

ATLAS OF VESSEL ELEMENTS

Identification of Asian Timbers

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BRILL

PREFACE

Pulp production is increasing worldwide, especially in Southeast Asia and China (WWF 2009; Williams 2014; FAO 2015), and the use of tropical timbers from natural forests is not uncommon (Greenpeace 2012). To ensure that no protected timbers are used, those detected in pulp and paper products must be identified.

Individual vessel elements are best suited for the microscopic identification of wood species in those products on the basis of typical morphological features such as type of perforation plates, presence *vs.* absence of helical thickenings, and type and arrangement of vessel-ray pits (Core *et al.* 1979; Carlquist 2001).

To allow identification, a standardized morphological description of these features is required for commonly used timber. The fiber atlases by Carpenter and Leney (1952), Ezpeleta and Simon (1970, 1971), Harders-Steinhäuser (1974), Parham and Gray (1982) and Ilvessalo-Pfäffli (1995) describe these characteristics for the main species grown in the temperate zone and in plantations. There is, however, no corresponding database available for important Asian timbers.

In recent years, the rapid and reliable identification of wood species and their origin has become necessary (*e.g.* Dormontt *et al.* 2015; Koch & Schmitt 2015; Koch *et al.* 2015), owing to the following laws that have recently come into effect: the U.S. Lacey Act (USA, 1900/amended in 2008), the Illegal Logging Prohibition Act 2012 (Australia), and the European Timber Regulation (EUTR, No. 995/2010, implemented in 2013). Besides other timber products, these laws subject the fiber components of pulp and paper to strict controls, aiming to minimize the trade and use of illegally logged timber or products derived from it. Both producers and traders of wood products are responsible for the correct declaration of the species and origin (Koch & Schmitt 2015).

To support the request for due diligence, our team from the University of Hamburg and the Thünen Institute (Hamburg, Germany) developed this atlas of vessel elements for the identification of Asian timbers, with funding from the German Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU). The vessel atlas describes 38 tropical and temperate Asian timbers, known for their potential in utilization of pulp and paper, including for the first time also lesser known species and the monocots Bamboo and Coconut palm. Each species is illustrated with high-quality photomicrographs at standard magnification.

Important diagnostic features are highlighted in the text and figures for easy identification. The taxonomy of the individual species is described in detail in the PROSEA Timber volumes (Soerianegara *et al.* 1993; Lemmens *et al.* 1995; Sosef *et al.* 1998). The selection of the taxa depends on the evaluation of about 2,150 official reports prepared at the Thünen Centre of Competence on the Origin of Timber since the implementation of the EUTR (2013) in Germany. Based on this experience, the atlas includes the commonly used timbers regularly identified in fiber boards, pulp, and paper from Asia, *e.g.* *Liquidambar*, *Nyssa* and *Schima*. Furthermore, taxa with wide distribution and high economic potential, *e.g.* of the families Dipterocarpaceae, Sapotaceae, etc. are considered (Helmling *et al.* 2016).

Reference materials for the morphological description of the vessel elements are provided from vouchered specimens of the scientific wood collection (RBHw) of the Thünen Institute. Furthermore, well-documented assortments of mono-fractioned pulp (each pulp consisting of specimens belonging to a single genus) were produced separately to study the influence of mechanical impact on the morphology of carefully macerated vessel elements (not damaged) and mechanically pulped fibers (partly damaged). Paper sheets of unknown mixtures (blind test) were also produced and microscopically analyzed to assess the applicability of the information contained in the atlas. The verifiable results of the blind tests clearly demonstrated the usefulness of the atlas.

Based on this experience, the atlas should be understood as an aid to wood identification in pulp and paper, to be used as a supplement to the existing fiber atlases, in particular the atlas by Ilvessalo-Pfäffli (1995) with descriptions of tree species mainly used in the pulp and paper production.

We trust that by displaying the considerable variety of vessel elements in Asian timbers, this atlas will assist in identifying tropical and temperate woody genera in pulp, paper, and fiber board. We also hope that it may help to preserve protected tree species.

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Hamburg, Germany 2018

HOW TO USE THE VESSEL ELEMENT ATLAS

This atlas contains the description of individual wood species, but the features may also be valid for the respective genus as the similarity within genera is often very high.

The identification of the material used in pulp, paper and fiber boards is a challenging task due to the missing tissue structure. The separated wood fibers offer less information than solid wood tissue. Furthermore, pulp often consists of a mixture of different wood species which makes identification even more difficult.

The wood identification also depends on the method of pulp production. If the pulp was strongly refined, the limits of wood identification have been reached.

It is possible to determine the family and often the genus. Individual species within a genus are too similar to distinguish them. To identify a timber the sample of pulp and paper products or fiber boards must be compared with the pictures of this atlas. In the case of having identified, e.g., *Eucalyptus globulus*, according to the similarity of investigated vessel elements with the pictures in this atlas, one can only conclude that the cells have highest similarity with cells of *Eucalyptus* spp.

The standard species for the production of pulp and paper from temperate zones are well described in the atlases of Parham and Gray (1982) and Ilvessalo-Pfäffli (1995). The present atlas deals with a selection of Asian timbers. For the identification of wood species in pulp and paper of unknown provenance it makes sense to use these atlases together.

PREPARATION OF PULP SAMPLES FOR IDENTIFICATION WITH THE LIGHT MICROSCOPE

Paper

To prepare the samples for investigation, a piece of paper (1.5 cm²) is put into a test tube filled with distilled water to soften the paper. After a few minutes the pulp mass is rolled to a ball between the fingers and placed in a tube with water again. By shaking the test tube the fibers are individualized and the fiber suspension is poured on a filter. Part of the material is then placed on 2 or 3 microscopic slides. Staining of the fibrous mix is done with two drops of Alexander and one drop of Herzberg solutions. Alexander solution (Merck KGaA, Darmstadt, Germany) consists of calcium nitrate tetrahydrate, Herzberg solution (Harders-Steinhäuser 1974) of zinc chloride and potassium iodide (Merck KGaA, Darmstadt, Germany). Cover glasses are placed on the stained pulp, and slides should be investigated immediately, since the staining is not permanent. After this process untreated cells with a high amount of lignin (mechanical pulp) are stained yellow, delignified cells (chemical pulp) are greyish blue (softwoods) or blue (hardwoods).

Medium Density Fiber board (MDF)

To prepare MDF samples, a piece of the material is boiled in water and the resulting pulp placed on a filter. For better contrast, the pulp is stained with nigrosin (1%) (alcohol soluble, Alfa Aesar GmbH & Co. KG, Karlsruhe). After 10–15 minutes the material is rinsed with de-ionised water and mounted in glycerine (86%, Carl Roth GmbH & Co. KG, Karlsruhe, Germany) on microscope slides.

Recommendations

Since there are many more fibers than vessel elements in the pulp it is important to obtain a representative range of vessel elements of the used species. Therefore, it is recommended to investigate enough material which usually requires observation of several microscope slides.

For the production of permanent slides it is useful to increase the contrast by staining the samples with nigrosin (1%, alcohol soluble, Alfa Aesar GmbH & Co. KG, Karlsruhe) or safranine (4%, alcohol soluble, Chroma-Gesellschaft Schmid & Co. Stuttgart-Untertürkheim). The stained vessel elements of the pulp are selected by needle, placed on microscope slides and mounted in Euparal (Carl Roth GmbH & Co. KG, Karlsruhe, Germany).

MATERIALS AND METHODS

This atlas contains 38 wood species that mainly originate from Southeast Asia (see Table 1). We selected commonly traded timbers, widely used plantation species, and species from endangered habitats. However, it should be stressed that the selection is far from comprehensive, and that other tree species than those treated here may be present in pulp and paper or MDF from Asia.

Authenticated specimens of the wood collection of the Thünen Institute (RBHw, Hamburg, Germany) served as reference material. The descriptions are generally based on one specimen per species only, but features were verified with slides and literature data from the databases in Hamburg and InsideWood (2004–onwards).

The selection of the material and the method (maceration according to Franklin, 1945) are also described by Helmling *et al.* (2016). Microscopy and staining are included.

The botanical names were taken from:

- Catalogue of life (<http://www.catalogueoflife.org/col/search>).
- Flora of China (www.efloras.org).
- Grin (<https://npgsweb.ars-grin.gov>).
- Mabberley (2008).

The trade names were taken from:

- Brink M & Escobin RP (2003).
- Flora of China (www.efloras.org).
- Hayashi (1973), Wong (2002), and Jiang (2013).
- Lemmens RHMJ, Soerianegara I & Wong WC (1995).
- Richter HG & Dallwitz MJ (2000 onwards).
- Soerianegara I & Lemmens RHMJ (1993).
- Sosef MSM, Hong LT & Prawirohatmodjo S (1998).

The codes in the taxon descriptions refer to DIN EN 13556:2003.

The information on geographic distribution of the wood species was extracted from:

- Catalogue of life (<http://www.catalogueoflife.org/col/search>).
- Grin (<https://npgsweb.ars-grin.gov>).
- Lemmens RHMJ, Soerianegara I & Wong WC (1995).
- Richter HG & Dallwitz MJ (2000 onwards).
- Soerianegara I & Lemmens RHMJ (1993).
- Sosef MSM, Hong LT & Prawirohatmodjo S (1998).

The investigated characters of all species were compared with data in literature:

- Brink M & Escobin RP (2003).
- InsideWood (<http://insidewood.lib.ncsu.edu/search>).
- Lemmens RHMJ, Soerianegara I & Wong WC (1995).
- Richter HG & Dallwitz MJ (2000 onwards).
- Soerianegara I & Lemmens RHMJ (1993).
- Sosef MSM, Hong LT & Prawirohatmodjo S (1998).

Table 1. List of investigated species in alphabetical order of families (RBHw = vouchered material, * = commercial sample – genus verified).

| Family | Taxa / species | Trade name | RBHw No. |
|-------------------------------|---|------------------------|----------|
| Acanthaceae | <i>Avicennia marina</i> (Forssk.) Vierh. | Api-API (mangrove) | 24226 |
| Altingiaceae | <i>Liquidambar formosana</i> Hance | Formosan sweet gum | 23479 |
| Anacardiaceae | <i>Camptosperma</i> sp. | Terentang | * |
| Anacardiaceae | <i>Gluta reinghas</i> L. | Rengas | * |
| Anacardiaceae | <i>Mangifera</i> sp. | Mango | * |
| Anacardiaceae | <i>Swintonia</i> sp. | Merpauh | * |
| Aquifoliaceae | <i>Ilex triflora</i> var. <i>kanehirai</i> (Yamamoto) S.Y. Hu | Kecemang | 10148 |
| Arecaceae | <i>Cocos nucifera</i> L. | Coconut palm | * |
| Burseraceae | <i>Canarium</i> sp. | Kedondong | * |
| Calophyllaceae | <i>Calophyllum</i> sp. | Bintangor | * |
| Celastraceae | <i>Lophopetalum</i> sp. | Perupok | * |
| Dipterocarpaceae | <i>Shorea</i> subg. <i>Anthoshorea</i> | White Meranti | * |
| Dipterocarpaceae | <i>Shorea</i> subg. <i>Richetia</i> | Yellow Meranti | * |
| Dipterocarpaceae | <i>Shorea</i> subg. <i>Rubroshorea</i> | Dark/Light Red Meranti | * |
| Dipterocarpaceae | <i>Shorea</i> subg. <i>Shorea</i> | Bangkirai, Balau | * |
| Dipterocarpaceae | <i>Parashorea</i> sp. | Gerutu | * |
| Dipterocarpaceae | <i>Dipterocarpus</i> sp. | Keruing | * |
| Euphorbiaceae | <i>Hevea brasiliensis</i> (Willd. ex A.Juss.) Müll. Arg. | Rubberwood | 9880 |
| Fabaceae- Caesalpinioideae | <i>Intsia</i> sp. | Merbau | * |
| Fabaceae- Caesalpinioideae | <i>Koompassia malaccensis</i> Maingay ex Benth. | Kempas | * |
| Fabaceae-Mimosoideae | <i>Acacia mangium</i> Willd. | Acacia | * |
| Fabaceae-Mimosoideae | <i>Albizia procera</i> (Roxb.) Benth. | White siris, Kokko | 193 |
| Fagaceae | <i>Castanopsis argentea</i> (Blume) A. DC. | Berangan | 18490 |
| Lauraceae | <i>Litsea resinosa</i> Blume | Medang | 15426 |
| Malvaceae | <i>Durio</i> sp. | Durian | * |
| Malvaceae | <i>Heritiera</i> sp. | Mengkulang | * |
| Myrtaceae | <i>Eucalyptus globulus</i> Labill. | Eucalyptus | * |
| Myrtaceae | <i>Syzygium dyerianum</i> (King) Chantaran. & J. Parn. | Kelat | 3854 |
| Nyssaceae | <i>Nyssa javanica</i> (Blume) Wangerin | Tupelo, Nyssa | 13989 |
| Paulowniaceae | <i>Paulownia tomentosa</i> (Thunb.) Steud. | Paulownia | 5531 |
| Poaceae | <i>Dendrocalamus latiflorus</i> Munro | Bamboo | 22667 |
| Rhizophoraceae | <i>Rhizophora</i> sp. | Red Mangrove | 24661 |
| Sapotaceae | <i>Madhuca sericea</i> (Miq.) S. Moore | Bitis | * |
| Sapotaceae | <i>Palaquium</i> sp. | Nyato | * |
| Styracaceae | <i>Alniphyllum pterospermum</i> Matsum. | Mee Dong | 10151 |
| Tetrameristaceae | <i>Tetramerista glabra</i> Miq. | Punah | * |
| Theaceae | <i>Schima superba</i> Gardn. & Champ. | Samak, Puspa | 24166 |
| Thymelaeaceae | <i>Gonystylus</i> sp. | Ramin | * |

INTRODUCTION TO KEY FEATURES

The following section presents the main characters used in the descriptions of the individual wood species.

Shape of the vessel elements

The vessel elements are basically tubes that can be divided into three types. The shape of the vessel body (not considering the tails) resembles that of a “drum”, a “barrel”, or a “tube”, terms used in the descriptions of the wood species. Some species possess vessel elements of one type, others vessel elements of various types.

If the ratio of length to width is ≤ 1 the vessel element is designated drum-shaped (Fig. 1A).

If the ratio ranges from 1 to 2, the vessel element is designated barrel-shaped (Fig. 1B).

If the ratio is ≥ 2 , the vessel element is designated tube-shaped (Fig. 1C).

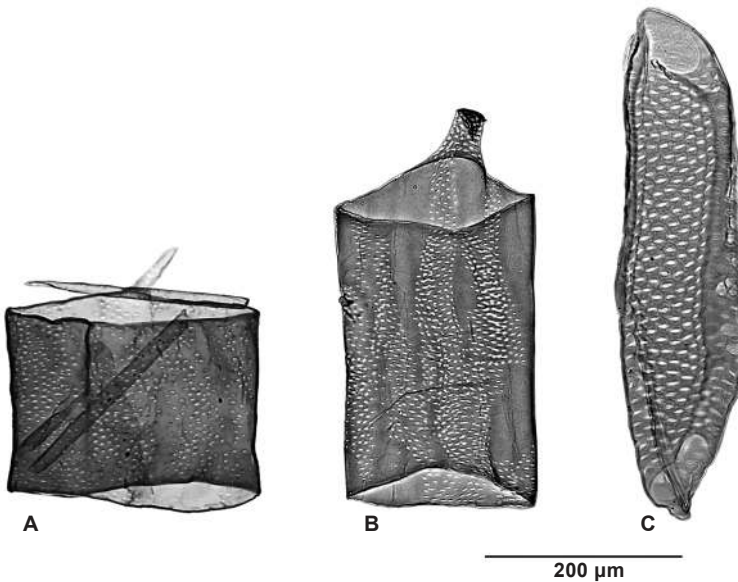


Figure 1. Shape of the vessel elements.

A: drum-shaped (*Albizia procera*, ratio length/width = 0.8. – B: barrel-shaped (*Acacia mangium*, ratio l/w = 1.7. – C: tube-shaped (*Swintonia* sp., ratio l/w = 3.5).

Tails

The vessel elements frequently possess tails at the top and/or the bottom. The transition from the more or less cylindrical vessel element body to the tail can be abrupt (Fig. 2A) or gradual (Fig. 2B).

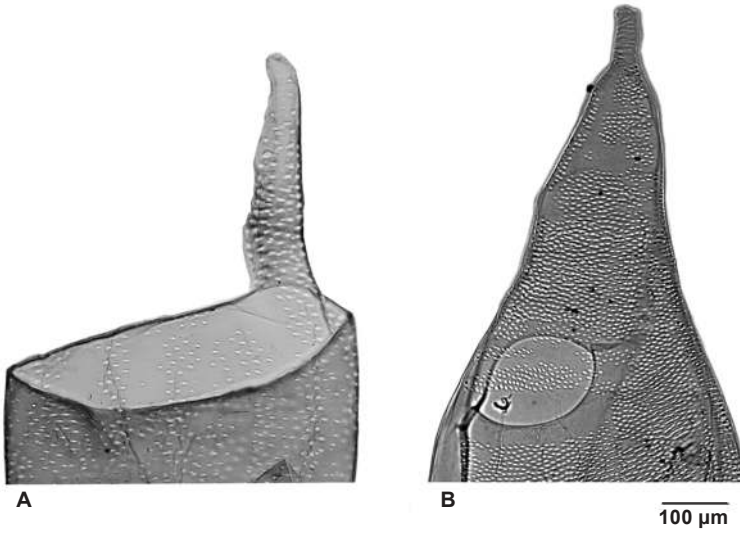


Figure 2. Tails.

A: with abrupt transition, *Albizia procera*. – B: with gradual transition and laterally positioned perforation plate, *Lophopetalum* sp.

Perforation plates

Perforation plates are mainly located at both ends of the vessel elements, sometimes positioned laterally (Fig. 2B).

The perforation plates can be simple (a perforation with a single circular or elliptical opening, Fig. 3A, C and D), or scalariform (a perforation plate with parallel openings separated by one to many mainly unbranched bars, Fig. 3B). The opening can comprise the entire lumen (Fig. 3A–C) or can be narrowed (of a lesser diameter, adapted to the vessel end taper, Fig. 3D).

Perforations can be horizontal (extending over the entire diameter and more or less perpendicular to the longitudinal axis (Fig. 3A) or inclined and elongated (Fig. 3E and F). The shape of vessel elements with inclined endings reminds of a parallelogram (inclination at vessel tips parallel, Fig. 3E) or a trapezium (inclination of vessel ends in opposite directions, Fig. 3F). Both conditions often occur within the same species.

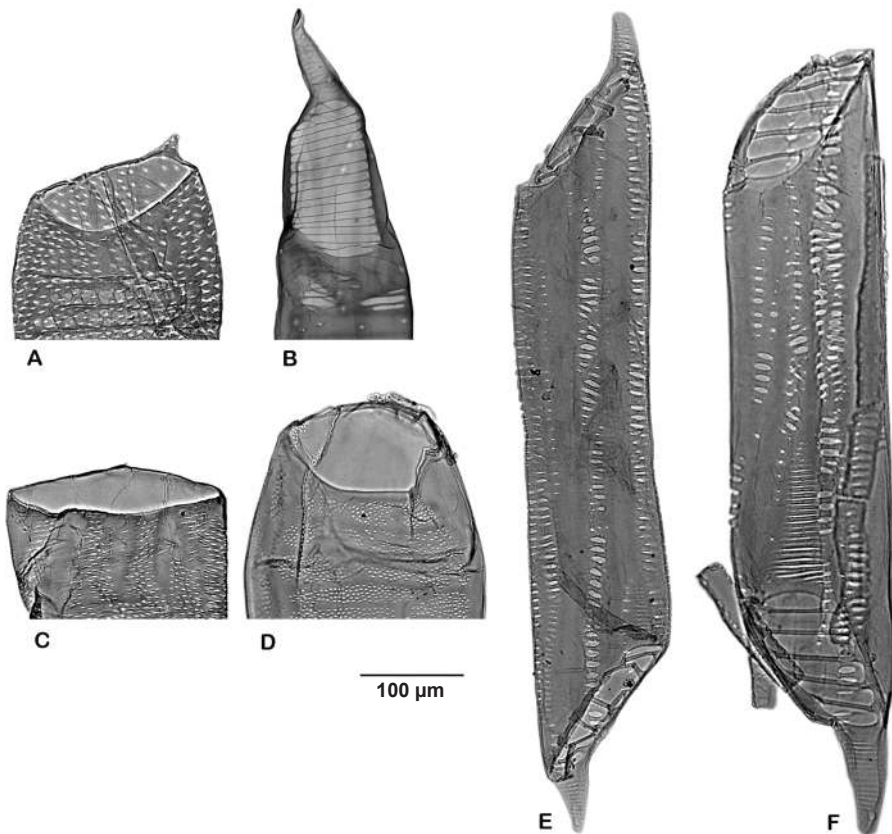


Figure 3. Perforation plates as defined in this atlas.

A: simple: *Eucalyptus globulus*. – B: scalariform: *Liquidambar formosana*. – C: opening horizontal, extending over the entire lumen: *Acacia mangium*. – D: narrowed: *Lophopetalum* sp. – E: inclined, parallelogram: *Rhizophora* sp. – F: inclined, trapezium: *Rhizophora* sp.

Pit types

The different pits constitute an important feature for wood identification. The fiber atlas of Ilvessalo-Pfäffli (1995) includes descriptions of the different pit types and their arrangements on vessel elements. It should be noted that the pit types are sometimes difficult to distinguish.

Intervessel pits are the connections between adjacent vessel elements. They can be recognized due to their arrangement in large fields. The arrangement can be alternate (arranged in diagonal rows), opposite (arranged in short to long horizontal rows, *i.e.*, rows orientated transversely across the length of the vessel) or scalariform (elongated or linear intervessel pits arranged in a ladder-like series, Fig. 4; IAWA Committee 1989). Within one species they have the same size range, a combination of features important for the identification of the timbers. The pit apertures can be circular to oval (Fig. 5A), slit-like (Fig. 5B) or coalescent (Fig. 5C, connecting several pits across their borders).

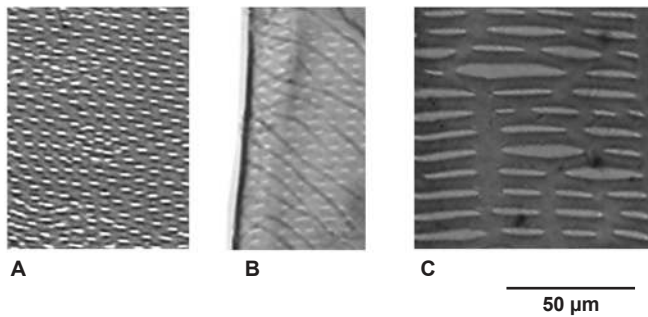


Figure 4. Arrangement of intervessel pits.

A: alternate, *Lophopetalum* sp. – B: opposite, *Ilex triflora*. – C: scalariform, *Nyssa javanica*.

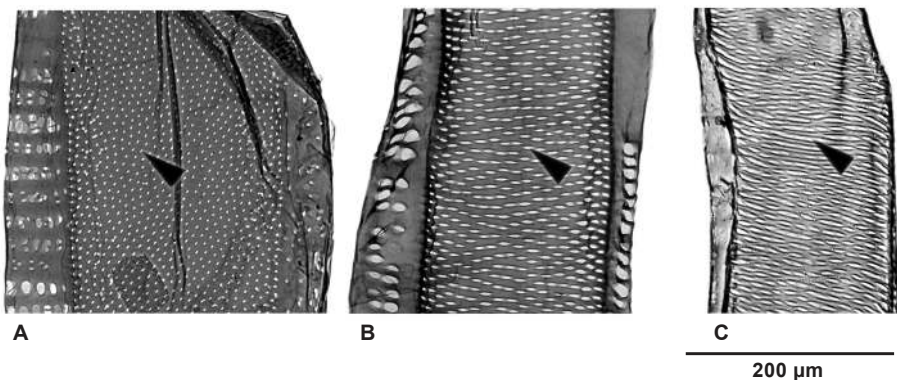


Figure 5. Intervessel pit apertures.

A: circular to oval, *Syzygium dyerianum*. – B: slit-like, *Canarium* sp. – C: coalescent, *Hevea brasiliensis*.

Vessel-ray pits connect vessel elements with ray parenchyma cells. They are arranged in horizontal rows, often several rows per ray cell. Vessel-ray pits are either similar in size and shape to intervessel pits or different. The species group possessing similar pits is denominated **APS** (**All Pits Similar** in size and shape) (see p. 272, Hardwoods with simple perforations).

The group of species with vessel-ray pits differing in appearance and morphology from intervessel pits is denominated **VAS** in this atlas (see p. 296 in the introductory comments to the species group **VAS** (**Vessel-ray pits Apparently Simple**)). They have much reduced borders, the apertures are elongated or window-like, small or large, circular or angular, extended horizontally ('gash-like') or vertically ('palisade'). Various combinations of vessel-ray pit features may occur within one species (Fig. 6A–C).

Pits to axial parenchyma cells are the connections between vessel elements and contact axial parenchyma cells. They usually resemble vessel-ray parenchyma pits and often form brick-like pit fields reflecting the outline of the respective parenchyma cells (Fig. 6A and D).

Pits to fibers are the connection between vessel elements and fibers. They are arranged in single vertical rows (Fig. 6A) and are rarely present.

Pits to tracheids connect vessel elements with tracheids. They are usually similar to intervessel pits in size and shape and are arranged in one to several, sinuous or straight vertical strips (Fig. 6A and C).

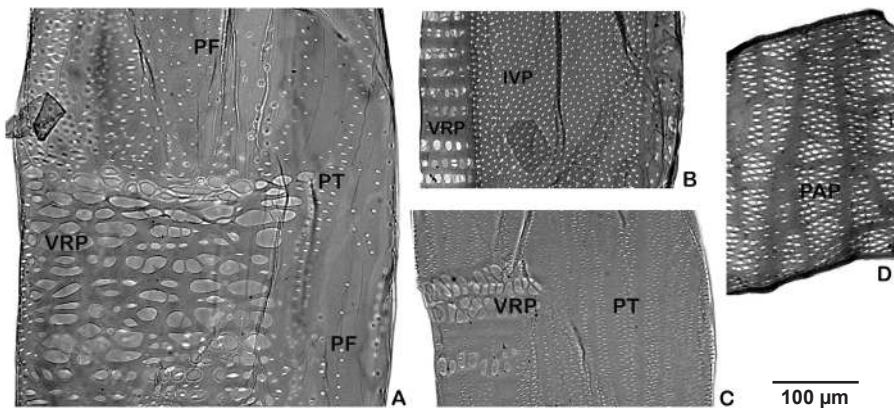


Figure 6. Pit type.

Vessel-ray pits (VRP), pits to axial parenchyma cells (PAP), pits to fibers (PF), pits to tracheids (PT), intervessel pits (IVP).

A: *Dipterocarpus* sp. – B: *Syzygium dyerianum*. – C: *Calophyllum* sp. – D: *Paulownia tomentosa*.

Areas without any pits

Some vessel elements possess very large (Fig. 7A) or large areas without any pits (Fig. 7, arrow in B), some have small areas (Fig. 7, arrowhead in B). Areas devoid of pits may also be absent (Fig. 7C).

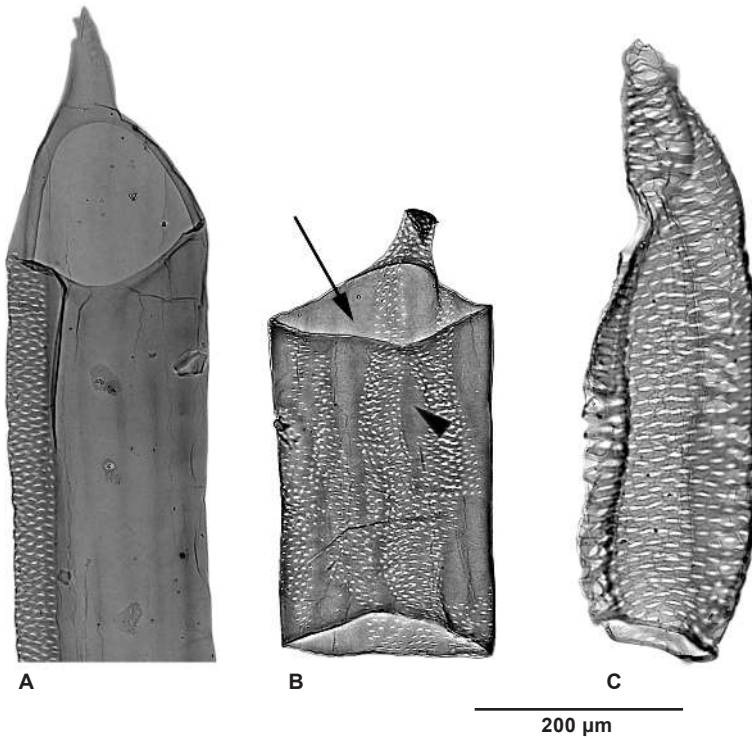


Figure 7. Areas without any pits.

A: very large, *Camptosperma* sp. – B: large (arrow), small (arrowhead), *Acacia* sp. – C: absent, *Swintonia* sp.

Tyloses

Certain wood species generate tyloses in the heartwood (Fig. 8A), less frequently also in the sapwood. Tyloses are outgrowths from an adjacent ray or axial parenchyma cell through a pit in a vessel wall, partially or completely blocking the vessel lumen. They constitute a feature which should only be used in a positive sense, *i.e.* if present. If they are absent the material studied may consist entirely of sapwood of a species capable of forming tyloses in the heartwood, or else the species in question does not produce tyloses. It is also possible that tyloses may be removed from the vessel elements during the pulping process.

Certain wood species can also contain tyloses due to compartmentalisation of damage in the tree after wounding (Schmitt & Liese 1994 and Liese 1995; Dujesiefken & Liese 2008) when normal wood does not form tyloses. Normal sapwood may also contain tyloses in embolized vessels (De Micco *et al.* 2016).

Helical thickenings

Some wood species possess helical thickenings (ridges on the inner face of the vessel element wall in a roughly helical pattern) throughout the vessels or restricted to the tails (IAWA Committee 1989). Helical thickenings are not removed during pulping (Fig. 8B and C).

