Rattan Resources, Properties, Biocomposites, and Chemical Modification: A Review

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Rattan is a climbing palm and belongs to the family of Calameae. It once was the most important non-timber forest product, especially in the Southeast Asia countries. Despite being labelled as an old or 'sunset' industry by many industry players in the region, the rattan global market has grown stronger, with significant increases from only USD 23.4 million in 2008 to 385 million in 2020. The increasing global demand for rattan products will require a systematic selection of rattan species for optimum utilization for a quality product and service life extension. As a result of increased interest by fashion designers for rattan, especially from EU-27 countries, there is a need to understand the rattan properties such as anatomical, physical, mechanical, chemical, and resistance to fungi. This review paper also considers the rattan resource grown in plantations and natural forests, drawing upon the experiences of a certain main producer country. New product development for rattan is also highlighted in this review, including potential new markets. These may include conventional biocomposites, rattan-polymer composites, and specialty rattan products prepared by chemical modification.

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INTRODUCTION

Rattans are renowned as the climbing palms that can grow to hundreds of metres long. The name rattan originates from the Malay "*Rotan*", which represents the Calameae tribe of palms and consists of approximately 600 species. The majority of rattans are discrete from other palms as they have flexible slender stems of 2 to 5 cm diameter with long internodes between the leaves. In contrast to trees, the rattan growth habit is vine-like, and they climb from side to side and over other plants with the aid of a special tool, the spine (Fig. 1).

The spines also deter surrounding herbivores. The spine is attached either with flagellum or cirri (Fig. 2). Some non-climbing genera, including *Metroxylon*, *Pigafetta*, and *Raphia*, are akin to typical palms with stouter and erect trunks. The rattans are indigenous to tropical regions of Asia, Africa, and Australasia.

(a) Tree canopy **(b)** Forest canopy

Fig. 1. (a) Rattan (*C. manan*) climbing up the rubber tree canopy; (b) Rattan (*C. manan*) climbing up the forest canopy.

Flagellum Cirrus

Fig. 2. The spine of rattan attaches either with flagellum or cirrus (red arrow).

Rattan Classification

Rattan classification is complex and has taken many years to resolve. The basic morphology includes leaves, inflorescence and its bracts, the arrangement of flowers on the rachillae, flora structure, and fruits. These are used for classification (Moore and Uhl 1982; Kurian *et al.* 2017).

Further classification involves using anatomical investigation, *i.e.*, examination of the epidermis, vascular bundles, and parenchyma tissues. The variation of the anatomical features among the rattan genera is very useful when identifying manufactured products and to resolve the trade disputes (Weiner and Liese 1990; Liese 2001). The relationship between anatomical and morphological aspects is recognizable, but the significance has not been clearly reported; hence there are minor differences between both forms of classification (Weiner and Liese 1990).

More recently, phylogeny has been examined using the chloroplast DNA, which has been compared with morphological and anatomical approaches. This has resulted in a new classification (Baker *et al.* 2000). The effects of such phylogenetic studies have given insights into the evolutionary process in rattan genera and their origin. In this way, Hahn (2002) explored the phylogeny of 65 palm genera that represents all six subfamilies and 14 tribes.

Rattan Classification Based on Morphology Characteristics

The first outline of palm classification was completed by Dransfield and Uhl (1986); this was followed by the classification of rattan genera (Uhl and Dransfield 1987). Tables 1 and 2 show the classification of subfamily Calamoideae and the members of the rattan genera.

Table 1. Classification of The Subfamily Calamoideae According to Dransfield and Uhl (1986)

Tribe	Subtribe	Genera
Calameae	Ancistrophyllinae	*Laccosperma* (G. mann & H. Wendl) Drude
		Eramospatha (G. mann & H. Wendl) H. Wendl.
	Eugeissoninae	*Eugeissona* Giff.
	Metroxylinae	*Eleiodoxa* (Becc.) Burret
		Salacca Reinw.
		Daemonorops Blume
		Calamus L.
		Calospatha Becc.
		Pogonotium J. Dransf.
		Ceratolabus Blume
		Restispatha J. Dransf.
	Plectocomiinae	*Myrialepis* Becc.
		Plectocomiopsis Becc.
		Plectocomia Mart. Ex Blume
	Pigafettinae	*Pigafetta* (Blume) Becc
	Pigafettinae	*Raphia* P. Beauv.
	Raphinaea	*Raphia* P. Beauv.
	Oncocalaminae	*Oncocalamus* (G. Mann & H. Wendl.) G. Mann & H. Wendl. Ex. Hook. F.
Lepidocaryeae		*Mauritia* L. f.
		Mauritiella Burret.
		Lepodocaryum Mart.

The subfamily is one of the six subfamilies from the family Aracaceae (Palmae) that comprise the remainder of Coryphoideae, Nypoideae, Ceroxyloideae, Arecoideae, and Phytelephantoideae. Members of the family are characterised by overlapping and reflexes scales on the fruit pericarp, and they consist of about 189 genera and 2000 species. The Calamoideae contains two tribes, Calameae and Lepidocaryeae. The subfamily has eight subtribes and 22 genera. Of these, only 13 genera and about 600 species represent the true “rattans” as defined earlier.

Dransfield (1992) described the most important distinguishing features among the rattan subtribes. The Ancistrophyllinae have hermaphrodite flowers; these have pairs of fertile stamens and pistils, and for this reason the genera *Laccosperma* and *Erasmopatha* are located in this subtribe. The hermaphrodite flowers of the Metroxylinae display singly on cylindrical branches and are represented on the key non-climbing sago palms (Metroxylon).

Korltasia is in the Metroxylinae group, having similar cylindrical branches. In addition to its inflorescences, the Calaminae are dioecious, *i.e.*, they have differences between male and female plants. The flowers of male inflorescences are single or in twos, while the flowers of female inflorescences are found collectively with sterile male flowers. Genera of *Calamus*, *Daemonorops*, *Ceratolobus*, *Pogonotium*, and *Calospatha* that share this feature are grouped under the subtribe Calaminae. Despite being dioecious, the sterile male flowers are not present amongst the female inflorescences of Plectocomiinae. The genera belonging to this subtribe are *Plectocomia*, *Plectocomiopsis*, and *Myrialepis*. They are also characterised by terminal flowering, which is followed by the death of the flowering stem. The subtribe Oncocalaminae is unisexual, either male or female, and the flowers are borne in stout intricate clusters in the empty space of bracts, the character that distinguishes them from the subtribe Ancistrophyllinae.

