Wood Anatomical Features of Anacardiaceae from Malaysia

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This study examined the anatomical features of Anacardiaceae from Malaysia. A total of 31 species from 13 genera of the family Anacardiaceae in Malaysia were obtained from Kepong Xylarium (KEPw), Forest Research Institute Malaysia. The genera in Anacardiaceae were distinguished based on anatomical features. The diagnostic anatomical features that were used to separate the genera are scalariform perforations plates present in *Campnosperma*, larger rays in *Pentaspadon* and *Spondias*, and radial canals in some genera. Mineral inclusion, *i.e.*, crystals and silica also could be diagnostic features to distinguish the genera in Malaysian Anacardiaceae; silica was observed in *Gluta*, *Parishia*, and *Swintonia*. Anatomical features could be used as indicators to the other wood properties and lead to potential usage of timber in Anacardiaceae. However, the presence of druses in individual *Toxicodendron succedaneum* indicated its adaptation to the local microclimatic conditions.

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INTRODUCTION

The importance of wood anatomical studies has been demonstrated in the classification and identification of plants based on certain diagnostic characteristics (Carlquist 2001; Akinloye *et al*. 2012; Macedo *et al*. 2014; Elamin 2018). Wood is identified by examining its anatomical features to determine its species, genera, or family. It is a necessary requirement to know the exact species, genera, or family in trade, customs, construction, and scientific research to avoid disputes in pricing, taxation, strength performance, and biological characteristics (Wheeler and Baas 1998; Lim *et al*. 2016). Wood identification is also important in forensics, archaeology, and paleontology (Wheeler and Baas 1998). There are several methods used to identify wood. Observation of the cross section of the wood using a hand lens of 10x magnification is sufficient. However, for timber groups that do not have distinct features, it is necessary to observe their microscopic features. Other important physical features, including colour, density, hardness, texture, grain, figure, and odour, are also useful in wood identification (Menon *et al.* 1993; Wheeler and Baas 1998; Nordahlia and Lim 2016).

Generally, anatomical features are used as indicators of wood properties (Bowyer *et al*. 2003; Dewi and Supartini 2017; Noraini *et al*. 2019). Toong *et al*. (2014)

and Zhang *et al*. (2020) found that the anatomical features namely, vessel diameter, fibre length, fibre wall thickness, ray width, and ray height determine the properties of wood. However, Wang *et al*. (2021) stated that vessel diameter and fiber wall thickness were the key factors affecting wood density. According to Sint *et al*. (2011), medium to large vessel size, absence of tyloses, and deposit in vessels resulted in the easy treatment of the wood.

The suitability of the timbers can be predicted from the anatomical features. Hamdan *et al*. (2020) showed that timber with the thinnest fibre wall is usually related to a lower density and strength, which means that the timbers are suitable for general utility usage but not heavy-duty use. This is in line with the study by Phongkrathung *et al*. (2016) and Elamin (2018), who also reported lower density due to thin fibre wall that make the timbers of *Spondias* suitable for agricultural utensils, whilst timbers of *Lannea* are used for packaging boxes. Fibre morphology is used also as an indicator on the suitability of timber for pulp and paper products (Dewi and Supartini 2017). Adeniyi *et al*. (2013) found that the absence of tyloses and deposits made the timbers suitable for plywood.

Wood anatomy also is very important as an indication of ecological adaptation. Faheed *et al*. (2013) and Gupta *et al*. (2017) observed that crystals are an indication of the response of the plant to their habitat. Marcati and Veronica (2005) indicated that the abundance of crystals is a response to a drought habitat. Similarly, Azahana *et al*. (2020) noted that crystals in *Pandanus* are important anatomical adaptations of the plant to alkaline soils.

The Anacardiaceae consists of 80 genera and 600 species of trees, shrubs, woody climbers, and herbs occurring mostly in the tropical and subtropical regions (Dong and Baas 1993; Ogata *et al*. 2008). The wood anatomical features of Anacardiaceae were studied and described by Dadswell and Ingle (1948) and Ogata *et al*. (2008). These authors reported vessel perforations exclusively simple in most genera, but scalariform in *Campnosperma*, intervessel pits and vessel-ray pits were large in size. The rays of Anacardiaceae generally are not very large with 1 to 3 cells in width, whereas larger rays were found in the species with radial canal. Axial parenchyma in Anacardiaceae was vasicentric, aliform, and sometimes in bands. Septate fibres, radial canals, and mineral inclusion, which was crystals and silica, were observed in some genera. According to Dong and Bass (1993) the family Anacardiaceae is of considerable economic value that produces of edible fruits, gum, resins, tannins, dyes, drugs, and timbers of commercial importance. Many of the plants of this family are poisonous and cause bad skin allergies (Ogata *et al*. 2008).

The previous study on the wood anatomy of the Anacardiaceae was carried out by many researchers that covers various important scopes such as the relationship with wood properties, potential products, wood identification, wood classification and the impact on the environment (Ogata *et al*. 2008; Dong and Baas 1993; Phongkrathung *et al*. 2016; Gupta *et al*. 2017). Ogata *et al*. (2008) and Dong and Baas (1993) studied wood anatomy for the purpose of wood identification and classification in the Anacardiaceae family. Phongkrathung *et al*. (2016) reported that wood anatomy is related with other properties in the study of the genus *Spondias*. Gupta *et al*. (2017) also found that the wood anatomical features of *Mangifera* are affected by the environment. According to Wong (2019), the most notorious timbers from the family Anacardiaceae in Malaysia are *Gluta* or its Malaysian trade name is rengas. These produce highly decorative timbers. Other timbers from Anacardiaceae in Malaysia are sold as mixed species or used as general utility timbers due to a lack of information for identification and wood properties. Therefore, the aim of this study was to examine the wood anatomical features of Anacardiaceae from Malaysia. Further, this anatomical data was used for wood identification, classification, and as an indication of other important wood properties that can lead to potential and suitable utilisation of the timbers in Anacardiaceae.

EXPERIMENTAL

Studies on the wood anatomical features were carried out on 31 species from 13 genera of the family Anacardiaceae in Malaysia. The authenticated wood samples were obtained from Kepong Xylarium (KEPw), Forest Research Institute Malaysia. Selected physical features were studied, including growth rings, ripple marks (present or absent), and density. These observations were made using a hand lens with 10x magnification. The density was determined using oven-dry weight and green volume (Wong 2019).

Microscope slides were prepared, according to Schweingruber *et al*. (2006) where wooden block of 1.0 × 1.0 × 1.5 cm was taken from each species studied and boiled in distilled water until they were well soaked and sank. A sledge microtome (Reichert, Vienna, Austria) was used to cut thin sections of between 15 and 20 µm from the transverse (TS), tangential (TLS), and radial (RLS) surfaces of each block. The thin sections were immersed in 1% aqueous Safranin-O (Sigma, New Delhi, India) for several minutes and dehydrated using alcohol series with increasing concentrations: 70%, 80%, 90%, and 95% (Merck, Selangor, Malaysia) until excess stains were removed. Clear the sections in clove oil and mount in Canada balsam (Merck, Darmsladt, Germany) and left to dry in an oven at 60 °C for a few days.

