Anatomical Characteristics, Fibre Morphologies, and Densities of Six Rattan Species from Malaysia

Nordahlia Abdullah Siam, Alia Syahirah Yusoh, Asniza Mustapha, Nur Syauqina Syasya Mohd Yusoff, Azharizan Mohamad Norizan, Wan Tarmeze Wan Ariffin, and Mohd Khairun Anwar Uyup *

The anatomical characteristics, fibre morphologies, and densities were evaluated for six rattan species, *i.e.*, *Calamus manan*, *Calamus ornatus*, *Calamus ridleyanus*, *Calamus crinitus* subsp. *sabut*, *Korthalsia scortechinii*, and *Korthalsia tenuissima* from the Forest Research Institute in Malaysia. Rattan samples of about 5 to 7 cm were cut at the middle portion of the internodes of a mature stem for assessment. The results allowed differentiation between the genera *Calamus* and *Korthalsia* based on anatomical characteristics such as the type of vascular bundle, ground tissue, and the presence of the 'yellow cap.' The fundamental properties of *C. manan*, including longer fiber length, thickest fibre wall, and higher density compared to other species, signified the superior quality of this species. Based on the density result, the study of other species of rattan would also find potential for furniture, decorations, and craft purposes.

DOI: 10.15376/biores.20.1.57-69

Keywords: Rattan species; Anatomical characteristics; Fibre morphology; Density; Vascular bundle

Contact information: Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia;
**Corresponding author: mkanwar@frim.gov.my*

INTRODUCTION

Rattans, a collection of spiny and climbing palms, hold significant importance as non-timber forest products within tropical and subtropical forest ecosystems. They fall under the subfamily Calamoideae of the Arecaceae family (Dransfield 1986, 1992). Worldwide, there are approximately 22 genera and over 650 rattan species (Govaerts *et al.* 2014). Out of these, only four genera, *i.e.*, *Calamus*, *Daemonorops*, *Korthalsia*, and *Plectocomia* are commercially traded (Jiang and Peng 2007). Rattan, characterized by its long, tough, slender stems, is a versatile plant resource primarily found in tropical rainforests. It holds substantial economic value, making it a material of considerable potential in the construction industry (Akpenpuun *et al.* 2017). Malaysia stands out as one of the leading rattan producers globally, with a burgeoning rattan industry contributing significantly to the country's economic growth. Ranked second only to Indonesia in the rattan industry, Malaysia has seen robust development in this sector (Razak *et al.* 2019). Rattan cane is extensively utilized for various purposes, including furniture, ropes, decorative items, mats, housing, baskets, crafts, and construction (Yang *et al.* 2020). According to Wan Tarmeze *et al.* (2018), larger diameter rattans find application in crafting furniture, carpet beaters, and walking sticks, whereas smaller diameter ones are employed in creating mats, baskets, marine traps, animal cages, and coarse wickerwork.

Numerous studies have been conducted to examine the anatomical properties of rattan for the purpose of classification and identification (Weiner and Liese 1993; Krisdianto and Jasni 2005; Krisdianto *et al.* 2018; Dewi *et al.* 2019). Furthermore, Yu *et al.* (2023) emphasized that an examination of the anatomical characteristics of rattan, including vascular bundle diameter, vascular bundle frequency, and tissue proportion was undertaken to observe their correlation with other important properties, *i.e.*, density, shrinkage, and mechanical properties. In contrast, study on the anatomical characteristics, such as fibre morphology, is also important as an indicator to the other properties and suitability for the potential product (Xu *et al.* 2014). Fibre length and fibre wall thickness are highly related to the density and strength, where longer and thicker fibres are related to the higher density and strength (Dewi *et al.* 2019; Yang *et al.* 2020; Sheikh *et al.* 2022). Hence, a comprehensive understanding of anatomical characteristics and density is pivotal, as it has implications for other important properties and final product distinctive features.

Rattan holds significant importance as a non-timber forest product in Malaysia. Dransfield (1992) documented 106 species from 8 genera in Peninsular Malaysia, with Sabah and Sarawak reporting approximately 79 and 105 species, respectively. Despite this diversity, only about 20 species, including *C. manan*, *C. tumidus*, *C. caesius*, *C. peregrinus*, *C. scipionum*, *C. ornatus*, and *Korthalsia rigida*, are extensively used commercially in Malaysia (Abd Razak *et al.* 1995). There is a belief that numerous potential rattan species in Malaysia remain unexplored for their possible commercial applications. This is primarily because most rattan species in Malaysia lack essential data on their anatomical, physical, and mechanical properties, which are crucial indicators for determining their suitability for various applications.

Thus, the current study focuses on six rattan species, encompassing *Calamus manan*, *Calamus ornatus*, *Calamus ridleyanus*, *Calamus crinitus* subsp. *sabut*, *Korthalsia scortechinii*, and *Korthalsia tenuissima*. The objectives of the research are to investigate fundamental properties, including anatomical characteristics, fibre morphology, and density. It is hoped that these basic properties will be useful to the furniture and handicraft industry to explore suitable products from the rattan species. As stated by Razak *et al.* (2010, 2016) rattan is of great economic importance in handicraft and furniture manufacturing because it is rich in fibre, possesses suitable toughness, and is easy to work with. Additionally, the anatomical characteristics information from this present study could also aid in the identification of rattan.