Table 2. Rattan Genera, Species and its Distribution as Modified from Uhl and Dransfield (1987)

Subtribe	Genera	Species (No.)	Distribution
Ancistrophyllinae	*Laccosperma*	7	Humid tropical Africa
	Eramospatha	12	Humid tropical Africa
Metroxylinae	*Korltasia*	26	Indochina, Burma to New Guinea
Calaminae	*Daemonorops*	115	India, China to western most New Guinea
	Calamus	370	Tropical Africa, India, Sri Lanka, China
			South and east Fiji, Vanuatu and
			Eastern Australia
	Calospatha	1	Endemic to Peninsular Malaysia
	Pogonotium	3	One in Peninsular Malaysia and Borneo
			Two endemic to Borneo, Peninsular
			Malaysia, Sumatra and Java
	Ceratolobus	6	Endemic to Borneo
	Retispatha	1	
Plectocomiinae	*Plectocomia*	16	Himalayas and South China to Western
			Malesia
	Plectocomiopsis	5	Thailand, Peninsular Malaysia, Sumatra
			Borneo
	Myrialepis	1	Indochina, Thailand, Burma, Peninsular
			Malaysia, Sumatra
Oncocalaminae	*Oncocalamus*	1-3	Humid tropical Africa

Rattan Classification Based on Morphology and Phylogeny Characteristics

Anzizar *et al*. (1998) studied the suitability of both RAPD and ITS for recognition of 62 species contained in 50 palm genera. They revealed the limitation of the techniques for analysing genetic similarities or inferring phylogeny above the species level. In ITS and RAPD, the cluster between different subfamilies, subtribes, and tribes were mingled with each other, although some similarities were found in the dendrograms. However, the markers were thought to be useful in fingerprinting and analysis of variability at the species level only.

Baker and Dransfield (2000) reformed the phylogeny analysis for the subfamily Calamoideae by combining the datasets of molecular makers and morphology. This combination overcame the dissimilarities between the results of morphological analyses (Baker *et al.* 1999) and poor resolution or low support in ITS and chloroplast *rps16* intron (Baker *et al.* 2000). The morphological character of the internodes length resolved into three conditions: internodes less than half the stem diameter (0), internodes with half and twice the stem diameter (1), and internodes more than twice the stem diameter (2). The inflorescence of the tree classified into either free of inflorescence, or adnate to internode, or adnate to internode and sheath.

In the combined dataset and analysis, the results revealed that the tribe Calameae is not monophyletic but is nested with the Lepidocaryeae. The subtribe Calaminae is not monophyletic, but it can be separated into two distinct clades. The subtribes Ancistrophyllinae and Oncocalaminae are sister to each other. In the new classification based on phylogeny features, the subfamily Calamoideae contains three tribes and nine subtribes (Table 3). It is clearly defined by morphology. The condition 0 is characterised by acaulescent palms, 1 is a typical palm tree, and 2 belongs to climbing palms and to all rattan genera.

Table 3. New Classification of Sub Family Calamoideae Based on Combine Datasets (Baker *et al.* 2000)

Tribe	Subtribe	Genera
Eugeissoneae		*Eugeissona*
Lepidocaryeae	Ancistrophyllinae	*Laccosperma, Erasmopatha, Oncocalamus*
	Raphiinae	*Raphia*
	Lepidocaryinae	*Mauritia, Mauritiella, Lepidocaryum*
Calameae	Salaccinae	*Eleiodoxa, Salacca*
	Pigafettinae	*Pigafetta*
	Metroxylinae	*Metroxylon*
	Korthalsinae	*Korthalsia*
	Plectocomiinae	*Myrialepis, Plectocomiopsis, Plectocomia*
	Calaminae	*Calamus, Daemonorops, Calospatha*
		Ceratolobus, Pogonotium, Restispatha

The Eugeissoneae is considered as the first tribe in new Calamoideae classification, which was resolved as a sister to Raphia-Laccosperma clade (or Asian clade) in morphological analysis and as sister to Raphia-Mauritia clade in ITS analysis data and on basal in-group polytomy in rps16 analysis. The genus was resolved as the sister to all remaining Calamoideae and is thus not part of the Asian clade *via* simultaneous analyses of two molecular datasets. The exclusion of Eugeissona from other Calamoideae clade is strongly supported by the inflorescence structure and the fruit. The peculiar structure of inflorescence in each rachilla bears a single dyad of flowers in the axils of the distal most rachilia bract. The fruit have a hard endocarp, which originates from a mid-fruit wall layer and the mesocarp is very fibrous, unlike other Calamoid mesocarps.

The Lepidocaryeae is the second tribe, which is comprised of the subtribes Ancistrophylinae, Raphiinae, and Lepidocaryinae. The clade from *Laccosperma*, *Raphia* and *Mauritia* has a jackknife value of 65% in the preferred tree, which is below the threshold of 90%. The members of the clade are accepted in the new classification from several analyses of DNA datasets, including the simultaneous analysis and its bio-geographic significance. In contrast to classification outline by Uhl and Dransfield (1987), Oncocalaminae and Ancistrophyllinae are merged in this tribe, as both have cirri with acanthophylls and have pistillate or hermaphroditic flowers in a terminal position in the dyad. This tribe is also known as an African-American clade. The three African genera are comprised of *Laccosperma*, *Eramospatha*, and *Oncocalamus*. They are located in a single subtribe of Ancistrophyllinae by remarkably similar vegetative morphologies.

The Calameae, the third tribe, affiliates to the Asian clade. This resolves in almost all analyses. The tribe is composed of six subtribes and is well supported with a 100% jackknife frequency in the preferred tree. In morphology, they share similar flower and pollen characters. The spines are combined with foliar organs and occur in whorls. The arrangement of the whorls is visible either on leaf sheaths, petioles, or climbing organs. The pollen is diaperturate and dioecious, with the exception of *Korltasia* and *Metroxylon* but this condition is also present in *Mauritia* clade. The Salaccinae is the sister group of the rest of the remaining Asian clade and is recognized by extremely short internodes and abaxial or adaxial split of the prophyll in the inflorescences. These characters are also observed in *Daemonorops* and *Pogonotium*. The flower clusters, which are subtended by the distal rachilla bracts, occur in Laccosperma, Lepidocaryum, and Salacca clades. However, *Korthalsia* rather than *Salaccinae* is resolved with good jackknife support as a sister to the remaining Asian clade members. The subtribe Pigafettinae is also held in tribe Calameae, with the only massive pleonantic tree palm of the genus *Pigafetta* (Baker *et al.* 2000).

The clade of Metroxylon-Plectocomia-Calamus is not assigned a proper rank because it lacks jackknife support in the preferred tree. They belong to the rattan genera, except that the Metroxylon and are strongly characterised by grapnel spines. Grapnel spines are also present in African rattans, but they are rarely stout as compared to Asian rattans. The Metroxylinae clade contains the only non-diecious genera in the Asian clade. These belong to the genera *Metroxylon* and *Korthalsia*. They can be recognised by hermaphroditic flowers in the lateral position of the flower cluster. This type of flower also display in Ancistrophyllinae. The genera Korthalsia is rejected from the Metroxylinae, as it is morphologically different. *Metroxylon* is grouped into the category of tree palms and *Korthalsia* as a robust rattan. In addition, the genera have a weak support for the monophyly of the Metroxylinae, and thus leaving *Korthalsia* as monogeneric in the subtribe Korthalsiinae (Baker *et al.* 2000).