For maceration (Wheeler *et al*. 1989), wood samples were split into small matchstick size pieces and transferred into a test tube containing a mixture of 30% hydrogen peroxide and glacial acetic acid at a ratio of 1:1. The test tube was then heated in a water bath at 45 °C until the sticks turned silvery white. Distilled water was used to wash the softened sticks in order to remove the excess acid. The cleaned sticks were then shaken in distilled water to break up fibres. One or two drops of Safranin-O were added into the test tubes to stain the fibres for easy observation. Microscopic observations and measurement of the wood structure were carried out using a light microscope. Descriptive terminology and measurements follow the IAWA List of Microscopic Features for Hardwood Identification (Wheeler *et al*. 1989), Menon *et al.* (1993), Ogata *et al*. (2008), and Lim *et al*. (2016). Twenty-five readings were taken randomly for each species, for all the quantitative measurements.

RESULTS AND DISCUSSION

Generic Wood Anatomical Descriptions

The images of wood anatomical features of the Anacardiaceae species are shown in Figs. 1 through 3. Wood anatomical and other selected physical features of these Anacardiaceae species are described for their identification and classification. Details of materials studied including species, specimen numbers, and locality are presented in the description. The Malaysian trade or common name of the timbers are given in parentheses.

Bouea **Meisn. (kundang)**

B. macrophylla Griff. (WT3683, WT3970, WT4468; Kelantan, Perak) and *B. oppositifolia* (Roxb.) Adelb. (WT7857, WT8117, WT8245; Johor, Terengganu, Kelantan) were examined (Fig. 1A, B, C). The wood was moderately heavy to heavy.

Ripple marks were absent. Growth rings were present and marked by terminal parenchyma bands. Wood was diffuse-porous. Vessels were solitary and in radial multiples of 2 to 3; tangential vessel diameters ranged from 180 to 250 µm and 10 to 14 vessels per mm^2. Perforation plates were simple. Intervessel pits were alternate, polygonal, and medium in size ranging from 7 to 10 µm. Vessel-ray pits were large, round, and gash-like. Tyloses were present and deposits absent. Fibres were non-septate, with simple to minutely bordered pits mainly occurring on the radial walls. Fibre length ranged from 880 to 1500 µm; thin to thick-walled. Axial parenchyma was vasicentric with irregularly spaced bands. Rays were 1 to 2 cells in width with height ranging from 700 to 1010 µm; there were heterogenous rays with procumbent and one row of upright cells. Radial canals were absent. Mineral inclusions with prismatic crystals was present in procumbent, upright ray cells and chambered axial parenchyma. Silica was absent.

Buchanania **Spreng. (otak udang)**

B. arborescens Blume (WT5961, WT5962, WT6136; Johor, Negeri Sembilan, Pahang), and *B. sessilifolia* Blume (WT4543, WT4576, WT8119, WT8167; Pulau Pinang, Selangor, Pahang, Kelantan) were examined (Fig. 1D, E, F, G). Wood is light to moderately heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary, in radial multiples of 2 to 5 or clusters, tangential vessel diameters ranged from 200 to 290 µm and 8 to 11 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 950 to 1450 µm, thin-walled. Axial parenchyma was vasicentric. Rays 1 to 3 cells in width and height ranges from 550 to 870 µm, body ray cells procumbent with one row of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with prismatic crystals was present in non-chambered axial parenchyma and fibre, two distinct sizes of crystals per cell was present in procumbent and upright ray cells. Silica was absent.

Campnosperma **Thwaites (terentang)**

C. auriculatum Hook.f. (WT2110, WT6610, WT6856, WT7380; Selangor, Perak, Terengganu, Pahang), *C. coriaceum* (Jack) Hallier f. ex Steenis (WT1577, WT3680, WT4797; Johor, Terengganu, Perak), and *C. squamatum* Ridl. (WT1633, WT3804, WT3870; Kelantan, Pahang, Perak) were examined (Fig. 1H, I, J). Wood is light to moderately heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 100 to 170 µm and 15 to 18 vessels per mm^2. Perforation plates simple and scalariform. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits absent. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1000 to 1800 µm, thin-walled. Axial parenchyma was absent. Rays 1 to 4 cells in width and height ranges from 300 to 800 µm, body ray cells procumbent with one row of upright marginal cells. Radial canals present in ray cells. Mineral inclusions which crystals and silica were absent.

Dracontomelon **Blume (sengkuang)**

D. dao (Blanco) Merr. & Rolfe (WT2160, WT3696, WT3984, WT5091; Sarawak, Kedah, Pahang, Perak) was examined (Fig. 1K, L, M). Wood is moderately heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 260 to 330 µm and 5 to 7 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 11 to 13 µm. Vessel-ray pits large, round and gash-like. Tyloses present and deposits absent. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1400 to 1900 µm, thin to thick-walled. Axial parenchyma was vasicentric and aliform. Rays 2 to 4 cells in width and height ranges from 850 to 1100 µm, body ray cells procumbent with one row rows of upright marginal cells. Radial canals absent. Mineral inclusions with prismatic crystals was present in procumbent, upright ray cells, non-chambered axial parenchyma and fibre. Silica was absent.

Gluta L. (rengas)

G. aptera (King) Ding Hou (WT1644, WT4622, WT4738; Pulau Pinang, Perak, Johor), *G. curtisii* (Oliver) Ding Hou (WT7462, WT7510, WT8174; Kedah, Johor, Selangor), *G. elegans* Kurz (WT1571, WT8247, WT8248; Pulau Pinang, Selangor, Kedah), and *G. wallichii* (Hook.f.) Ding Hou (WT1585, WT6562, WT8175; Johor, Selangor, Pahang) were examined (Fig. 1N, O, P). Wood is moderately heavy to heavy. Ripple marks absent. Growth rings present marked by irregularly spaced parenchyma bands. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 190 to 300 µm and 6 to 8 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 10–14 µm. Vessel-ray pits large, round and gash-like. Tyloses present and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 910 to 1500 µm, thin to thick-walled. Axial parenchyma was vasicentric and irregularly spaced bands. Rays 1 to 3 cells in width and height ranges from 300 to 760 µm, all ray cells procumbent, body ray cells procumbent with one row of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with crystal was absent. Silica was present in ray cells.

Koordersiodendron Engl. ex Koord. (ranggu)

K. pinnatum Merr. (WT6271, WT6474, WT6979, WT7013; Sabah) was examined (Fig. 2A, B, C). Wood is moderately heavy to heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels mainly solitary and in radial multiples of 2 to 4, tangential vessel diameters ranged from 200 to 280 µm and 10 to 14 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 11–13 µm. Vessel-ray pits large, round and gash-like. Tyloses were present but deposits were absent. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1430 to 1600 µm, thin to thick-walled. Axial parenchyma was vasicentric. Rays 2 to 3 cells in width and height ranges from 660 to 810 µm, body ray cells procumbent with 2 to 4 rows of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with prismatic crystals was present in upright ray cells, chambered upright ray cells and in enlarged cells (idioblast). Silica was absent.