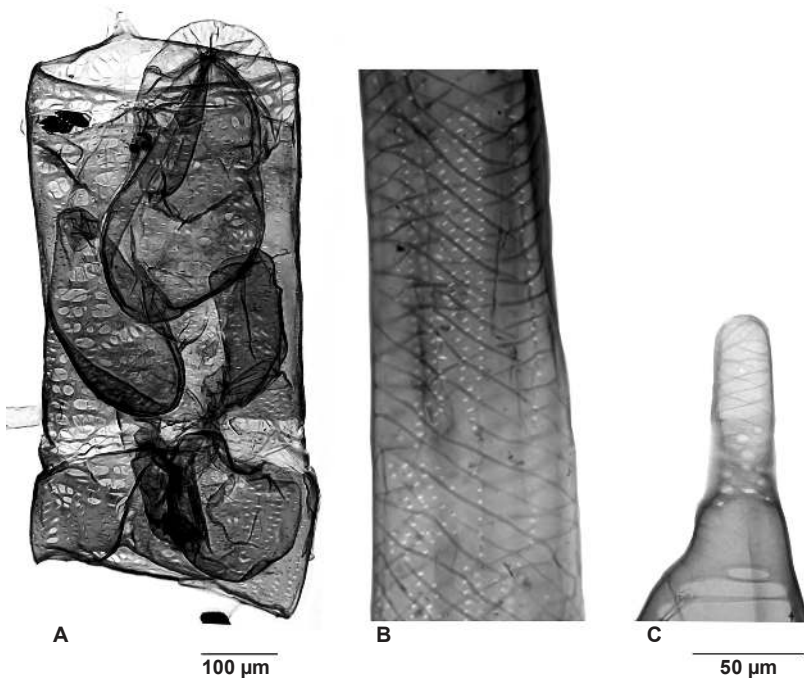


Figure 8. Tyloses and helical thickenings.

A: tyloses, *Castanopsis* sp. – B: helical thickenings in vessel elements, *Ilex triflora* var. *kanehirai*. – C: helical thickenings in vessel element tails, *Liquidambar formosana*; scale 50 µm is valid for B and C.

Dimensions of vessel elements

The dimensions of the vessel elements were determined as illustrated in Figure 9 (software: cellSens, Olympus Soft Imaging Solutions GmbH, Münster, Germany). At least 36 vessel elements of each species were measured (length, width [μm]).

Element length was measured excluding the tails, according to conventions maintained in Hamburg, despite international recommendations to include the tails in the length measurements (IAWA Committee 1989). In pulp, we often found the tails to be damaged. Vessel width in macerations probably corresponds most closely to radial vessel diameter. Note that our quantitative data for vessel width are often substantially higher than vessel diameters reported in the wood anatomical literature. This may be due to the flattening of macerated vessels in microscopic slides. Furthermore, the vertical dimensions [μm] of pit apertures and borders were determined.

Vessel and pit dimensions are helpful when identifying an unknown species. They must be seen as guidelines, not as absolute values due to the variability of the species. Please note that the vertical dimensions of the pit borders may deviate from horizontal diameters given in most wood anatomical descriptions in the literature (of alternate pits only; cf. IAWA Committee 1989 and InsideWood 2004-onwards).

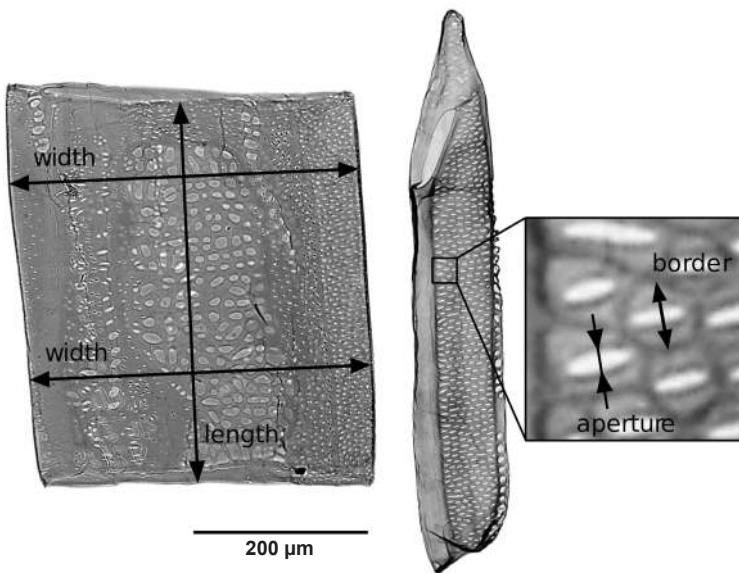


Figure 9. Measurement of vessel elements (length, width, vertical intervessel pit aperture and pit border size [μm]).

Fiber dimensions

The dimensions of the pulp fibers of Hardwoods were characterized morphologically with a Kajaani FiberLab® fiber analyzer. The fiber analyzer determines fiber length, fiber curl, fiber kinks, fibrillation, fractionation, and other parameters. The three important fiber characteristics length and width as well as cell wall thickness are presented in this atlas. All dimensions represent the weighted average (not the arithmetic average that is also calculated) because cell fragments, parenchyma cells and vessel elements in the pulp influence the measurement results. The length weighted average tends to reduce this influence (Nygård 2006).

$$\text{Arithmetic average fiber length [mm]: } L(n) = \frac{\sum (n_i \cdot l_i)}{\sum n_i}$$

$$\text{Length weighted fiber length [mm]: } L(l) = \frac{\sum (n_i \cdot l_i^2)}{\sum n_i l_i}$$

l_i = average length in class i ($i = 1 \dots 152$)

n_i = number of fibers in class i

Since for *Dendrocalamus latiflorus* (Bamboo) the data obtained with the fiber analyzer were much lower than what we observed in the microscopes, the algorithm for length weighted average of fiber length apparently does not sufficiently reduce the influence of parenchyma cells and cell fragments. Therefore the length of fibers of Monocots was determined by measuring 90 fibers in the light microscope (software: cellSens, Olympus Soft Imaging Solutions GmbH, Münster, Germany).

DESCRIPTIONS OF WOODY ANGIOSPERMS OF TROPICAL AND TEMPERATE ASIA

The following pages contain the descriptions and accompanying images of 38 species. For quicker orientation, the taxa are roughly divided into three groups and two sub-groups in the following order:

Monocots: without vessel-ray pits; with axially oriented pit fields and lines void of pits (p. 267)

Hardwood species with (mainly) simple perforation plates (p. 272)

APS: All Pits Similar (in size and shape) (p. 272)

VAS: Vessel-ray pits Apparently Simple (p. 296)

Hardwood species with exclusively scalariform perforation plates (p. 336)

The descriptions start with two monocots, Bamboo and Coconut palm, followed by the group of Hardwoods with simple perforations and with two subgroups:

“APS” (All Pits Similar). Species summarized in this subgroup possess the common feature of vessel-ray and vessel-axial parenchyma pits similar to intervessel pits. The similarity refers to the size and shape of the pits.

“VAS” (Vessel-ray pits Apparently Simple). The pits of vessel elements connecting to parenchyma cells – like vessel-ray pits or pits to axial parenchyma cells – are characterized by large apertures and their borders are much reduced and not or hardly visible under the light microscope. They differ in size and shape from the intervessel pits or pits to tracheids or fibers.

The second Hardwood group contains wood species with all perforation plates scalariform. It is also possible to distinguish these species into APS and VAS but since there are only six species in this group, such a fine subdivision was deemed unnecessary.

At the beginning of each chapter of the groups and subgroups introductory comments are given about the main features characteristic of the different wood species in these groups.

Monocots

introductory comments

This chapter contains two monocots: *Dendrocalamus latiflorus* (Bamboo) and *Cocos nucifera* (Coconut palm). They are included in this atlas because the material is expected to appear in paper products as an easily available resource from plantations.

As *Dendrocalamus latiflorus* is a grass and not a tree species it produces only a primary shoot without secondary growth (Liese 1998). There are no rays so the vascular bundles do not possess any vessel-ray pits. The vessel pits existing in vascular bundles connect with parenchyma cells or fibers.

Cocos nucifera is, like bamboo, a monocot. There is no secondary growth. The vascular bundles include very long vessel elements. They are by far the longest included in this atlas (Fig. 10a). The vessel pits present in the vascular bundles connect with adjacent parenchyma cells or fibers or with other metaxylem vessels.

Figure 10 shows the variation of vessel element length and width of the two monocots as well as the diameter of the apertures and borders of intervessel pits. The length of the vessel elements shows a significant difference whereas the width is similar and overlapping.

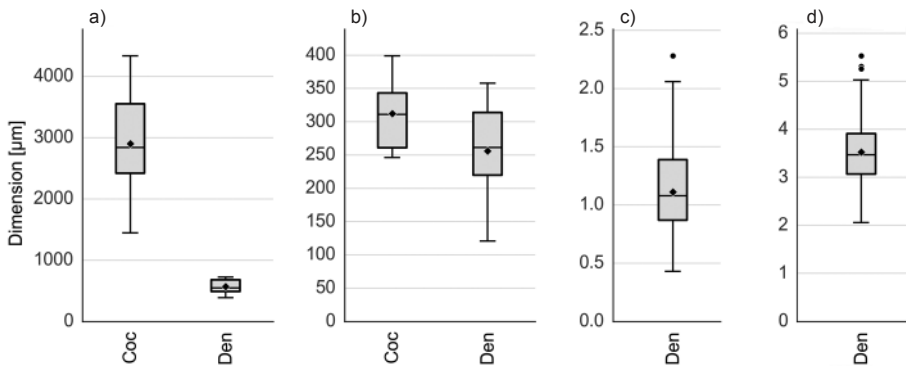
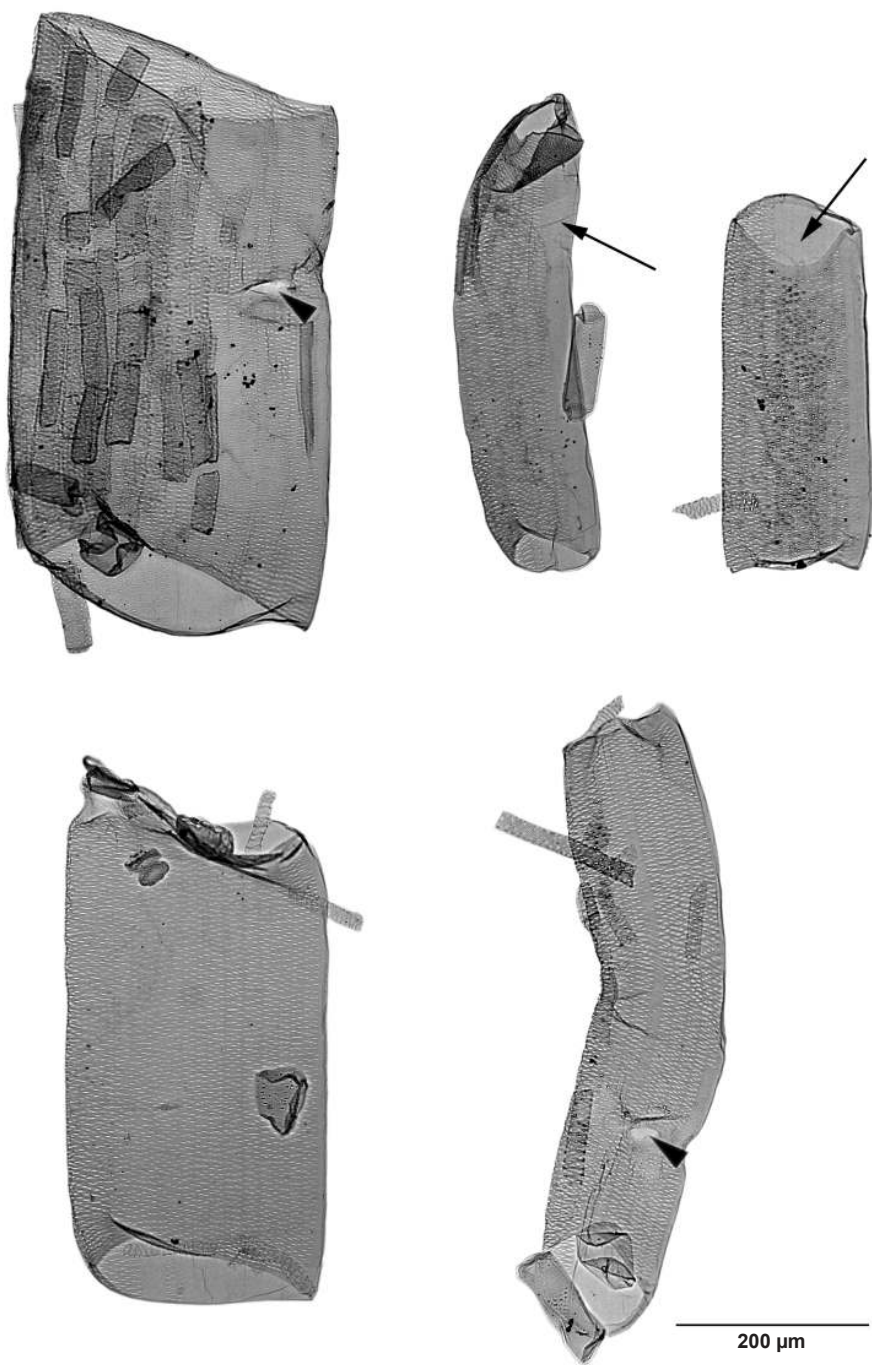


Figure 10. Boxplots of *Cocos nucifera* (Coc) and *Dendrocalamus latiflorus* (Den).

a) length and b) width of the vessel elements, c) diameter of pit apertures and d) borders; aperture and border sizes of the pits of *Cocos nucifera* are missing in this figure because scalariform pits can be deformed in macerations or pulp (p. 271).



Dendrocalamus latiflorus

***Dendrocalamus latiflorus* Munro (Poaceae)**

Trade names: bamboo, Taiwan giant bamboo.

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: from Myanmar to Southern China and Taiwan; cultivated in India, Thailand, Vietnam, Philippines and Japan.

Dendrocalamus latiflorus, a monocot; culms consist of parenchyma cells (about 50%), fibers (about 40%) and conducting tissue (about 10%, vessel elements included) (Liese 1997).

Vessel elements: rather long (about 550 μm), of average width (about 260 μm), either tube-shaped (those with a smaller diameter) or barrel-shaped (those with a larger diameter).

Tails: absent.

Perforation plates: simple, extending over the entire lumen; slightly inclined or horizontal.

Pits to parenchyma cells: alternate; 2–4–6 μm ; present in large fields over a wide area; apertures slit-like.

Areas without any pits: in the cell wall areas that border fiber sheaths, oriented vertically (arrows).

Tyloses: present.

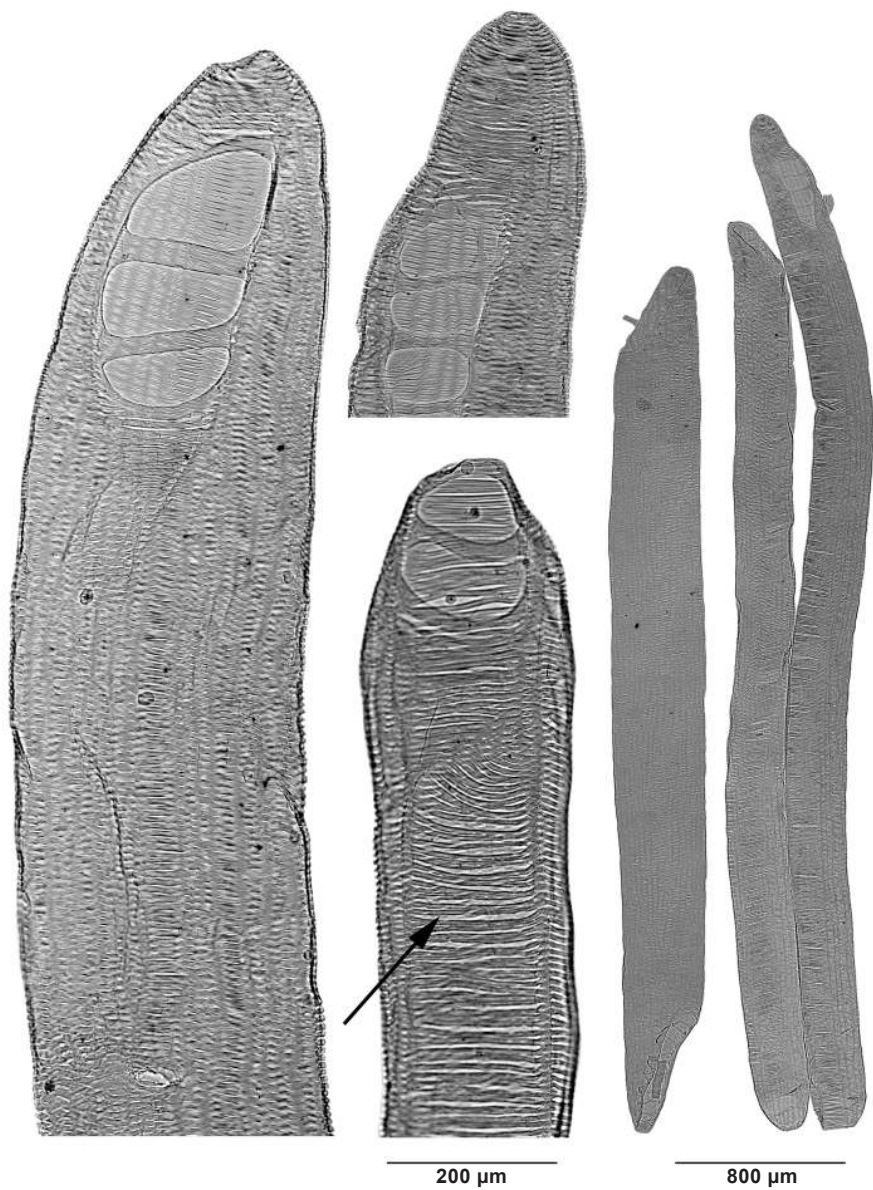
Helical thickenings: absent.

Notes on identification: Sometimes the vessel elements of *Dendrocalamus* spp. reveal small lateral holes due to vessel branching at the internodes (arrowheads). The vessel elements possess a similar appearance as those of wheat, corn and sugar cane with the maximum vessel element length of wheat: 1.0 mm; corn: 0.6 mm; sugar cane: 2.1 mm (according to Ilvessalo-Pfäffli 1995).

Quantitative data:

Vessel elements (388–)546(–723) μm long, and (121–)261(–358) μm wide; l/w ratio 2.3.

Fibers (487–)1262(–2575) μm long. Fiber diameter and fiber wall thickness very variable.



Cocos nucifera

***Cocos nucifera* L. (Arecaceae)**

Trade name: coconut palm.

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Tropics worldwide. Widely cultivated.

Cocos nucifera, a palm tree, is a monocot. The stems are built up of vascular bundles (vessels, fibers, parenchyma, phloem) embedded in ground tissue parenchyma.

Vessel elements: very long (about 2840 μm , width about 310 μm), much longer than vessel elements in dicotyledons, tube-shaped.

Tails: absent.

Perforation plates: scalariform with few and very thick bars (2–4 bars), inclined.

Intervessel pits: scalariform (arrow), with slit-like apertures.

Pits to parenchyma cells: apertures oval to slit-like.

Areas without any pits: absent.

Tyloses and helical thickenings: absent.

Quantitative data:

Vessel elements (1447–)2840(–4334) μm long and (246–)311(–399) μm wide; l/w ratio 8.4 (contrary to the descriptions of the other species, the apertures and borders of the pits of *Cocos nucifera* are missing in the data because the apertures can be deformed in macerations or pulp).

Fibers (1151–)2646(–4358) μm long. Fiber diameter and fiber wall thickness very variable.

Hardwoods with simple perforations

“APS” (All Pits Similar in size and shape) – introductory comments

The eleven wood species described in the following chapter possess the common feature of similar pits. All pit types in the vessel walls are similar in size and shape. The vessel-ray and vessel-axial parenchyma pits have the same appearance and size as the intervessel pits but their grouping may be different. In many cases the vessel-ray pits can be detected due to their specific arrangement in horizontally oriented pit areas separated by pitless zones (due to cell walls perpendicular to the vessel wall), *e.g.* *Acacia* sp., while the intervessel pits are arranged in continuous fields or areas (Figure 11).

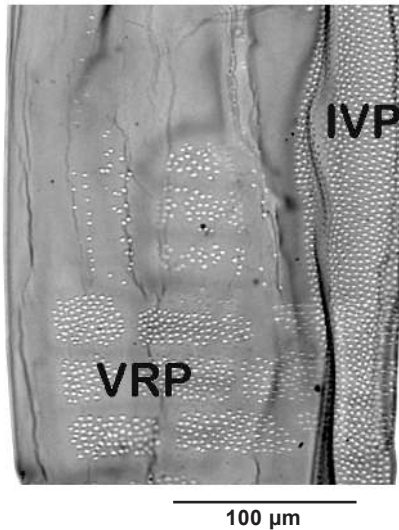


Figure 11. Similarity in size and shape of vessel-ray pits (VRP) and intervessel pits (IVP), *Lophopetalum* sp.

Figure 12 shows the variation of the vessel element parameters length and width as well as the diameter of the apertures and borders of intervessel pits. The boxplots show how variable the dimensions of the different species can be.

Tetramerista glabra possesses the longest vessel elements in this group. At the same time it reveals the smallest pit apertures. This is a useful combination well-suited for identification and illustrates the potential importance of the quantitative data. However, more specimens per species should be measured for using the quantitative features as robust diagnostic characters.

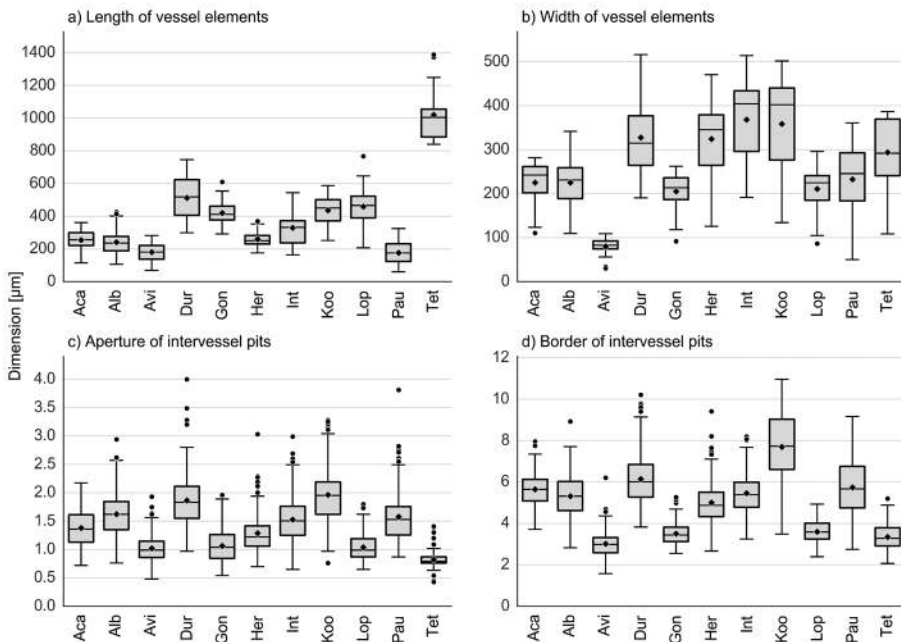
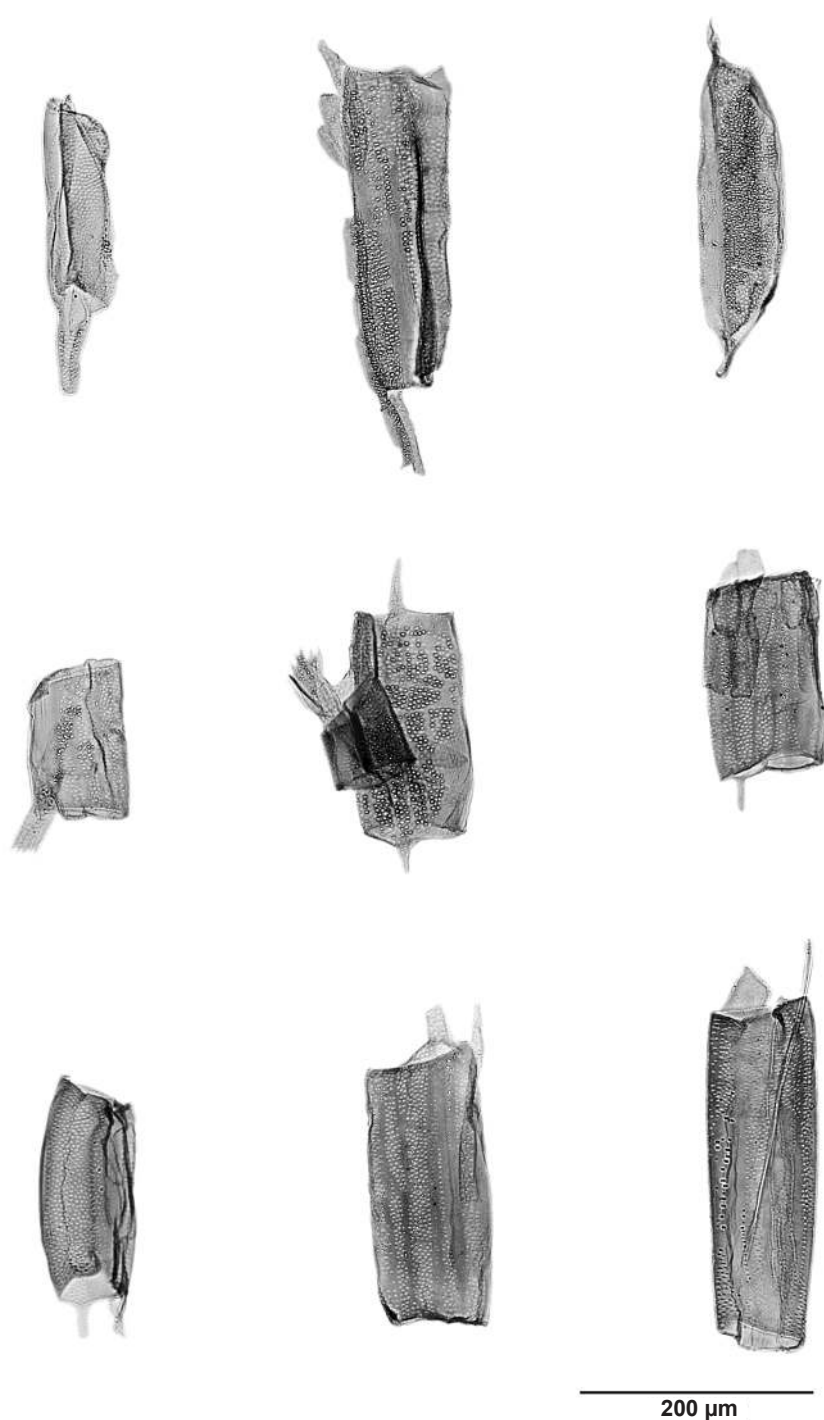


Figure 12. Boxplots of 11 wood genera/species: length and width of the vessel elements, diameter of pit apertures and borders.

Aca = *Acacia mangium*; Alb = *Albizia procera*; Avi = *Avicennia marina*; Dur = *Durio* sp.; Gon = *Gonystylus* sp.; Her = *Heritiera* sp.; Int = *Intsia* sp.; Koo = *Koompassia malaccensis*; Lop = *Lophopetalum* sp.; Pau = *Paulownia tomentosa*; Tet = *Tetramerista glabra*.



Avicennia marina

***Avicennia marina* (Forssk.) Vierh. (Acanthaceae)**

Trade name: api-api.

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: throughout the Tropics.

Avicennia is a genus of mangroves.

Vessel elements: very small (length about 180 μm , width 80 μm), mainly barrel-shaped.

Tails: often short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal or inclined.

Intervessel pits: alternate; vertical diameter 2–3–6 μm ; present over a wide area and in the tails.

Vessel-ray pits: APS; rarely present; in horizontal rows (3–5 rows per ray cell); oval apertures.

Pits to axial parenchyma cells: numerous; in longitudinal bands or blocks comprising 3–5 rows of pits.

Areas without any pits: present, small.

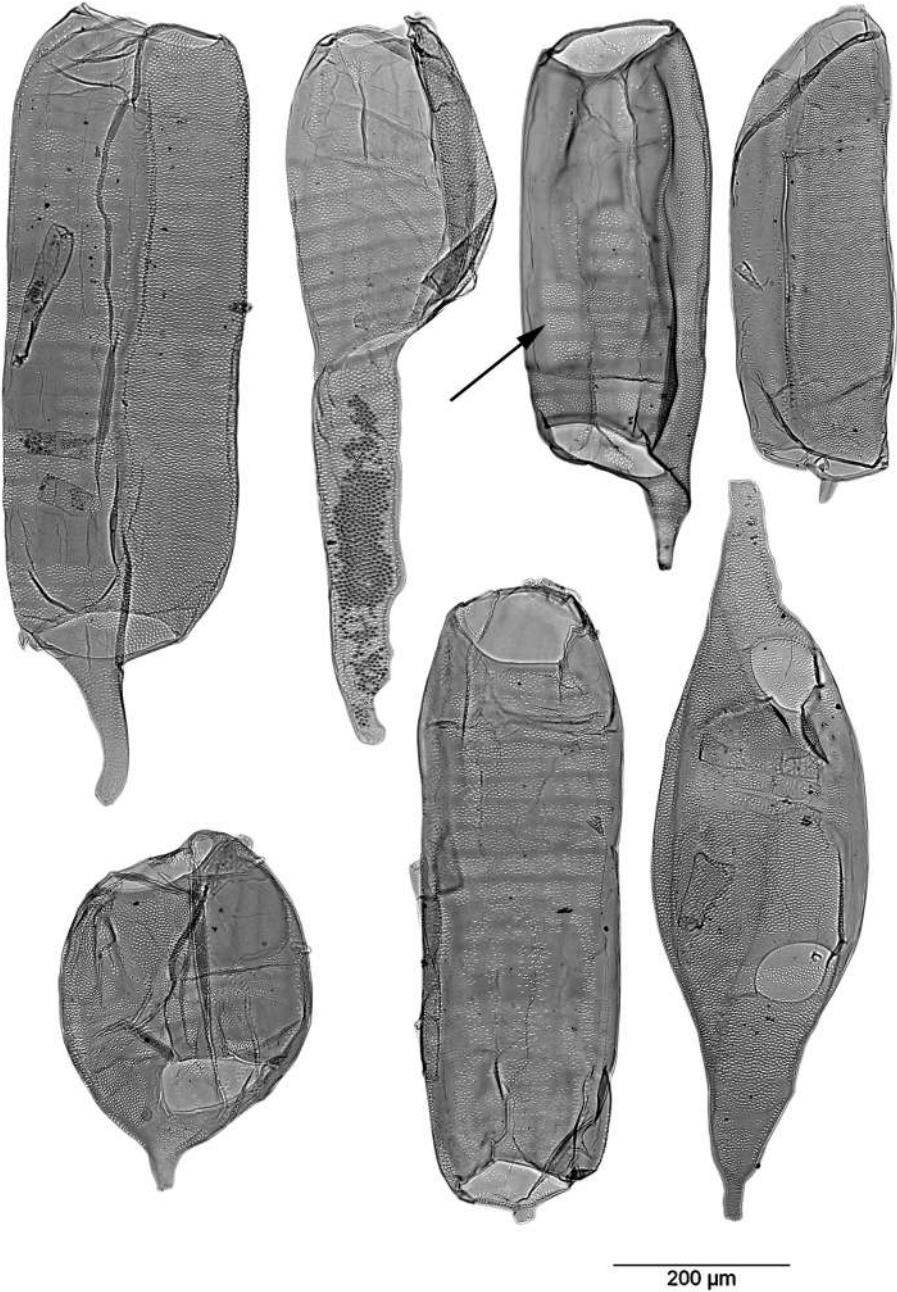
Tyloses and helical thickenings: absent.