The Plectocomia-Calamus clade is highly supported by the jackknife value of 92% and is comprised of rattan genera only. Members of this clade have fewer stalks in rachillae, excluding the genus *Calamus*. The bract is a tubular rachilla, distichously-organised and subtends flower clusters at both proximal and distal ends of the rachilla itself. The clade is identified by lacking lateral flowers in staminate flower clusters, but this is different in the genus *Plectocomia*. The *Plectocomia* clade comprises the only climbing group with cirri and pistillate flower clusters, but it lacks flowers in the terminal position.

The *Calamus* clade is well known by the adnation of the inflorescences at both internodes and sheaths above the axils of origin. The presence of a knee-like swelling below the petiole and the possession of dorsifixed anthers and divergent stigmas are remarkable in this clade. Despite being well supported in two molecular and one morphology dataset of simultaneous analyses, the position of *Eugeissona* as sister to all remaining Calamoideae clade and the relationships between *Pigafetta*, *Korthalsia*, *Metroxylon*, the *Salacca* clade and the Plectocomia-Calamus clade remain unclear. Table 3 shows a new phylogenetic classification of subfamily Calamoideae.

Resource Issues

Rattans as a raw material for industrial use are totally sourced from the natural forest. The boom of rattan products with the export growth from 20 to 50% in Southeast Asia and China during the 1970s to 1980s led to over-exploitation and wasteful utilization of the resource. This resulted in stock depletion, especially of the main commercial species. The shortage of rattan, restrictive government policies, and economic crisis impacted the industries, causing a slower growth rate during mid of 1990s (ESCAP 1991; Inbar 1998).

In efforts to sustain the rattan industry, the governments of the producer nations such as Malaysia and Indonesia enforced a ban policy on the export of raw rattan. This action succeeded in stimulating the production of domestic value-added rattan products, especially furniture. This policy shift improved the growth of local rattan industry. A remarkable increase of about 200% in term of cane furniture exported was reported by Malaysia in the mid 1990s (Sastry 2001), while Indonesia as a main producer country showed an increment of export from USD 200 million in 1987 to USD 300 million in mid 1990s (Soedarto 1999).

In Malaysia, the export ban of raw rattans resulted in the reduction of rattan oil curing centres, as most industrial players stopped their operations. The reduction of rattan oil curing centres affected the supply of semi-processes rattan for furniture industries. The number of small and medium scale rattan furniture industries have been declining every year since the late 1990's (Pratono 2020; Sulaiman *et al.* 2020).

PLANTATION PROGRAM AND CONSERVATION STATUS OF THE RATTAN RESOURCE

Sustainable management is a major policy applied by almost all producer countries in order to sustain future rattan resources. Plantation programs started as early as 1979 in Malaysia. Currently, almost 31,000 ha of land have been planted with various rattan species by government agencies and public organisations. Apart from that, about 7,000 ha of land are filled with *Calamus manan* in an agro forestry system with the rubber tree plantations (Mohmod 2000). By 1997, the Malaysian Forestry Department had cultivated about 15,000 ha of *C. manan* in logged-over natural forest for conservation purposes. This species represents about 80% of the planting program, while the remaining was from small diameter species of *C. ceasius* and *C. trachycoleus* (Mohd. Ali and Raja Shaari 2002).

Meanwhile, Indonesia had cultivated approximately 37,000 ha of high value rattan species and China had established about 20,000 of rattan plantation using both domestic and imported species. The Philippines, however, had only planted about 6,000 ha of rattan. (Sastry 2001).

Quality of Cultivated Rattan Grown under Rubber Tree Canopy

This issue is more focused towards the large diameter rattan species, *i.e.* of more than 18 mm diameter, rather than the small diameter ones and in Malaysia is particularly important for *C. manan*. The harvesting age of 8 to 10 years old was recommended for *C. manan* grown under the rubber tree canopy for utilisation purposes. Maturation was indicated by the changes of the stem colour from green to yellow (Mohammad and Liese 1990; Nur Supardi and Mohmod 1991).

These age ranges gave a very optimistic growth rate, ranges from 1.67 to 3.58 m year^{-1}. This gave projections of a good recovery rate. In terms of diameter, the first three metres length of stick at the basal portion, ranged from 18 to 24 mm, and the eighth stick had a greater diameter of 40 mm. Other criteria examined included the oven-dry density and basic density, which ranged from 400 to 800 kg m^{-3} and from 750 to 1170 kg m^{-3}. The density ranges gave a recovery rate between 1.33 to 7.33 usable sticks, when it was measured at a standard industrial length of three metres (Nur Supardi and Mohmod 1991).

The optimistic study results and growth rate projections were not met in industrial practice. Many owners of oil curing centres who buy rattan from the rubber tree plantations made technical claims that the canes shrink after oil curing and are not suitable for further processing. As a result, a number of rattan plantations, especially of *C. manan* under agroforestry have been converted to other crops, especially oil palms, which had a more sustainable demand and price in the global market (Wahab *et al*. 2001).

In addition, there is no standard mechanism to determine the price of raw rattan. It is always up to the oil curing entrepreneur to decide the final price. Nevertheless, some local farmers in Malaysia still keep their rattan growing under the rubber tree canopy and have extended the age-maturation in order to secure a better selling price. The age-maturation factor which influences the cane quality is still unsolved and questionable, as the growth and maturation are also influenced by other factors such as individual stem survival, soil type, site conditions, and other external factors that may vary between site locations. Some farmers claimed that cultivated agroforestry rattan has excellent growth, especially diameter and height, but is less mature than natural forest grown rattan due to oversupply of nutrients present around the rubber tree stump. This problem has not affected the conservation status of rattan in the selectively harvest management forest, as no statement has been declared about the utilization of rattan resources at the recommended age of 8 to 10 years. Similarly, the optimum harvesting age for cultivated rattan grown under this forest management regime is still unknown. The unsuccessful rattan plantation program under the rubber tree canopy has resulted in continual replanting of the rattan under logged over forest areas; this is done by the stakeholder, for example, the Malaysia Forestry Department (Pratono 2020; Sulaiman *et al.* 2022)

CURRENT RATTAN RESOURCE

In Malaysia, the slower exploration of raw rattan from the natural forest due to a lower demand from the rattan oil curing centre during late 1990s until now has gradually led to an increase of abundant new rattan stock in the natural forest. About 269 million of rattan clumps were recorded in natural forest in Malaysia based on the National Forest Inventory 5 (NFI-5) in 2017, and the *Calamus manan* is a dominant species as compared to others (Fig. 3).