Mangifera L. (machang)

M. foetida Lour. (WT2014, WT3874, WT3882; Johor, Pahang, Selangor), *M. griffithii* Hook.f. (WT3937, WT8133, WT8211; Terengganu, Negeri Sembilan, Kelantan), *M. indica* L. (WT6376, WT8147, WT8162; Melaka, Perak, Kuala Lumpur), and *M. odorata* Griff. (WT6401, WT8165; Selangor, Pahang) were examined (Fig. 2D, E, F, G). Wood is moderately heavy to heavy. Ripple marks absent. Growth rings present marked by irregularly spaced parenchyma bands. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 200 to 330 µm and 4 to 8 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 10–14 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 910 to 1250 µm, thin to thick-walled. Axial parenchyma was aliform and irregularly spaced bands. Rays 1 to 2 cells in width and height ranges from 400 to 800 µm, body ray cells procumbent with one row of upright marginal cells. Radial canals absent. Mineral inclusions with prismatic crystals were present in procumbent and upright ray cells. Silica was absent.

Melanochyla **Hook.f. (rengas)**

M. auriculata Hook.f. (WT1608, WT1629; Johor, Pahang), *M. bracteata* King (WT3634; Selangor), and *M. fulvinervia* (Blume) Ding Hou (WT1620; Kelantan) were examined (Fig. 2H, I, J). Wood is moderately heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 120 to 200 µm and 12 to 16 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses present and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1050 to 1650 µm, thin to thick-walled. Axial parenchyma was vasicentric and aliform. Rays 1 to 4 cells in width and height ranges from 400 to 760 µm, body ray cells procumbent with one row of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with prismatic crystals was present in procumbent and upright ray cells. Silica was absent.

Parishia **Hook.f. (sepul)**

P. insignis Hook.f. (WT8178, WT8180, WT9837; Kedah, Perak, Pahang), *P. maingayi* Hook.f. (WT2557, WT5680; Terengganu, Johor), and *P. paucijuga* Engl. (WT1563, WT1724, WT6817; Johor, Pahang, Selangor) were examined (Fig. 2K, L, M). Wood is light to moderately heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels mainly solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 130 to 195 µm and 13 to 15 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1314 to 1646 µm, thin-walled. Axial parenchyma was vasicentric. Rays 1 to 5 cells in width and height ranges from 500 to 800 µm, body ray cells procumbent with 2 to 4 rows of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with prismatic crystals was absent. Silica was present in ray cells.

Pentaspadon **Hook.f. (pelong)**

P. motleyi Hook.f. (WT1605, WT2461, WT6613; Terengganu, Negeri Sembilan, Johor), and *P. velutinus* Hook.f. (WT2571, WT3444, WT9812; Kelantan, Pahang, Perak) were examined (Fig. 3A, B, C). Wood is moderately heavy to heavy. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 4, tangential vessel diameters ranged from 120 to 200 µm and 12 to 15 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits present. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1263 to 1550 µm, thin to thick-walled. Axial parenchyma was vasicentric. Rays 2 to 6 cells in width and height ranges from 500 to 810 µm, body ray cells procumbent with 2 to 4 rows of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with prismatic crystals was present in procumbent and upright ray cells. Silica was absent.

Spondias L. (kedondong)

S. dulcis G. Forst. (WT7166, WT7935; Pahang, Perak) and *S. pinnata* (L.f.) Kurz (WT7934; Kedah) were examined (Fig. 3D, E). Wood is light. Ripple marks absent. Growth rings absent. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 4, tangential vessel diameters ranged from 250 to 340 µm and 5 to 8 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 11 to 14 µm. Vessel-ray pits large, round and gash-like. Tyloses and deposits absent. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1000 to 1800 µm, thin-walled. Axial parenchyma was vasicentric. Rays 2 to 6 cells in width and height ranges from 600 to 1010 µm, body ray cells procumbent with 2 to 4 rows of upright cells. Radial canals present in ray cells. Mineral inclusion which crystals and silica were absent.

Swintonia Griff. (merpauh)

S. floribunda Griff. (WT1574, WT9877, WT9980; Kedah, Johor, Selangor), *S. schwenckii* (Teijsm. & Binn.) Teijsm. & Binn. (WT5064, WT7919, WT8253; Selangor, Kelantan, Kedah), and *S. spicifera* Hook.f. (WT7295, WT7441, WT7453; Perak, Pulau Pinang, Kedah) were examined (Fig. F, G, H). Wood is moderately heavy to heavy. Ripple marks absent. Growth rings present marked by irregularly spaced parenchyma bands. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 220 to 300 µm and 4 to 7 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, large in size range of 12 to 16 µm. Vessel-ray pits large, round and gash-like. Tyloses present and deposits absent. Fibres non-septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 890-1500 µm, thin to thick-walled. Axial parenchyma was vasicentric and irregularly spaced bands. Rays 1 to 3 cells in width and height ranges from 400 to 760 µm, all ray cells procumbent, body ray cells procumbent with one row of upright marginal cells. Radial canals present in ray cells. Mineral inclusions with crystals was absent. Silica was present in ray cells.

Toxicodendron Mill.

T. succedaneum (L.) Kuntze (WT2295, WT2334, WT2418; Pahang) was examined (Fig. 3I, J, K, L, M). Wood is moderately heavy. Ripple marks absent. Growth rings indistinct, marked by fiber thickness. Wood diffuse-porous. Vessels solitary and in radial multiples of 2 to 3, tangential vessel diameters ranged from 140 to 200 µm and 12 to 15 vessels per mm^2. Perforation plates simple. Intervessel pits alternate and polygonal, medium in size range of 7 to 10 µm. Vessel-ray pits large, round and gash-like. Tyloses present and deposits absent. Fibres septate, with simple to minutely bordered pits mainly occur on the radial walls, fibre length ranged from 1230 to 1451 µm, thin to thick-walled. Axial parenchyma was vasicentric. Rays 1 to 3 cells in width and height ranges from 600 to 750 µm, body ray cells procumbent with one row of upright marginal cells. Radial canals absent. Mineral inclusions with prismatic crystals was present in procumbent and upright ray cells. Silica was absent. Note: Present of druses in one slide (WT2418) of *Toxicodendron succedaneum*. The druses were present in the procumbent and upright ray cells. Besides, chambering was also observed in the upright cells, forming 2-3 chambers, occupied by solitary druse.

Classification and Identification

Based on the results shown in Tables 1, 2, and 3, the physical and anatomical features were consistent throughout the species in the genera of Anacardiaceae from Malaysia. Therefore, the wood identification and classification in Malaysian Anacardiaceae were performed at the genera level. This is in line with Barker (2005) who also reported wood identification to species level is often difficult and frequently impossible, and is generally accurate to genera level. Table 1 tabulated the selected physical features of the species in Anacardiaceae. Genera of Anacardiaceae could be classified into two groups based on density (Table 1) which were light to moderately heavy, and moderately heavy to heavy. Light to moderately heavy with thin fibre wall was observed in *Buchanania*, *Campnosperma*, *Parishia* and *Spondias*. Other genera of Anacardiaceae can be categorised as moderately heavy to heavy with thin to thick-walled fibre.