Quantitative data:

Vessel elements (69–)180(–282) μm long, and (30–)83(–109) μm wide; l/w ratio 2.3.

Intervessel pit borders (1.6–)3.0(–6.2) μm in vertical diameter; pit apertures (0.5–)1.0(–1.9) μm .

Fibers 810 μm long, 16.8 μm wide. Fiber wall thickness 6.3 μm (weighted averages).



Lophopetalum sp.

***Lophopetalum* sp.** (Celastraceae)

Trade names: perupok, perupuk (MY, ID); adau, dual (BN); medang kerupuk, pasana (ID); abuab (PH); taung-yemará (MM); phuamphrao, dimi, samet-thung (TH).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Eastern Pakistan, Western India, Indochina and throughout Malesia; main centers of endemism are Borneo and New Guinea.

Vessel elements: average length about 470 μm , width about 230 μm ; mostly rather slim (tube-shaped), sometimes shorter and “drop-shaped”.

Tails: short to very long, with abrupt or gradual transition.

Perforation plates: simple; in tapering end walls; sometimes positioned laterally.

Intervessel pits: alternate; vertical diameter 2–4–5 μm ; present in large fields covering a wide area; apertures oval.

Vessel-ray pits: APS; often present, in long horizontal rows (6–8 rows per ray cell) separated by well-defined pitless zones (arrow).

Pits to axial parenchyma cells: present, arranged in sinuous vertical bands.

Pits to fibers: rarely present in single vertical rows.

Areas without any pits: sometimes present; large.

Tyloses and helical thickenings: absent.

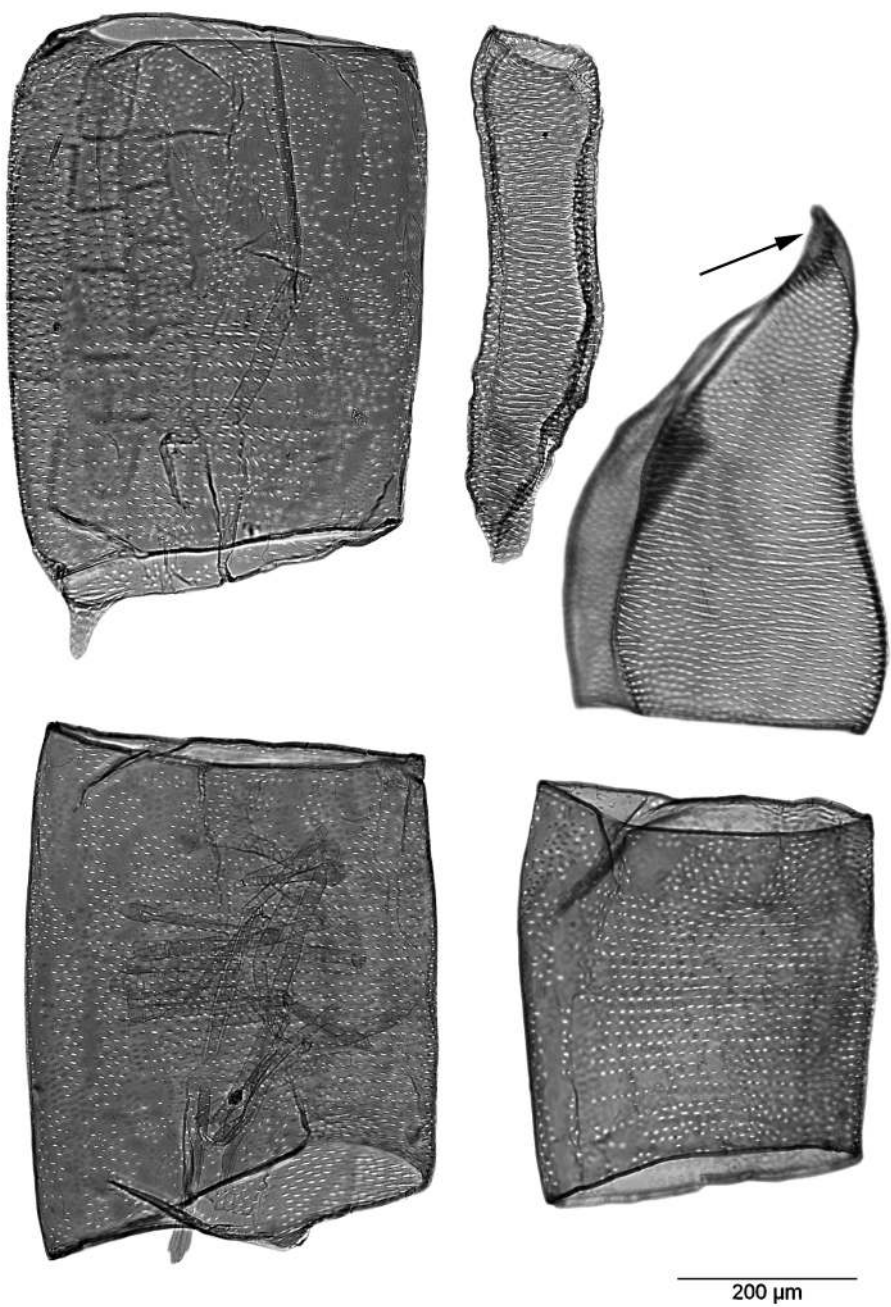
Notes on identification: The vessel elements of *Lophopetalum* spp. are similar to those of *Gonystylus* spp. and *Durio* spp. (see *Gonystylus* sp., p. 294).

Quantitative data:

Vessel elements (207–)467(–767) μm long, and (87–)225(–296) μm wide; l/w ratio 2.2.

Intervessel pit borders (2.4–)3.6(–4.9) μm in vertical diameter; pit apertures (0.7–)1.0(–1.8) μm .

Fibers 980 μm long, 25.3 μm wide. Fiber wall thickness 7.2 μm (weighted averages).



Koempassia malaccensis

***Koompassia malaccensis* Maingay ex Benth.**
(Fabaceae–Caesalpinioideae)

Trade names: kempas (MY, ID, MY-swk, GB, NL); hampas, pah, mengris, impas, toemaling, garis, ajam (ID).

DIN EN 13556:2003 code: KOML.

CITES regulations: not protected.

Geographic distribution: Southern Thailand and Malesia (except Philippines).

Vessel elements: two size classes (length about 450 μm , width about 400 μm), barrel-shaped (those with a larger diameter) or tube-shaped (those with a smaller diameter).

Tails: small with abrupt transition, or absent.

Perforation plates: simple; extending over the entire lumen; horizontal, rarely inclined and pointed (arrow).

Intervessel pits: alternate; vertical diameter 4–8–11 μm ; present in fields, sometimes over the whole area; apertures slit-like, sometimes coalescent.

Vessel-ray pits: APS; numerous, in horizontal pattern (1–2 rows per ray cell).

Pits to axial parenchyma cells: in vertically oriented blocks.

Areas without any pits: regularly present; small.

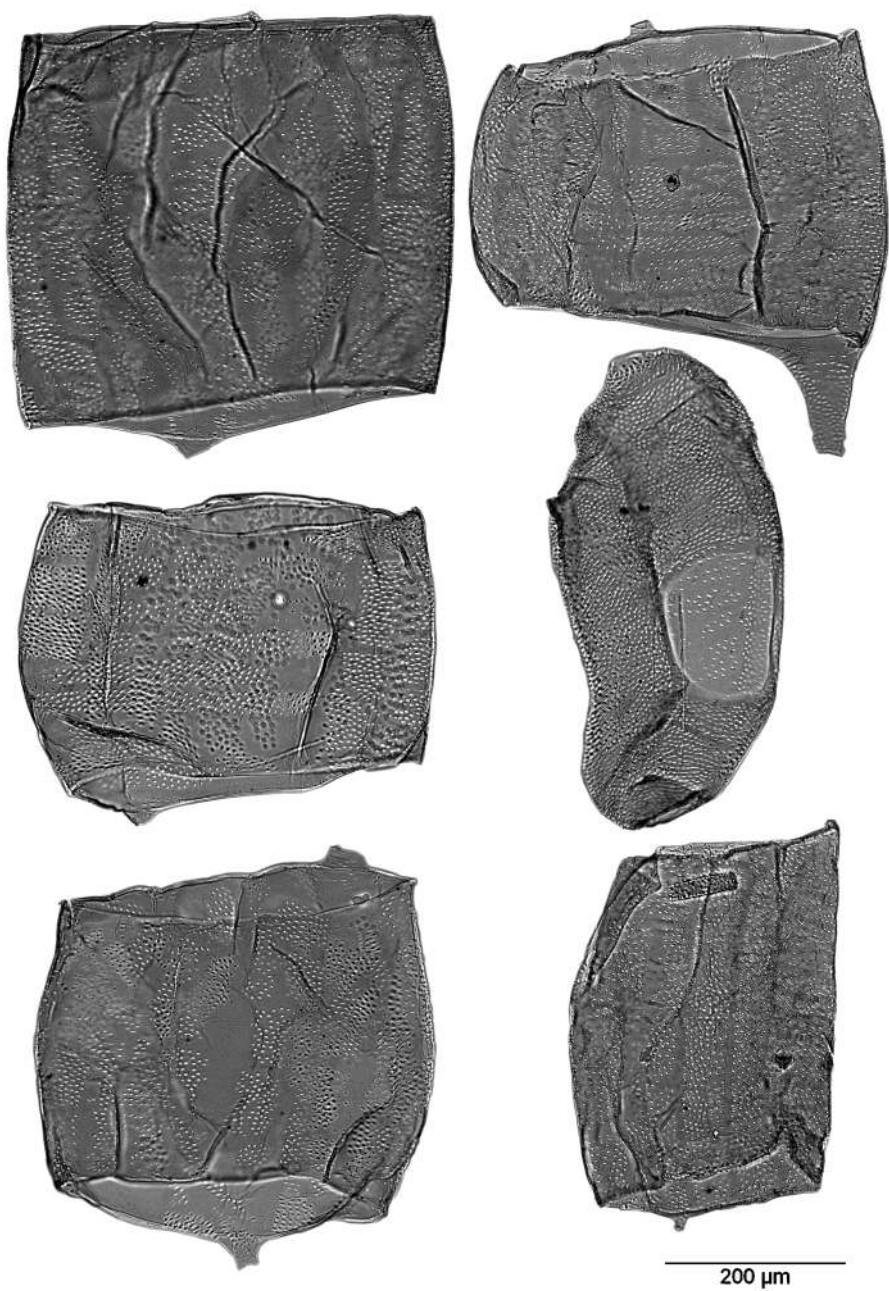
Tyloses and helical thickenings: absent.

Quantitative data:

Vessel elements (251–)450(–588) μm long, and (134–) 402(–502) μm wide; l/w ratio 1.2.

Intervessel pit borders (3.5–)7.7(–11.0) μm in vertical diameter; pit apertures (0.8–) 2.0(–3.3) μm .

Fibers 1310 μm long, 21.7 μm wide. Fiber wall thickness 4.9 μm (weighted averages).



Intsia sp.

***Intsia* sp.** (Fabaceae–Caesalpinioideae)

Trade names: merbau (MY); Malacca teak, mirabow, Moluccan ironwood (GB); ipil, kayu besi (ID); kwila, bendora (PG); ipil, ipil laut, malaipil (PH); tat-takun (MM); krakas prak (KH); lumpho, lumpho thale (TH); hintzy (MG).

DIN EN 13556-2003 code: INXX (main species are *I. bijuga* and *I. palembanica*).

CITES regulations: not protected.

Geographic distribution: Indochina, Indomalesia, Pacific Islands, Australia, Madagascar, East Africa.

Vessel elements: rather short, but wide (length about 330 μm , width about 400 μm); often drum-shaped (those with a larger diameter), complemented by some barrel-shaped elements (those with a smaller diameter).

Tails: rather short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; rarely positioned laterally; horizontal.

Intervessel pits: alternate; vertical diameter 3–5–8 μm ; present over a wide area and in the tails; apertures oval.

Vessel-ray pits: APS; in 3–5 horizontal rows.

Pits to parenchyma cells: blocks arranged in sinuous longitudinal bands mirroring the parenchyma strands.

Areas without any pits: regularly present; small.

Tyloses and helical thickenings: absent.

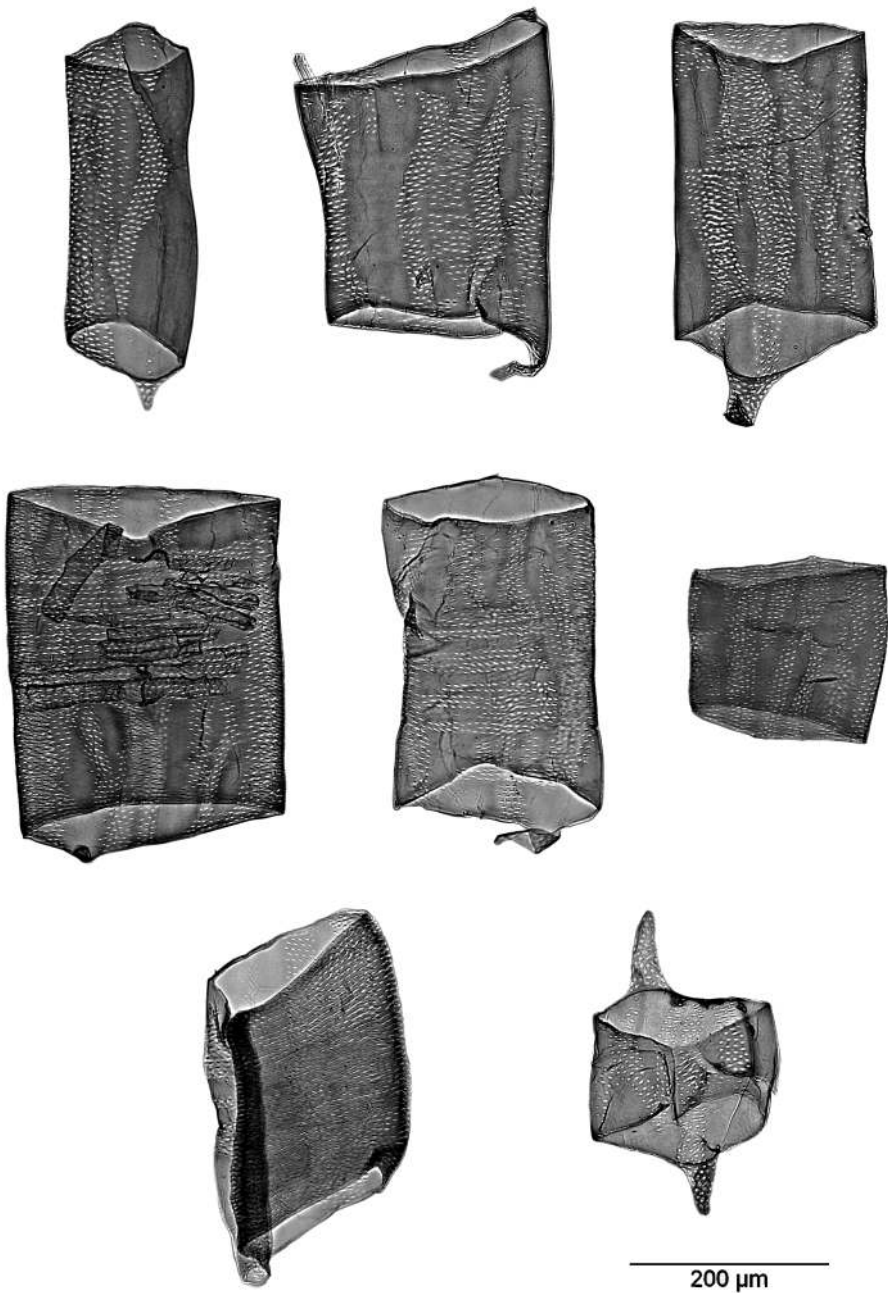
Notes on identification: The intervessel pitting is similar to that of *Acacia* spp. but the vessel elements of *Intsia* spp. are larger in diameter.

Quantitative data:

Vessel elements (164–)333(–544) μm long, and (191–)405(–514) μm wide; l/w ratio 0.9.

Intervessel pit borders (3.2–)5.4(–8.2) μm in vertical diameter; pit apertures (0.7–)1.5(–3.0) μm .

Fibers 1590 μm long, 21.9 μm wide. Fiber wall thickness 5.3 μm (weighted averages).



Acacia mangium

***Acacia mangium* Willd. (Fabaceae–Mimosoideae)**

Trade names: acasia, mangium (ID, MY).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: native to Australia and the Moluccan Islands; introduced in many countries, most notably in Asia (Bangladesh, China, Indonesia, Laos, Malaysia, Nepal, Philippines, Thailand, Vietnam) but also in Brazil, Cameroon, Costa Rica, Hawaii.

Acacia mangium plantations provide solid wood and short fiber raw material for the pulp and paper industry.

Vessel elements: rather small (length about 260 μm , width about 240 μm), often elongated (barrel-shaped), sometimes shorter (drum-shaped).

Tails: mostly short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: pits alternate; vertical diameter 4–6–8 μm ; rather scarce; apertures oval to slit-like.

Vessel-ray pits: APS; arranged in 2–3 horizontal rows per ray cell, separated by spaces free of pits.

Pits to axial parenchyma: frequent blocks, arranged in sinuous longitudinal rows mirroring the parenchyma strands.

Areas without any pits: regularly present; small to large.

Tyloses and helical thickenings: absent.

Notes on identification: Vessel elements of *Acacia* spp. are similar in appearance to *Albizia* spp. (same family). The tails of *Acacia* spp. are shorter than those of *Albizia*.

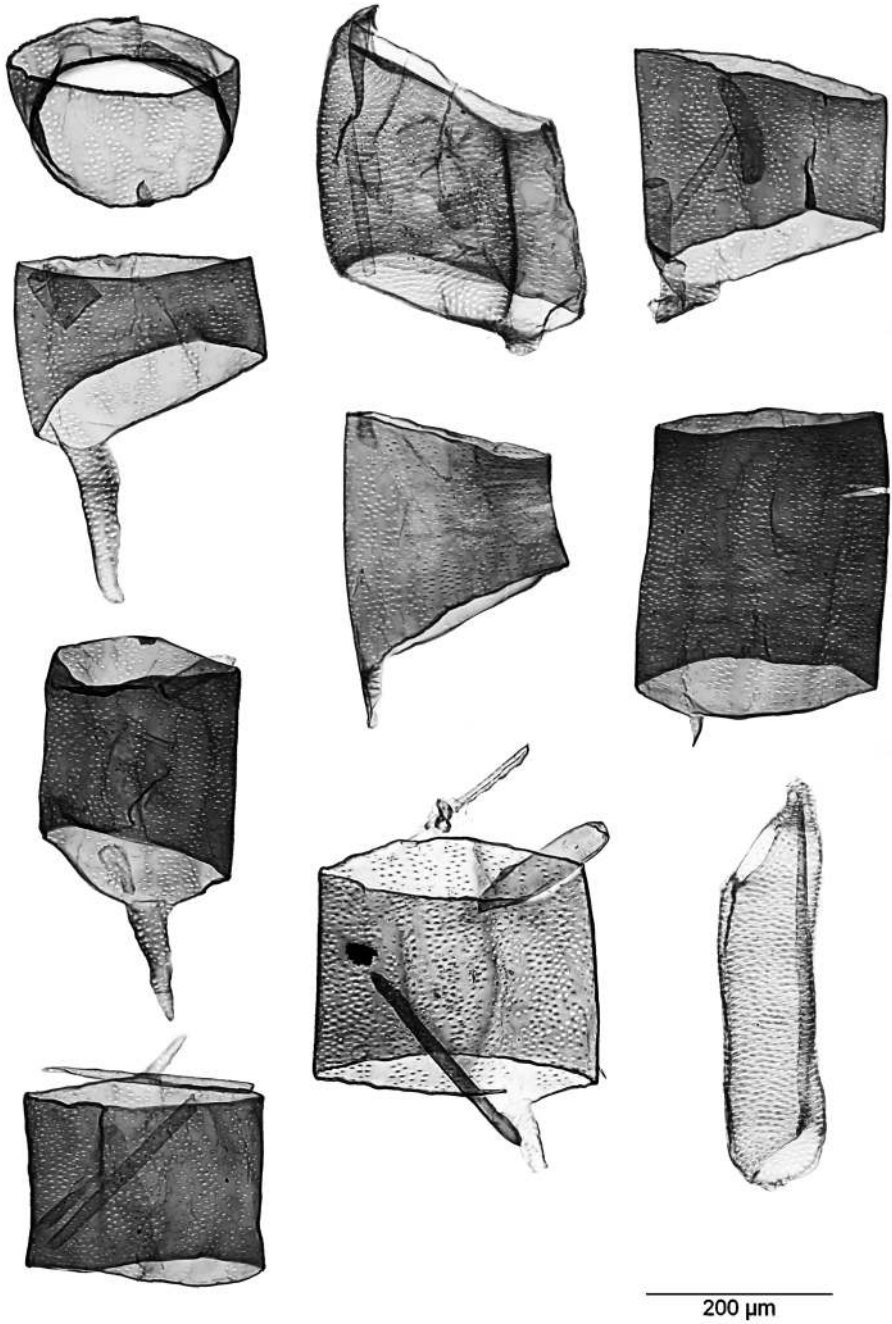
The intervessel pits are rather scarce whereas the ones of *Albizia* spp. are regularly present.

Quantitative data:

Vessel elements (114–)256(–361) μm long, and (111–)243(–282) μm wide; l/w ratio 1.0.

Intervessel pit borders (3.7–)5.6(–8.0) μm in vertical diameter; pit apertures (0.7–)1.4(–2.2) μm .

Fibers 830 μm long, 17.9 μm wide. Fiber wall thickness 4.3 μm (weighted averages).



Albizia procera

***Albizia procera* (Roxb.) Benth. (Fabaceae–Mimosoideae)**

Trade names: tall albizia (GB); ki hiyang, wangkal, weru (ID); brown albizia (PG); akleng parang (PH); kokko-sit, sit, sitpen (MM); suan, thing thon (TH); muong xanh (VN); karangro, karak, baro, dun-siris, gurar (IN); oriang (MY); seto siris (NP); tramkang (KH); rain siris (AU).

DIN EN 13556:2003 code: AZXX (*Albizia* spp.).

CITES regulations: not protected.

Geographic distribution: China, Indochina, Indomalesia, Pacific Islands, Australia.

Vessel elements: quite short (about 240 μm , width about 230 μm); mainly drum-shaped (with larger diameter), sometimes tube and barrel-shaped (with smaller diameter).

Tails: sometimes short to mostly rather long, with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal to slightly inclined.

Intervessel pits: alternate; vertical diameter 3–5–9 μm ; arranged in large fields, also in the tails; apertures circular to oval.

Vessel-ray pits: APS; similar to intervessel pits.

Pits to axial parenchyma cells: present in blocks (2–4 rows of pits wide) forming vertical strips.

Pits to fibers: rarely present; arranged in single vertical rows; rather small.

Areas without any pits: regularly present; small.

Tyloses and helical thickenings: absent.

Notes on identification: Vessel elements of *Albizia* spp. are similar to those of *Acacia* spp. in their appearance (same family, p. 282).

Quantitative data:

Vessel elements (106–)235(–426) μm long, and (110–)231(–342) μm wide; l/w ratio 1.0.

Intervessel pit borders (2.8–)5.3(–8.9) μm in vertical diameter; pit apertures (0.8–)1.6(–2.9) μm .

Fibers 890 μm long, 23.2 μm wide. Fiber wall thickness 2.3 μm (weighted averages).



Durio sp.

***Durio* sp. (Malvaceae)**

Trade names: durian (DE, ID, MY); punggai, durian isa (MY).

DIN EN 13556:2003 code: DUXX.

CITES regulations: not protected.

Geographic distribution: Indochina, Indomalesia.

Durio spp. is cultivated as plantation tree for fruit production. The wood is used for furniture or ply-wood.

Vessel elements: rather large (length about 520 μm , width about 320 μm), mainly barrel-shaped.

Tails: short with abrupt transition, sometimes longer with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal or inclined.

Intervessel pits: alternate; vertical diameter 4–6–10 μm ; numerous; present over a wide area and in the tails; pit apertures oval to slit-like.

Vessel-ray pits: APS; cross-fields arranged in neat horizontal series with 3–6 rows of pits per ray cell.

Pits to axial parenchyma cells: cross-fields arranged in longitudinal series (3–5 pits wide) of mostly irregular outline; apertures oval to slit-like.

Areas without any pits: regularly present; small.

Tyloses and helical thickenings: absent.

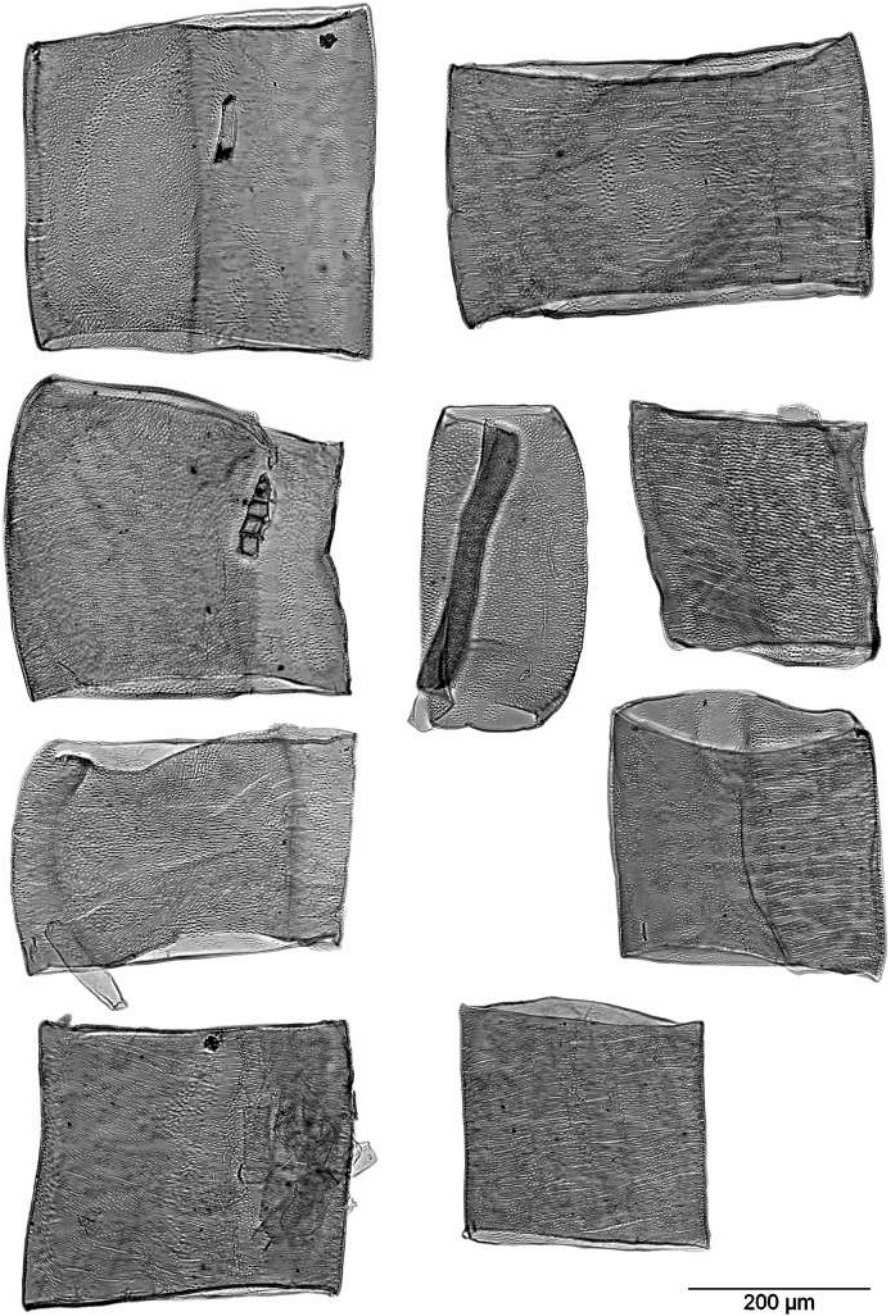
Notes on identification: Vessel elements of *Durio* spp. are similar in appearance to those of *Gonystylus* spp. and *Lophopetalum* spp. (see *Gonystylus* sp., p. 294).

Quantitative data:

Vessel elements (299–)519(–746) μm long, and (191–)315(–516) μm wide; l/w ratio 1.6.

Intervessel pit borders (3.8–)6.0(–10.2) μm in vertical diameter; pit apertures (1.0–)1.8(–4.0) μm .