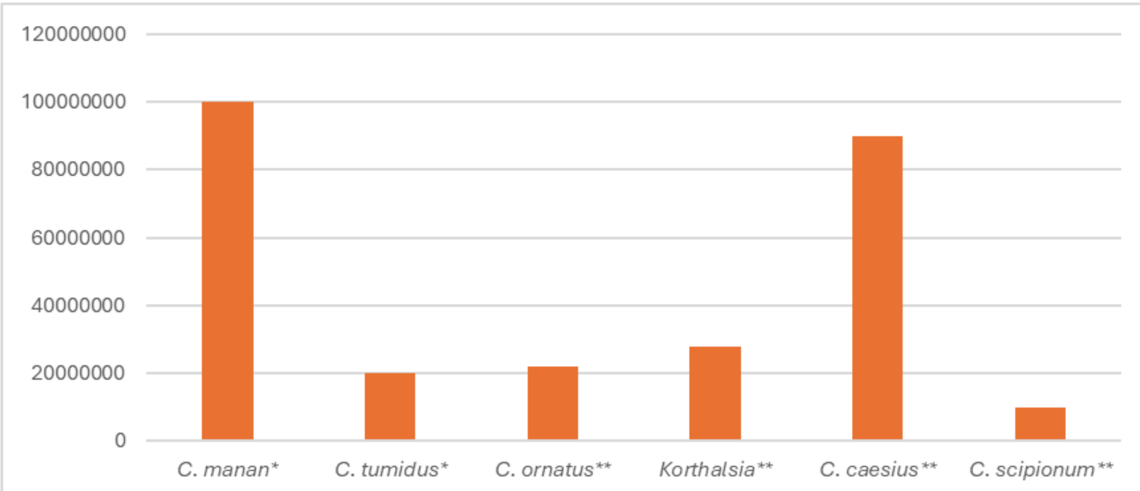

Fig. 3. The number of rattan by species in Malaysia based on the National Forest Inventory 5 (*is number of individuals and **is number of clumps)

Rattan Trade

Despite being labelled as 'the sun set industries' since early 2000, the world export of rattan products has increased significantly from only USD 23.4 million in 2012 to USD 385 million in 2020. In 2008, Indonesia was the dominating rattan cane exporter, with 37,500 tonnes, which represented 60 per cent of global exports with a value of US$34 million. Malaysia exported 3,929 tonnes of rattan canes in 2008 with the export value of US$4 million. Myanmar is the third largest export country, with export almost 10,000 tonnes, and accounting for 16 per cent of global exports with a value of US$2.8 million. In contrast, the Philippines and Viet Nam exported significantly more rattan canes than they imported (Inbar 2012; Inbar 2020).

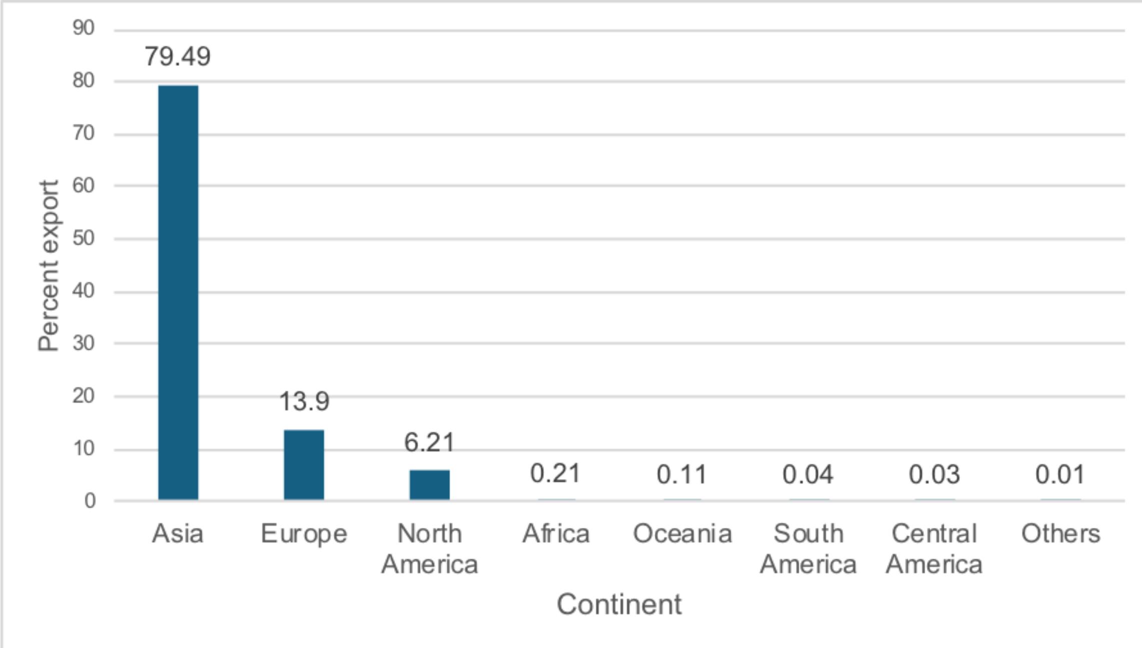

Fig. 4 The export of rattan by region (Source: Inbar 2020)

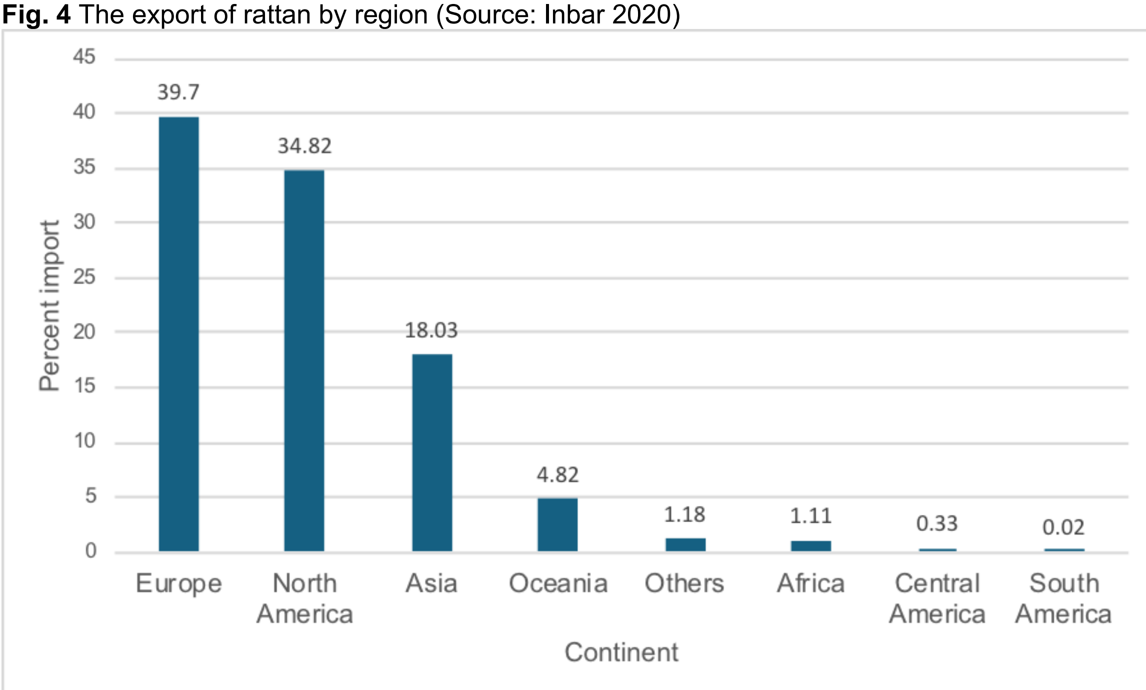

Fig. 5. The import of rattan by region (Source: Inbar 2020)