Wood anatomical features (Tables 2 and 3) in all species of Anacardiaceae are diffuse-porous, parenchyma vasicentric, aliform, some species with banded parenchyma, medium to the large size of vessels and inter-vessels pits. Large, round and gash-like vessel-ray pits in all studied species were observed. On the other hand, all species in Anacardiaceae characterised as narrow ray which is 1-3 cells in width except large rays in *Pentaspadon* and *Spondias* which were 2 to 6 cells in width. In terms of anatomical features (Tables 2 and 3), it shows diagnostic features to distinguish between the genera of Anacardiaceae. The presence of radial canals in the rays served as the most important characteristic for the delimitation of genera in Anacardiaceae. This feature can be observed in some genera of Anacardiaceae in Malaysia, *i.e.*, *Buchanania*, *Campnosperma*, *Gluta*, *Koordersiodendron*, *Melanochyla*, *Parishia*, *Pentaspadon*, *Spondias*, and *Swintonia*. This is also confirmed by the previous study of Anacardiaceae (Pearson and Brown 1932; Menon 1971; Metcalfe and Chalk 1983; Dong and Baas 1993). The distribution of radial canals in rays among the genera of Anacardiaceae and their common occurrence in the related family of the Burseraceae suggests that they may be a primitive feature in the family which was subsequently lost several times during evolution (Dong and Baas 1993). Septate fibres could also be a diagnostic feature to distinguish the genera in Anacardiaceae, for which this feature was observed in *Campnosperma*, *Dracontomelon*, *Koordersiodendron*, *Pentaspadon*, *Spondias*, and *Toxicodendron*. A similar finding was also discussed by Menon (1971) and Ogata *et al*. (2008) in Anacardiaceae. *Campnosperma* could be easily identified from other genera in Anacardiaceae with the presence of scalariform perforation plates. The presence of this feature in *Campnosperma* was also reported by Menon (1971) and Ogata *et al*. (2008).

Table 1. Selected Physical Features of Anacardiaceae in Malaysia

Taxon	Timber trade name	Density (kg/m^3)	Classification based on density	Growth rings
Bouea	kundang	680-910	moderately heavy to heavy	present
B. macrophylla		650-880	moderately heavy to heavy	present
B. oppositifolia				
Buchanania	otak udang	465-610	light to moderately heavy	absent
B. arborescens		485-630	light to moderately heavy	absent
B. sessilifolia				

Campnosperma	terentang	425-510	light to moderately heavy	absent
C. auriculatum		375-540	light to moderately heavy	absent
C. coriaceum		452-560	light to moderately heavy	absent
C. squamatum				
Dracontomelon	sengkuang	510-710	moderately heavy	absent
D. dao				
Gluta	rengas	580-790	moderately heavy to heavy	present
G. aptera		610-820	moderately heavy to heavy	present
G. curtisii		640-950	moderately heavy to heavy	present
G. elegans		715-1010	moderately heavy to heavy	present
G. wallichii				
Koordersiodendron	ranggu	675-980	moderately heavy to heavy	absent
K. pinnatum				
Mangifera	machang	680-725	moderately heavy	present
M. foetida		652-710	moderately heavy	present
M. griffithii		700-815	moderately heavy to heavy	present
M. indica		725-860	moderately heavy to heavy	present
M. odorata				
Melanochyla	rengas	640-720	moderately heavy	absent
M. auriculata		528-610	moderately heavy	absent
M. bracteata		625-730	moderately heavy	absent
M. fulvinervia				
Parishia	sepul	512-760	light to moderately heavy	absent
P. insignis		480-685	light to moderately heavy	absent
P. maingayi		492-742	light to moderately heavy	absent
P. paucijuga				
Pentaspadon	pelong	535-580	moderately heavy	absent
P. motleyi		548-672	moderately heavy	absent
P. velutinus				
Spondias	kedondong	320-506	light	absent
S.dulcis		310-495	light	absent
S.pinnata				
Swintonia	merpauh	720-845	moderately heavy to heavy	present
S. floribunda		770-882	moderately heavy to heavy	present
S. schwenckii		680-815	moderately heavy to heavy	present
S. spicifera				
Toxicodendron	-	655-792	moderately heavy	present
T. succedaneum				

Table 2. Anatomical Features of Anacardiaceae in Malaysia: Vessels and Rays

Taxon	Vessels						Rays		
	Size µm	I-V pit size µm	V-R pit shape	P-P	T	D	Cells wide	Ray height µm	Ray CC
Bouea									
B. macrophylla	180-210	7-10	LRG	Si	+	-	1-2	850-1010	I
B. oppositifolia	200-250	8-9	LRG	Si	+	-	1-2	700-900	I
Buchanania									
B. arborescens	200-250	7-10	LRG	Si	-	-	1-2	650-850	I
B. sessilifolia	210-250	7-9	LRG	Si	-	-	2-3	550-750	I
Campnosperma									
C. auriculatum	110-160	8-10	LRG	Si,Sc	-	-	1-4	500-800	I
C. coriaceum	100-150	7-9	LRG	Si,Sc	-	-	1-4	300-600	I
C. squamatum	120-170	8-9	LRG	Si,Sc	-	-	2-4	400-700	I
Dracontomelon									
D. dao	260-330	11-13	LRG	Si	+	-	2-4	850-1100	I
Gluta									
G. aptera	190-220	11-13	LRG	Si	+	-	1-3	350-650	Pr,I
G. curtisii	210-230	10-12	LRG	Si	+	-	1-2	300-500	Pr,I
G. elegans	200-250	10-12	LRG	Si	+	-	1-2	400-760	Pr,I
G. wallichii	250-300	11-14	LRG	Si	+	-	1-3	450-750	Pr,I
Koordersiodendron									
K. pinnatum	200-280	11-13	LRG	Si	+	-	2-3	660-810	II
Mangifera									
M. foetida	210-260	10-11	LRG	Si	-	-	1-2	400-700	I
M. griffithii	270-330	11-13	LRG	Si	-	-	1-2	650-800	I
M. indica	200-260	11-14	LRG	Si	-	-	1-2	500-740	I
M. odorata	250-300	10-12	LRG	Si	-	-	1-2	500-800	I
Melanochyla									
M. auriculata	120-180	8-10	LRG	Si	+	-	1-3	400-700	I
M. bracteata	150-200	7-9	LRG	Si	+	-	1-4	450-760	I
M. fulvinervia	165-190	7-9	LRG	Si	+	-	1-4	500-750	I
Parishia									
P. insignis	130-150	7-9	LRG	Si	-	-	1-4	550-710	II
P. maingayi	145-170	7-9	LRG	Si	-	-	1-5	500-700	II
P. paucijuga	150-195	8-10	LRG	Si	-	-	1-3	650-800	II
Pentaspadon									
P. motleyi	120-160	7-8	LRG	Si	+	+	3-6	550-710	II
P. velutinus	160-200	8-10	LRG	Si	+	+	2-4	650-810	II
Spondias									
S.dulcis	250-310	11-13	LRG	Si	-	-	2-6	600-950	II
S.pinnata	280-340	12-14	LRG	Si	-	-	2-5	700-1010	II
Swintonia									
S. floribunda	220-290	12-14	LRG	Si	+	-	1-2	400-690	Pr,I
S. schwenckii	250-300	13-15	LRG	Si	+	-	1-3	480-710	Pr,I
S. spicifera	240-290	14-16	LRG	Si	+	-	1-3	540-760	Pr,I
Toxicodendron									
T. succedaneum	140-200	7-10	LRG	Si	+	-	1-3	600-750	I