MATERIALS AND METHODS

Field Sampling

Six species of Malaysian rattan, *i.e.*, *Calamus manan* (rotan manan), *Calamus ornatus* (rotan dok), *Calamus ridleyanus* (rotan kerai), *Calamus crinitus* subsp. *sabut* (rotan cincin), *Korthalsia scortechinii* (rotan dahan semut), and *Korthalsia tenuissima* (rotan dahan tikus) were obtained from Forest Research Institute Malaysia (FRIM, Kepong, Selangor, Malaysia). Rattan was identified in the field based on morphological traits, including its habits, leaves arrangement and shape, ocrea, flagella, inflorescence, knee, spine, and fruits. This identification process was conducted by trained and expert botanists to accurately identify the species for this research.

Three rattan canes from each species were selected and harvested. The rattan canes were cut at approximately 20 cm above the ground level. The upper leafy portion of each sample was removed, and samples of about 5 to 7 cm were cut at the middle portion of the internodes of a mature stem and packed in polythene bags for further processing in laboratory. Assessments on the anatomical characteristics, fibre morphology, and density were tested approximately at 12% moisture content. Moreover, anatomical study was also conducted from the outer and inner parts of the bamboo culm.

Determination of the Anatomical Characteristics, Fibre Morphology, and Density of Rattan

The anatomical characteristics were examined following the procedure outlined by Weiner and Liese (1993). Rattan sample blocks were cut into sections measuring 10 mm × 10 mm × culm wall thickness. Subsequently, these blocks were boiled in distilled water until the rattan samples softened. Sections, 25 µm in thickness, were then cut using a sledge microtome. Each section underwent staining with aqueous safranin-O, followed by washing with 50% ethanol and dehydration through a series of ethanol solutions with concentrations of 70%, 80%, 90%, and 100%. Then, the thin wood sections were cleaned twice using xylene solution, before mounting on the glass slides. Finally, a drop of Canada Balsam was applied at top each section, covered with a cover slip, and the slides were oven-dried at 60 ºC for three days.

For assessing fiber morphology, rattan samples of 10 mm × 10 mm × culm wall thickness were chipped into matchstick-sized pieces. These splits were subjected to maceration using a mixture of 30% hydrogen peroxide and glacial acetic acid (1:1 ratio) at 45 °C (Weiner and Liese 1993) for 2 to 3 h, until all lignin was dissolved, leaving the cellulose fibres appearing whitish. After thorough washing with distilled water, the cellulose fibres were retained in vials, gently agitated for proper separation. Vials, half-filled with distilled water and securely capped, were then used to spread the macerated fibres on a glass slide, adding drops of safranin-O, and covering with a cover slip.

Quantitative measurements of fibre length, vascular bundle, metaxylem, phloem, fibre and lumen diameter, and cell wall thickness were conducted from the slides using an optical microscope (Olympus Corporation, Tokyo, Japan). Vascular bundle distributions were determined by counting the number of bundles per mm² on a cross section. Fibre wall thickness was calculated by subtracting the fibre lumen diameter from the fibre diameter and dividing by two. The anatomical terminology adheres to the descriptions provided by Weiner and Liese (1988, 1990, and 1993). For all the measurements 25 readings were taken randomly.

The density was determined in accordance with BS 373 (1957). Discs approximately 20 mm thick were cut from the rattan samples. There were 20 replicates used for density determination. Samples were initially weighed on a balance with 0.001 g accuracy. Calculation used for the density is based on Eq. 1,

$$Density\ (\frac{kg}{m3}) = Wo \div Vg \qquad (1)$$

where W_o denotes oven-dry weight (kg), and V_g is green volume (m^3)

Statistical Analysis

Statistical analysis was performed using SAS software (SAS Inc., version 9.1.3, Cary, NC, USA). A one-way analysis of variance (ANOVA) was conducted to determine whether the differences in means were significant. If the differences were significant, the least significant difference (LSD) test was used to determine which of the means were significantly different from one another.

RESULTS AND DISCUSSION

Anatomical Characteristics of Rattan

The epidermis layer is one of the anatomical characteristics that could be used to distinguish plant rattan to the species, genera, and family level (Ebanyenle and Oteng-Amoako 2003; Krisdianto *et al.* 2018; Dewi *et al.* 2019). Epidermis is the outermost part of the rattan stem, consisting of unlignified parenchyma cells and covered by a siliceous layer (Weiner and Liese 1988). The thicknesses of the epidermis layer of six rattans are given in Table 1. The obtained results, indicate a significant difference in epidermal thickness among the studied species, with *C. manan* exhibiting the thickest epidermal layer of 50.8 µm. Whereas the thicknesses of *K. tenuissima*, *K. scortechinii*, *C. ridleyanus*, *C. ornatus*, and *C. crinitus* subsp. *Sabut*'s epidermis layer were 43.6, 40.0, 36.4, 34.4, and 24.0 µm, respectively. The results were comparable with previous studies by Krisdianto *et al.* (2018) and Dewi *et al.* (2019).

According to Weiner and Liese (1988) and Krisdianto *et al.* (2018), arrangement of fibre bundles in the peripheral area could also be diagnostics features in rattan identification. The fibre bundles are arranged in one layer with no specific pattern in the peripheral area observed in all six species studied (Figs 1a and 2a). This observation was similar with the finding by Krisdianto *et al.* (2018) who also found fibre bundles in the peripheral area in nine species of Indonesian rattan, which are arranged in one or two layers. However, it was contradicted with the study by Dewi *et al.* (2019) who reported there was no fibre bundle found in the peripheral zone in their study of six *Calamus* species.