In 2020, about 80% of world rattan exports came from the Asia countries, followed by Europe (13.9%) and North America (6.2%), with a value of USD 310 million (Fig. 4 and 5). Amongst the Asia pacific region (Table 4), Indonesia is the biggest rattan products exporter (41.18%, USD 158 million), followed by China (18.03%, USD 69 million), and the EU-27 (12.87%, USD 50 million). Malaysia, once the second world rattan products exporter in 2008, is not on the list for 2020 (Inbar 2012, 2020).

Table 4. Main Exporters of Rattan Products in 2020

Country	USD (million)	%
Indonesia	158	41.18
China	69	18.03
EU-27	50	12.87
Vietnam	38	9.76
USA	23	6.09
Philippines	17	4.43
Singapore	9	2.36
Hong Kong	5	1.31
United Kingdom	3	0.72
Myanmar	2	0.60

(Source: Inbar 2020)

In 2020, the total import value of rattan commodities in Europe was about USD 200 million (39.7%), followed by North America with about (USD 170 million, 34.8%) and Asia (USD 90 million, 18%). Amongst the countries, the EU-27 are the biggest rattan importers (30.68%, USD 153 million), followed by U.S.A (29.22%, 145 million), Canada (5.04%, USD 0.25 million), and United Kingdom (5.03%, USD 0.25 million) (Inbar 2012, 2020).

Table 5. Main Importers of Rattan Products in 2020

Country	USD (million)	%
EU-27	153	30.68
USA	145	29.22
Japan	25	5.04
China	25	5.03
Canada	23	4.53
Australia	22	4.39
Singapore	19	3.90
South Korea	10	1.93
United Arab Emirates	9	1.74
Switzerland	9	1.74

(Source: Inbar 2020)

PROPERTIES

Anatomical Properties

Rattan properties are important, as they can been used for identification purposes and to solve trade disputes. They are also important for grading and quality control for manufacturing and finished products. The characterisation of rattan properties is important for the determination of maturation properties (*i.e.* when to harvest) and to introduce any new treatment, processing, and technology applications.

The anatomical properties of rattan such as the different shape of vascular bundles and its components are being used routinely to identify such material is indigenous or an imported species during disputed in court for a smuggling case.

Besides the lignin, the two other major structural cell wall components in rattan cell walls are cellulose and hemicellulose. Inorganic elements (ash) and extractive materials are also other minor components. The chemical constituents of Malaysian rattans are significantly different by species, height, and the interaction of species and height, except for the holocellulose content (Mohmod *et al.* 1997). The species with a higher extractive content needs a longer time for oil curing, and an extra bleaching process is required to render its color uniform. A higher silica content influences the knife sharpening costs, as it causes dulling. Species that contain higher starch content are easily attacked by fungus and termites and require an extra processing cost for sulphur fumigation and preservative. Therefore, the amount and composition of chemicals in rattan is important to consider before selecting a species for a specific product.

Function of Structural Cells in Rattan Stem

Rattan tissues are similar to other monocotyledon plants and comprise the epidermis (EC), cortex (CR), and central cylinder (CC) cells, as shown in the transverse section (Fig. 6), ground parenchyma (GP), vascular bundles (VB), and leaf traces (LX).

The epidermis consists of a single unlignified cell layer which envelopes the stem and its outer tangential wall and is either impregnated with silica dioxide or covered by a layer of wax. The sub-epidermal zone or cortex is the area between the epidermis and the first vascular bundles of the central cylinder. It comprises lignified parenchyma cells, incomplete vascular bundles and small fibres. The zone provides substantial strength and gives a tight seal to the central part against loss of moisture. During impregnation with liquids for processing, this layer hinders lateral penetration. The central cylinder consists of vascular bundles (VB), ground parenchyma tissue (GP), and raphide sacs. Vascular bundles are surrounded by the parenchyma cells. The vascular bundles with thick walls (heavily stained fibres in Fig. 5) give structural support to the stem. The sac is a thin walled raphide bundle. It is characterised by having unlignified mucilage fill cells (Weiner and Liese 1990; Weiner and Liese 1993; Liese 1994).

Fig. 6. The structural cell of wild *C. manan*. EC-epidermis cell, CR-cortex, VB-vascular bundle, GP-ground parenchyma, LX-leaf traces

Besides structural support, the main function of vascular bundle elements in rattan is for water transport from the root system through the stem towards the leaf. Metaxylem vessels with wide diameters are responsible for longitudinal water uptake from the root. Although vascular bundles and metaxylem vessels taper at both ends and are not directly connected longitudinally, this discontinuity is linked by the pitted parenchyma cells. In contrast, the protoxylem is less efficient for water conduction in rattans because the cells are interrupted, their lumina are narrow, and cell ends are imperforate and less in quantity within a single axial bundle. Lateral water movement from metaxylem vessel to adjacent metaxylem vessel is through narrow tracheid elements. Longitudinally, water moves *via* metaxylem cells, but when it reaches the leaves, it can only move from metaxylem to protoxylem and hence finally into leaves across the conjunctive parenchyma that covers the metaxylem. A substantial resistance of longitudinal water movement to the stem and from the stem to leaf could be explained by the "safety" *vs*. "efficiency" concept to avoid permanent loss of transport capacity caused by frequent vessel cavitations during water stress. Lack of hydraulic efficiency in rattan stems is due to pits and tracheids element activities. It has been suggested that the main function of metaxylem vessels is as water storage tissue (Tomlinson *et al.* 2001).

The Cell Dimensions

Variation of vascular bundles within the wild rattan stem

Cell dimensions, frequency, patterns, and distribution are measured in anatomical studies of vascular bundles in rattan stems. Trends vary in location between individual species. Density or frequency of vascular bundles is inversely proportional to stem diameter of rattan grown in China. Small diameter species of *C. dioicus* with average diameter of 4.8 mm have greater frequency of vascular bundles (9 to14 mm^2) than the largest species (*Daemonorops margaritae*), with the stem diameter and frequency of 12.2 mm and 3 to 5 mm^2 respectively. In contrast, the diameter of vascular bundles increases in proportion to the stem diameter. The average vascular bundle length for *D. margaritae* and *C. dioicus* 500 µm and 381 µm, respectively (Cai 1989).