Fibers 1375 μm long, 29.4 μm wide. Fiber wall thickness 8.0 μm (weighted averages).



Heritiera sp.

***Heritiera* sp. (Malvaceae)**

Trade names: mengkulang (MY); palapi, teraling, tarrietia (ID); huynh (VN); dong chem, sempong, sonloc (KH); lumbayau (PH); may nhom pa (LA), kanzo (MM).

DIN EN 13556:2003 code: HEXM.

CITES regulations: not protected.

Geographic distribution: Tropical Africa, Southern Asia from India to New Guinea, Micronesia and tropical Australia.

Vessel elements: rather short and wide (length about 250 μm , width about 350 μm); mainly drum-shaped, sometimes barrel-shaped.

Tails: rarely present; long with gradual transition; pitted.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 3–5–9 μm ; present in large fields over a wide area.

Vessel-ray pits and pits to parenchyma cells: APS; cross-fields aligned in horizontal (vessel-ray pits) or vertical (pits to parenchyma cells) series, similar to those of *Tetramerista* sp.; apertures slit-like, in centre of the cross-fields sometimes coalescent.

Areas without any pits: if present, very small.

Tyloses and helical thickenings: absent.

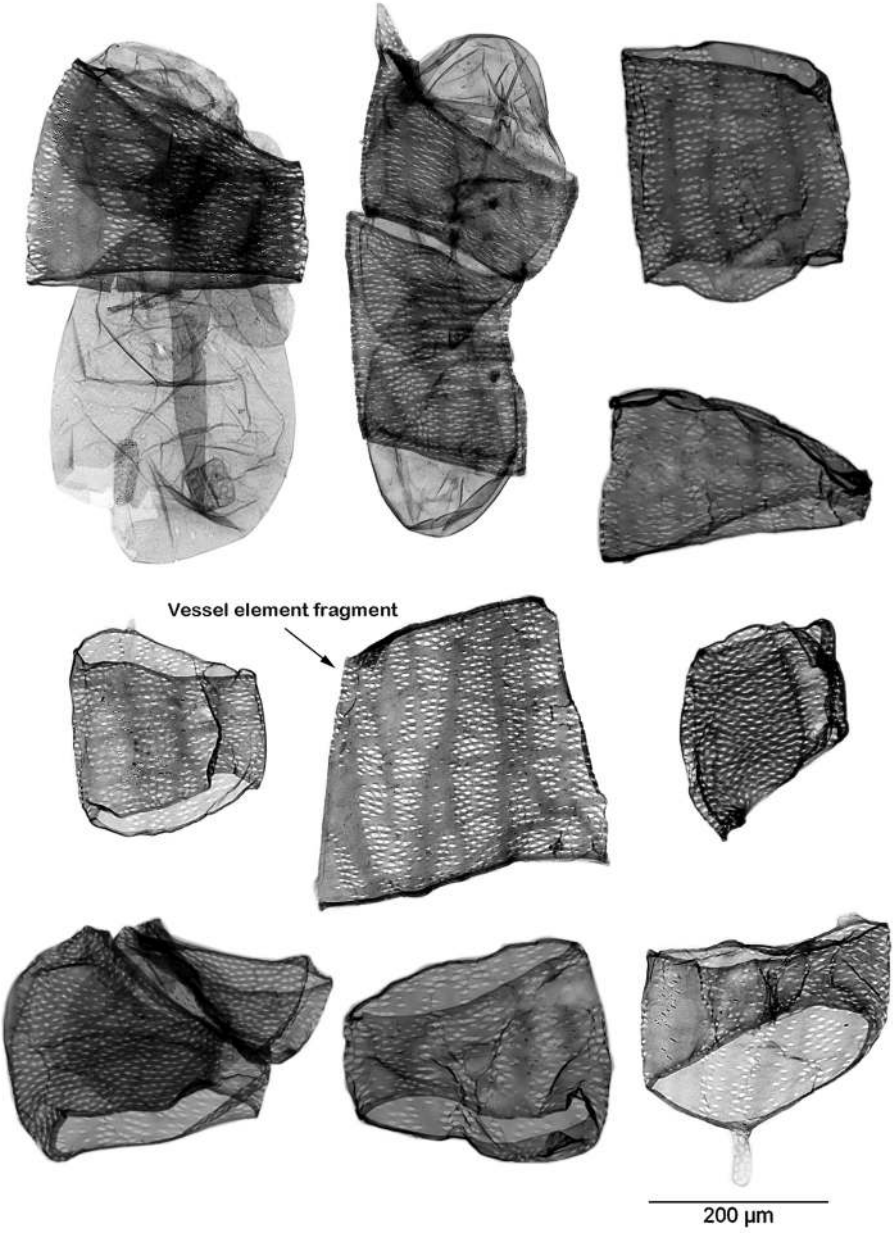
Notes on identification: see *Tetramerista glabra* (p. 292).

Quantitative data:

Vessel elements (175–)250(–369) μm long, and (126–)345(–471) μm wide; l/w ratio 0.8.

Intervessel pit borders (2.7–)4.9(–9.4) μm in vertical diameter; pit apertures (0.7–)1.2(–3.0) μm .

Fibers 1290 μm long, 21.0 μm wide. Fiber wall thickness 5.1 μm (weighted averages).



Paulownia tomentosa

***Paulownia tomentosa* (Thunb.) Steud. (Paulowniaceae)**

Trade names: kiri, shima-giri (JP); mao pao tong (CN); paulownia impérial (FR); empresstree (GB, US); Chinesischer Blauglockenbaum (DE).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Temperate Asia. Cultivated worldwide in regions with a temperate or subtropical climate.

Vessel elements: rather short and wide (length about 180 μm , width about 250 μm); mainly drum-shaped (those with a larger diameter, earlywood vessel elements), sometimes barrel-shaped (those with a smaller diameter, latewood vessel elements).

Arrow: One vessel element was cut in half to improve the presentation of the characteristics (pit arrangement).

Tails: rare, short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal or inclined.

Intervessel pits: alternate; vertical diameter 3–6–9 μm ; distributed over a wide area on the entire vessel element wall; apertures oval.

Vessel-ray pits: APS; cross-fields in horizontal series of mostly two rows of pits; pits occasionally with large apertures resembling simple pits.

Pits to axial parenchyma cells: numerous, sometimes larger than the intervessel pits; cross-fields in neatly vertical series.

Areas without any pits: regularly present; small.

Tyloses: present.

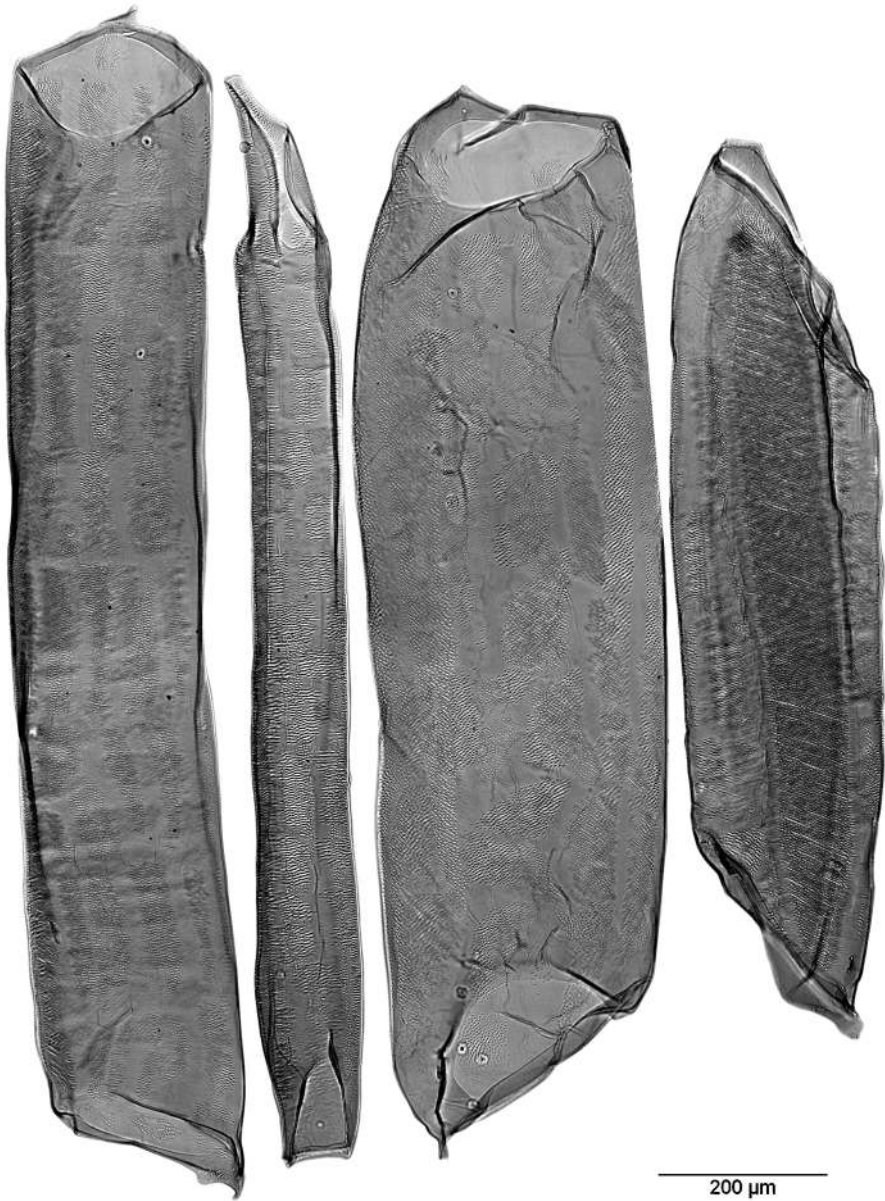
Helical thickenings: absent.

Quantitative data:

Vessel elements (60–)175(–325) μm long, and (50–)245(–361) μm wide; l/w ratio 0.7.

Intervessel pit borders (2.7–)5.7(–9.2) μm in vertical diameter; pit apertures (0.9–)1.5(–3.8) μm .

Fibers 560 μm long, 25.8 μm wide. Fiber wall thickness 3.0 μm (weighted averages).



Tetramerista glabra

***Tetramerista glabra* Miq. (Tetrameristaceae)**

Trade names: punah (MY); entuyut (MY-swk); tuyut (MY-sab); punak (ID).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Western Indomalesia.

Vessel elements: very long (about 980 μm), width varies from slim to quite wide (average about 290 μm); mainly tube-shaped.

Tails: short with abrupt transition or longer with gradual transition.

Perforation plates: simple, often extending over the entire lumen; inclined.

Intervessel pits: alternate; very small; vertical diameter 2–3–5 μm ; covering large vessel wall areas; apertures circular to oval; inner pit apertures slit-like and coalescent; forming diagonal striations (similar to *Heritiera* sp., p. 288).

Vessel-ray pits: APS; in horizontal series of small cross-fields, pits with oval apertures.

Pits to axial parenchyma cells: in vertical series of elongated cross-fields separated by pit-free lines; inner pit apertures slit-like, partly coalescent, connecting 2–4 pits.

Areas without any pits: regularly present; rather small to sometimes large.

Tyloses and helical thickenings: absent.

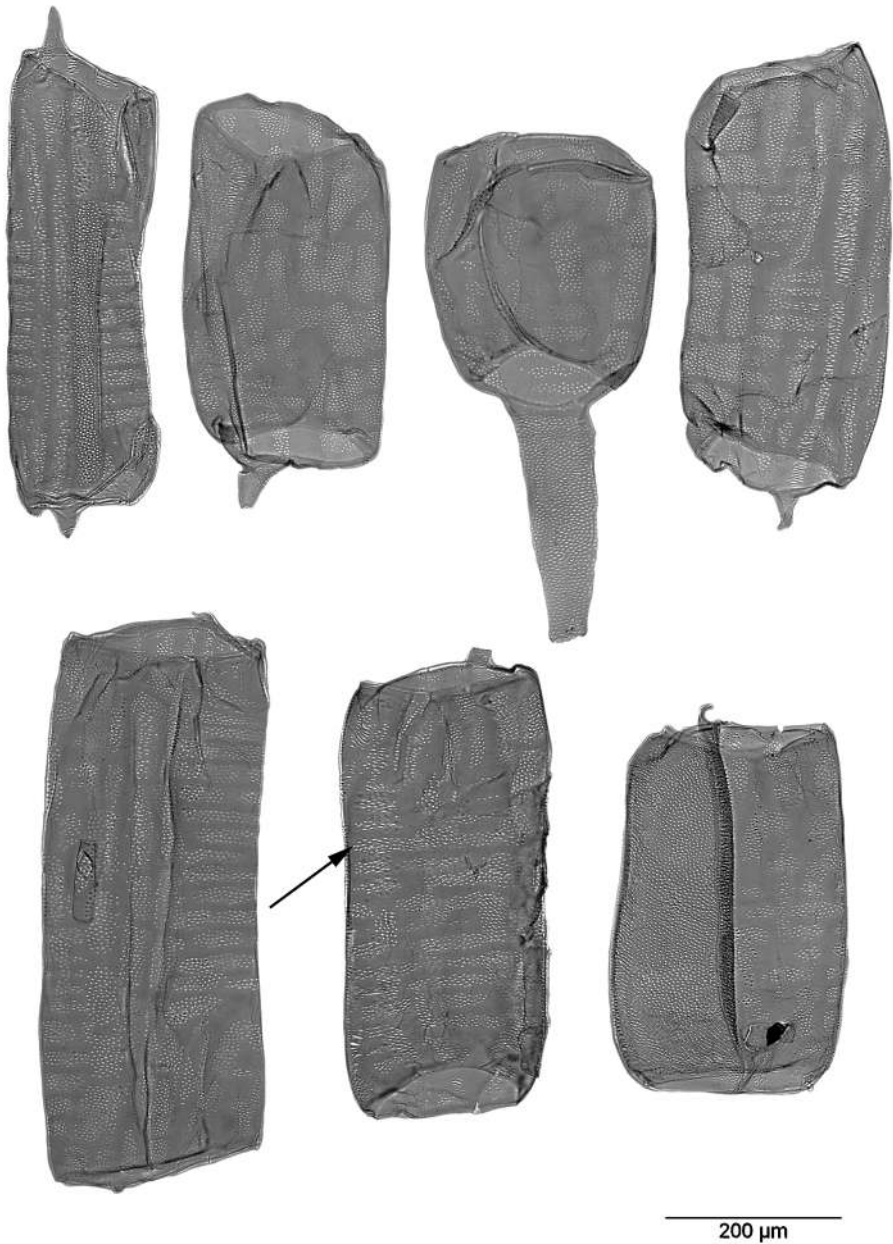
Notes on identification: The pit shape of *Tetramerista* spp. is similar to that of *Heritiera* spp. (p. 288), but the vessel elements are longer.

Quantitative data:

Vessel elements (479–)978(–1390) μm long, and (108–)288(–387) μm wide; l/w ratio 3.5.

Intervessel pit borders (2.1–)3.3(–5.2) μm in vertical diameter; pit apertures (0.4–)0.8(–1.4) μm .

Fibers 895 μm long, 30.2 μm wide. Fiber wall thickness 7.0 μm (weighted averages).



Gonystylus sp.

***Gonystylus* sp. (Thymelaeaceae)**

Trade name: ramin (DE, GB, MY, ID).

DIN EN 13556:2003 code: GYBN (*G. bancanus* (Miq.) Kurz).

CITES regulations: protected (Annex II).

Geographic distribution: Indomalesia and West Pacific islands (Fiji).

The wood was often used for furniture, broomsticks and moldings.

Vessel elements: of medium size or large (length 410 μm , width 210 μm); often elongated (barrel-shaped), rarely drum-shaped.

Tails: often short and rarely long; both with abrupt transition.

Perforation plates: simple, mostly extending over the entire lumen; horizontal or slightly inclined and narrowed.

Intervessel pits: alternate; vertical diameter 3–5 μm ; present over a wide area and in the tails.

Vessel-ray pits: APS; cross-fields in horizontal series (3–6 pit rows per ray cell); apertures oval, sometimes slit-like.

Pits to axial parenchyma cells: cross-fields arranged in vertical series, separated by pitless strips.

Areas without any pits: regularly present; rather small, sometimes larger.

Tyloses and helical thickenings: absent.

Notes on identification: Vessel elements of *Gonystylus* spp. are similar in their appearance to those of *Durio* spp. and *Lophopetalum* spp. Corners of cross-fields of vessel-ray pits often rounded (arrow) as pits in the corners are often missing (*Lophopetalum* spp.: cross-fields rectangular, “corner pits” present, p. 276).

Quantitative data:

Vessel elements (292–)412(–607) μm long, and (92–)214(–262) μm wide; l/w ratio 2.0.

Intervessel pit borders (2.6–)3.4(–5.3) μm in vertical diameter; pit apertures (0.5–)1.0(–2.0) μm .

Fibers 1160 μm long, 29.0 μm wide. Fiber wall thickness 7.4 μm (weighted averages).

“VAS” (Vessel-ray pits Apparently Simple) introductory comments

In the 19 genera and subgenera belonging to this group the vessel-ray pits differ in type and shape from the intervessel pits. The borders of the vessel-ray pits are not or hardly visible under the light microscope – and pits are called “apparently simple”, represented by the acronym “VAS” (Vessel-ray pits Apparently Simple). Due to the different shapes of the pit apertures they can be subdivided into three groups. Figure 13 shows three different types of pit shapes and arrangement.

The numerous vessel-ray pits and pits to axial parenchyma cells of Anacardiaceae have a remarkable appearance. The apertures are elongated and resemble eyes (Fig. 13A).

Reticulate vessel-ray pits are common in the species of *Canarium*, *Calophyllum*, *Hevea brasiliensis*, *Castanopsis argentea*, *Eucalyptus globulus*, *Madhuca sericea*, and *Syzygium dyerianum*. The vessel-ray pits are arranged in horizontal rows along the rays and resemble a net-like structure (Fig. 13B).

Furthermore, this group also includes the important subgenera of *Shorea* and two further genera of the Dipterocarpaceae. The vessel elements are mainly barrel-shaped.

Based on practical experience, it is possible to identify the vessel elements of the genus *Shorea* but it is impossible to separate the individual subgenera. Considering the family as a whole, there is a high risk to confuse the economically important genera, e.g. *Shorea*, *Parashorea*, and *Dipterocarpus*. However, the appearance of the simple vessel-ray pits and the pits to axial parenchyma cells of *Shorea* differ remarkably in size and shape (Fig. 13C).

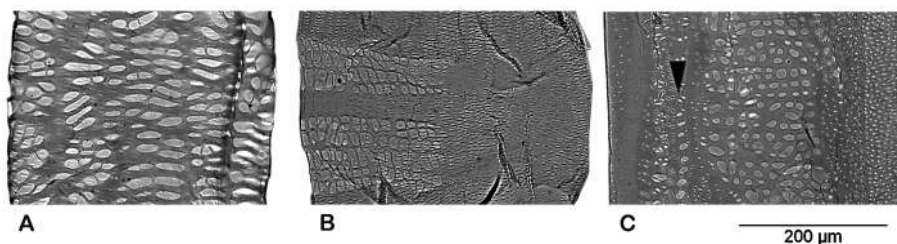


Figure 13. – A: gash-like vessel-ray pit apertures, *Swintonia* sp. – B: reticulate (and partly palisade) vessel-ray pits, *Calophyllum* sp. – C: diversity of pit sizes and shapes: vessel-ray pits and pits to axial parenchyma cells (arrowhead), *Shorea* subg. *Rubroshorea*.

Figure 14 shows the variation of vessel element length and width as well as the vertical diameter of the apertures and borders of intervessel pits. The boxplots of the length (Fig. 14a), width (Fig. 14b) and the borders of the intervessel pits (Fig. 14d) show how variable the dimensions of the different species can be. The dimensions of the apertures of the intervessel pits (Fig. 14c) lie close together, with some deviations (*e.g.* *Calophyllum* sp., *Madhuca sericea*, and *Canarium* sp.).

Mangifera sp. possesses the shortest vessel elements in this group (Fig. 14a) whereas the width of *Mangifera* sp. is average (Fig. 14b). *Syzygium dyerianum* reveals the longest vessel elements (Fig. 14a) whereas the width is similar to that of *Mangifera* sp. (Fig. 14b).

Because we only studied one sample per genus or species, these differences must be tested with much broader sampling.

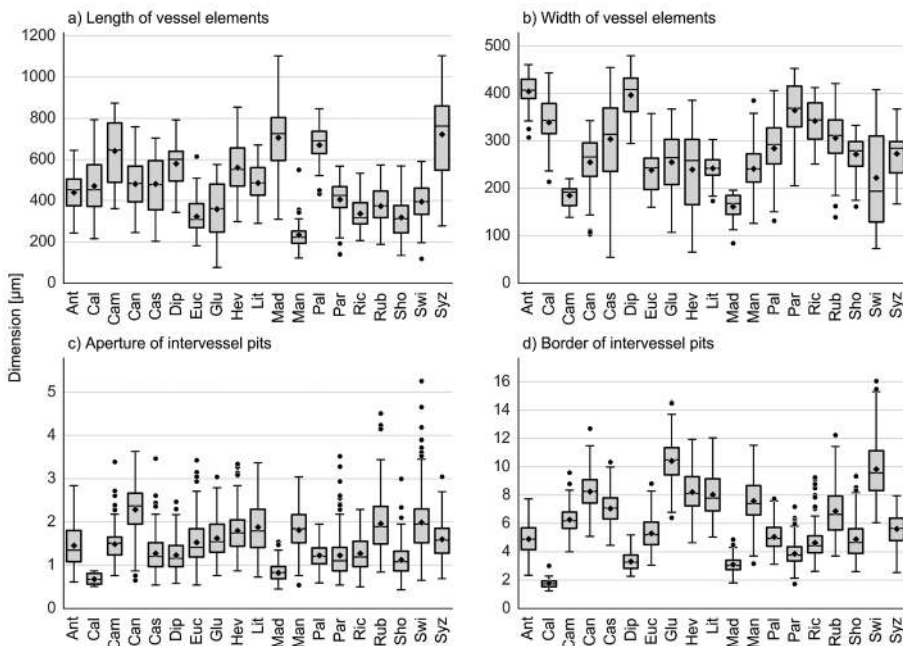
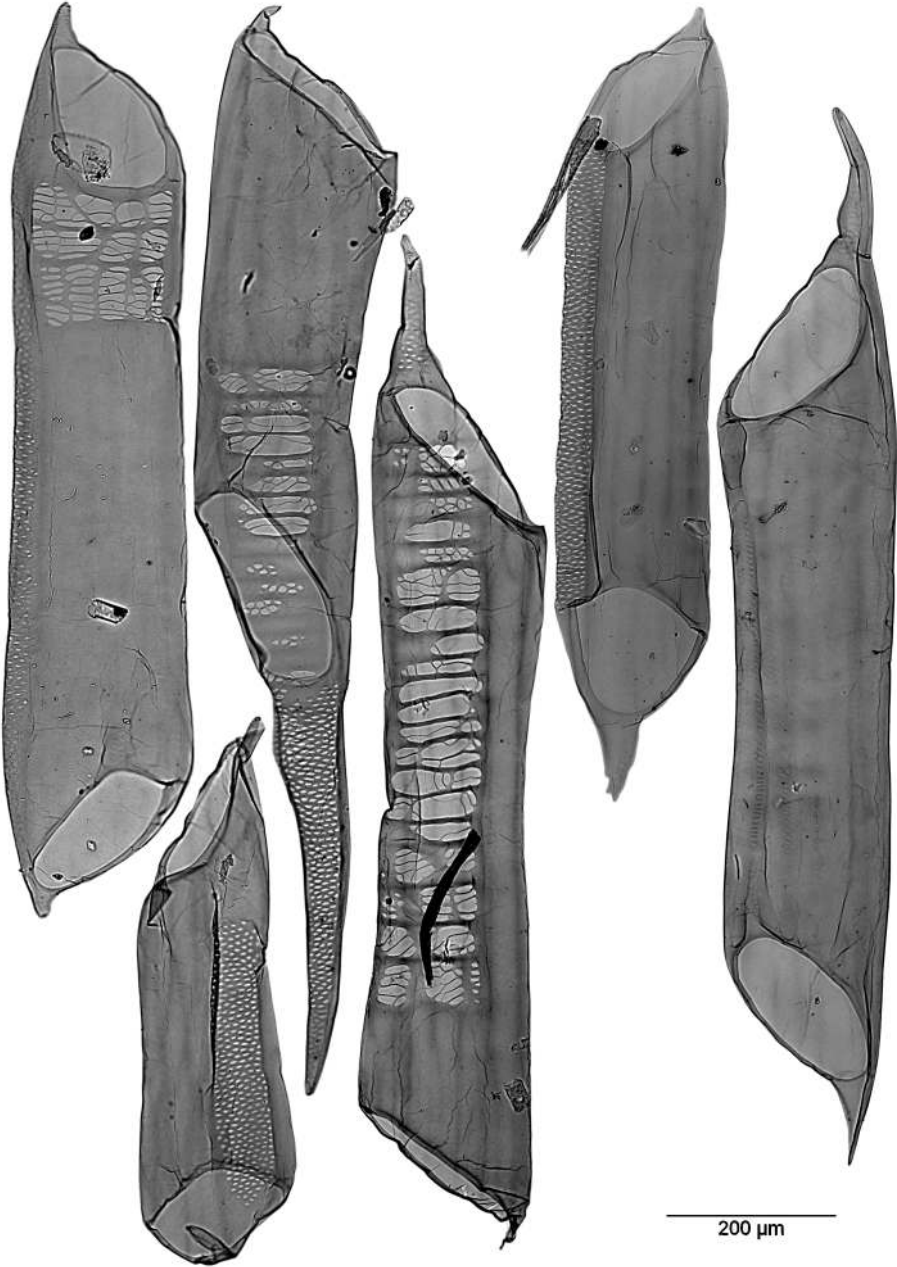


Figure 14. Boxplots of 19 wood genera/species (length and width of the vessel elements, diameter of pit apertures and borders).

Ant = *Shorea* subg. *Anthoshorea*; Cal = *Calophyllum* sp.; Cam = *Camptosperma* sp.; Can = *Canarium* sp.; Cas = *Castanopsis argentea*; Dip = *Dipterocarpus* sp.; Euc = *Eucalyptus* sp.; Glu = *Gluta renghas*; Hev = *Hevea brasiliensis*; Lit = *Litsea resinosa*; Mad = *Madhuca sericea*; Man = *Mangifera* sp.; Pal = *Palaquium* sp.; Par = *Parashorea* sp.; Ric = *Shorea* subg. *Richetia*; Rub = *Shorea* subg. *Rubroshorea*; Sho = *Shorea* subg. *Shorea*; Swi = *Swintonia* sp.; Syz = *Syzygium dyerianum*.



Campnosperma sp.

***Campnosperma* sp. (Anacardiaceae)**

Trade names: terentang, kelinting, melumut, serentang (MY); pauh lebi, tumbus (ID); campnosperma (PG); nangpron, huasum sangtrang (TH); nisperillo, oreya, sajo (PA).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: South and Central America, Madagascar, Seychelles, Sri Lanka, the whole Southeast Asia, Micronesia and Melanesia.

Vessel elements: long and slim (tube-shaped), length about 650 μm , width about 190 μm .

Tails: either short or long with gradual transition; larger tails often covered with pits.

Perforation plates: simple and more rarely scalariform (with 6–36 bars; Richter & Dallwitz 2000); extending over the entire lumen; inclined (parallelogram or trapezium).

Intervessel pits: alternate; vertical diameter 4–6–10 μm ; present over a wide area; apertures oval to slit-like.

Vessel-ray pits: VAS; large; apertures window-like, sometimes subdivided into smaller units but still large; shape varies from elongated to oval or circular.

Pits to fibers: rarely present, arranged in short single vertical rows.

Areas without any pits: regularly present; very large.

Tyloses: present.

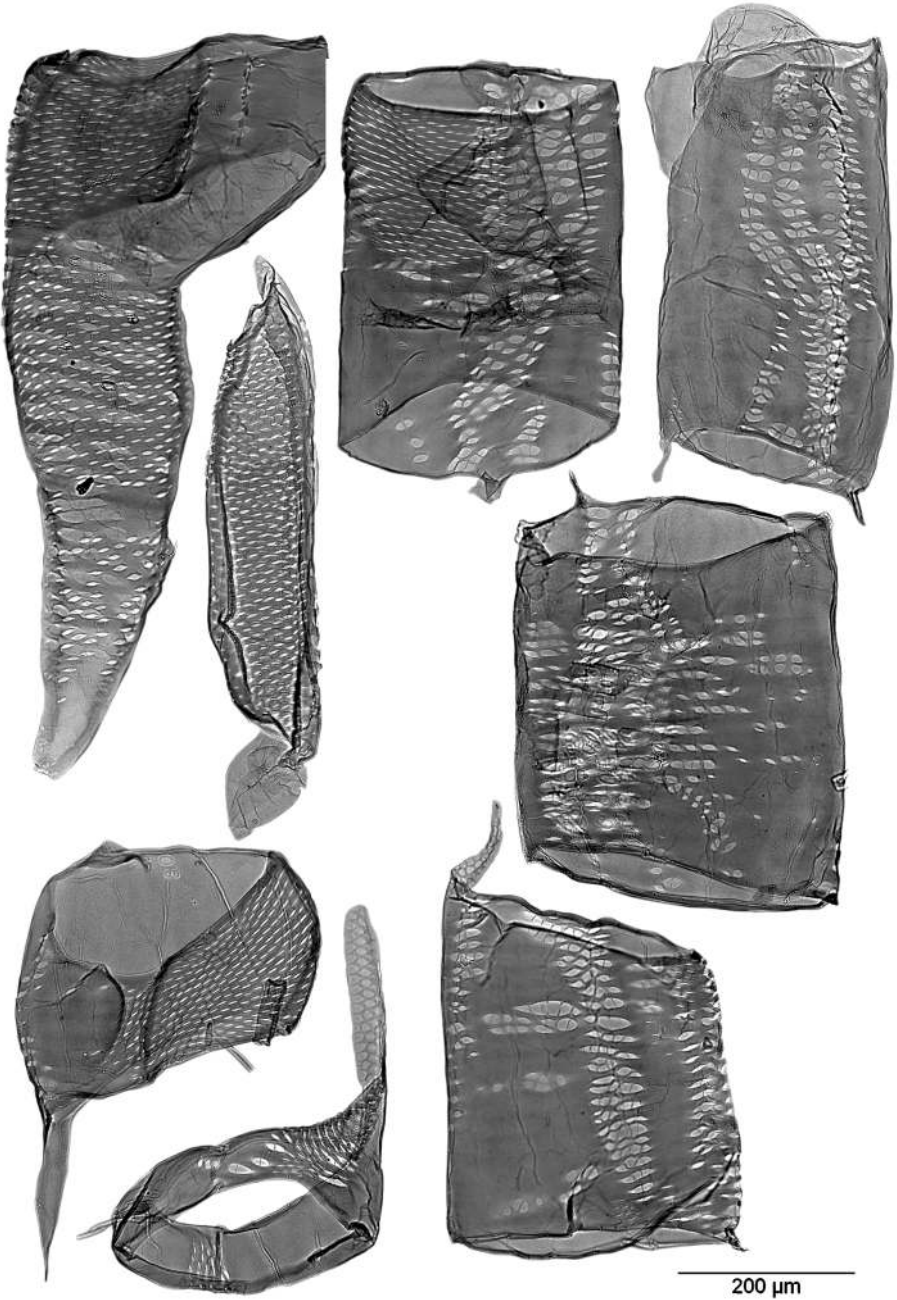
Helical thickenings: absent.