Note: A: aliform; B: banded; C: chambered axial parenchyma cells; CR: chambered upright ray cells; CWT: cell wall thickness; D: deposit; DR: druses; F: fibre; FL: fibre length; E: crystal in enlarged cells (idioblast); LRG: large, round, gash-like; I-V: intervessel pits; N: non-chambered axial parenchyma cells; P: procumbent ray cells; PC: prismatic crystals; P-P: perforation plates; Pr: all ray cells procumbent; PY: parenchyma; RC: radial canals; Ray CC: rays cellular composition; S: septate fibres; Sc: scalariform perforation plates; Si: Simple perforation plates; T: tyloses; TW: two distinct sizes of crystals per cell or chamber; U: upright ray cells, V:vasicentric; V-R: vessel-ray pitting, X: thin to thick-walled; Y; thin-walled; I: body ray cells procumbent with one row of upright marginal cells; II: body ray cells procumbent with mostly 2-4 rows of upright marginal cells; +: present; -: absent

Table 3. Anatomical Features of Anacardiaceae in Malaysia: Fibres, Parenchyma, Radial Canals, and Mineral Inclusion

Taxon	Fibres			PY	RC	Mineral Inclusion			
	FL µm	CWT class	S			Crystal			Silica
						PC	TW	DR	
Bouea									
B. macrophylla	1000-1500	X	-	V,B	-	U,P,C	-	-	-
B. oppositifolia	880-1010	X	-	V,B	-	U,P,C	-	-	-
Buchanania									
B. arborescens	950-1240	Y	-	V	+	N,F	U,P	-	-
B. sessilifolia	1200-1450	Y	-	V	+	N,F	U,P	-	-
Campnosperma									
C. auriculatum	1400-1800	Y	+	-	+	-	-	-	-
C. coriaceum	1000-1440	Y	+	-	+	-	-	-	-
C. squamatum	1050-1500	Y	+	-	+	-	-	-	-
Dracontomelon									
D. dao	1400-1900	X	+	V,A	-	U,P,N,F	-	-	-
Gluta									
G. aptera	1200-1500	X	-	V,B	+	-	-	-	+ ray
G. curtisii	1000-1200	X	-	V,B	+	-	-	-	+ ray
G. elegans	985-1100	X	-	V,B	+	-	-	-	+ ray
G. wallichii	910-1000	X	-	V,B	+	-	-	-	+ ray
Koordersiodendron									
K. pinnatum	1430-1600	X	+	V	+	U,CR,E	-	-	-
Mangifera									
M. foetida	910-1050	X	-	A,B	-	U,P	-	-	-
M. griffithii	1010-1250	X	-	A,B	-	U,P	-	-	-
M. indica	800-1000	X	-	A,B	-	U,P	-	-	-
M. odorata	980-1150	X	-	A,B	-	U,P	-	-	-
Melanochyla									
M. auriculata	1471-1650	X	-	V,A	+	U,P	-	-	-
M. bracteata	1050-1300	X	-	V,A	+	U,P	-	-	-
M. fulvinervia	1220-1450	X	-	V,A	+	U,P	-	-	-
Parishia									
P. insignis	1314-1552	Y	-	V	+	-	-	-	+ ray
P. maingayi	1322-1598	Y	-	V	+	-	-	-	+ ray
P. paucijuga	1388-1646	Y	-	V	+	-	-	-	+ ray
Pentaspadon									
P. motleyi	1263-1471	X	+	V	+	U,P	-	-	-
P. velutinus	1398-1550	X	+	V	+	U,P	-	-	-
Spondias									
S.dulcis	1200-1800	Y	+	V	+	-	-	-	-
S.pinnata	1000-1500	Y	+	V	+	-	-	-	-
Swintonia									
S. floribunda	1120-1500	X	-	V,B	+	-	-	-	+ ray
S. schwenckii	890-1011	X	-	V,B	+	-	-	-	+ ray
S. spicifera	950-1230	X	-	V,B	+	-	-	-	+ ray
Toxicodendron									
T. succedaneum	1230-1451	X	+	V	-	U,P	-	U,P	-

Note: A: aliform; B: banded; C: chambered axial parenchyma cells; CR: chambered upright ray cells; CWT: cell wall thickness; D: deposit; DR: druses; F: fibre; FL: fibre length; E: crystal in enlarged cells (idioblast); LRG: large, round, gash-like; I-V: intervessel pits; N: non-chambered axial parenchyma cells; P: procumbent ray cells; PC: prismatic crystals; P-P: perforation plates; Pr: all ray cells procumbent; PY: parenchyma; RC: radial canals; Ray CC: rays cellular composition; S: septate fibres; Sc: scalariform perforation plates; Si: Simple perforation plates; T: tyloses; TW: two distinct sizes of crystals per cell or chamber; U: upright ray cells, V:vasicentric; V-R: vessel-ray pitting, X: thin to thick-walled; Y; thin-walled; I: body ray cells procumbent with one row of upright marginal cells; II: body ray cells procumbent with mostly 2-4 rows of upright marginal cells; +: present; -: absent