The vascular bundle size has a higher tendency to be smaller, where there are more vascular bundles in Indian rattans. The frequency is not significantly different to the stem portion, and ranges from 0.041 mm^2 in small diameter rattan species (*Calamus rancorous*, 3.9 mm) to 0.201 mm^2 in large diameter rattan species of *C. thwaitesii* (20 mm). Vascular bundles are smaller at the outer than at the centre section but the difference between the centre and the intermediate is often insignificant. In the longitudinal direction, the size is slightly smaller from the bottom towards the top portions at the outer section but no specific trends are seen at the centre and the intermediate sections. In ascending order, the size increases with increasing stem diameter in *C. travancoricus*, *C. hookerianus*, and *C. thwaitesii* (Bhat *et al.* 1990).

In *C. palustris* grown at the natural forest in Malaysia with the diameter classes between 13 to 20 mm, the vascular bundle size is larger at the inner section but gets smaller and denser towards the peripheral section. The frequency of *C. palustris* vascular bundles ranging from 4 to 6 mm^2 which is higher than in *C. manan* (2 to 4 mm^2) aged 11 years (Mohmod *et al*. 1996).

Variation of metaxylem vessel within the rattan stem

The vessel diameter increases with height in four Chinese rattans. The diameter is less variable in *C. dioicus*. The vessel diameter decreases from the outer section toward the inner section in all species. The average diameters are 171, 213, 178, and 114 µm for *D. margaritae*, *C. simplicifolius*, *C. dioicus*, and *C. tetradactylus*, respectively (Cai 1989).

In contrast, vessel diameter varies with species and stem diameter in Indian rattans. The large diameter rattan species of *C. dransfieldii* and *C. thwaitesii* (12 to 43 mm) has the biggest vessel diameters, ranging from 175 to 420 µm. In comparison, medium and small diameter rattan species have vessel diameters ranging from 180 to 280 µm and 120 to 320 µm, respectively. The variation between the medium and the small rattan species is minor, and much less than in the large diameter species. Rattan with stem diameters ranging from 5 to 26 mm can be grouped as medium diameter and they include *C. gamblei, C. hookerianus, C. pseudotenuis* and *C. vattayila*. Meanwhile, the small stem diameter rattan species can be grouped as ranging from 2 to 13 mm and they include *C. metzianus, C. rotang* and *C. travancoricus* (Bhat 1991). In Malaysian rattan, the vessel diameters of *C. palustris* significantly increases with the stem height and ranging from 198 to 248 µm (Mohmod *et al*. 1996).

Variation of lignin content within rattan stem

A comparison of six rattan species from Thailand reveals that the lignin content is lowest in species which are graded as top quality by the local manufacturer (Siripatanadilok 1984). They are including *C. manan* and a *Calamus* sp.

Variation of the fibre dimension within rattan stem

The fibre wall thickness decreases from the peripheral towards the centre at all the height levels (*i.e.* basal, middle and top portions) in *C. metziamus* and *C. thwaitesii*. The former species has thinner cell walls than *C. thwaitesii*, with averages of 1.9 and 3.8 µm, respectively. Despite the differences in wall thickness, these differences between the intermediate and central sections are not statistically significant; the variation occurs within the individual vascular bundles. Generally, the fibre walls at the centre of the central cylinder are thinner than the outer parts, but the reverse also occurs in some vascular bundles. In descending order, the fibre wall thickness decreases from basal (old) portion to the top (younger) portion in all radial sections. This distinction of cell wall thickness is less between the middle and top portions than those between the basal portion and middle portion (Bhat *et al.* 1990).

In comparison, the fibre dimensions of five Malaysian rattans at different ages are significantly different with species, height (except for fibre diameter), and the interaction of species and height. Regardless of species, the fibre is longest at the basal portion but tends to be shorter at the top portion. The variation between the middle portion and top portion is not statistically significant. The decrease of fibre length towards the top could be due to the immature stage of this region as compared to the basal and middle portions (Bhat *et al.* 1990).

Variation of fibre percentage within rattan stem

Dependent on the species and locality, the fibre percentage is generally higher in *C. pseudotenuis* (40.1) than *C. travancoricus* (52), respectively. Although there is no statistical relationship between fibre percentage and physical characteristics, the latter species has larger diameter stems (20 mm) than *C. pseudotenus* (3.9 mm). The fibre percentage decreases from the outer section towards the centre section as well as from the basal portion towards the top portion. The higher fibre percentage in any species and locality will commonly give a higher density value (Bhat *et al.* 1990). Stem age does not influence the fibre percentage in cultivated *C. scipionum* (27.3%) and *D. angustifolia* (20.75%) respectively. The fibre percentage is highest at the basal portion and decreasing towards the top portion (Kadir 2001).

The Chemical Constituents

The wai nam phueng with the lignin contents of 21.1% and 22.5% as compared to the lower quality grade species such as *C. longisetus* (28.6%), *C. rudentum* (29.0%), and another *Calamus* sp. (waai phiu boh, 30.1%), respectively. Despite there being no significant difference with age, the lignin content varies at different heights within individual stems and between the species. Although this variation is high there are no specific trends.

The lignin content of Malaysian rattans is highest in *K. rigida* (25.9%), followed by *C. palustris* (25.5%), *C. sciponium* (24.2%), and *C. manan* (22.0%). In almost all of these species, the lignin content decreases from the basal portion towards the middle portion but slightly increases at the top portion (Mohmod *et al.* 1997).

In the Pilipino rattan (*C. merrillii*), a consistent reduction in cellulose content occurs at transverse and longitudinal directions, where the values are gradually decreasing from the outer section towards the centre section and from the basal portion towards the top portion. The reverse trend occurs with the hemicellulose content. It slightly increases from the outer section towards the centre section of all the three different portions. On average, the hemicellulose content increases from the basal portion, achieves a maximum at the middle portion, but slightly declines towards the top. The pattern of lignin content across the transverse section is indefinite. At the top portion, the lignin content slightly increases from the periphery towards the intermediate and maintain at the centre section. At the middle portion, the lignin content increases from the outer section and reaches a maximum value at the intermediate section but slightly decline towards the centre section. In comparison to the basal portion, the lignin content decreases from the periphery section towards the intermediate section but slightly increases towards the centre section. In the longitudinal direction, the lignin content increases from the basal portion and attains a maximum value at the middle portion but declining towards the top portion (Abasolo *et al.* 2005).

Variation of holocellulose content within rattan stem

The holocellulose content is not significantly different with species and stem portion, with averages of 74.8% and 78.6% in *C. palustris* and *C. manan* respectively (Mohmod *et al.* 1997). Nevertheless, the holocellulose contents in *P. griffithii, C. sciponium* and *K. rigida* increases with increasing stem height.