Quantitative data:

Vessel elements (361–)646(–873) μm long, and (139–)192(–220) μm wide; l/w ratio 3.7.

Intervessel pit borders (4.0–)6.2(–9.6) μm in vertical diameter; pit apertures (0.8–)1.5(–3.4) μm .

Fibers 950 μm long, 24.5 μm wide. Fiber wall thickness 7.7 μm (weighted averages).



Gluta renghas

***Gluta reinghas* L. (Anacardiaceae)**

Trade names: rengas, rengas kerbau jalang (MY); rengas tembaga (ID); hekakoro (PG); thayet-thitsi (MM); kroetul (KH); rakban (TH).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Indochina to Indomalesia (one species in Madagascar).

Vessel elements: rather large, some very short (length about 360 μm , width about 270 μm); barrel or drum-shaped.

Tails: either short with abrupt transition or very long with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: alternate; vertical diameter 6–11–15 μm ; present over a wide area; apertures oval.

Vessel-ray pits: VAS; arranged in horizontal rows; similar to pits to axial parenchyma cells.

Pits to axial parenchyma cells: similar to vessel-ray pits in size and shape; arranged in vertical series.

Areas without any pits: regularly present; large to very large.

Tyloses: present.

Helical thickenings: absent.

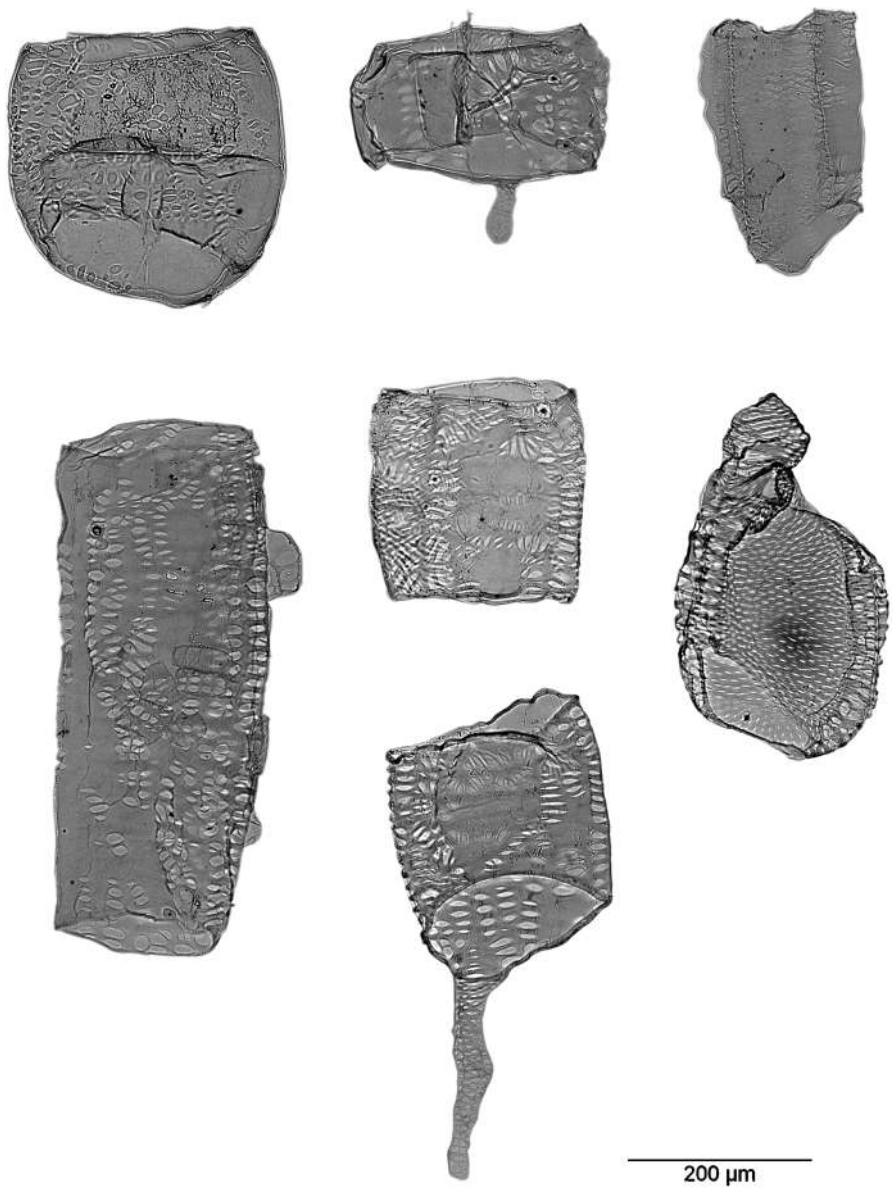
Notes on identification: The vessel elements of *Gluta reinghas* are similar to those of *Mangifera* spp. and *Swintonia* spp. (see *Mangifera* sp., p. 302).

Quantitative data:

Vessel elements (76–)361(–576) μm long, and (107–)265(–367) μm wide; l/w ratio 1.4.

Intervessel pit borders (6.4–)10.5(–14.6) μm in vertical diameter; pit apertures (0.8–)1.5(–3.0) μm .

Fibers 945 μm long, 20.9 μm wide. Fiber wall thickness 6.0 μm (weighted averages).



Mangifera sp.

***Mangifera* sp. (Anacardiaceae)**

Trade names: machang, tiger wood (MY), mango (IN).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: India, Pakistan, Sri Lanka, Indochina, Indomalesia.

***Mangifera* sp.** is cultivated as a fruit tree. The wood is commonly used for furniture and plywood cores.

Vessel elements: rather short (length about 220 μm , width about 250 μm), often drum-shaped, sometimes elongated (tube-shaped).

Tails: often long with abrupt transition or short with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: pits alternate; vertical diameter 3–7–12 μm ; present over a wide area and in the tails; apertures oval.

Vessel-ray pits: VAS; isodiametric or stretched (eye-shaped); in one ray cell all the pits are of the same type; present on nearly every vessel element.

Areas without any pits: regularly present; small to large.

Tyloses: present, thin-walled.

Helical thickenings: absent.

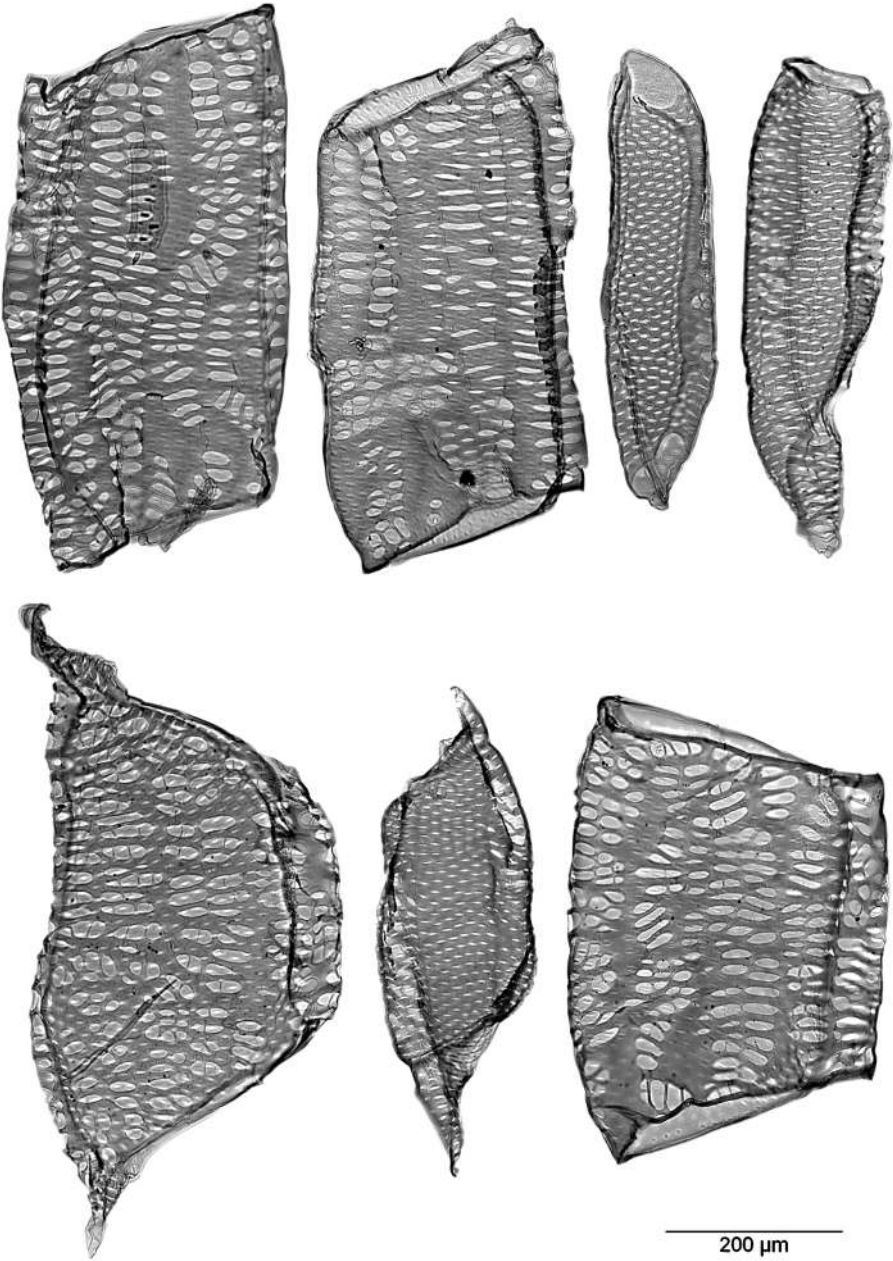
Notes on identification: The vessel elements of *Mangifera* spp. are similar to those of *Gluta renghas* spp. and *Swintonia* spp. *Mangifera* sp. has the smallest vessel elements with small intervessel pits. *Swintonia* sp. is characterized by the largest intervessel pits. The three genera show very similar pit features.

Quantitative data:

Vessel elements (75–)221(–550) μm long, and (126–)241(–385) μm wide; l/w ratio 0.9.

Intervessel pit borders (3.2–)7.4(–11.5) μm in vertical diameter; pit apertures (0.5–)1.8(–3.0) μm .

Fibers 700 μm long, 20.8 μm wide. Fiber wall thickness 5.8 μm (weighted averages).



Swintonia sp.

***Swintonia* sp.** (Anacardiaceae)

Trade names: merpauh, selan (MY-swk); kaluis, lomarau (PH); civit, taung-thayet (MM); muom (KH, VN).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Bangladesh, Indochina to Indomalesia.

Vessel elements: of average size (length about 400 μm , width about 190 μm); mainly barrel-shaped (those with a larger diameter), sometimes tube-shaped (those with a smaller diameter); width varies from average to slim dimensions.

Tails: if present often short with gradual transition.

Perforation plates: simple, extending over the entire lumen; inclined (trapezium or parallelogram).

Intervessel pits: alternate; quite large; vertical diameter 6–10–16 μm ; present over a wide area and in the tails; apertures oval.

Vessel-ray pits: VAS; very large, window-like arranged in 2–3 rows per cross-field.

Pits to axial parenchyma cells: elongate, often present over the entire vessel element wall.

Areas without any pits: if present, very small.

Tyloses: present.

Helical thickenings: absent.

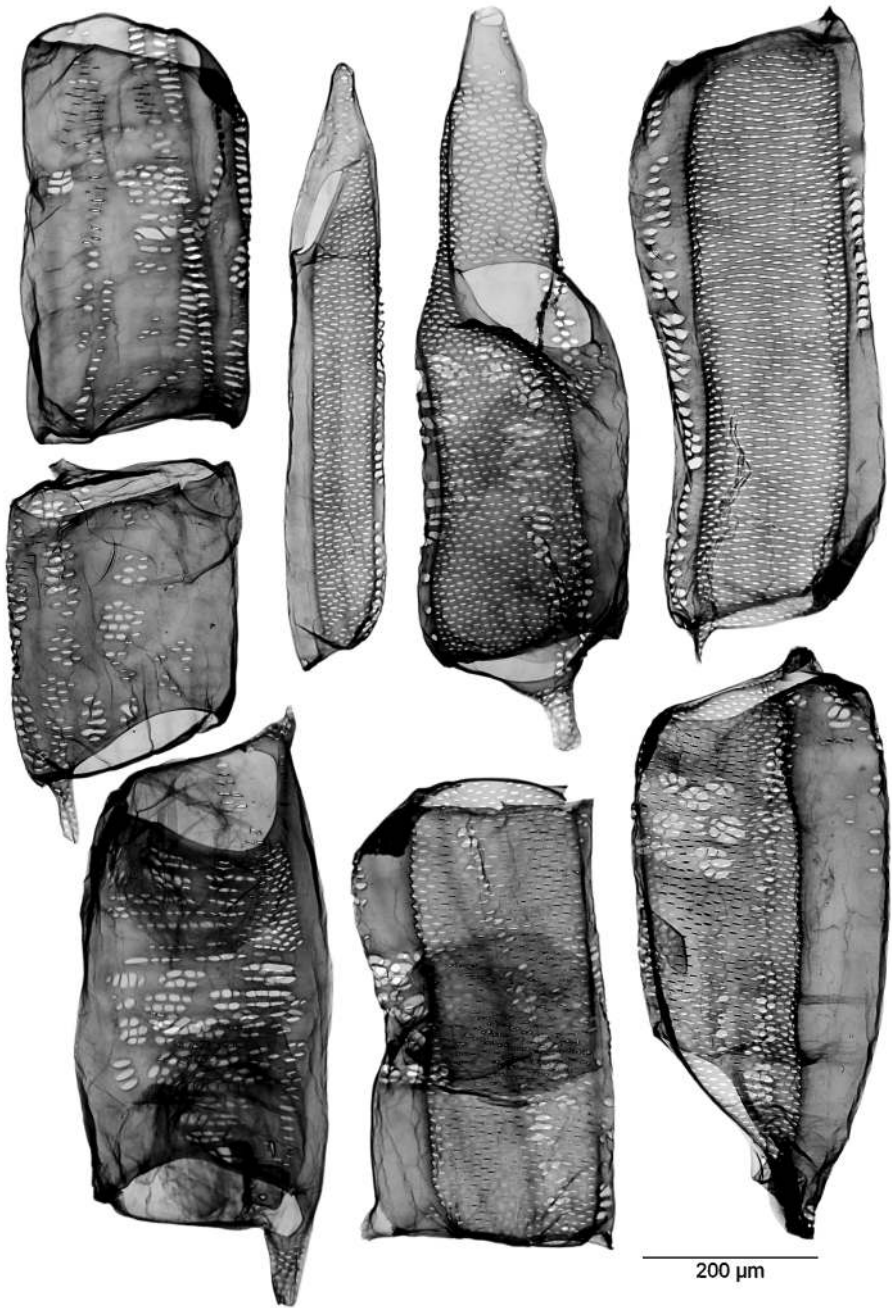
Notes on identification: The vessel elements of *Swintonia* spp. are similar to those of *Gluta renghas* spp. and *Mangifera* spp. (see *Mangifera* sp., p. 302).

Quantitative data:

Vessel elements (119–)396(–590) μm long, and (73–)194(–408) μm wide; l/w ratio 1.8.

Intervessel pit borders (6.1–)9.6(–16.1) μm in vertical diameter; pit apertures (0.7–)2.0(–5.3) μm .

Fibers 930 μm long, 23.5 μm wide. Fiber wall thickness 8.7 μm (weighted averages).



Canarium sp.

***Canarium* sp. (Burseraceae)**

Trade names: kedondong, kenari, kerantai (ID); kerantai, upi, seladah (MY); upi (BN, MY-swk); canarium, galip (PG); pili, pilingliitan, pagsahingin (PH); makoem (TH); tram (VN).

DIN EN 13556:2003 code: CNXX.

CITES regulations: not protected.

Geographic distribution: “Old world tropics” from tropical Africa to tropical Asia, northern Australia and the Pacific.

Vessel elements: rather large (length about 480 μm , width about 270 μm); mainly barrel-shaped (those with a larger diameter), sometimes tube-shaped (those with a smaller diameter).

Tails: if present, rather short with abrupt transition or very long with gradual transition.

Perforation plates: simple, often extending over the entire lumen; horizontal or inclined.

Intervessel pits: alternate; vertical diameter 5–8–13 μm ; often present over a wide area covering the entire vessel element wall.

Vessel-ray pits: VAS; cross-fields arranged in horizontal series, with one or several rows of pits variable in size.

Pits to fibers: rarely present, arranged in single vertical rows.

Areas without any pits: present on radial faces; large to very large.

Tyloses: present.

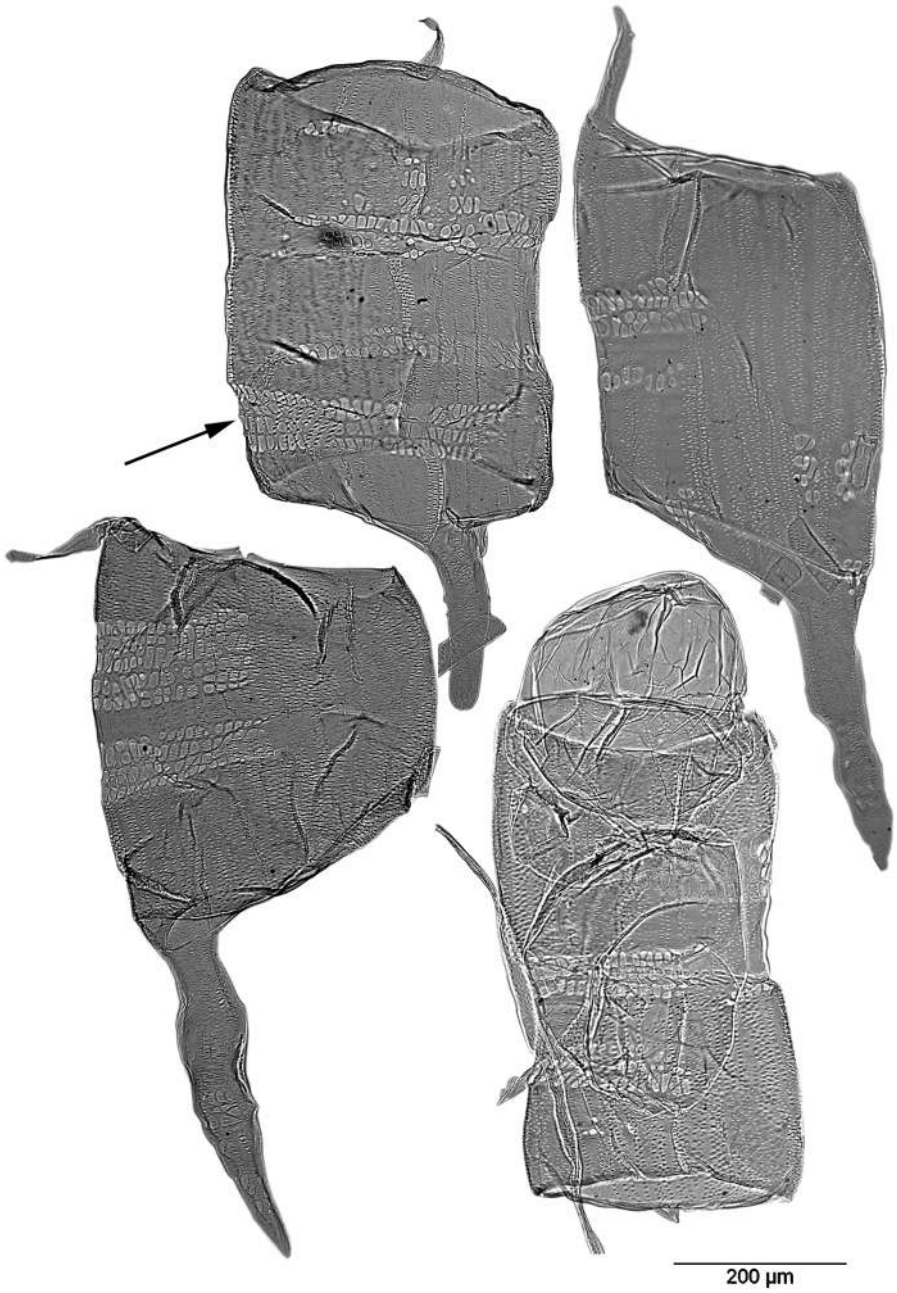
Helical thickenings: absent.

Quantitative data:

Vessel elements (246–)484(–759) μm long, and (103–)266(–343) μm wide; l/w ratio 1.9.

Intervessel pit borders (5.1–)8.3(–12.7) μm in vertical diameter; pit apertures (0.7–)2.4(–3.6) μm .

Fibers 920 μm long, 24.7 μm wide. Fiber wall thickness 4.2 μm (weighted averages).



Calophyllum sp.

***Calophyllum* sp.** (Calophyllaceae)

Trade names: bintangor (MY, DE); bitaog, kalofilum, kamdeb, tamanu, bakokol, entangor, mentangor (MY); ponnyet, tharapi (MM); domba-gassa (LK); bansangal, vutalau, zarumayen (PH); vintanina (MG); palo maría (PH = *C. inophyllum*), Alexandrien laurel (IN = *C. inophyllum*).

DIN EN 13556:2003 code: CLXX.

CITES regulations: not protected.

Geographic distribution: Indomalesia, Micronesia, Melanesia and northern Australia, also in Central and South America, Madagascar and surrounding islands.

Vessel elements: rather large (length about 450 μm , width about 340 μm); elongated (barrel-shaped) or shorter (drum-shaped).

Tails: long with abrupt transition, sometimes shorter.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: absent (due to vessels being almost exclusively solitary in the intact wood).

Vessel-ray pits: VAS; window-like (angled to oval), cross-fields with 2–5 horizontal rows of pits arranged in a reticulate pattern (arrow).

Pits to tracheids: numerous; in 2–3-seriate bands; vertical diameter 1–2–3 μm ; apertures oval to slit-like; pits alternate.

Areas without any pits: if present, small.

Tyloses: present.

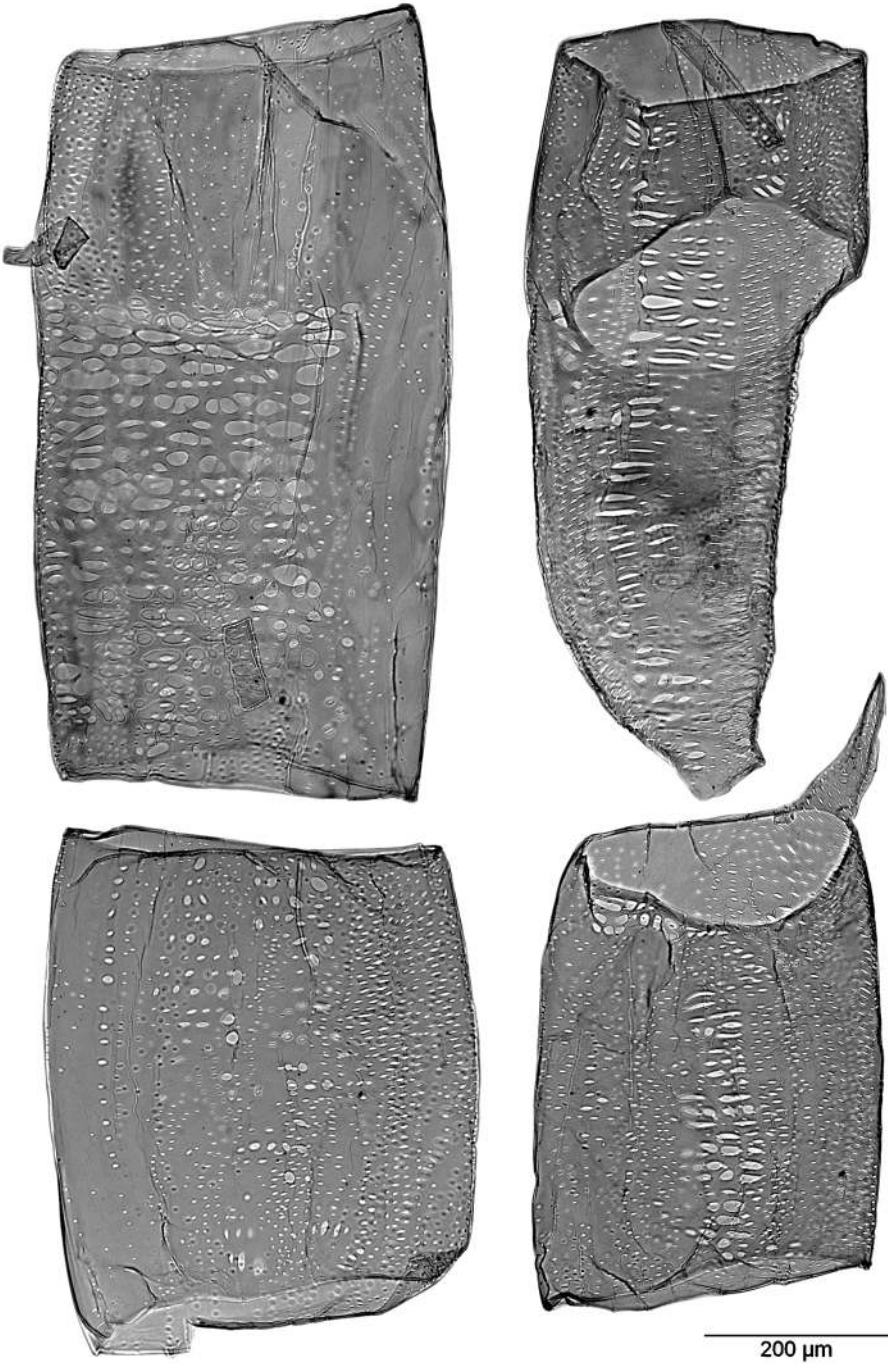
Helical thickenings: absent.

Quantitative data:

Vessel elements (216–)453(–794) μm long, and (214–)343(–443) μm wide; l/w ratio 1.3.

Vessel to tracheid pit borders (1.2–)1.7(–3.0) μm in vertical diameter; pit apertures (0.5–)0.7(–0.9) μm .

Fibers 1120 μm long, 24.4 μm wide. Fiber wall thickness 7.2 μm (weighted averages).



Dipterocarpus sp.

***Dipterocarpus* sp.** (Dipterocarpaceae)

Trade names: keruing (ID, MY, DE); yang (FR, TH, VN); gurjun (IN, MM, LK); dau (VN, FR); white kanyin, kanyin-byu (MM); choeuteal (KH); nhang (LA); keroewing (NL); yang hin, yang na (TH); dzao long (VN).

DIN EN 13556:2003 code: DPXX.

CITES regulations: not protected.

Geographic distribution: India, Pakistan, Sri Lanka, Indochina and Western Indomalaysia.

Vessel elements: rather large (length about 600 μm , width about 410 μm); elongated (barrel-shaped), rarely shorter (drum-shaped).

Tails: short with abrupt transition, long with gradual transition or absent.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: absent (due to vessels being almost exclusively solitary in intact wood).

Vessel-ray pits: VAS; huge variety of size classes and shapes; the larger pits gash-like, the smaller ones circular or oval; cross-fields sometimes covering the entire vessel element wall.

Pits to tracheids: alternate; vertical diameter 2–3–5 μm ; arranged in sinuous strips; sometimes broadened in horizontal direction.

Pits to fibers: present in single vertical rows.

Areas without any pits: regularly present; small to large.

Tyloses: present.