The vascular bundles were embedded in the ground parenchyma. As is typical, the inner vascular bundles exhibited a greater diameter and lower frequency compared to those in the outer part of the stem (Yu *et al.* 2023). These vascular bundles comprised metaxylem, protoxylem, phloem, and fiber sheath. The variability in vascular bundle characteristics can serve as distinctive features at the species, genera, and family levels of rattan. These features encompass both quantitative and qualitative aspects. The quantitative parameters include the diameter and frequency of vascular bundles, as well as the diameters of metaxylem, protoxylem, and phloem. Additionally, the number of cells in the phloem and protoxylem within the vascular bundle can be diagnostic features for distinguishing rattan taxa (Weiner and Liese 1993; Krisdianto *et al.* 2018; Dewi *et al.* 2019).

The results of the vascular bundle, metaxylem, protoxylem, and phloem analysis are presented in Tables 1 and 2. Significantly different results were observed within the six rattan species. *C. manan* exhibited the largest vascular bundle diameter in both the outer and inner parts of the rattan stem, while having a lower vascular bundle frequency. Conversely, *C. ridleyanus* showed the smallest diameter and higher frequency of vascular bundles. Additionally, larger metaxylem was observed in *C. manan*. There was an absence of tyloses in the metaxylem of all six species studied (Table 3). Previous studies by Mathew and Bhat (1997), Renuka *et al.* (2010), Sharma *et al.* (2018), and Selim and Himu (2021) reported tyloses-like structures present in metaxylem vessels of certain rattan species, which were *C. palustris*, *K. rogersii*, *Plectocomia bractealis*, and

C. meghalayensis. The larger diameter of metaxylem and absence of tyloses as observed in this study, align with the findings of Sint *et al*. (2011), suggesting that these characteristics may contribute to the ease of treatment of the species.

Furthermore, larger protoxylem was observed in *C. ornatus* and *K. scortechinii*, while the largest diameter of phloem was found in *K. tenuissima*. The results regarding vascular bundle, metaxylem, protoxylem, and phloem diameter, as well as the vascular bundle frequency in mm^2, are consistent with previous studies by Weiner and Liese (1993) and Ebanyenle and Oteng-Amoako (2003).

In contrast, the important qualitative characteristics of the vascular bundle that could be used for the rattan identification is the vascular bundles type. As described by Weiner and Liese (1993), from the cross section of rattan, there were four types of vascular bundles that were type A (comprising one phloem field and one metaxylem vessel), type B (comprising two phloem fields and one metaxylem vessel), type C (comprising one phloem field and two metaxylem vessels), and type D (comprising two phloem fields with uniseriate and biseriate sieve tubes and one metaxylem vessel). Based on the observation of microscopic anatomical characteristics from the cross section, the six species of rattan, *i.e.*, *C. manan*, *C. ornatus*, *C. ridleyanus*, *C. crinitus* subsp. *sabut*, *K. scortechinii*, and *K. tenuissima* show the type B vascular bundle with one metaxylem and two phloem (Figs. 1b to 1e and 2b, 2c). The analysis of all six species reveals that the number of phloem cells ranges from 4 to 6 cells, and the number of protoxylem cells ranges from 3 to 5 cells (Table 2).

Another diagnostics characteristic that can distinguish the rattan taxa is the ground tissue. The ground tissue consists of isodiametric parenchyma cells with simple pits. Three forms can be distinguishing in a cross section: type A (cells are weakly branched leaving regular rounded intercellular spaces between them, “jigsaw puzzle-like”), type B (smaller, rounded cells with irregularly shaped intercellular spaces, “pebble-like”), and type C (thin-walled cells, large and round with relatively small intercellular spaces, “net-like”). Whereas, when viewed longitudinally, types A and B appear like ‘stacks of coins,’ type C shows short and elongated cells oriented perpendicularly to each other. In accordance with the findings, observation on the cross section of the genus of *Calamus*, *i.e.*, *C. manan*, *C. ornatus*, *C. ridleyanus*, and *C. crinitus* subsp. *sabut* shows the type A ground tissue (Fig. 1f). The type B ground tissue was found in the genus of *Korthalsia*, *i.e.*, *K. scortechinii* and *K. tenuissima* (Fig. 2d). All six species show ‘stacks of coins’ of ground tissue in the longitudinal section (Figs. 1g and 2e). In the longitudinal section, the ground parenchyma of all species studied contains reddish cell contents (Figs. 1g and 2e), which were described as tannins by Tomlinson (1961), Siripatanadilok (1974), and Teoh (1978). This finding was also described by Weiner and Liese (1988) in the study of genus *Calamus*, *Daemonorops*, and *Korthalsia*.

Table 1. Epidermis Layer and Vascular Bundle Characteristics of Six Rattan Species of Malaysia

Species	Local Name	Epidermis Layer (µm)	Vascular Bundle (µm)		Vascular Bundle (µm)		Vascular Bundle Frequency per mm^2	
			Outer		Inner		Outer	Inner
			Width	Length	Width	Length		
C. manan	Rotan manau	50.8^{a} (6.0)	425.2^{a} (39.7)	524.0^{a} (38.5)	654.4^{a} (53.8)	731.2^{a} (70.3)	9.0^{b} (2.0)	4.0^{c} (0.6)
C. ornatus	Rotan dok	34.4^{d} (5.8)	268.4^{c} (31.7)	334.8^{e} (43.1)	604.8^{b} (49.9)	677.2^{c} (58.3)	12.0^{a} (1.7)	5.0^{c} (0.6)
C. ridleyanus	Rotan kerai	36.4^{d} (4.9)	240.8^{e} (37.6)	308.8^{f} (40.5)	486.8^{d} (54.9)	586.0^{d} (62.7)	14.0^{a} (2.0)	5.0^{c} (0.7)
C. crinitus subsp. *sabut*	Rotan cincin	24.0^{e} (4.3)	254.4^{d} (35.5)	353.6^{d} (50.1)	388.4^{f} (40.4)	498.0^{f} (51.1)	13.0^{a} (1.2)	9.0^{a} (0.8)
K. scortechinii	Rotan dahan semut	40.0^{c} (6.0)	352.8^{b} (31.8)	488.8^{b} (35.1)	408.0^{e} (55.5)	517.6^{e} (65.0)	10.0^{b} (1.2)	7.0^{b} (0.6)
K. tenuissima	Rotan dahan tikus	43.6^{b} (4.8)	350.0^{b} (34.5)	465.2^{c} (43.2)	573.0^{c} (47.1)	700.8^{b} (61.8)	10.0^{b} (1.2)	5.0^{c} (1.0)

Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05

Table 2. Metaxylem, Protoxylem, and Phloem Characteristics of Six Rattan Species of Malaysia

Species	Metaxylem Diameter (µm)		Protoxylem Diameter (µm)		No. of Protoxylem Cells	Phloem Diameter (µm)		No. of Phloem Strand per Vascular Bundle	No. of Phloem Cells per Strand
	Outer	Inner	Outer	Inner		Outer	Inner		
C. manan	200.4^{a} (25.6)	353.2^{a} (30.8)	36.0^{a} (8.6)	51.2^{c} (8.8)	4.0^{a} (1.6)	22.8^{e} (6.8)	32.0^{e} (7.1)	2.0^{a} (0.0)	5.0^{a} (1.0)
C. ornatus	170.8^{c} (25.3)	344.4^{a} (34.1)	34.4^{b} (6.5)	59.2^{a} (7.6)	5.0^{a} (1.6)	25.6^{d} (9.0)	40.4^{c} (7.5)	2.0^{a} (0.0)	6.0^{a} (1.4)
C. ridleyanus	167.6^{c} (31.5)	336.4^{a} (34.5)	32.0^{c} (6.7)	47.6^{d} (8.8)	3.0^{a} (0.6)	28.8^{c} (9.7)	31.2^{e} (7.1)	2.0^{a} (0.0)	4.0^{a} (1.1)
C. crinitus subsp. *sabut*	119.2^{d} (23.5)	214.8^{c} (29.0)	29.2^{d} (8.6)	47.2^{d} (9.5)	4.0^{a} (0.7)	29.2^{c} (8.6)	33.6^{d} (4.9)	2.0^{a} (0.0)	4.0^{a} (0.7)
K. scortechinii	182.0^{b} (31.1)	297.6^{b} (31.6)	37.2^{a} (9.8)	57.6^{b} (8.1)	3.0^{a} (0.9)	34.0^{b} (6.5)	42.0^{b} (6.4)	2.0^{a} (0.0)	4.0^{a} (0.9)
K. tenuissima	120.0^{d} (28.8)	306.0^{b} (28.4)	30.4^{d} (6.4)	50.0^{c} (8.9)	4.0^{a} (1.0)	36.0^{a} (8.7)	48.4^{a} (6.9)	2.0^{a} (0.0)	5.0^{a} (0.6)

Values in parentheses are standard deviations; cell values differing by a letter in the superscript in each column are significantly different at 0.05

The rattan fibre sheath is found on the vascular bundle, and it is formed as a 'horse-shoe' shape in all six species studied (Figs. 1b to 1e and 2b, 2c). As stated by Liese (1988, 1990, and 1993) the fibre sheath is normally 'horse-shoe' shaped. According to Siripatanadilok (1974) and Teoh (1978), another diagnostic feature that can distinguish the rattan taxa was the 'yellow caps'. This characteristic of 'yellow caps', *i.e.*, fibre sclereids at the outer side of the fibre sheath of the first vascular bundles below the cortex. The 'yellow caps' get their name by the striking appearance of those features. The 'yellow caps' characteristics are present in the species of the genus of *Korthalsia i.e., K. scortechinii,* and *K. tenuissima* (Fig. 2a). Whereas these characters are absent in the species of the genus *Calamus*, *i.e.*, *C. manan*, *C. ornatus*, *C. ridleyanus*, and *C. crinitus* subsp. *sabut.* The silica 'star-like' form located in the parenchyma cells (Figs. 1h and 2f) was present in all six species studied. This finding was similar to the study by Liese (1993) and Abasolo *et al.* (2001).

The presence of the silica could affect the processing of the rattan because the particles of silica have an abrasive effect on the saw teeth, producing rapid blunting of cutting edges and heating of the saw blade (Abasolo *et al.* 2001).

Based on the results obtained, the quantitative anatomical characteristics, *i.e.*, type of vascular bundle, type of ground tissue, and presence of 'yellow cap' could be diagnostic features to distinguish rattan to the genera level. This study shows that the genus of *Calamus* could be differentiated from *Korthalsia* based on the anatomical characteristics as shown in Table 3. The genus *Calamus* (Figs. 1a through h) was observed with type B vascular bundle, type A ground tissue, and absence of 'yellow cap'. Moreover, type B vascular bundle, type B ground tissue, and presence of 'yellow cap' was found in the genus of *Korthalsia* (Figs. 2a through f). The resemblances and connections identified through these anatomical characteristics align closely with the taxonomic classifications suggested by Uhl and Dransfield (1987) and Weiner and Liese (1988, 1990, and 1993).

