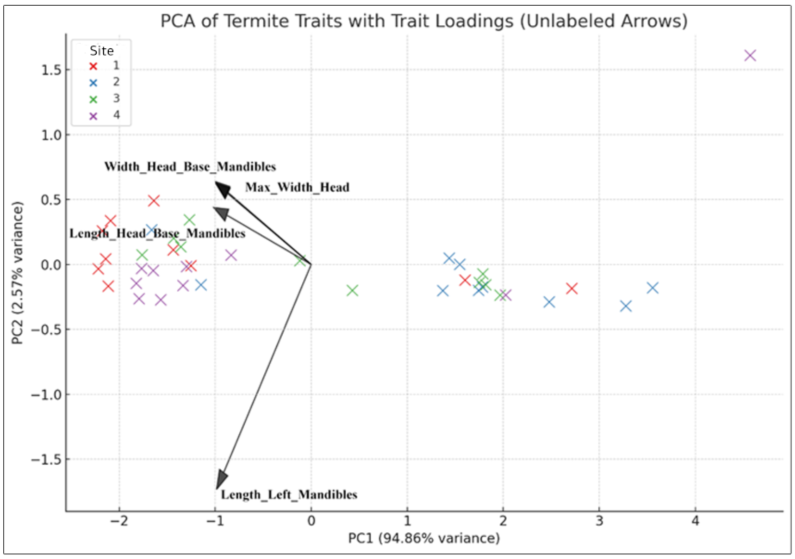

Figure 6. PCA biplot showing trait loadings of soldier morphometric characters on principal components

PCA scatterplots with convex hulls showed clear site-based clustering (Figure 7). Site 1 and Site 4 formed compact, tightly bounded groups, indicating internal morphological consistency. However, Site 4 featured a single outlier colony, reminiscent of extreme morphotypes observed in *C. gestroi* (Wikantyoso et al. 2021), hinting at the potential for site-specific extremes even within a species. In contrast, Site 3 exhibited the widest within-site variation, possibly reflecting mixed colony maturity or heterogeneous microhabitat conditions.

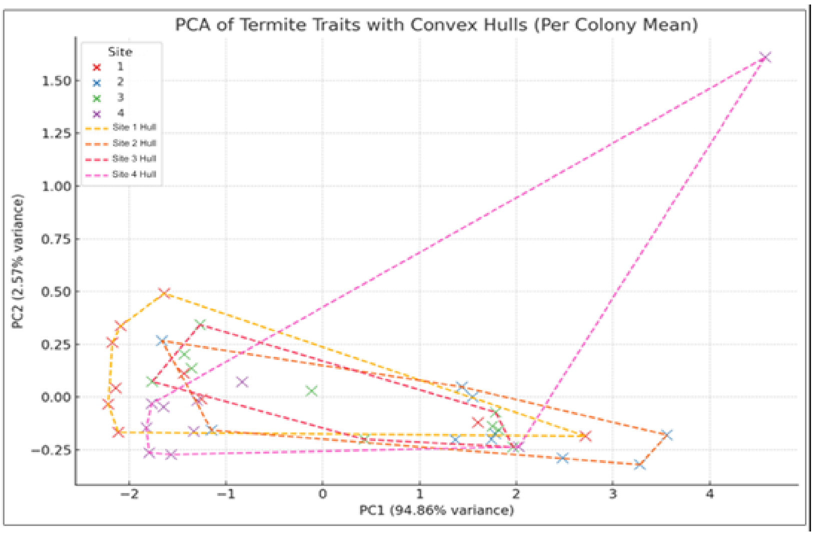

Figure 7. PCA score plot with convex hulls representing morphological variation within sites

These patterns support the hypothesis of phenotypic plasticity in *C. curvignathus*, a known adaptive trait in eusocial insects allowing caste morphology to adjust to local ecological pressures (Corona et al. 2016; Manfredini et al. 2019). Larger head traits observed in Sites 1 and 4 may reflect resource abundance or mature colony stages, enhancing defence and foraging capacity (Deligne 1999) while smaller and more variable forms in Site 2 suggest developmental or environmental constraints (Chouvenc & Su 2014).

Overall, this study affirms that termite soldier morphology is not static but responsive to environmental heterogeneity. The observed variations likely result from a combination of colony age, resource availability, and microhabitat conditions, rather than fixed genetic divergence (Slatkin 1985; Vargo & Husseneder 2011). As termites are key ecological engineers in tropical systems (De Bruyn & Conacher 1990) understanding how their morphology responds to site-specific pressures has implications not only for taxonomy and systematics but also for ecosystem function and pest management. In our study we analysed four soldier-morphology traits, which provides strong precision due to large replication but limits the dimensionality that PCA can explore; subtle shape contrasts may therefore be underrepresented. We acknowledge this as a conservative design choice and note that future work incorporating a broader trait set would likely reveal additional, biologically meaningful components while retaining our colony/site replication for robust inference. Future research incorporating genetic and behavioural analyses would be valuable to distinguish between environmentally induced plasticity and heritable morphological differentiation.

CONCLUSION

This study examined 400 *Coptotermes curvignathus* soldiers from four sites within a peat-soil oil palm plantation and found clear differences in head width, maximum head width, and head length while left mandible length remained comparatively stable. These patterns are likely shaped by a combination of local resources, microclimate, colony age, and genetic differences. Practically, this trait pattern refines *C. curvignathus* species identification by showing which measurements are most reliable for measurement and which are most informative for distinguishing local populations, reducing misidentification when specimens fall near reference limits. Better *C. curvignathus* identification can lead to improved pest control measures, potentially reduce usage of termiticide, while promoting sustainable oil palm management. To better understand what drives these morphological changes, future research should include detailed measurements of site conditions, assessments of colony age, and genetic analysis of termite populations.

ACKNOWLEDGEMENT

The authors thank Palmgroup Holdings Sdn. Bhd., particularly the management and staff of the Agronomy and Sustainability Department and Palmcol 1 Estate, Sibu, Sarawak, for their support during fieldwork and for granting permission to publish this study. We also acknowledge the School of Biological Sciences, Universiti Sains Malaysia, for providing laboratory facilities, technical support, and academic guidance.

AUTHORS DECLARATION

Funding Statement
No funding was obtained for this project.

Conflict of Interest
The authors have no conflict of interest to declare.

Data Availability Statement
Data from this study is available upon request from the corresponding author.

Authors' Contributions
HJM was involved in the study conception and design, material preparation, and data collection and analysis. EBJ was involved in material preparation, and data collection and analysis. LBK was involved in material preparation and data collection. AHAM was involved with study design and data analysis. AHA was involved in the study conception and design. HS was involved with the study conception and design and project supervision. The original draft of the manuscript was prepared by HJM and EBJ. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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