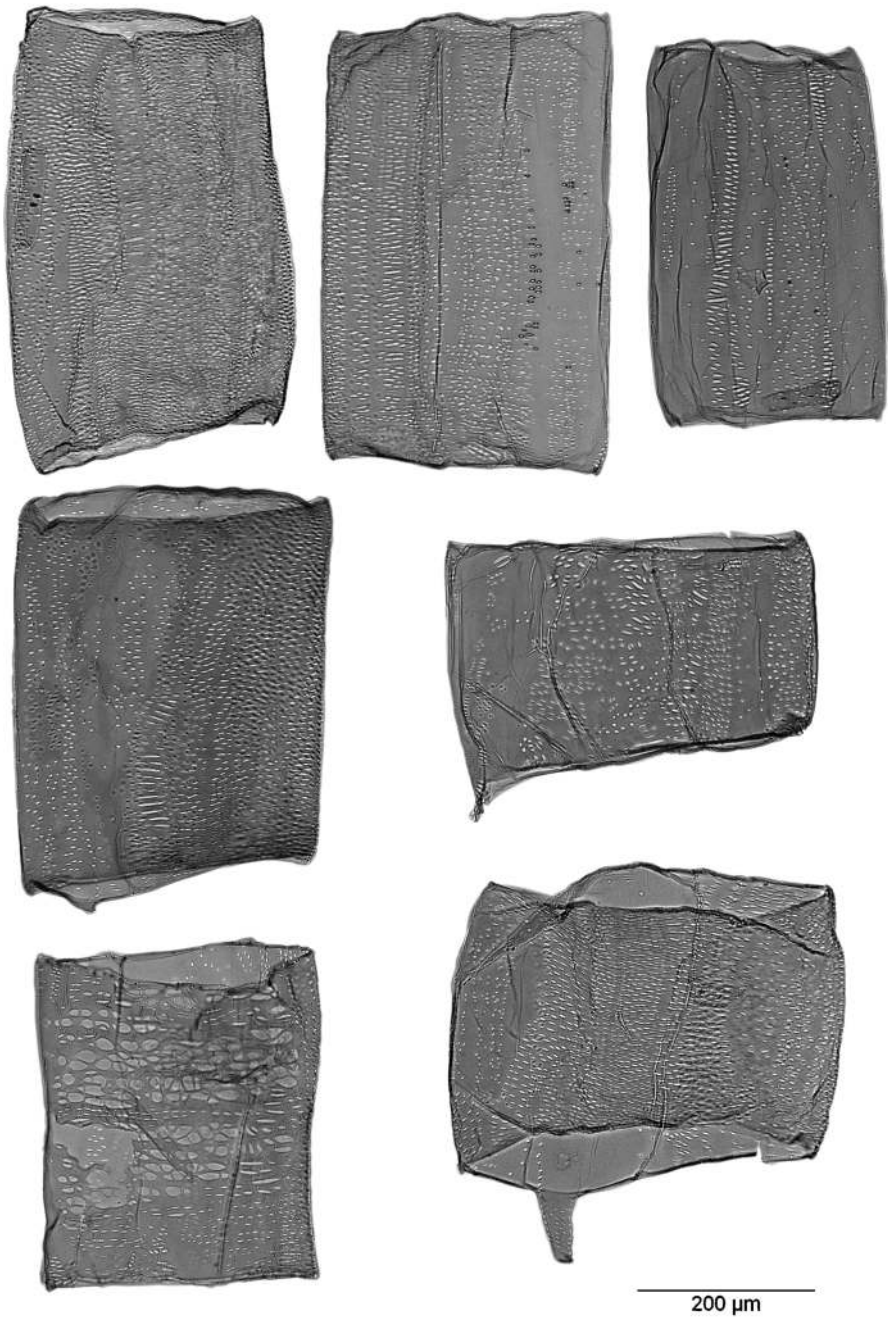
Helical thickenings: absent.

Quantitative data:

Vessel elements (343–)601(–792) μm long, and (294–)409(–480) μm wide; l/w ratio 1.4.

Vessel to tracheid pit borders (2.3–)3.3(–5.2) μm in vertical diameter; pit apertures (0.6–)1.2(–2.5) μm .

Fibers 1390 μm long, 26.5 μm wide. Fiber wall thickness 6.1 μm (weighted averages).



Parashorea sp.

***Parashorea* sp.** (Dipterocarpaceae)

Trade names: light wood (0.4–0.6 g/cm³): white seraya, white lauan (DE); white seraya, urat mata (MY-sab); seraya puteh (MY-swk); white lauan, bagtikan (PH); pendan (ID). — heavy wood (0.6–0.8 g/cm³): heavy white seraya, urat mata batu (MY-sab); gerutu, meranti gerutu (MY); khai kheo, khiansai (TH); thinkadu, tavoy wood (MM); cho chi (VN).

DIN EN 13556:2003 code: PHWS/PHMG.

CITES regulations: not protected.

Geographic distribution: Indochina, Indomalesia.

Vessel elements: rather short and wide (length about 430 µm, width about 370 µm), barrel or drum-shaped, shape well-defined with almost rectangular outlines.

Tails: mostly absent, few long or short tails present with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 2–4–7 µm; if present, in large fields over a wide area; apertures oval or sometimes elongated.

Vessel-ray pits: VAS; rarely present; pits window-like or elongated.

Pits to tracheids: in vertical strips (3–5 pit rows), apertures oval to slit-like or gash-like.

Pits to fibers: present in single vertical rows.

Areas without any pits: regularly present; small to sometimes large.

Tyloses: present.

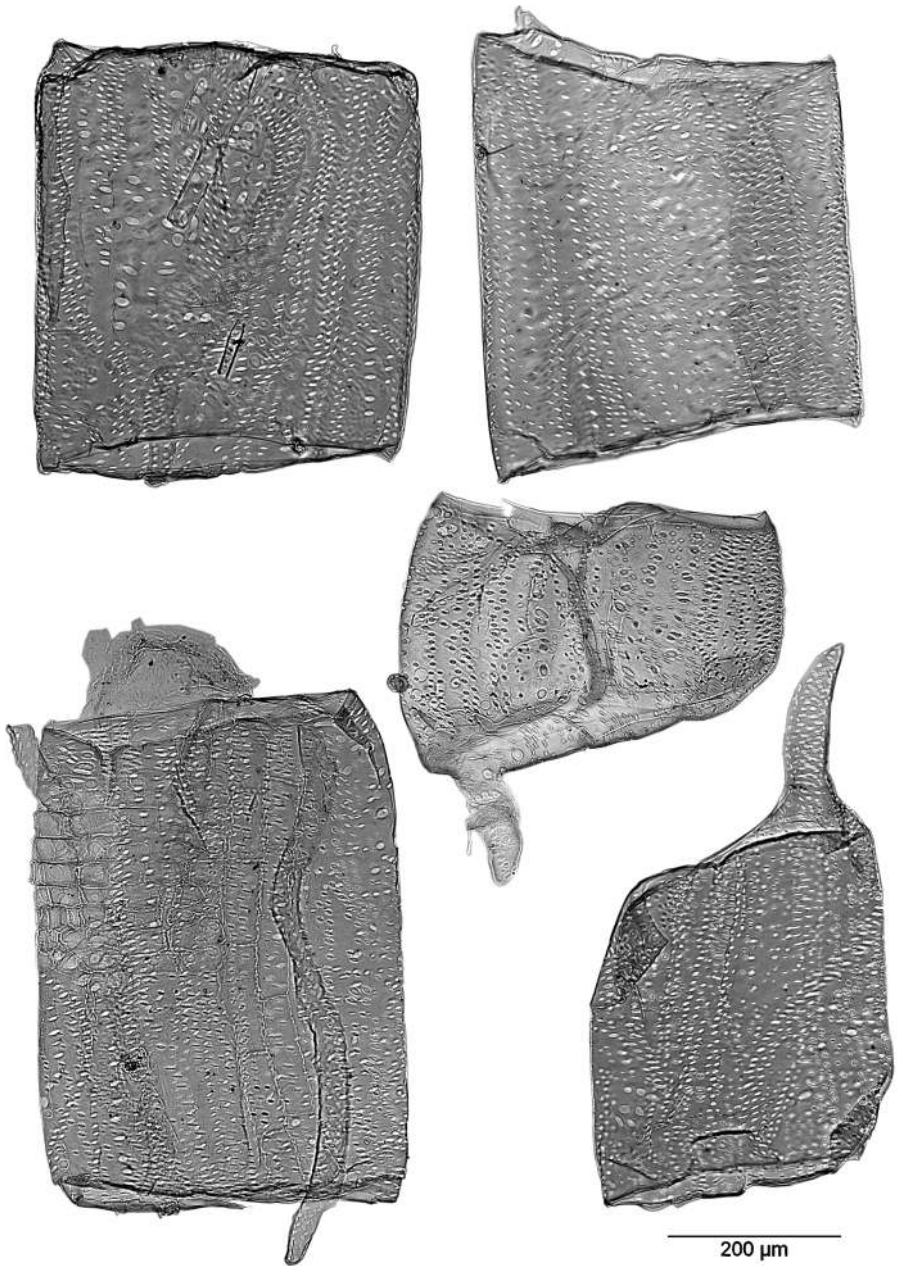
Helical thickenings: absent.

Quantitative data:

Vessel elements (140–)425(–568) µm long, and (205–)369(–453) µm wide; l/w ratio 1.1.

Intervessel pit borders (1.7–)3.8(–7.2) µm in vertical diameter; pit apertures (0.5–)1.1(–3.5) µm.

Fibers 1145 µm long, 19.9 µm wide. Fiber wall thickness 3.6 µm (weighted averages).



Shorea subg. *Anthoshorea*

***Shorea* subg. *Anthoshorea* (Dipterocarpaceae)**

Trade names: white meranti (MY, ID); meranti putih, kayu tahan (ID); melapi (MY-sab, ID-kal); white lauan (PH); luombor (KH); khiem kha norng, takhian-sai, chai (TH); bo-bo (VN).

DIN EN 13556:2003 code: SHWM.

CITES regulations: not protected.

Geographic distribution: Indochina, Indomalesia.

Vessel elements: average length (about 450 μm), quite wide (410 μm), often barrel-shaped and sometimes drum-shaped.

Tails: if present, rather short with abrupt transition or longer with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 2–5–8 μm ; apertures oval.

Vessel-ray pits: VAS; window-like, sometimes elongated; in alternately or separately arranged rows; apertures circular, sometimes elongated.

Pits to axial parenchyma cells: similar in size and shape to vessel-ray pits.

Pits to tracheids: alternate; similar to intervessel pits and pits to fibers, present in sinuous or straight vertical strips of 1–2 pits.

Pits to fibers: present in single vertical rows.

Areas without any pits: if present, rather small.

Tyloses: present.

Helical thickenings: absent.

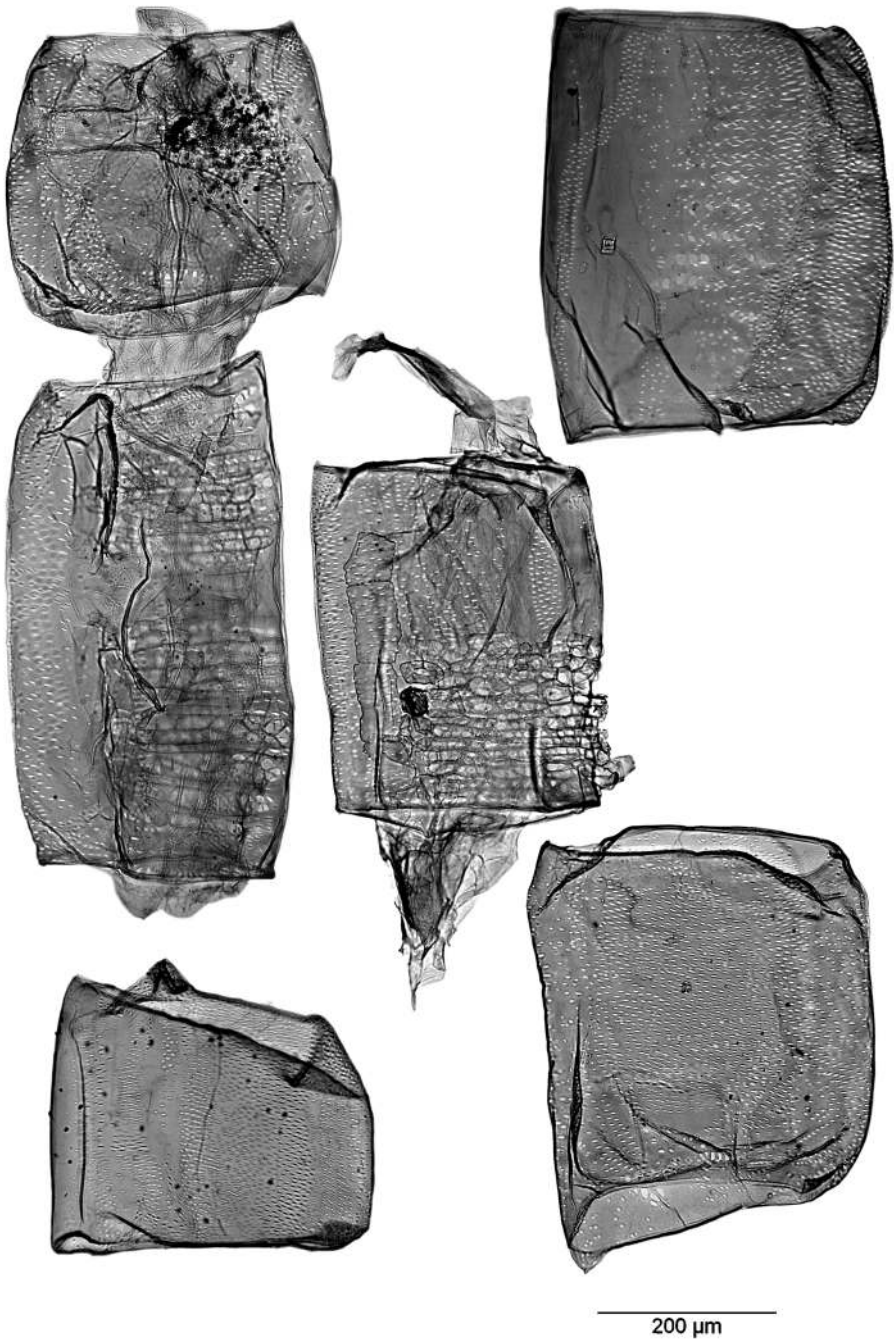
Notes on identification: The subgenera of *Shorea* cannot be separated by means of vessel element features as they are of similar appearance.

Quantitative data:

Vessel elements (244–)453(–645) μm long, and (307–)407(–461) μm wide; l/w ratio 1.1.

Intervessel pit borders (2.3–)4.9(–7.7) μm in vertical diameter; pit apertures (0.6–)1.4(–2.8) μm .

Fibers 1460 μm long, 21.8 μm wide. Fiber wall thickness 3.7 μm (weighted averages).



Shorea subg. *Richetia*

***Shorea* subg. *Richetia* (Dipterocarpaceae)**

Trade names: yellow meranti (MY); yellow seraya (MY-sab); yellow lauau (PH); meranti kuning (ID); meranti damar hitam (MY); selangan kuning, selangan kacha (MY-sab).

DIN EN 13556:2003 code: SHYM.

CITES regulations: not protected.

Geographic distribution: Indomalesia.

Vessel elements: rather short and wide (length about 320 μm , width about 340 μm), drum or barrel-shaped.

Tails: if present, short with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 3–4–9 μm ; covering large fields over a wide area; apertures oval to slit-like.

Vessel-ray pits: VAS; apertures window-like (rectangular) or oval; of variable size and shape; arranged in one to several rows per ray cell.

Pits to tracheids: forming long vertical strips (3–5 pits wide); apertures elongated.

Pits to fibers: present in single vertical rows.

Areas without any pits: if present, small to large.

Tyloses: often present.

Helical thickenings: absent.

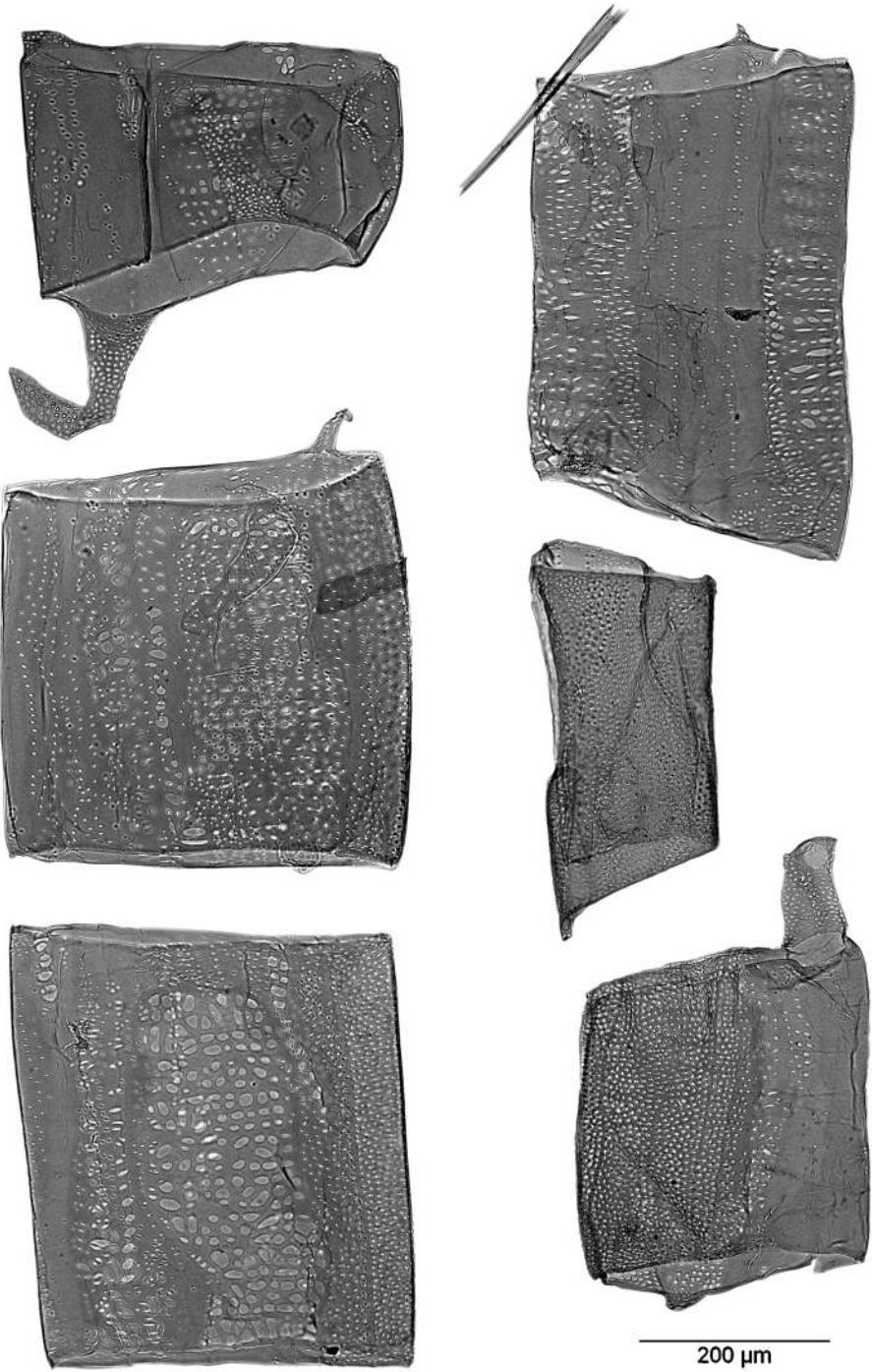
Notes on identification: See *Shorea* subg. *Anthoshorea* (p. 314).

Quantitative data:

Vessel elements (206–)317(–533) μm long, and (251–)344(–413) μm wide; l/w ratio 0.9.

Intervessel pit borders (2.6–)4.4(–9.3) μm in vertical diameter; pit apertures (0.5–)1.2(–2.3) μm .

Fibers 895 μm long, 22.0 μm wide. Fiber wall thickness 5.2 μm (weighted averages).



Shorea subg. *Rubroshorea*

***Shorea* subg. *Rubroshorea* (Dipterocarpaceae)**

Trade names: dark/light red meranti, seraya, lauan (DE); kawang, seraya bunga, red seraya (MY-sab); red lauan (PH); meranti merah (ID).

DIN EN 13556:2003 code: SHDR/SHLR.

CITES regulations: not protected.

Geographic distribution: Indomalesia.

Vessel elements: rather short and wide (length about 380 μm , width about 310 μm); mainly barrel- or drum-shaped (those with a larger diameter), sometimes tube-shaped (those with a smaller diameter).

Tails: if present, long or short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 4–7–12 μm ; present in large fields over a wide area; apertures oval.

Vessel-ray pits: VAS; apertures window-like (more or less circular) or elongated horizontally (gash-like); of variable size and shape; in several rows per ray cell.

Pits to axial parenchyma cells: similar to vessel-ray pits; in narrow vertical bands.

Pits to tracheids: arranged in wide vertical strips; 1–4 pit rows wide.

Pits to fibers: present in single vertical rows.

Areas without any pits: regularly present; small or large.

Tyloses: often present.

Helical thickenings: absent.

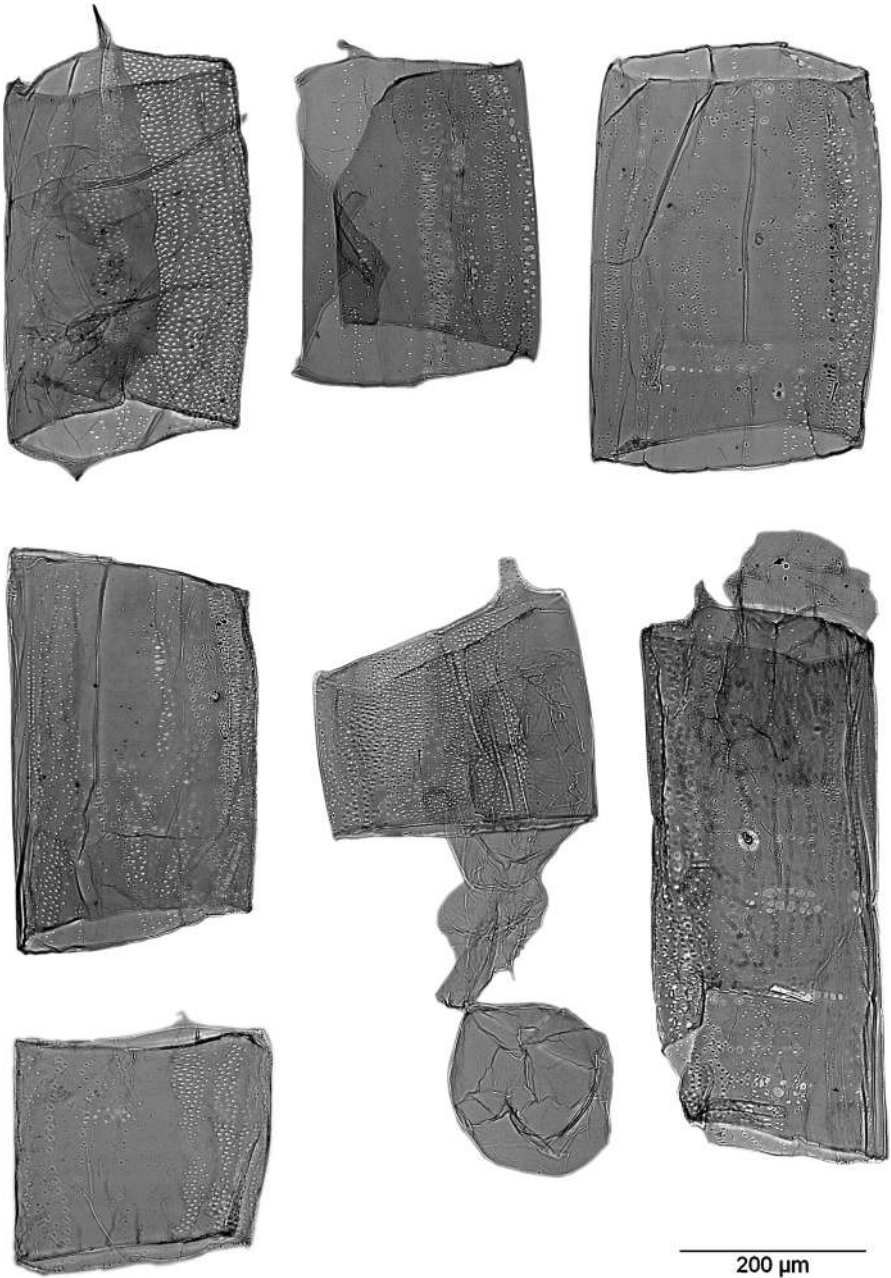
Notes on identification: See *Shorea* subg. *Anthoshorea* (p. 314).

Quantitative data:

Vessel elements (188–)376(–573) μm long, and (139–)312(–421) μm wide; l/w ratio 1.2.

Intervessel pit borders (3.7–)6.6(–12.2) μm in vertical diameter; pit apertures (0.8–)1.9(–4.5) μm .

Fibers 1230 μm long, 21.0 μm wide. Fiber wall thickness 4.3 μm (weighted averages).



Shorea subg. *Shorea*

***Shorea* subg. *Shorea* (Dipterocarpaceae)**

Trade names: balau, selangan batu no. 1 – no. 2 (MY, DE), selangan batu tatuk, balau bukit, hitam, kumus hitam, laut, laut merah, sengkawang, damar laut (MY), balau bunga, bangkirai, semantok lungkik (ID), yakal (PH), teng (TH), sal (IN).

DIN EN 13556:2003 code: SHRB.

CITES regulations: not protected.

Geographic distribution: India, Pakistan, Sri Lanka, Indochina, Indomalesia.

Vessel elements: rather short (length about 310 μm , shorter than the other subgenera of *Shorea*, width about 280 μm); mostly barrel-shaped, sometimes drum-shaped.

Tails: rather short with abrupt transition, rarely longer with gradual transition.

Perforation plates: simple, extending over the entire lumen; horizontal.

Intervessel pits: alternate; vertical diameter 3–5–9 μm ; wide fields; apertures oval.

Vessel-ray pits: VAS; apertures circular or oval, rather small; in horizontal rows (1–3 rows per ray cell).

Pits to axial parenchyma cells: similar to vessel-ray pits but somewhat larger; arranged in vertical bands.

Pits to fibers: present in long single vertical rows.

Pits to tracheids: similar to intervessel pits; in vertical strips, 3–5 pits wide.

Areas without any pits: regularly present; small or large.

Tyloses: often present.

Helical thickenings: absent.

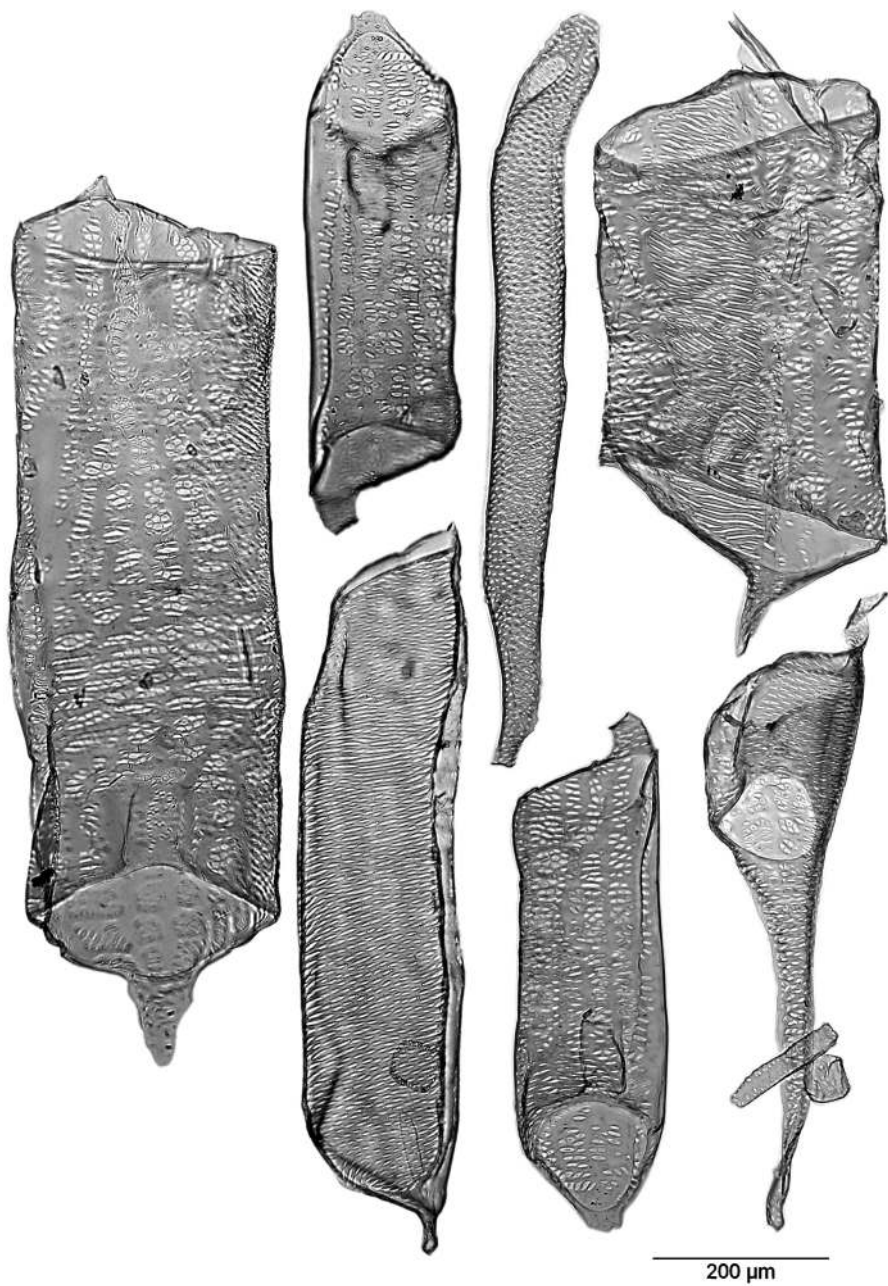
Notes on identification: See *Shorea* subg. *Anthoshorea* (p. 314).

Quantitative data:

Vessel elements (135–)312(–568) μm long, and (161–)279(–333) μm wide; l/w ratio 1.2.

Intervessel pit borders (2.6–)4.7(–9.4) μm in vertical diameter; pit apertures (0.4–)1.1(–3.0) μm .

Fibers 905 μm long, 18.2 μm wide. Fiber wall thickness 4.7 μm (weighted averages).



Hevea brasiliensis

Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg. (Euphorbiaceae)

Trade names: rubberwood; hevea (GB, DE, MY, TH, IN); Gummibaum (DE); seringá, seringueira (BR); kayu karet (ID); arbol de caucho (sAM).

DIN EN 13556:2003 code: HVBR.

CITES regulations: not protected.

Geographic distribution: native to tropical South America, widely cultivated in Indomalaysia and Africa.

Vessel elements: rather long and often slim (length about 550 μm , width about 260 μm); mainly tube-shaped (those with a smaller diameter), sometimes barrel-shaped (those with a larger diameter).

Tails: short with abrupt transition or very long with gradual transition.

Perforation plates: simple, extending over the entire lumen; inclined or transverse.

Intervessel pits: alternate; vertical diameter 5–8–12 μm ; numerous; apertures slit-like, often coalescent; sometimes out of center (irregular appearance).

Vessel-ray pits: VAS; rarely present; window-like (rectangular) or elongated horizontally (gash-like).

Pits to axial parenchyma cells: similar to vessel-ray pits in size and shape; cross-fields well-defined.

Pits to fibers: present in single vertical rows.

Areas without any pits: regularly present; small.