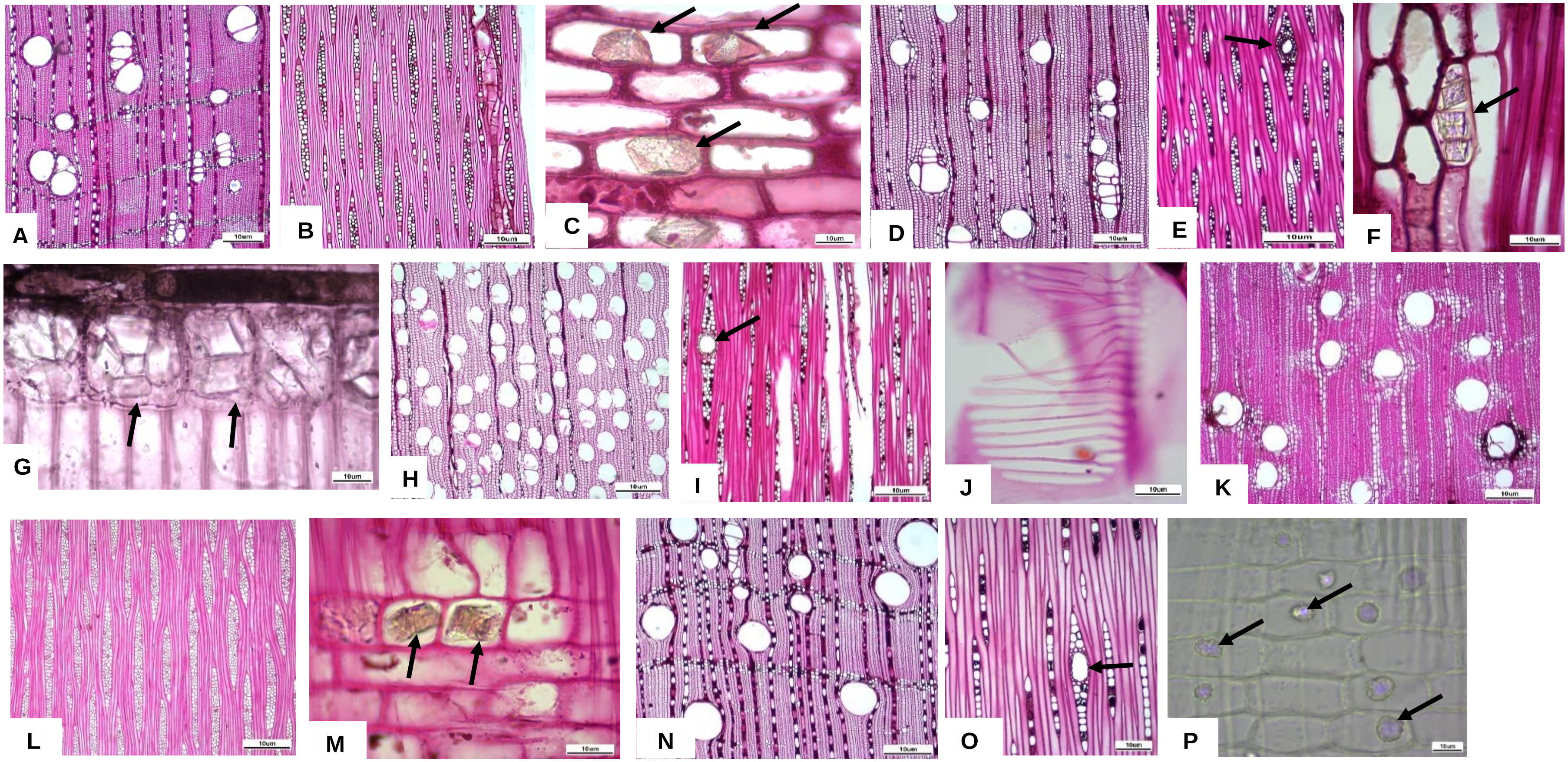

Fig. 1. (A) *Bouea macrophylla*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric and terminal parenchyma bands. (B) *Bouea macrophylla*; TLS, x 4, rays 1 to 2 cells width, radial canals absent. (C) *Bouea oppositifolia*; RLS,x 40, crystals in procumbent ray cells (arrows). (D) *Buchanania arborescens*; TS, x 4, vessels solitary and in radial multiples of 2 to 5 or clusters, axial parenchyma vasicentric. (E) *Buchanania arborescens*; TLS, x 4, rays 1 to 3 cells width, radial canals present (arrow). (F) *Buchanania sessilifolia*; RLS, x 40, prismatic crystals in non-chambered axial parenchyma (arrow). (G) *Buchanania arborescens*; RLS, x 40, two distinct sizes of crystals per cell (arrows). (H) *Campnosperma coriaceum*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma absent. (I) *Campnosperma auriculatum*; TLS, x 4, rays 1 to 4 cells width, radial canals present (arrow). (J) *Campnosperma squamatum*; TLS, x 40, scalariform perforation plates. (K) *Dracontomelon dao*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric and aliform. (L) *Dracontomelon dao*; TLS, x 4, rays 2 to 4 cells width, radial canals absent. (M) *Dracontomelon dao*; RLS, x 40, prismatic crystals in procumbent ray cells (arrows). (N) *Gluta aptera*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric and irregularly spaced bands. (O) *Gluta wallichii*; TS, x 4, rays 1 to 3 cells width, radial canals present (arrow). (P) *Gluta wallichii*; RLS, x 40, silica in ray cells (arrows).