Variation of the extractive and ash contents

In Indonesian rattan, the extractive materials differ with rattan species. The lipophilic compounds, substances extractable with methylene chloride, are low in all rattans species and range from 0.6% in *D. angustifolia* and *P. geminifloras* to 2.4% in *Plectocomuipsis wrayii*. In considerably higher amounts, the hydrophilic compounds extracted by acetone/water extraction, range from 1.3% in *C. manan* to 7.4% in *Korthalsia rigida*. In *M. paradoxa*, extraction produces a red colour as compared to a yellowish colour in some species, while other species give colourless extracts. In further chromatographic analysis, at least one yellow pigment is present in *M. paradoxa* and at least three different colour pigments are separated from *K. rigida* (Simatupang 1987).

Quantitative studies have been done on Malaysian rattans (Mohmod *et al.* 1997). In relation to the stem height, the alcohol-toluene extractives content increases from the basal portion and reaches a maximum value at the middle portion but decreases again towards the top portion. The highest values are in *C. palustris* (5.8%) and the lowest is in *K. rigida* (2.4%). *C. palustris* also has the highest hot (13.3%) and cold (10.6%) water soluble extractives, while *K. rigida* has the lowest with the averages of 5.8% and 4.2% respectively. Other species such as *P. griffithii*, *C. manan*, and *C. sciponium* have hot and cold-water soluble extractives that range from 5.9% to 8.0% and from 3.5% to 5.6% respectively. Regardless of species, the hot water extractive content decreases from the basal portion towards the top portion. In contrast, the cold-water extractive content increases from the basal portion and reaches the maximum value at the middle portion but further declines at the top portion. The *C. palustris* contains the highest alkali soluble extractive content while the lowest occurs in *C. manan*, with averages of 33.9% and 18.8% respectively. In relation to the stem height, the alkali soluble extractive content behaves similar to the alcohol toluene extractive contents.

A study on the extractive distribution across Pilipino rattan stems by Abasolo *et al.* (2005) showed that the ethanol-toluene extractive content in *C. merrillii* is greatest at the centre section and the differences between the peripheral section and the intermediate section are negligible at the basal portion. At the middle portion, the extractive content is highest at the periphery section, but the distinction between the intermediate section and centre section is small. At the top portion, the extractive content increases from the outer section and reaches a maximum value before slightly decreasing towards the centre section. In the longitudinal direction, the extractive content gradually increases from the basal portion towards the top portion.

In studies on Malaysian rattans, the ash content is highest in *C. palustris* (3.9%) followed by *P. griffithii* (3.4%), *C. sciponium* (2.1%), *C. manan* (1.4%), and *K. rigida* (1.4%) (Mohmod *et al.* 1997). The ash content differs with stem height of each species. In *K. rigida* and *P. griffithii*, the ash content increases from the basal portion and achieves a maximum value at the middle portion but then decreases towards the top portion. However, in *C. sciponium* and *C. manan*, the ash content increases from the basal portion towards the top portion. The ash content in *C. palustris* decreases from the basal portion towards the top portion.

In the Pilipino studies (Abasolo *et al.* 2005), the ash content ranges from 1.3% to 1.6% in the longitudinal direction. Transversely, the ash content gradually decreases from the periphery section towards the centre section of the middle and top portions. At the basal portion, the ash content is greater at the outer section than at the intermediate and centre sections. Overall, the *C. merrillii* has about 40.8%, 30.4%, 23.9%, 1.6% and 1.7% of cellulose, hemicelluloses, lignin, ash and extractive contents respectively.

Physical and Mechanical Properties

Akin to wood, the physical and mechanical properties of wild rattan are paramount criteria for all production and economy stages, beginning with selecting the harvesting age, determination the number of economic value stick, duration time for oil curing process, grading of quality and determining of selling price, selection to use either for structural or semi structural final products, and overall production cost.

The younger rattan generally has lower physical and mechanical properties, as most of the fibres are thinner, and harvesting a younger rattan will produce a huge wastes. The immature portion of the upper most wild rattan is always discarded, as it is soft and perishable. The number of economical and usable stick count with 10 metres each from the basal portion is also determined with density and static bending criterion. Generally, a higher density of the basal portion and rattan species requires more time to cure in oil medium due to its higher compactness of cells. Water and extractives are slowed in the longitudinal direction, while the radial surface is covered with a skin that is rich in silica content. Higher density and static bending properties of *Calamus manan* correspond to higher selling and marketed prices than the lower density and mechanical properties of *Calamus ornatus*. This species is also selected for a structural application such as handles for hammers and hoes, as it has higher mechanical properties than other species. The finishing cost for low density rattan may be higher than a high-density rattan, as more finishing materials absorb in the porous rattan cells. Bhat (1991) and Yang *et al*. (2020) mentioned that the physical and mechanical properties of rattan are important indicator for processing and utilization.

Physical Properties

Variation of density within rattan stem

The anatomical properties, which include the percentage of fibre in the vascular bundles, fibre wall thickness, and metaxylem vessel diameter, are the three factors that influence the density of rattan stems. In Indian rattan, higher percentages of fibres in *C. pseudotenuis* (52.0) than *C. travancoricus* (40.1) resulted in density values of 0.48 and 0.40 g/cm^3, respectively. Increasing fibre wall thickness from the centre section outwards increases the density value; this is valid at any height. In the middle portion of *C. thwaitesii*, the density is greater at the outer section (0.71 g/cm^3) than those of intermediate (0.44 g/cm^3) and centre (0.38 g/cm^3) sections. Analogous trends are found in *C. pseudotenuis* and C. *thwaitesii*, where the density differences between the intermediate and centre sections are always small. In the longitudinal direction, the decrease of fibre wall thickness from the basal portion towards the top portion at all three radial sections inversely affected the density. Although the density slowly declines from the basal portion towards the top portion, the differences between the middle portion and top portion are smaller than those between the basal portion and the middle portion. In *C. hookerianus*, the density values are 0.53, 0.43, and 0.44 g/cm^3 at the basal, middle, and top portions. The thicker fibre cell walls at the periphery section and at the basal portion are due to the addition of lamellae as a result of stem ageing. The polylamellate structure of the cell wall consists of alternating broad and narrow lamella that bordering each other and connecting through a transition zone. The fibril orientation proceeds helically at an angle of 40^o to the longitudinal axis; the deposition of the secondary walls is greater at the periphery section than at the intermediate section and centre section. In the transverse section at different heights, this indicates that the fibre bundles are more mature at the periphery section than in the other two sections. Similarly, the lowest density at the top portion is related to the age of the tissues, *i.e.* young tissue, as the stem matures from the base towards the top (Bhat *et al.* 1990; Bhat 1990).

In relation to the physical characteristics of Indian rattans, indefinite relationships have been defined between density and stem diameter. Large rattan species with diameter more than 18 mm, such as *C. andamanicus*, *C. longisetus*, and *D. kurziana* have average densities ranging from 0.45 to 0.47 g/cm^3. The average density of medium diameter rattan species (10 to 18 mm) such as *C. palustris*, *C. pseudorivalis*, *C. unifarius*, *C. viminalis*, and *K. laciniosa*, range from 0.40 to 0.48 g/cm^3. In small diameter rattan species (less than 10 mm), the average densities of *Calamus* sp. and *K. rogersii* range from 0.53 to 0.60 g/cm^3 (Bhat *et al.* 1996).