Tyloses: present.

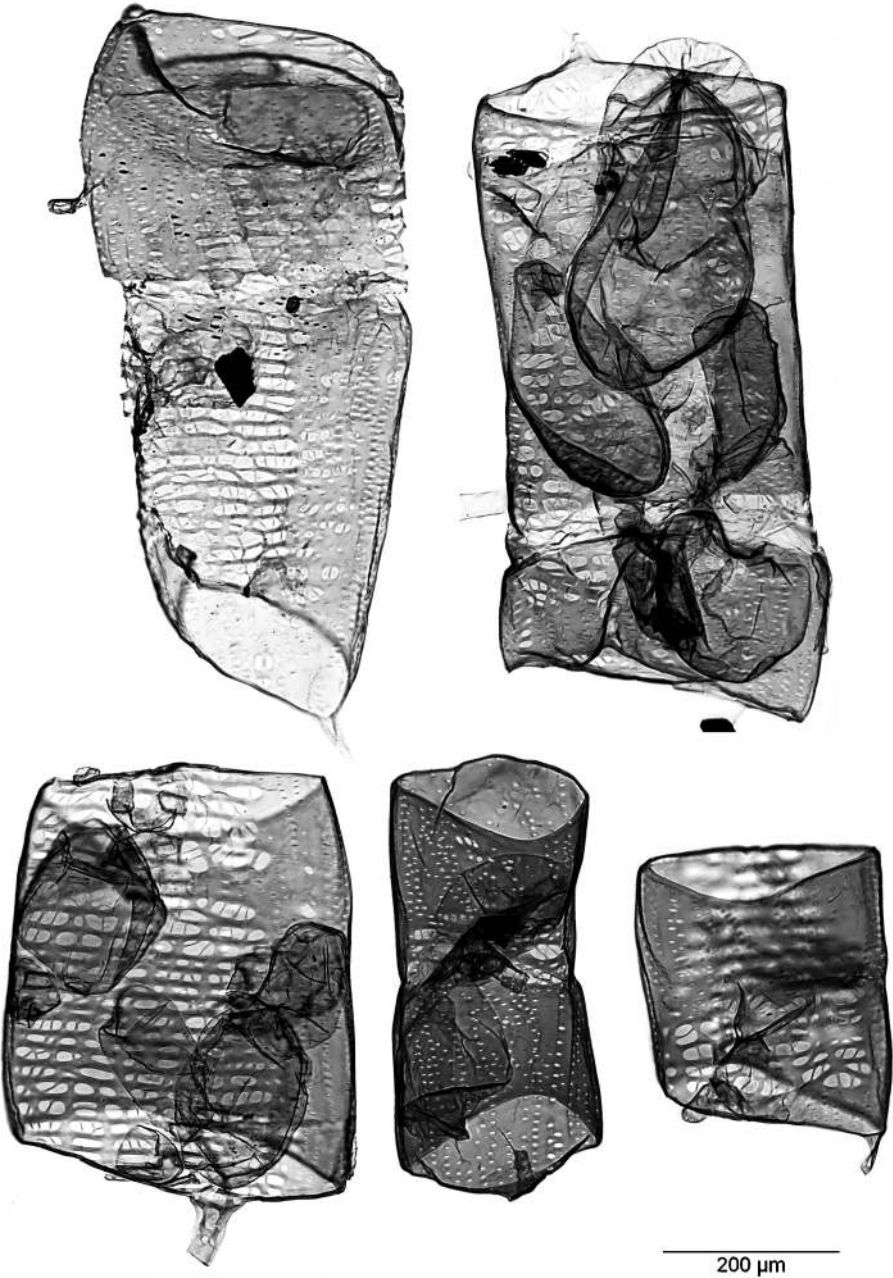
Helical thickenings: absent.

Quantitative data:

Vessel elements (298–)551(–854) μm long, and (66–)259(–386) μm wide; l/w ratio 2.2.

Intervessel pit borders (4.6–)8.1(–11.9) μm in vertical diameter; pit apertures (0.9–)1.7(–3.3) μm .

Fibers 1190 μm long, 24.4 μm wide. Fiber wall thickness 3.1 μm (weighted averages).



Castanopsis argentea

***Castanopsis argentea* (Blume) A.DC. (Fagaceae)**

Trade names: berangan, saninten, New Guinea oak (PG); Malayan chestnut, jertek tangga kata (MY); Philippine chestnut (PH); katia (MM); ko (LA, TH); ko-nam (TH).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Sumatra and Java. (*Castanopsis* spp.: India, Pakistan, Sri Lanka, Indochina, Indomalaysia).

Vessel elements: rather large and wide (length about 480 μm , width about 310 μm); mainly barrel-shaped (those with a larger diameter), sometimes tube-shaped (those with a smaller diameter).

Tails: short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: absent (due to almost exclusively solitary vessels in intact wood).

Vessel-ray pits: VAS; forming remarkably extensive pitted areas with single, horizontal rows of large to sometimes smaller pits (two size classes).

Pits to fibers: present in single vertical rows.

Pits to tracheids: numerous, arranged in vertical sinuous strips (2–3 pits wide), apertures oval; vertical diameter 5–7–10 μm .

Areas without any pits: regularly present; small to large.

Tyloses: present.

Helical thickenings: absent.

Notes on identification: *Castanopsis* spp. are similar to *Lithocarpus* spp. and *Castanea* spp. (not treated in this atlas).

Quantitative data:

Vessel elements (204–)479(–704) μm long, and (55–)314(–455) μm wide; l/w ratio 1.6.

Vessel to tracheid pit borders (4.5–)7.1(–10.3) μm in vertical diameter; pit apertures (0.5–)1.2(–3.5) μm .

Fibers 1160 μm long, 22.7 μm wide. Fiber wall thickness 2.8 μm (weighted averages).



Litsea resinosa

***Litsea resinosa* Blume (Lauraceae)**

Trade name: medang (ID, MY).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Java, Borneo, Peninsular Malaysia.

Vessel elements: rather long (length about 490 μm , width about 240 μm); mainly barrel-shaped.

Tails: long or short with gradual transition.

Perforation plates: simple; extending over the entire lumen; inclined (parallelogram or trapezium-shaped) to horizontal. Sometimes with tapering end walls.

Intervessel pits: alternate; vertical diameter 5–8–12 μm ; covering wide areas and the tails; apertures slit-like.

Vessel-ray pits: VAS; quite large, window-like, circular or elongated horizontally (gash-like), sometimes vertically (palisade).

Pits to axial parenchyma cells: similar to vessel-ray pits in size and shape.

Pits to fibers: present in longitudinal single rows.

Areas without any pits: regularly present; small to large.

Tyloses: present.

Helical thickenings: absent.

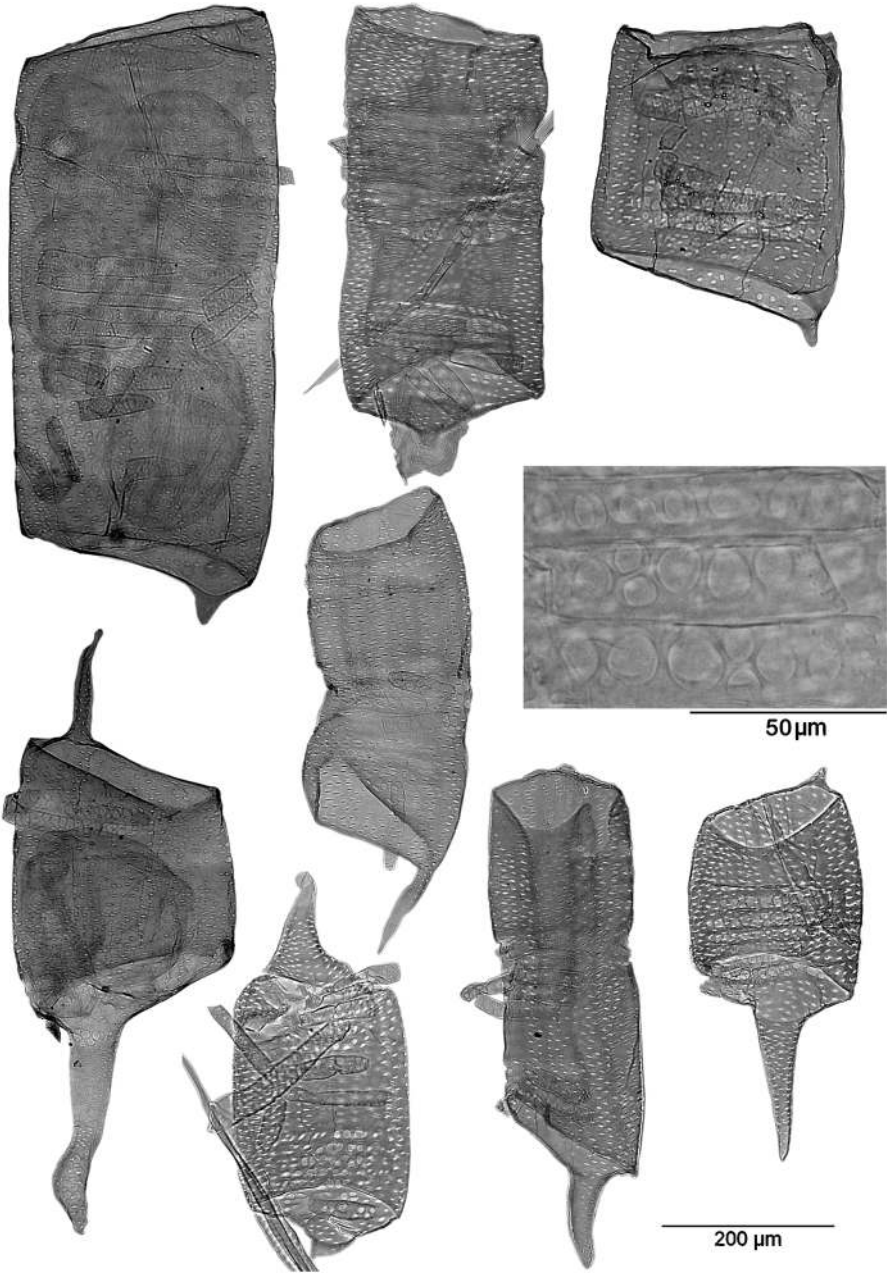
Notes on identification: vessel element features of this species resemble those of some Anacardiaceae but vessel-ray pits are larger and arranged in more well-defined blocks.

Quantitative data:

Vessel elements (290–)486(–671) μm long, and (173–)242(–303) μm wide; l/w ratio 2.0.

Intervessel pit borders (5.0–)7.8(–12.0) μm in vertical diameter; pit apertures (0.7–)1.8(–3.4) μm .

Fibers 1055 μm long, 26.3 μm wide. Fiber wall thickness 6.7 μm (weighted averages).



Eucalyptus globulus

***Eucalyptus globulus* Labill. (Myrtaceae)**

Trade names: blue gum, Tasmanian blue-gum, southern blue-gum (AU).

DIN EN 13556:2003 code: EUGL.

CITES regulations: not protected.

Geographic distribution: native to Australia; introduced in many countries, most notably in the Mediterranean, North Africa, Southwest Asia, South Africa, North America, Temperate South America.

***Eucalyptus* spp.** plantations provide short fiber raw material for the pulp and paper industry.

Vessel elements: slim (length about 310 μm , width about 240 μm); barrel or tube-shaped.

Tails: long with gradual or abrupt transition or short with abrupt transition.

Perforation plates: simple, extending over the entire lumen; horizontal or slightly inclined.

Intervessel pits: very rarely present; alternate; vertical diameter 3–5–9 μm ; arranged in fields; present in the tails; similar in size and shape to pits to tracheids; apertures slit-like.

Vessel-ray pits: VAS; large apertures circular to oval (see detail in box); sometimes with adhering parenchyma cells.

Pits to tracheids: in vertical strips 2–3 pits wide.

Pits to fibers: regularly present in single vertical rows.

Areas without any pits: if present, rather small.

Tyloses: present.

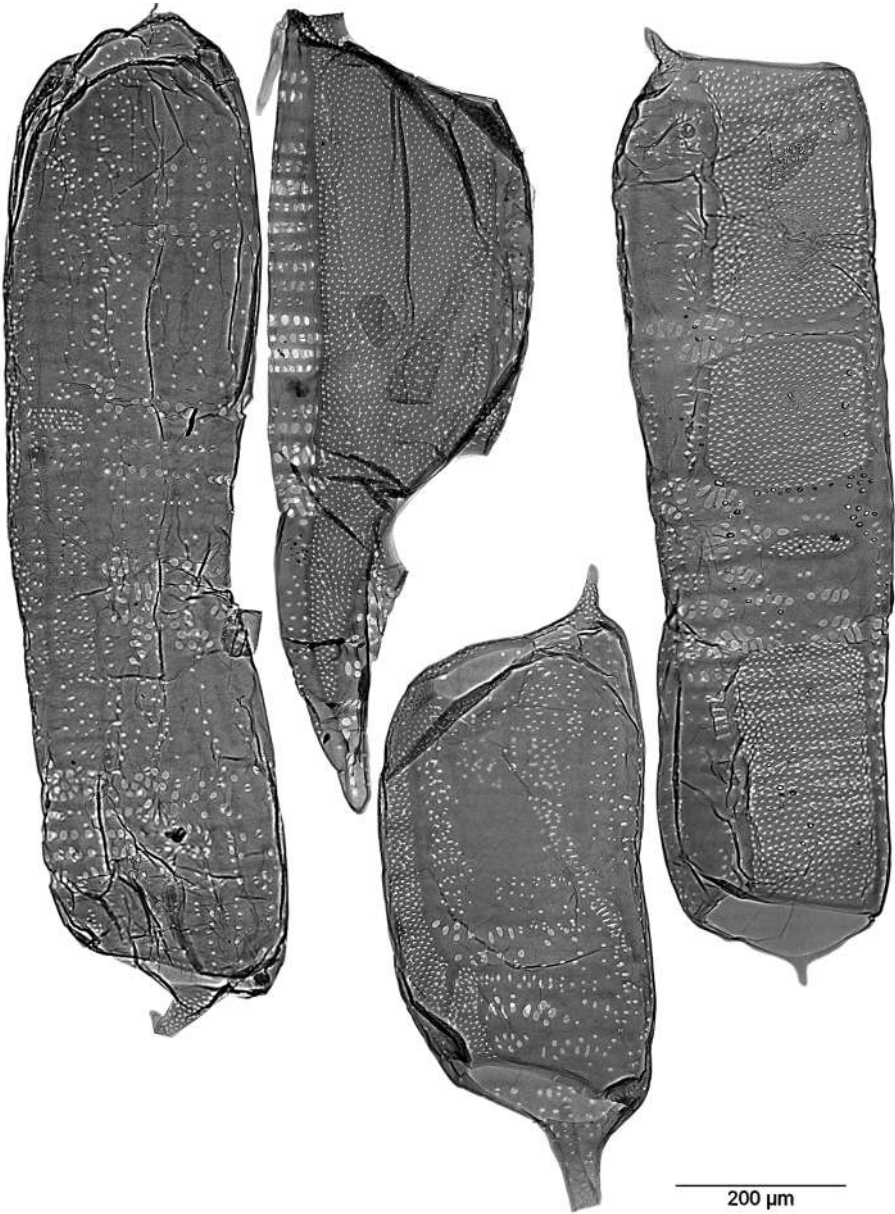
Helical thickenings: absent.

Quantitative data:

Vessel elements (182–)309(–615) μm long, and (160–)243(–358) μm wide; l/w ratio 1.4.

Intervessel pit borders (3.1–)5.2(–8.8) μm in vertical diameter; pit apertures (0.6–)1.4(–3.4) μm .

Fibers 800 μm long, 18.9 μm wide. Fiber wall thickness 6.0 μm (weighted averages).



Syzygium dyerianum

***Syzygium dyerianum* (King) Chantaran. & J. Parn. (Myrtaceae)**

Trade name: kelat (MY).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: Thailand, Peninsular Malaysia.

Vessel elements: quite large and elongated (length about 760 μm , width about 290 μm); often tube-like, sometimes barrel-shaped.

Tails: long with gradual transition or short with abrupt transition.

Perforation plates: simple; slightly narrowed, slightly inclined or horizontal.

Intervessel pits: alternate; vertical diameter 3–6–8 μm ; forming fields covering a wide area; also in the tails; apertures circular to oval.

Vessel-ray pits: VAS; distributed over a great part of the vessel element wall; arranged in exact horizontal rows; window-like circular to oval apertures or extended diagonally, giving rise to a reticulate pattern in cross fields.

Pits to axial parenchyma cells: in vertically oriented blocks, with circular apertures.

Areas without any pits: regularly present; small to large.

Tyloses: present.

Helical thickenings: absent.

Notes on identification: the vessel element features are in part similar to those observed in species of Dipterocarpaceae.

Quantitative data:

Vessel elements (278–)763(–1104) μm long, and (167–)285(–367) μm wide; l/w ratio 2.7.

Intervessel pit borders (2.5–)5.7(–8.0) μm in vertical diameter; pit apertures (0.7–)1.6(–3.1) μm .

Fibers 1345 μm long, 28.8 μm wide. Fiber wall thickness 8.8 μm (weighted averages).



Madhuca sericea

***Madhuca sericea* (Miq.) S. Moore (Sapotaceae)**

Trade names: bitis, nyatoh batu (MY, ID).

DIN EN 13556:2003 code: MDXX (*Madhuca* spp.).

CITES regulations: not protected.

Geographic distribution: Peninsular Malaysia, Sumatra, Borneo. (*Madhuca* spp: India, Pakistan, Sri Lanka, Indochina, Indomalesia, Pacific Islands).

Vessel elements: long and slim (length about 730 μm , width about 170 μm); tube-shaped.

Tails: very long with gradual transition or short with abrupt or gradual transition.

Perforation plates: simple, often extending over the entire lumen; inclined.

Intervessel pits: alternate; vertical diameter 2–3–5 μm ; numerous; large fields covering a wide area of the vessel element wall; also in the tails; apertures oval.

Vessel-ray pits: VAS; apertures window-like, circular to oval to elongated horizontally (gash-like); irregularly shaped.

Pits to axial parenchyma cells: similar to vessel-ray pits in size and shape.

Pits to tracheids: if present, in longitudinal well-defined strips (6–8 pits wide); similar to intervessel pits.

Pits to fibers: present in longitudinal single rows.

Areas without any pits: regularly present; large to very large.

Tyloses: often present.

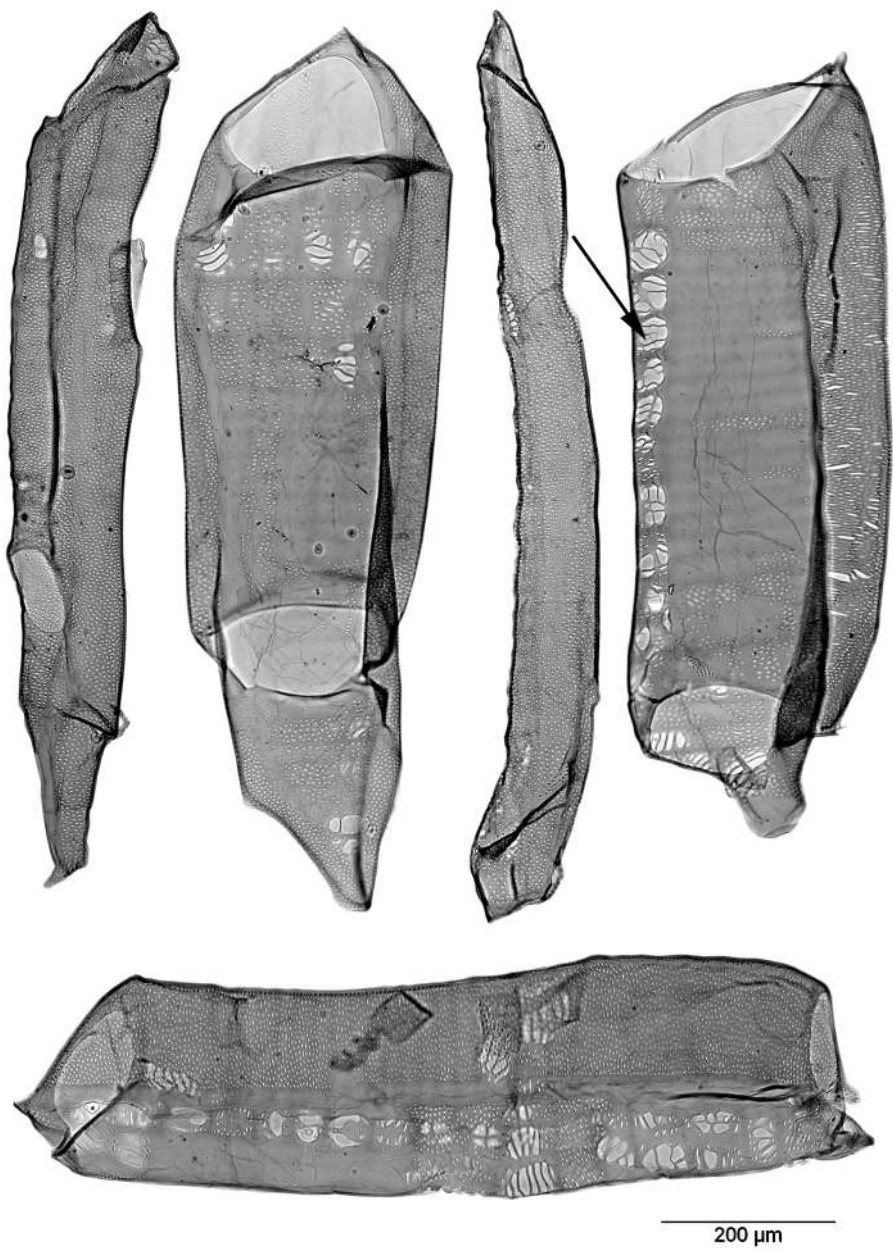
Helical thickenings: absent.

Quantitative data:

Vessel elements (310–)725(–1103) μm long, and (84–)168(–196) μm wide; l/w ratio 4.2.

Intervessel pit borders (1.8–)3.0(–4.9) μm in vertical diameter; pit apertures (0.5–)0.8(–1.5) μm .

Fibers 1485 μm long, 27.5 μm wide. Fiber wall thickness 7.7 μm (weighted averages).



Palaquium sp.

***Palaquium* sp.** (Sapotaceae)

Trade names: nyatoh (MY, ID, DE); chay (VN); pencil cedar, red planchonella (PG); pali (IN); nato (PH); kha-nunnok (TH); riam jangka (MY-swk); hangkang, balam teruing puteh, balam masin, kayu tanjung hutan, mayang, taban (MY, ID); moor-dooke (AU).

DIN EN 13556:2003 code: PPXX.

CITES regulations: not protected.

Geographic distribution: India, Sri Lanka, South China, Indochina, Indomalesia and Pacific Islands.

Vessel elements: large (length about 690 μm , width 290 μm); elongated: those with a smaller diameter are tube-shaped; those with a larger diameter are barrel-shaped.

Tails: short to very long, with gradual transition.

Perforation plates: simple or very rarely scalariform (with 3–10 bars, Richter & Dallwitz 2000); extending over the entire lumen; inclined; few positioned laterally.

Intervessel pits: regularly present; alternate; vertical diameter 3–5–8 μm ; large areas with numerous intervessel pits; apertures circular to oval.

Vessel-ray pits: VAS; in two size classes: larger ones mostly elongated, in groups of 4–8 pits per ray cell (arrow); smaller ones similar to intervessel pits, cross-fields with 3–5 pit rows; apertures oval.

Areas without any pits: regularly present; large to very large.

Tyloses: present.

Helical thickenings: absent.

Quantitative data:

Vessel elements (434–)691(–846) μm long, and (132–)292(–406) μm wide; l/w ratio 2.4.

Intervessel pit borders (3.1–)4.9(–7.8) μm in vertical diameter; pit apertures (0.6–)1.2(–2.0) μm .

Fibers 1900 μm long, 27.5 μm wide. Fiber wall thickness 6.6 μm (weighted averages).

Hardwoods with scalariform perforation plates

introductory comments

This chapter deals with six wood species that possess exclusively scalariform perforation plates. The monocot *Cocos nucifera* (p. 270) also has scalariform perforations. The bars can be thick or thin and differ in number (Fig. 15). These genera could also be included in the groups of APS (p. 272) and VAS (p. 296) but the highly diagnostic feature of the scalariform perforation plates justifies assigning them to a separate group.

There are some genera in the VAS group (p. 296) that, according to literature reports, occasionally have scalariform perforation plates (*Camposperma* sp. (p. 298) and *Palaquium* sp. (p. 334)).

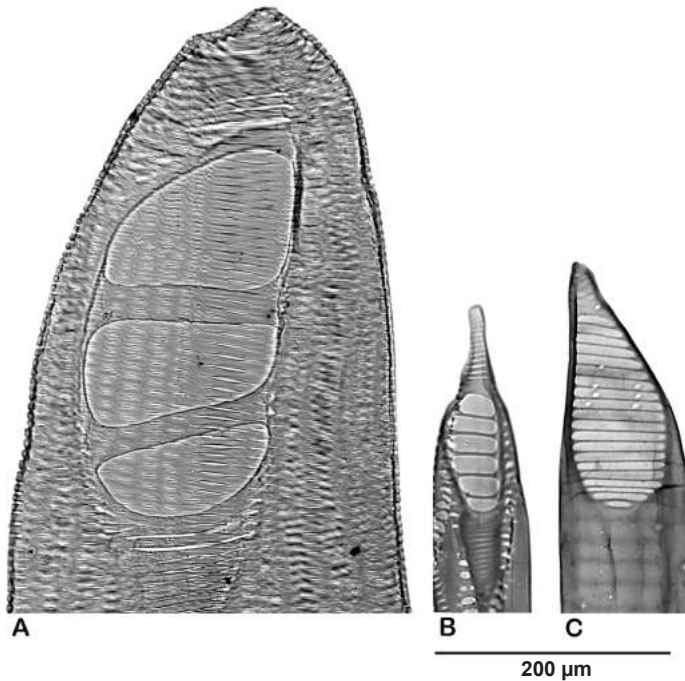


Figure 15. Scalariform perforation plates.

A: 2–4 thick bars, *Cocos nucifera*. – B: 3–10 thin bars, *Rhizophora* sp. – C: 15–30 thin bars, *Liquidambar formosana*.

Figure 16 shows the variation of vessel element length and width as well as the diameter of the apertures and borders of intervessel pits. The boxplots of the length show similar dimensions for *Alniphyllum pterospermum*, *Ilex triflora*, *Liquidambar formosana* and *Schima superba* (Fig. 16a) whereas the values of the width vary (Fig. 16b). *Nyssa javanica* possesses the longest and widest vessel elements and *Rhizophora* sp. the shortest ones. The apertures of intervessel pits of all six species are of similar size with small deviations, the vertical diameters of the pit borders are correspondingly larger.

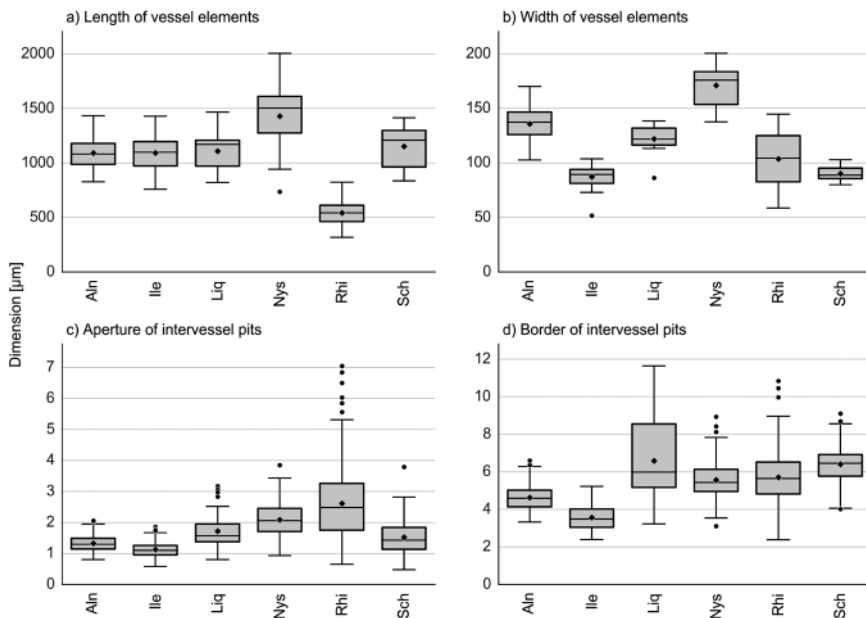


Figure 16. Boxplots of six wood genera/species (length and width of the vessel elements, diameter of pit apertures and borders):

Aln = *Alniphyllum pterospermum*; Ile = *Ilex triflora* var. *kanehirai*; Liq = *Liquidambar formosana*; Nys = *Nyssa javanica*; Rhi = *Rhizophora* sp.; Sch = *Schima superba*.