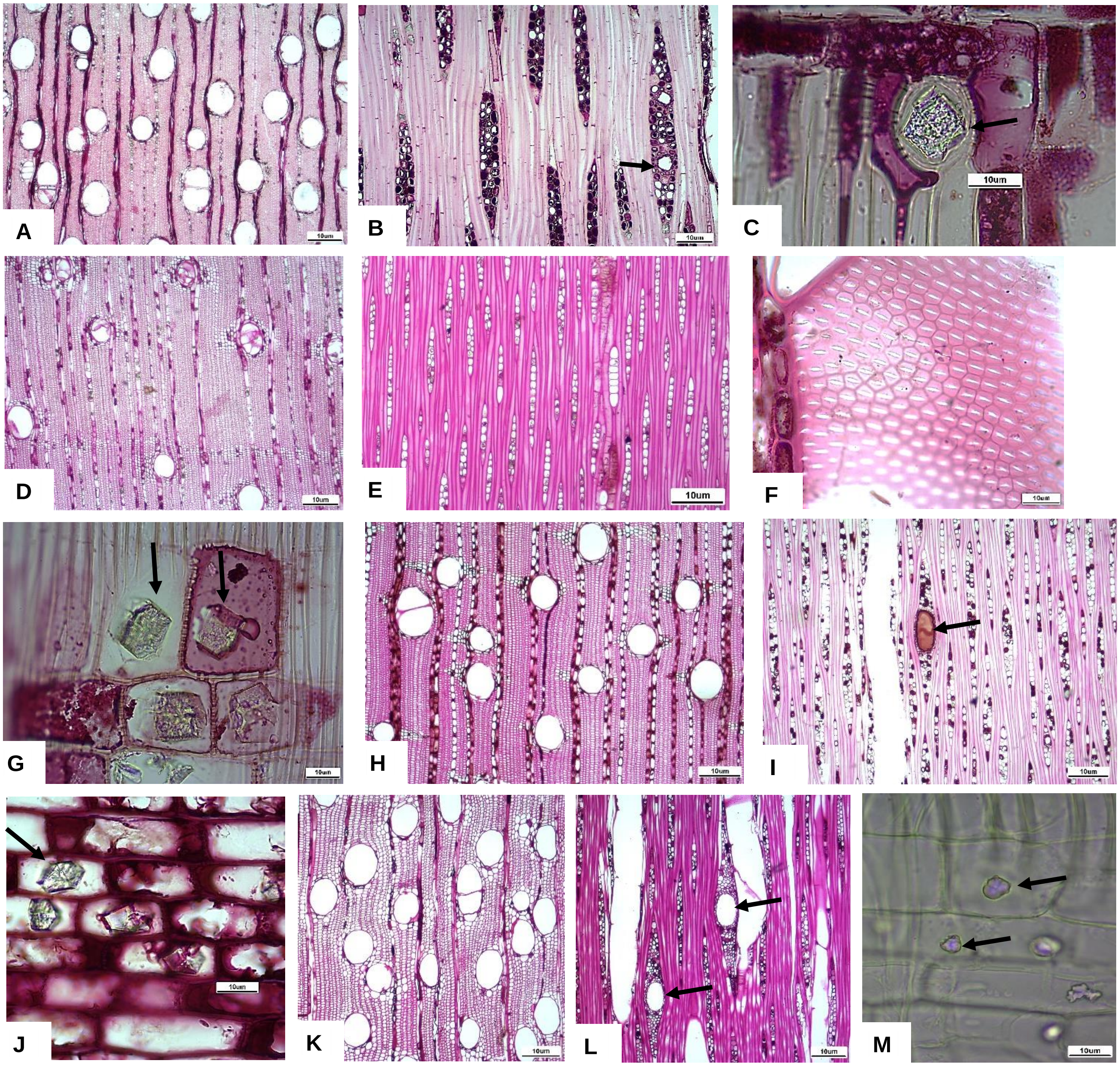

Fig. 2. (A) *Koordersiodendron pinnatum*; TS, x 4, vessels solitary and in radial multiples of 2 to 4, axial parenchyma vasicentric. (B) *Koordersiodendron pinnatum*; TLS, x 4, rays 2 to 3 cells width, radial canals present (arrow), septate fibres. (C) *Koordersiodendron pinnatum*; RLS,x 40, prismatic crystals in enlarged cells (arrow). (D) *Mangifera odorata*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma aliform and irregularly spaced bands. (E) *Mangifera griffithii*; TLS, x 4, rays 1 to 2 cells width, radial canals absent. (F) *Mangifera foetida*; TLS, x 40, typical intervessel pitting found in Anacardiaceae which is intervessels pits alternate and polygonal. (G) *Mangifera indica*; RLS, x 40, prismatic crystals in procumbent and upright ray cells (arrows).
(H) *Melanochyla fulvinervia*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric and aliform. (I) *Melanochyla bracteata*; TLS, x 4, rays 1 to 4 cells width, radial canals present (arrow). (J) *Melanochyla auriculata*; RLS, x 40, prismatic crystals in procumbent ray cells (arrow). (K) *Parishia maingayi*; TS, x 4, vessels mainly solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric. (L) *Parishia maingayi*; TS, x 4, rays 1 to 5 cells width, radial canals present (arrows). (M) *Parishia insignis*; RLS, x 40, silica in ray cells (arrows).

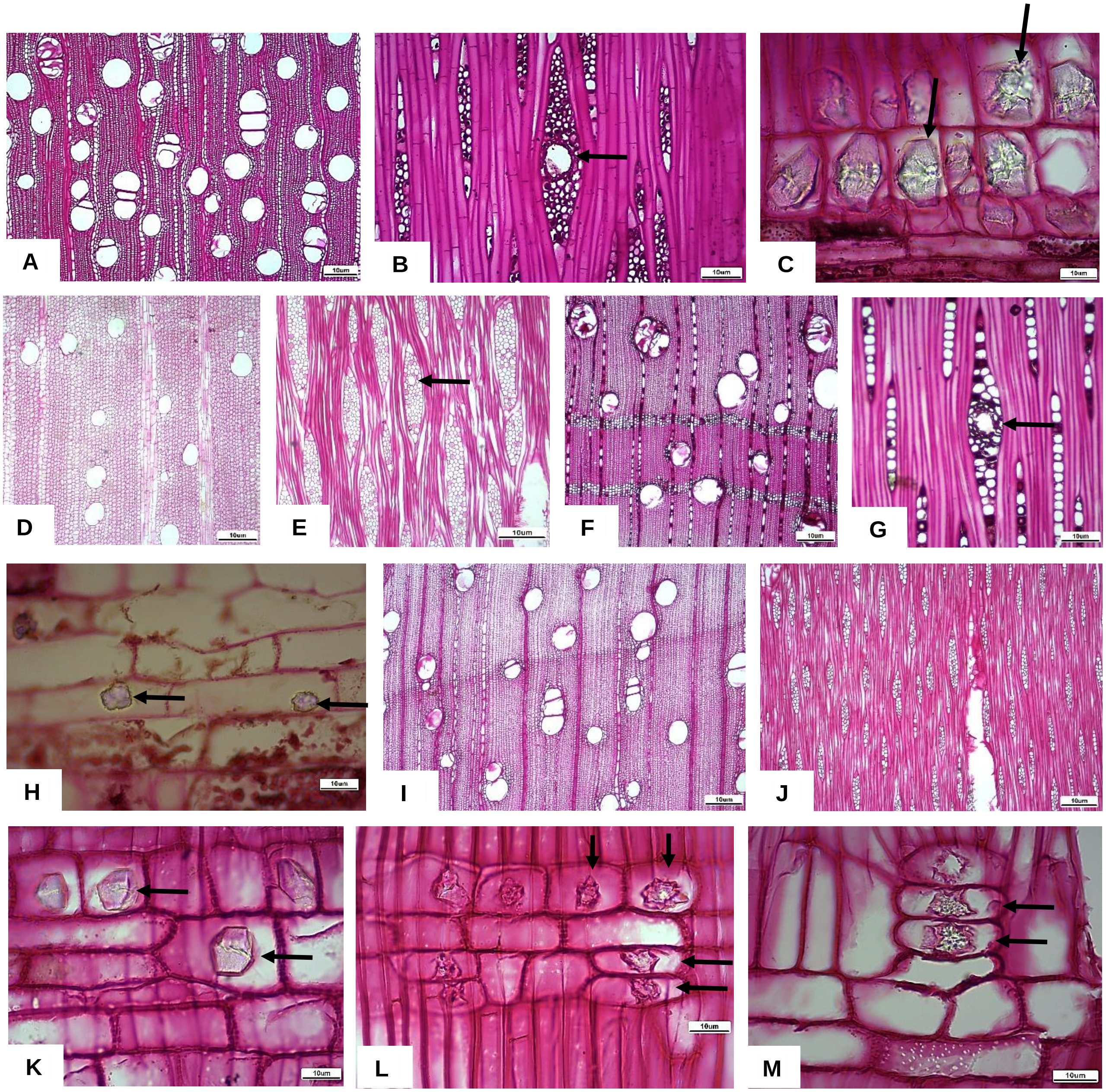

Fig. 3. (A) *Pentaspadon motleyi*; TS, x 4, vessels solitary and in radial multiples of 2 to 4, axial parenchyma vasicentric. (B) *Pentaspadon motleyi*; TLS, x 10, rays 2 to 6 cells width, radial canals present (arrow), septate fibres. (C) *Pentaspadon velutinus*; RLS, x 40, prismatic crystals in upright ray cells (arrows). (D) *Spondias pinnata*; TS, x 4, vessels solitary and in radial multiples of 2 to 4, axial parenchyma vasicentric. (E) *Spondias pinnata*; TLS, x 4, rays 2 to 6 cells width, radial canals present (arrow). (F) *Swintonia schwenckii*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric and irregularly spaced bands. (G) *Swintonia schwenckii*; TLS, x 10, rays 1 to 3 cells width, radial canals present (arrow). (H) *Swintonia floribunda*; RLS, x 40, silica in ray cells (arrows). (I) *Toxicodendron succedaneum*; TS, x 4, vessels solitary and in radial multiples of 2 to 3, axial parenchyma vasicentric. (J) *T. succedaneum*; TS, x 4, rays 1 to 3 cells width, radial canals absent. (K) *Toxicodendron succedaneum*; RLS, x 40, prismatic crystals in upright ray cells (arrows). (L, M) *Toxicodendron succedaneum*; RLS, x 40, druses present in upright ray cells, chambering also observed in the upright cells, forming 2-3 chambers, occupied by solitary druse (arrows).