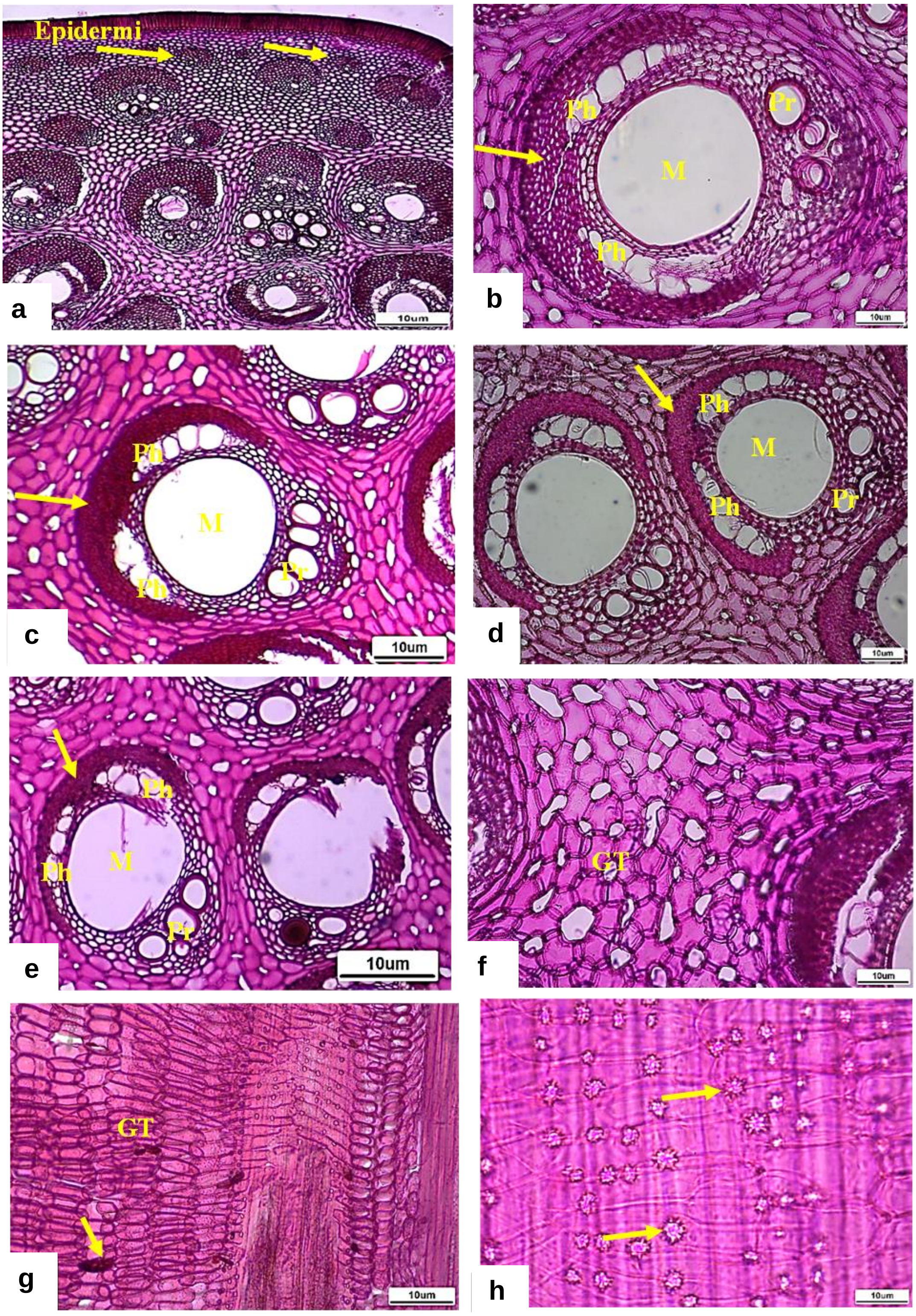

Fig. 1. Anatomical characteristics of the genus *Calamus:* a) Cross section (4x): Epidermis layer and fibre bundle (arrow); b) through e) Cross section (10x): Vascular bundle type B that consists of two phloem fields (Ph) and one metaxylem vessel (M), absence of tyloses in metaxylem, Protoxylem (Pr) and fibre sheath 'horse-shoe' shaped (arrow); f) Cross section (10x): Type A ground tissue "jigsaw puzzle-like" (GT); g) Longitudinal section (10x): Ground tissue (GT) 'stacks of coins' and reddish cell contents (arrow); and h) Longitudinal section (40x): Silica of 'star-like' form (arrow). a, b, and h: *C. manan*; c and g: *C. ornatus*; d: *C. ridleyanus*; e and f: *C. crinitus* subsp. *Sabut*; Scale bars = 10 µm