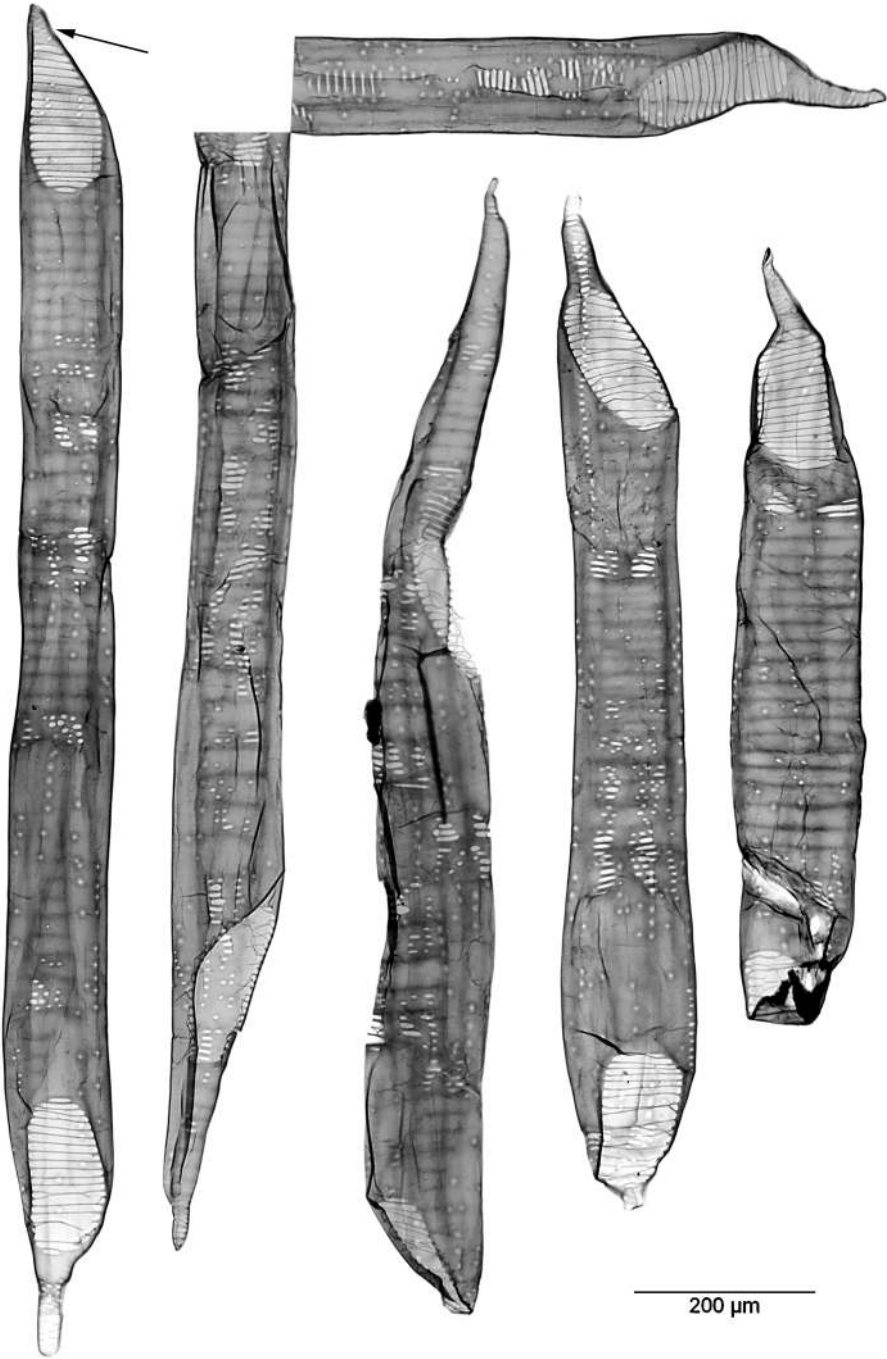
Table 2, a comparison of the eight species with scalariform perforation plates, shows similarities and major differences.

Vessel elements of *Nyssa* spp. are similar to those of *Liriodendron* spp. and *Alniphyllum* spp. *Nyssa* spp. have more numerous thin bars and opposite intervessel pits that distinguish them from *Liquidambar* spp. and *Schima* spp. (see notes on identifications at the end of the individual species descriptions). *Rhizophora* stands out with very extensive scalariform intervessel pits.

Table 2. Species with scalariform perforation plates.

| Species | Length of vessel elements (µm) | Number of bars | Intervessel pits | Size of intervessel pits (µm) | Pits to ray parenchyma cells |
|-----------------------|--------------------------------|----------------|----------------------|-------------------------------|------------------------------|
| <i>Alniphyllum</i> | 830–1080–1430 | 8–15 | Opposite/alternate | 3–5–7 | APS |
| <i>Cocos</i> | 1450–2840–4330 | 2–4 | Scalariform | – | – |
| <i>Ilex</i> | 760–1100–1430 | 20–40 | Opposite | 2–4–5 | APS |
| <i>Liquidambar</i> | 820–1170–1470 | 15–30 | Scalariform | 3–6–12 | VAS |
| <i>Liriodendron</i> * | – | 3–5–10 | Scalariform/opposite | 10–11 | VAS |
| <i>Nyssa</i> | 740–1500–2000 | 20–30(–50) | Opposite/scaleiform | 3–5–9 | VAS |
| <i>Rhizophora</i> | 320–540–820 | 3–10 | Scalariform | 2–6–11 | VAS |
| <i>Schima</i> | 840–1210–1410 | 5–15 | Scalariform | 4–7–9 | VAS |

**Liriodendron* is not treated in this atlas but is commonly used for pulp and paper from North America and temperate China (data: Richter & Dallwitz 2000).



Liquidambar formosana

***Liquidambar formosana* Hance (Altingiaceae)**

Trade names: Chinese sweet gum, Formosan sweet gum (US), feng xiang shu (CN).

DIN EN 13556:2003 code: LQST (*Liquidambar styraciflua* L.).

CITES regulations: not protected.

Geographic distribution: China and Indochina. (*Liquidambar* spp.: temperate Asia (*L. formosana*), North America, Mexico and Central America).

Vessel elements: quite long and slim (length about 1170 μm , width about 120 μm), tube-shaped.

Tails: short or long, with gradual transition.

Perforation plates: scalariform (15–30 thin bars); extending over the entire lumen; inclined.

Intervessel pits: rarely present; vertical diameter 3–6–12 μm ; scalariform.

Vessel-ray pits: VAS; oval or elongated horizontally (gash-like); giving rise to a scalariform pattern in the cross-fields.

Pits to fibers: often present in single vertical rows.

Areas without any pits: regularly present; large.

Tyloses: present.

Helical thickenings: sometimes present at the end of the tails (arrow).

Notes on identification: Vessel elements of *Liquidambar* spp. are similar to those of *Schima* spp. but the number of bars differs (*Liquidambar* spp. 15–30 bars, *Schima* spp. 5–15 bars). They cannot be easily distinguished in mixed pulp.

Quantitative data:

Vessel elements (822–)1172(–1467) μm long, and (86–)122(–138) μm wide; l/w ratio 9.4.

Intervessel pit borders (3.2–)6.0(–11.6) μm in vertical diameter; pit apertures (0.8–)1.6(–3.2) μm .

Fibers 1720 μm long, 27.3 μm wide. Fiber wall thickness 2.8 μm (weighted averages).



Ilex triflora var. *kanehirai*

***Ilex triflora* var. *kanehirai* (Yamamoto) S.Y. Hu (Aquifoliaceae)**

Trade names: san hua dong qing, yuan bian zhong (CN), kecemang (ID).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: China, Taiwan; The genus *Ilex* is almost cosmopolitan and occurs throughout tropical, subtropical and temperate regions of the world.

Vessel elements: quite long and slim (length about 1100 μm , width about 90 μm); tube-shaped.

Tails: long or short with gradual transition.

Perforation plates: scalariform (20–40 thin bars); extending over the entire lumen; inclined.

Intervessel pits: opposite; occasionally merging into a scalariform pattern; vertical diameter 2–4–5 μm ; oval to almost rectangular; sometimes covering a wide area of the vessel element wall.

Vessel-ray pits: APS; rarely present; arranged in blocks of several horizontally oriented, elongated pits (gash-like).

Pits to fibers: in single vertical rows.

Areas without any pits: regularly present; very large.

Tyloses: absent.

Helical thickenings: present in vessel elements, possibly also in fibers.

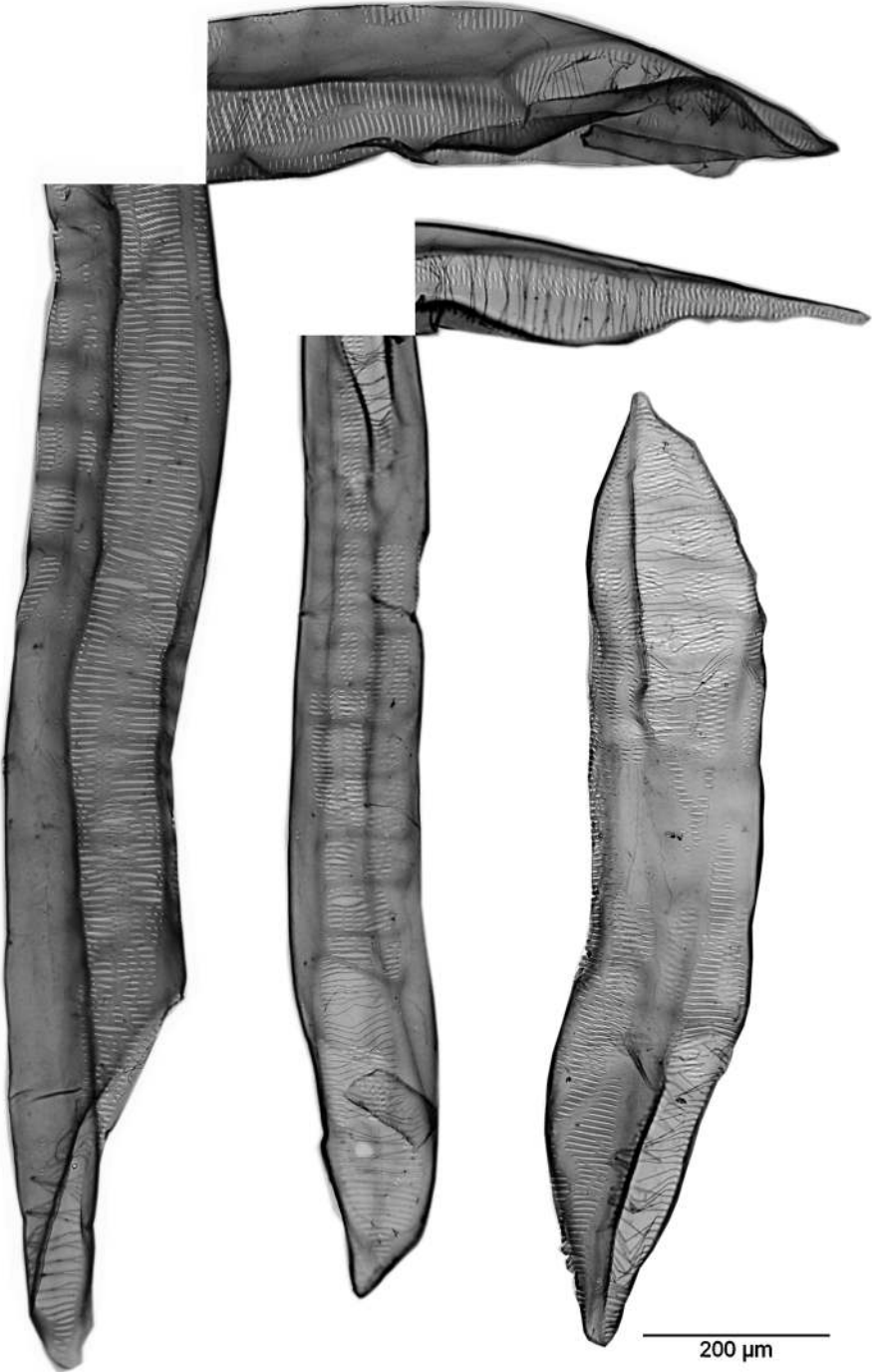
Notes on identification: In pulp and paper, the vessel elements of *Ilex* spp. are often accompanied by fibers with helical thickenings if they originate from subtropical or temperate regions. Most tropical species (like *I. cymosa*) do not have helical thickenings (Baas 1973).

Quantitative data:

Vessel elements (759–)1098(–1430) μm long, and (52–)89(–104) μm wide; l/w ratio 12.4.

Intervessel pit borders (2.4–)3.5(–5.2) μm in vertical diameter; pit apertures (0.6–)1.1(–1.9) μm .

Fibers 1290 μm long, 34.4 μm wide. Fiber wall thickness 4.1 μm (weighted averages).



Nyssa javanica

***Nyssa javanica* (Blume) Wangerin (Nyssaceae)**

Trade names: kalay, hirun, chilauni (IN); thang khok, khai pla, khueng khak, mueat khon khao (TH); kirung, hirung, wuru gading, kapi dengkung (ID); terang bulu (MY); theun (LA). Similar species occur in North America.

DIN EN 13556:2003 code: NYAQ (*Nyssa aquatica*).

CITES regulations: not protected.

Geographic distribution: India, S-China, Malaysia, Indonesia, Indochina.

Vessel elements: very long and slim (length about 1500 μm , width about 180 μm); tube-shaped.

Tails: long with gradual transition.

Perforation plates: scalariform (20–30(–50) thin bars); bars sometimes branched; extending over the entire lumen; inclined.

Intervessel pits: opposite and scalariform; vertical diameter 3–5–9 μm ; more or less rectangular or elongated horizontally.

Vessel-ray pits: VAS; oval or elongated horizontally.

Pits to fibers: circular to oval in single vertical rows.

Areas without any pits: regularly present; large to very large.

Tyloses and helical thickenings: absent.

Notes on identification: Vessel elements of *Nyssa* spp. are similar to those of *Liriodendron* spp. and *Alniphyllum* spp. The pits to ray parenchyma cells differ (*Nyssa* spp. and *Liriodendron* spp. = VAS type, *Alniphyllum* spp. = APS type).

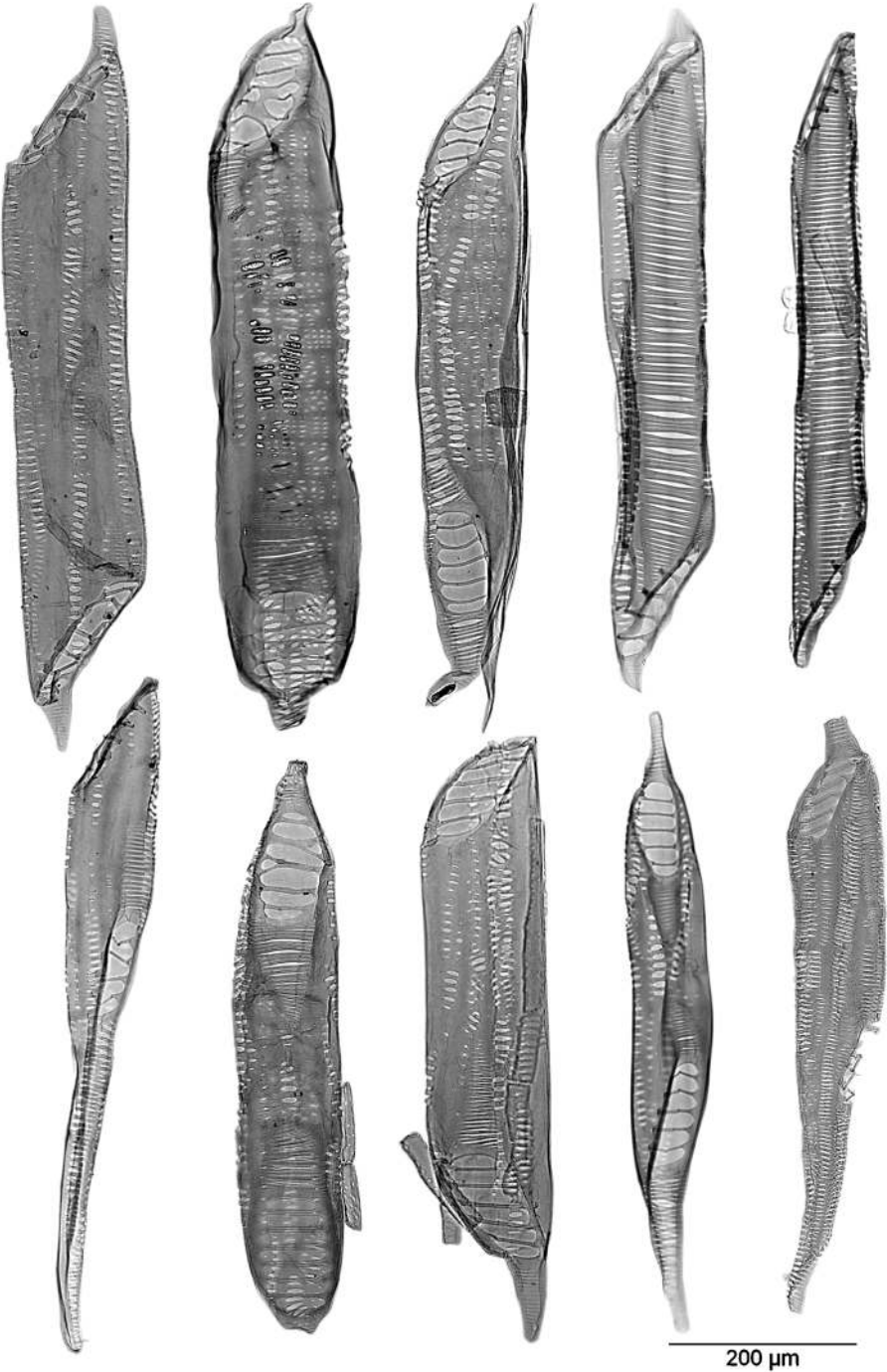
Nyssa spp. and *Liriodendron* spp. possess more numerous thin bars and opposite intervessel pits that distinguish them from *Liquidambar* spp. and *Schima* spp.

Quantitative data:

Vessel elements (736–)1502(–2006) μm long, and (137–)176(–200) μm wide; l/w ratio 8.7.

Intervessel pit borders (3.1–)5.4(–8.9) μm in vertical diameter; pit apertures (0.9–)2.1(–3.9) μm .

Fibers 1350 μm long, 27.0 μm wide. Fiber wall thickness 3.0 μm (weighted averages).



Rhizophora sp.

***Rhizophora* sp. (Rhizophoraceae)**

Trade name: red mangrove.

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: *Rhizophora* is a pantropical mangrove genus, also widely distributed in the Asia-Pacific region.

Vessel elements: quite long and slim (length about 540 μm , width about 100 μm); tube-shaped.

Tails: long or short with gradual transition, covered with pits.

Perforation plates: scalariform (3–10 thin bars); bars can be branched; extending over the entire lumen; inclined (parallelogram or trapezium).

Intervessel pits: scalariform; vertical diameter 2–6–11 μm .

Vessel-ray pits: VAS; oval to rectangular, sometimes opposite.

Pits to axial parenchyma cells: oval to gash-like; in vertical bands.

Areas without any pits: regularly present; large.

Tyloses: present.

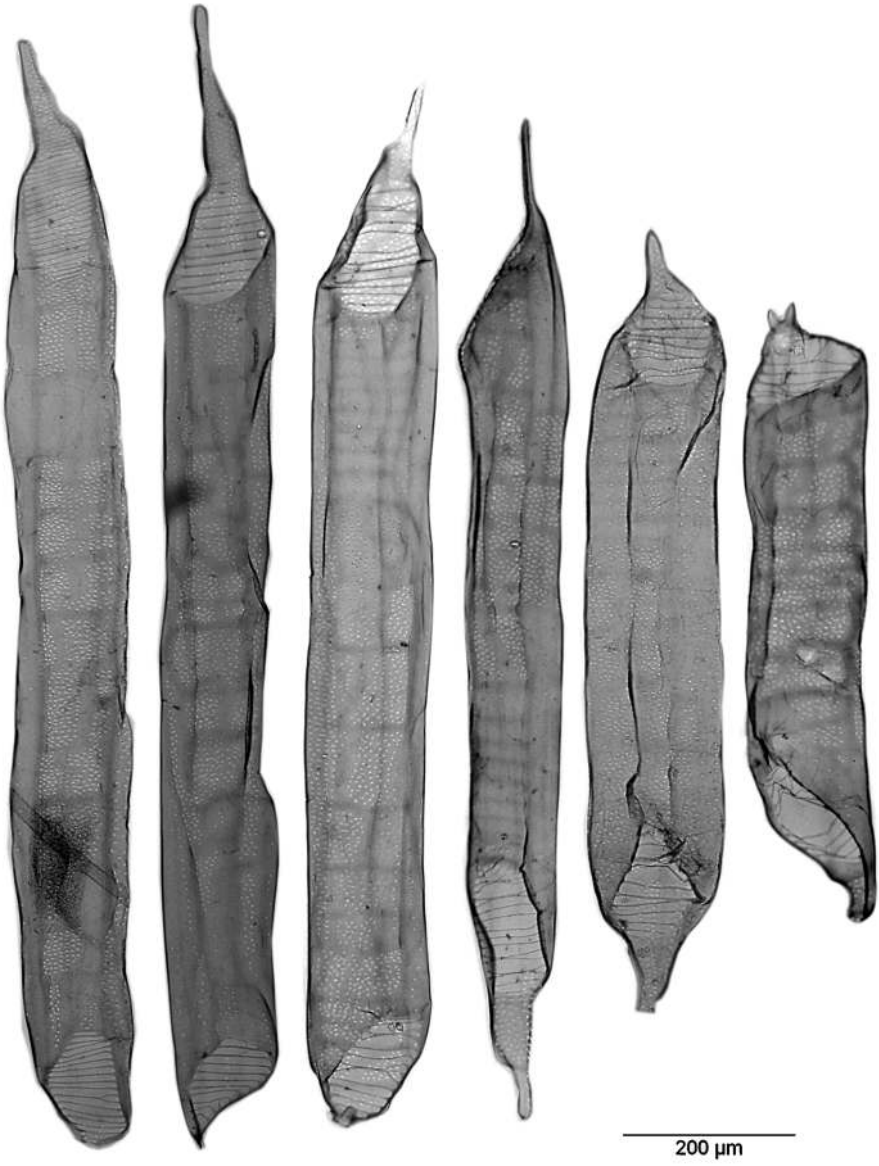
Helical thickenings: absent.

Quantitative data:

Vessel elements (317–)543(–824) μm long, and (59–)104(–145) μm wide; l/w ratio 5.3.

Intervessel pit borders (2.4–)5.6(–10.8) μm in vertical diameter; pit apertures (0.7–)2.5(–7.1) μm .

Fibers 1065 μm long, 26.4 μm wide. Fiber wall thickness 5.9 μm (weighted averages).



Alniphyllum pterospermum

***Alniphyllum pterospermum* Matsum. (Styracaceae)**

Trade names: chi-yang-ye (CN); mee dong (LA).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: China, Taiwan, Laos, Vietnam.

Vessel elements: rather long and slim (length about 1080 μm , width about 140 μm); tube-shaped.

Tails: mostly long with gradual transition, or short.

Perforation plates: scalariform (8–15 bars); bars can be branched; extending over the entire lumen; inclined.

Intervessel pits: alternate or opposite; vertical diameter 3–5–7 μm .

Vessel-ray pits: APS; similar to intervessel pits; forming well-defined blocks of a shape corresponding to the respective ray cells.

Pits to fibers: present in single vertical rows.

Areas without any pits: regularly present; large.

Tyloses and helical thickenings: absent.

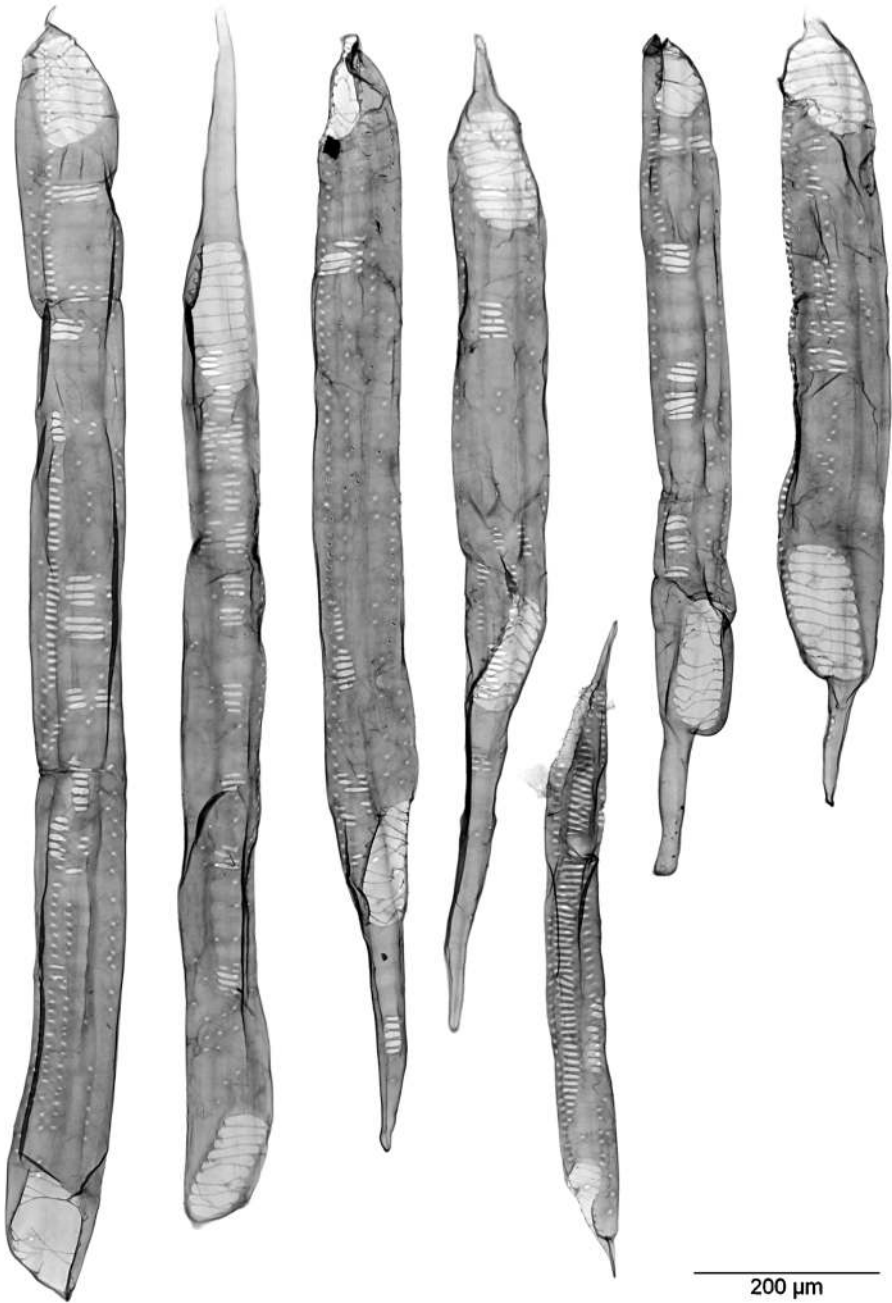
Notes on identification: Vessel elements of *Alniphyllum* spp. are similar to those of *Nyssa* spp. (see *Nyssa javanica*, p. 342).

Quantitative data:

Vessel elements (828–)1081(–1433) μm long, and (103–)137(–170) μm wide; l/w ratio 8.1.

Intervessel pit borders (3.3–)4.6(–6.6) μm in vertical diameter; pit apertures (0.8–)1.3(–2.1) μm .

Fibers 1440 μm long, 35.7 μm wide. Fiber wall thickness 3.7 μm (weighted averages).



Schima superba

***Schima superba* Gardn. & Champ. (Theaceae)**

Trade names: puspa, seru (ID); medang gatal, samak (MY); Chinese guger tree (TW, US); laukya (MM); gaobei, huazi (CN); needlewood (GB); chilauni (IN); thalo, champa dong (TH).

DIN EN 13556:2003 code: not listed.

CITES regulations: not protected.

Geographic distribution: China, Taiwan, Ryukyu Islands. The genus *Schima* also occurs in tropical Malaysia and Indonesia.

Vessel elements: long and slim (length about 1210 μm , width about 90 μm); tube-shaped.

Tails: long with gradual transition.

Perforation plates: scalariform (5–15 bars); bars can be branched; extending over the entire lumen; inclined.

Intervessel pits: rarely present; vertical diameter 4–7–9 μm ; scalariform; forming vertical series of horizontally elongated pits.

Vessel-ray pits: VAS; two size classes; oval or elongated horizontally (gash-like) arranged in short to long horizontal rows (opposite) or in a ladder-like series (scalariform).

Pits to fibers: circular, often present in single vertical rows.

Areas without any pits: regularly present; large.

Tyloses: present.

Helical thickenings: may be present at the end of the tails.

Notes on identification: Vessel elements of *Schima* spp. are similar to those of *Liquidambar* spp. (see *Liquidambar formosana*, p. 338).

Quantitative data:

Vessel elements (836–)1208(–1414) μm long, and (80–)89(–103) μm wide; l/w ratio 13.6.

Intervessel pit borders (4.0–)6.5(–9.1) μm in vertical diameter; pit apertures (0.5–)1.4(–3.8) μm .

Fibers 1350 μm long, 30.5 μm wide. Fiber wall thickness 3.3 μm (weighted averages).

CONCLUSION

The identification of internationally traded wood and wood products is of prime importance in enforcing the legal utilization of wood, especially in pulp and paper which is traded on the largest scale. The identification of individual cell elements (vessels) requires a standardized morphological description with high quality images which is now available for the most important tropical timber species from Asia. Since the fiber components of pulp and paper are subjected to the strict control of the European Timber Regulation (EUTR) from March 2013 onwards, we daily receive samples for checking the declarations from trading companies and competent authorities. In this context, we successfully tested earlier versions of this vessel atlas as an integrated part of our identifications. However, it is obvious that the present Atlas still has weaknesses such as: 1) limited number of taxa included; 2) insufficient sampling to evaluate the full range of variation in vessel element morphology, especially for quantitative parameters at both the species, subgenus and genus level. Future work is necessary to continuously extend the database by describing further unknown or lesser known species.

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ABBREVIATIONS

| | |
|--|--|
| APS - all pits similar in size and shape | PF - pit to fiber |
| EUTR - European Timber Regulation | PT - pit to tracheid |
| IVP - intervessel pit | VAS – vessel-ray pit apparently simple |
| MTH - Mixed Tropical Hardwood | VRP - vessel-ray pit |
| PAP - pit to axial parenchyma cell | |

Codes of two capital letters are according to ISO 3166 (except BN)

| | | |
|-------------------------------|---------------------------|-------------------------------|
| AU = Australia | JP = Japan | NP = Nepal |
| BN = Borneo | KH = Cambodia | PA = Panama |
| BR = Brazil | LA = Laos | PG = Papua New Guinea |
| CN = China | LK = Sri Lanka | PH = Philippines |
| DE = Germany | MG = Madagascar | sAM = South Americas |
| FR = France | MM = Myanmar (Burma) | TH = Thailand |
| GB = Great Britain | MY = Malaysia | TW = Taiwan |
| ID = Indonesia | MY-sab = Malaysia-Sabah | US = United States of America |
| ID-kal = Indonesia-Kalimantan | MY-swk = Malaysia-Sarawak | VN = Vietnam |
| IN = India | NL = Netherlands | |

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