Mineral inclusions, *i.e*., crystals and silica, are common in wood, and they can be used for wood identification and classification (Metcalfe and Chalk 1983; Negi *et al.* 2003). Some crystal and silica patterns have diagnostic significance in identifying species and genera within the family (Bamber and Lanyon 1960; Menon 1965; Richter 1980). As in the present study of Anacardiaceae, the crystal and silica patterns were useful in identifying genera within the family. *Gluta*, *Parishia*, and *Swintonia* were characterised by abundant silica in the ray cells. This result is supported by Menon (1965). Other genera show prismatic crystals in different wood cells, *i.e*., in upright ray cells, procumbent ray cells, fibres, and axial parenchyma, as summarised in Table 2. *Buchanania* showed two distinct sizes of crystals presence in upright and procumbent ray cells in all species. Crystals were observed in the enlarged cells (idioblast) of *Koordersiodendron*. There is absence of mineral inclusion in *Campnosperma* and *Spondias*.

Druses were observed in *Toxicodendron*, but only in one individual specimen. The presence of druses has not been reported before in *Toxicodendron*. The druses found in the current study were medium sized, with a dense globular form, and the constituent units had a star-shaped appearance. They were present in the procumbent and upright ray cells. Chambering was observed also in the upright cells, forming 2 to 3 chambers, occupied by a solitary druse. The other two samples of *T. succedaneum* absence of druses, containing only prismatic crystal in upright and procumbent ray cells. Prismatic crystal in upright and procumbent ray cells was observed in previous studies (Dadswell and Ingle 1948; Metcalfe and Chalk 1983; Dong and Bass 1993). Druses are reported present only in *Rhus* species in the Anacardiaceae family (Dadswell and Ingle, 1948; Dong and Bass 1993; Carlquist 2001). However, Gupta *et al*. (2017) reported druses in one stress individual sample of *M. indica* collected from a coal mine area in India where the presence of druses has not been reported before by previous researchers (Pearson and Brown 1932; Dadswell and Ingle 1948; Metcalf and Chalk 1983; Dong and Bass 1993). The present study suggested the presence of druses in individual *T. succedaneum* as a result of adaptation of the individual plant to the local microclimatic conditions. The microclimate conditions include intracellular regulation of pH, calcium ions, gravity perception, mechanical support, and plant defence (Monje and Baran 2002), which can lead to the formation of druses at the stressed site. As reported by van Vliet (1979), druses were observed in all specimens of *Terminalia catappa* except cultivated ones, which indicated the greater tendency of druse formation in stressed sites than cultivated sites.

Anatomical Features and Wood Properties

Tables 1 and 2 summarize selected features in which timber properties, and potential usage can be tentatively predicted. *Bouea*, *Gluta*, *Mangifera*, and *Swintonia* show growth rings, which are formed by the parenchyma bands that will make decorative figures on the flat-sawn boards. Moreover, these four timbers have attractive heartwood colour and are classified as moderately heavy to heavy. Based on these characteristics, the timbers of *Bouea*, *Gluta*, *Mangifera*, and *Swintonia* have high potential as high-class joinery, furniture, cabinet wood, flooring, paneling, interior finishing, decorative veneers, and medium construction under cover. *Dracontomelon* and *Koordersiodendron* also have potential as highly prized of cabinet wood and furniture, as these timbers are classified as moderately heavy to heavy and have attractive heartwood. Zairul *et al*. (2021) reported similar findings in the study of *Eucalyptus* hybrid. As shown in Table 1, *Buchanania*, *Campnosperma*, *Parishia*, and *Spondias* are classified as light to moderately heavy; these timbers are suitable for light construction, picture frames, boxes, and packing cases.

Silica was observed in ray cells in *Gluta*, *Parishia*, and *Swintonia*. The presence of mineral inclusions in wood, particularly silica, can affect the processing of timber during the conversion of logs to sawn timber by slowing the machine tools and feed speeds. The particles of silica have an abrasive effect on the saw teeth, producing rapid blunting of cutting edges and heating of the saw blade. Modifications to the machine tools such as saw teeth are necessary for the conversion of timbers with high silica content (Desch and Dinwoodie 1981). The timber of *Gluta* must be handled carefully during the sawing process because the sawdust can cause irritation and allergic reactions (Wong 2019). According to Sint *et al*. (2011), medium to large size of vessels diameter and intervessel pits with absence of tyloses and deposit occluded in the vessels contributed to the easily treatment of the timbers. However, the presence of tyloses that blocked the vessels contributed to the difficulty of treatment in *Bouea*, *Dracontomelon*, *Gluta*, *Koordersiodendron*, *Melanochyla*, *Pentaspadon*, and *Swintonia*, but formation of tyloses indicated these timbers as having high durability. This is supported by Dickson (2000), who reported that tyloses are correlated with the increased resistance to Dutch elm disease; tyloses assist in restricting pathogen movement (Romero *et al.* 2020).

Based on the anatomical features, almost all of the species of Anacardiaceae have narrow rays, which indicated that they might have excellent nailing properties. However, the species of *Pentaspadon* and *Spondias* showed larger rays that indicated poor nailing. *Buchanania*, *Campnosperma*, *Parishia*, and *Spondias* classified as thin fibre wall thickness that related to the lower density and strength. Besides, thin to thick-walled fibre classification was observed in *Bouea*, *Dracontomelon*, *Gluta*, *Koordersiodendron*, *Mangifera*, *Pentaspadon*, and *Swintonia* could account for higher density and strength in these timbers. Hamdan *et al*. (2020) reported that fibre wall thickness is closely linked with density, where the thicker wall is associated with higher density.

CONCLUSIONS

1. Anatomical and other selected physical features can be used for the identification and classification of the genera in Malaysian Anacardiaceae. The anatomical features of Malaysian Anacardiaceae can be characterised as radial canals often present in most genera, intervessel pits, and vessel diameters medium to large in size.
2. Scalariform perforation plates were only present in *Campnosperma*. They make this genus easily identified from other genera in Anacardiaceae. Rays were narrow in most genera, which was 1 to 3 cells in width, except for larger rays in *Pentaspadon* and *Spondias*. Axial parenchyma in most genera was characterised as vasicentric, aliform, or banded parenchyma.
3. The anatomical features indicate other wood properties and their potential usage. Wood with banded parenchyma reflects the presence of growth rings that give attractive features to the woods.

4. Wood with thin walls and medium to large vessels have a lower density that is suitable for general utility usage. The presence of tyloses and deposits in some genera indicate them as high in durability but difficult in treatment.
5. Most of the genera in Malaysian Anacardiaceae show narrow rays that might result in excellent nailing properties. The silica content of *Gluta*, *Parishia*, and *Swintonia* indicates that more precautions should be taken during the processing of these timbers.
6. Wood anatomical features are ecological adaptations. Druses in individuals of *Toxicodendron succedaneum* demonstrate adaptation to the microclimatic conditions.

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