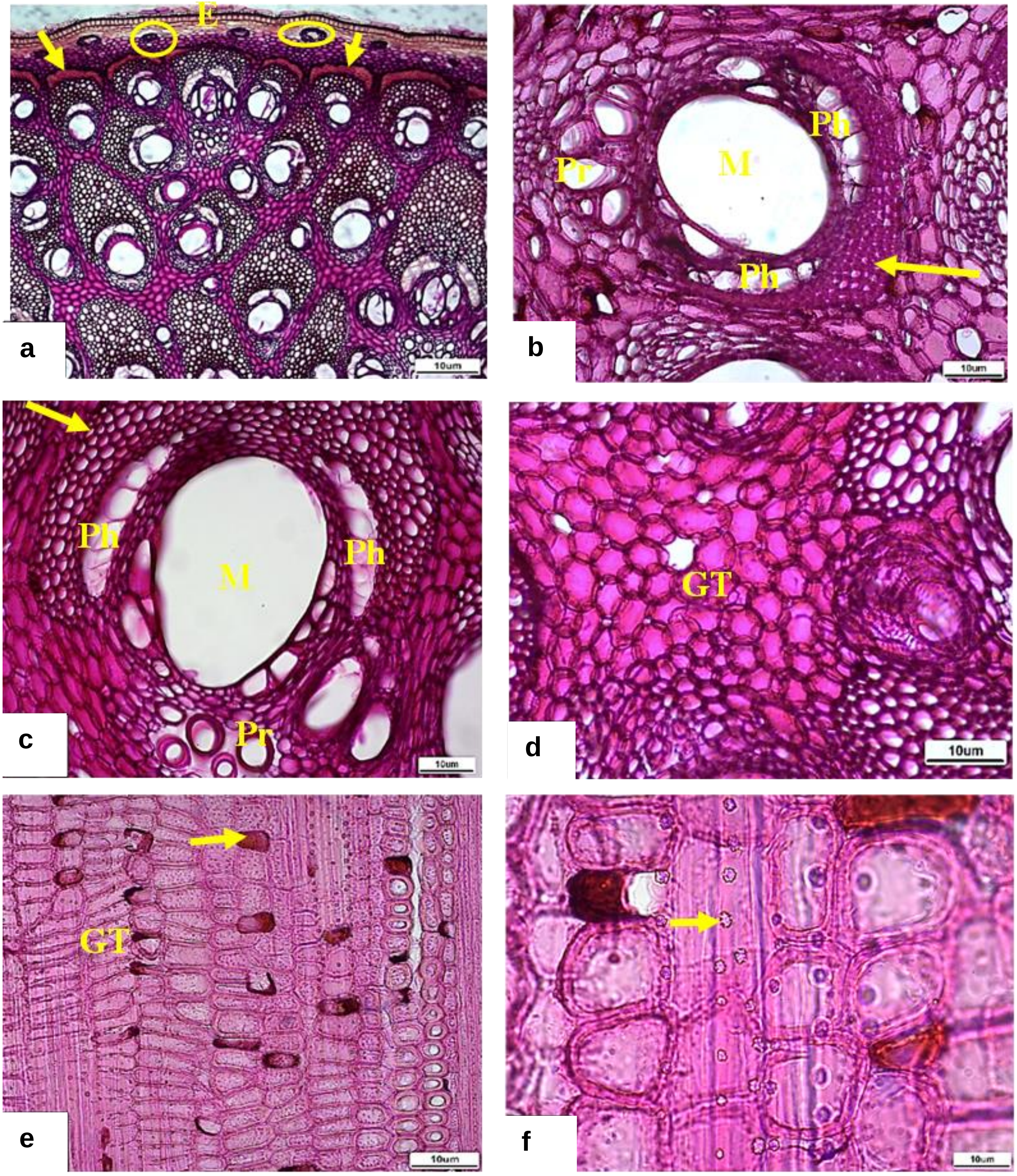

Fig. 2. Anatomical characteristics of the genus *Korthalsia*: a) Cross section (4x): Epidermis layer (E), fibre bundle (circle) and 'yellow cap' (arrow); b) and c) Cross section (10x): Vascular bundle type B that consists of two phloem fields (Ph) and one metaxylem vessel (M), absence of tyloses in metaxylem. Protoxylem (Pr) and fibre sheath 'horse-shoe' shaped (arrow); d) Cross section (10x): Type B ground tissue 'pebble-like' (GT); e) Longitudinal section (10x): Ground tissue (GT) 'stacks of coins' and reddish cell contents (arrow); f) Longitudinal section (40x): Silica of 'star-like' form (arrow); a, b, and d: *K. tenuissima*, c, e, and f: *K. scortechinii*; Scale bars = 10 µm

Table 3. Comparative Anatomical Characteristic of Six Rattan Species

Species	Type of Vascular Bundle	Tyloses	Type of Ground Tissue		Reddish Cells Contents	Presence of 'Yellow Caps'	Silica
			Cross Section	Longitudinal			
C. manan	Type B	Absent	Type A	Stacks of coins	Present	Absent	Present
C. ornatus	Type B	Absent	Type A	Stacks of coins	Present	Absent	Present
C. ridleyanus	Type B	Absent	Type A	Stacks of coins	Present	Absent	Present
C. crinitus subsp. *sabut*	Type B	Absent	Type A	Stacks of coins	Present	Absent	Present
K. scortechinii	Type B	Absent	Type B	Stacks of coins	Present	Present	Present
K. tenuissima	Type B	Absent	Type B	Stacks of coins	Present	Present	Present

Fibre Morphology and Density

Table 4 lists fibre morphology results of six rattan species, and the values are significantly different among them. Fibre length, fibre diameter, fibre lumen diameter, and fibre wall thickness of the six rattan species ranged from 1519 to 1819 µm, 18.5 to 21.8 µm, 11.1 to 12.5 µm, and 3.5 to 4.7 µm, respectively. The results of the present study were slightly lower compared to the study by Abd Razak *et al.* (1995) in which the fibre length ranged from 1340 to 2170 µm and fibre wall thickness ranged from 3.82 to 8.28 µm. Based on the classification by Wheeler *et al.* (1989), the fibre length of the six rattans is classified as medium to long, whilst the fibre wall thickness was categorized as thin- to thick-walled. As shown in Table 4, the longest and thickest fibres were observed in *C. manan*, which were 1819.0 µm and 4.7 µm, respectively. Ani and Lim (1991) reported shorter (1380 to 1570 µm) and thicker fibre (8.67 to 12.33 µm) in *C. manan* compared to this present study.

The density varied among the six rattan species, as presented in Table 4. The results indicate that the mean value for density of the six rattan species ranged from 396 to 627 kg/m^3. This finding is comparable to the study by Abd Razak *et al.* (1995) who also reported the density of five species of Malaysian rattan ranged from 330 to 610 kg/m^3. From the six species study, *C. manan* had the highest density, which were in the range 611 to 643 kg/m^3 and the mean was 627 kg/m^3. Highest density in *C. manan* could be related to the longer and thickest fibre of this species. Zhan *et al.* (2015), Dewi *et al*. (2019), Sheikh *et al*. (2022), and Yu *et al.* (2023) also stated fibre length and thickness as an important parameter to determine the rattan cane density and strengths. Based on the study by Yang *et al*. (2020) in three rattan species in China, namely *C. simplicifolius*, *C. nambariensis* var. *xishuangbannaensis*, and *C. nambariensis* var. *yingjiangensis*, the density range was 330 to 600 kg/m^3. According to Yang *et al*. (2020) the rattan cane becomes fragile when its basic density was lower than 250 kg/m^3. As presented in Table 4, the six species of rattan have higher basic density that will contribute to better flexibility. These results indicate that the six rattan species could have potential use for furniture, decorations, and craft applications.

Table 4. Fibre Morphology and Density of Six Rattan Species of Malaysia

Species	Fibre Length (µm)	Fibre Diameter (µm)	Fibre Lumen Diameter (µm)	Fibre Wall Thickness (µm)	Density (kg/m^3)
C. manan	1819.0[a] (155.1)	21.8[a] (2.5)	12.5[a] (2.8)	4.7[a] (2.0)	626.75[a] (15.98)
C. ornatus	1584.0[d] (141.1)	18.9[c] (3.0)	11.1[b] (2.6)	3.9[b] (1.9)	488.74[c] (15.86)
C. ridleyanus	1702.0[c] (200.1)	19.3[ab] (3.0)	11.3[b] (2.6)	4.0[b] (1.8)	519.97[b] (13.05)
C. crinitus subsp. *sabut*	1519.0[e] (213.5)	18.5[c] (2.8)	11.1[b] (2.1)	3.5[c] (1.6)	395.52[e] (17.23)
K. scortechinii	1734.0[b] (214.1)	19.1[ab] (2.6)	12.0[a] (2.4)	3.5[c] (1.0)	473.80[c] (12.64)
K. tenuissima	1732.0[b] (163.8)	18.5[c] (3.2)	11.5[b] (2.0)	3.8[b] (1.2)	438.31[d] (12.10)

Values in parentheses are standard deviations. Cell values differing by a superscript letter in each column are significantly different at 0.05.

CONCLUSIONS

1. The results from this study showed that both quantitative and qualitative anatomical traits could be diagnostic features for the identification of rattan species. The genus *Calamus* could be distinguished from the genus *Korthalsia* based on the anatomical characteristics such as the epidermis thickness, vascular bundle size and frequency, type of vascular bundle, ground tissue, and the presence of the 'yellow cap'.
2. Density is a crucial basic property for assessing the quality of rattan species. In this study, the basic properties of *C. manan*, including fibre length, fibre wall thickness, and density were found to be higher compared to other species, indicating its good quality. Consequently, this species is deemed suitable and preferable to produce furniture, furniture components, walking sticks, and handicrafts.
3. Furthermore, other species examined in this study exhibit better flexibility due to their favourable density values, suggesting their potential for use in furniture, decorations, and crafts.

REFERENCES CITED

Abasolo, W. P., Masato, Y., Hiroyuki, Y., and Takashi, O. (2001). "Silica in several rattan species," *Holzforschung* 55(6), 595-600. DOI: 10.1515/HF.2001.097

Abd Razak, M. A., Abd Latif, M., Khoo, K. C., and Jamaluddin, K. (1995). "Physical properties, fibre dimensions and proximate chemical analysis of Malaysia Rattan," *Thai Journal of Forestry* 14, 59-70.

Akpenpuun, T. D., Adeniran, K. A., and Okanlawon, O. M. (2017). "Rattan cane reinforced concrete slab as a component for agricultural structures," *Nigerian J. Pure Appl. Sci.* 30(1), 3007-3013. DOI: 10.19240/njpas.2017.A20

Ani, S., and Lim, S. C. (1991). “Anatomical and physical features of 11-year-old cultivated *Calamus manan* in Peninsular Malaysia,” *J. Trop. For. Sci.* 3(4), 372-379.
BS 373 (1957). “Method of testing small clear specimens of timber,” British Standard Institute, London, UK.
Dewi, A. P., Ariyanti, N. S., and Walujo, E. B. (2019). “Anatomical characteristics of six *Calamus* species of Kalimantan Barat,” *IOP Conf. Ser.- Earth Enviro. Sci.* 394, article ID 012047. DOI: 10.1088/1755-1315/394/1/012047
Dransfield, J. (1986). “A guide to collecting palms,” *Annals of the Missouri Botanical Garden* 73(1), 166-176. DOI: 10.2307/2399148
Dransfield, J. (1992). *The Rattans of Sarawak*, Lubrecht & Cramer, Limited, Port Jervis, NY, USA.
Ebanyenle, E., and Oteng-Amoako, A. (2003). “Anatomy and identification of five indigenous rattan species of Ghana,” *Ghana J. For.* 11(2), 77-90. DOI: 10.4314/gjf.v11i2.36895
Govaerts, R., Dransfield, J., Zona, S., Hodel, D. R., and Henderson, A. (2014). *World Checklist of Arecaceae,* Royal Botanic Gardens, Kew Publishing, UK.
Jiang, Z.-H., and Peng, Z.-H. (2007). *Bamboo and Rattan in the World*, China Forestry Publishing House, Beijing, China.
Krisdianto, Jasni, and Tutiana (2018). “Anatomical properties of nine indigenous rattan species of Jambi, Indonesia,” *Indon. J. For. Res.* 5(2), 147-161. DOI: 10.20886/ijfr.2018.5.2.147-161
Krisdianto, and Jasni. (2005). “Struktur anatomi tiga jenis batang rotan [Anatomical structure of three types of rattan stems],” *Jurnal Ilmu dan Teknologi Kayu Tropis [Journal of Tropical Wood Science and Technology]* 3(2), 1-8.
Mathew, A., and Bhat, K. M. (1997). “Anatomical diversity of Indian rattan palms (Calamoideae) in relation to biogeography and systematic,” *Bot. J. Linn. Soc.* 125(1), 71-86. DOI: 10.1111/j.1095-8339.1997.tb02243a.x
Razak, W., Nasihah, M., Ros Syazmini, M. G and Mohamad Saiful, S. (2019). “An overview of rattan industry status and its economic aspect in setting up rattan-based industry in Malaysia,” *Journal of Social Science and Humanities* 16(3), 1-10. ISSN: 1823-884x
Razak, W., Sulaiman, O., Mustafa, M. T., Sidek, S., and Rasat, M. S. (2016). “Chapter 4: Rattan cultivated in natural forest. Rattan: propagation, properties and utilization,” University Malaysia Kelantan Publication. Kelantan, Malaysia.
Razak, W., Othman, S. and Hashim W. S. (2010). *The Rattan Processing and Transformation Industry in Malaysia*, University Malaysia Sabah Publication. Sabah Malaysia.
Renuka, C., Bhat, K. V., and Pandalai, R. C. (2010). *Rattans of India-Taxonomy, Biology and Utilization*, Kerala Forest Research Institute, Peechi, Thrissur, Kerala, India.
Selim, M., and Himu, R. (2021). “An additional note on morphology and stem anatomy of *Calamus meghalayensis* Henderson,” *Journal of Bamboo and Rattan* 20(4), 75-80.
Sharma, M., Sharma, C. L., and Haokip, D. (2018). “Anatomical and physical characteristics of some rattan species,” *J. Indian Acad. Wood Sci.* 15(2), 132-139. DOI: 10.1007/s13196-018-0218-1
Sheikh, A. A., Reza, H., Christian, B., and Stergios, A. (2022). “Anatomical, physical, chemical and biological durability properties of two rattan species of different diameter classes,” *Forests* 13(1), article 132. DOI: 10.3390/f13010132

Sint, K. M., Militz, H., Hapla, F., and Adamopoulos, S. (2011). "Treatability and penetration indices of four lesser-used Myanmar hardwoods," *J. Wood Res.* 56(1), 13-22.

Siripatanadilok, S. (1974). *Anatomical Investigation of Javanese Rattan Canes as a Guide to Their Identification*, unpub MS Thesis, BIOTROP Faculty of Forestry, Kasetsart University, Bangkok, Thailand.

Teoh, B. W. (1978). *An Exploratory Anatomical Survey of Some Malayan Rattan*, Unpub. Ms Thesis, Department of Zoology, School of Biology Science, University of Malaya, Kuala Lumpur, Malaysia.

Tomlinson, P. B. (1961). *Anatomy of the Monocotyledons. II. Palmae*, Clarendon Press, Oxford, UK.

Wan Tarmeze, W. A., Rene, K., Muralidharan, E. M.,Sreekumar, V. B., Chowdhary, C., Sheng, L. R.,Viet, T. L., Sunderland, T., Haider, R., Tekpetey, S., Olorunnisola, A. O., Achdiawan, R., and Hourt, K. E. (2018). "Rattan terminologies," INBAR Technical Report No 39. International Bamboo and Rattan Organization (INBAR). Beijing, China.

Weiner, G., and Liese, W. (1988). "Anatomical structures and differences of rattan genera from Southeast Asia," *J. Trop. For. Sci*. 1(2), 122-132.

Weiner, G., and Liese, W. (1990). "Rattans – Stem anatomy and taxonomic implications," *IAWA Bull.* 11(1), 61-70.

Weiner, G., and Liese, W. (1993). "Generic identification key to rattan palms based on stem anatomical characters," *IAWA J.* 14(1), 55-61.

Wheeler, E. A., Baas, P., and Gasson, P. E. (1989). "IAWA list of microscopic features for hardwood identification," *IAWA Bull.* 10(3), 219-332.

Xu, B., Huangfei, L. V., and Xing'e, L. (2014). "The characteristics of vascular and fiber in *Plectocomia himalayana*," *J. Chem. Pharm. Res.* 6(6), 2801-2804.

Yang, S., Xiang, E., Shang, L., Liu, X., Tian, G., and Ma, J. (2020). "Comparison of physical and mechanical properties of four rattan species grown in China," *J. Wood Sci.* 66, article 3. DOI: 10.1186/s10086-020-1850-0

Yu, L.-P., Zhang, K.-J., Dai, F.-K., Jiang, Z.-H., Chen, Y.-X., Wang, Y.-H., and Tian, G.-L. (2023). "Variations in the vascular bundle and fiber structure during the stem development of Rattan (*Calamus caesius* Blume)," *Forests* 14(12), article 2288. DOI: 10.3390/f14122288

Zhan, H., Tang, G., Wang, C., Wang, S. (2015). "Chemical properties and fibre morphology of *Fargesia Fungosa* at different culm ages and heights," *BioResources* 10(3), 5666-5676. DOI: 10.15376/biores.10.3.5666-5676

Article submitted: July 16, 2024; Peer review completed: September 7, 2024; Revised version received: September 10, 2024; Accepted: October 7, 2024; Published: November 4, 2024.
DOI: 10.15376/biores.20.1.57-69