Variation of shrinkage within rattan stem

The mode of shrinkage depends on the direction. In *C. palustris*, the shrinkage values range from 0.01% to 0.59% in the longitudinal direction, 1.94 % to 3.81% in the radial direction, and from 5.88% to 20.4% by volumetric measurement (Mohmod *et al*. 1996).

The microfibril angle of *C. merrillii* fibres varies with location. It increases from the periphery section towards the centre section and from the basal portion towards the top portion. It ranges from 23º to 34º. Similar to wood, a higher microfibril angle in any cells will generate greater longitudinal shrinkage so that any local variations will affect shrinkage. The influence of microfibril angle on the longitudinal shrinkage of rattan fibres and wood tracheids has been shown to be basically similar (Abasolo *et al*. 2000).

Variation of water absorption and permeability within the rattan stem

The tangential adsorption of water by *C. manan*, *C. peregrinus*, and *C. ornatus* using vacuum-pressure, thermal (hot and cold bath) and soaking processes is reported by Ashaari and Petty (1997). The fractional volumetric absorption (F_{VL}) of water by rattan treated either by vacuum-process or thermal process was found to be linearly proportional to the immersion time over a 240 min. period. In the soaking process, the F_{VL} slightly increases for the first 200 min of flow but increases remarkably from this point onwards. The F_{VL} values of the rattans after 120 min impregnation in water ranging from 0.07 to 0.23 and from 0.06 to 0.16 when treating using the vacuum-pressure and thermal processes, respectively. For the same time of impregnation, the F_{VL} values for air dried (about 12% MC) *C. ornatus* are higher than those of *C. manan* and *C. peregrinus* when treating by vacuum-pressure and thermal processes. Partly dry (60 to 80% MC) *C. manan* and *C. peregrinus* absorbs more water than drier samples. The F_{VL} value for partially dry samples of the three species, after soaking in warm water (50 ºC) is 0.04. Thus, the water absorption of the rattans by soaking process is not correlated with the permeability but is mostly related to the development of cracks in the epidermis, *i.e.*, the outer skin layer. From a preservation point of view, vacuum-pressure is only advantageous for *C. ornatus*. Vacuum-pressure and thermal processes are of similar efficiency for both *C. manan* and *C. peregrinus*.

In the longitudinal direction, the flow of water in *C. manan*, *C. peregrinus*, and *C. ornatus* obey the Darcy's Law, except for a small decrement of flow rate with time under constant pressure difference. The Reynold's number (Re) for rattans (0.44 to 0.23) indicate that the flow of liquid in rattan is viscous or laminar. The permeability of internode and nodal regions are not significantly different. *C. manan* is the most permeable in the longitudinal direction (16.19 X 10^{-11} m^2), followed by *C. ornatus* (9.93 X 10^{-11} m^2) and *C. peregrinus* (6.88 X 10^{-11} m^2) (Ashaari and Petty 1998a).

In the radial direction, the water flow in rattans obeys Darcy's Law only approximately. The flow rate is nearly proportional to the pressure difference and there is a slight decrease of flow rate with time under constant pressure difference. The radial permeability of the inner part is from 0.9 and 3.3 X 10^{-16} m^2 when using rectangular samples and the maximum pressure difference of 16 kN m^{-2}. The radial permeability is 1.8 to 7.1 X 10^{-8} for annular samples (without any treatment and including epidermis) when using a pressure difference of about 100 kN m^{-2}. Treatment by boiling in petroleum increases the radial permeability from 7.0 to 9.3 X 10^{-18} and from 1.8 to 6.2 X 10^{-18} m^{-2} for *C. manan* and *C. peregrinus* respectively. The ratio of longitudinal to radial permeability is about 10^6:1 (Ashaari and Petty 1998b).

Static Bending Properties

The four main factors that influence the mechanical properties of Indian rattans are species, diameter, age, and stem locality. Large diameter species range from 26.6 to 29.2 mm in *C. nagbettai* and *C. thwaitesii*; these have the highest modulus of rupture (MoR) and modulus of elasticity (MoE) values. The average MoR and MoE values for *C. nagbettai* are 91 and 4057 MPa, while they are 51.3 and 2156 MPa for *C. thwaitesii*. Medium diameter species range from 12.3 to 18.1 mm including *C. gamblei*, *C. hookerianus*, *C. karnalakensis*, *C. lacciferus*, and *C. pseudotenuis*. The highest MoR and MoE values are in *C. gamblei* (71.5 and 3098 MPa) and the lowest are in *C. hookeranus* (52.7 and 1754 MPa). Despite having slightly lower MoR and MoE, the medium diameter species, *C. gamblei* has a higher maximum tensile strength (96.6 MPa) than the large diameter species, *C. nagbettai* (86.5 MPa). The small diameter species ranging from 6.3 mm to 8.5 mm including *C. metzianus*, *C. rotang*, and *C. travancoricus*, and these have the lowest mechanical strength. *C. metzainus* has the lowest MoR (37.0 MPa) and the highest is *C. rotang* (59.3 MPa). The MoE and maximum tensile stress of *C. metzianus* is similar to *C. rotang*, with averages of 1666 and 22.5 MPa, respectively. In almost all the species, the MoR and maximum tensile strength decrease from the periphery section towards the centre section at a given internode and also from the basal portion towards the top portion. The variation in the radial direction is higher than the longitudinal direction, where the maximum tensile strength was generally two to three times higher at the periphery section than the centre section. In terms of variation in mechanical properties with age, the older *C. thwaitesii* and *C. hookerianus* had higher mechanical properties than those of the younger ones. The mechanical properties of rattan are also influenced by moisture content, specific gravity, and fibre content. Similar to wood below fibre saturation point, the strength increases with loss of moisture and it has a positive correlation with specific gravity and percentage of fibre (Bhat *et al.* 1992).

Decay Resistance

Calamus manan aged 10 years is classified as moderately resistant and non-resistant to white rot, *Coriolus versicolor*. Crosswise, the resistance class of periphery section is improved with the increasing stem height, ranging from moderate resistant to resistant. The decay resistance in the older rattan is identical with the younger ones. The resistance classes of periphery section declines with the increasing stem height, ranging from resistant to moderate resistant (Norul Hisham and Hale 2013).

Table 6. The Average Percent Weight Loss and Decay Resistance Classes of *C. Manan* Aged 10- and 13-Years Decay by *C. versicolor* According to ASTM D2017-81 (1986)

Portion	Section	Age (years)			
		10		13	
		Weight loss	Class	Weight loss	Class
Basal	Periphery	36.47	MR	17.65	R
	Intermediate	21.58	R	36.58	MR
	Centre	27.31	MR	33.64	MR
	Average	28.45	MR	29.29	MR
Upper basal	Periphery	29.73	MR	22.38	R
	Intermediate	57.71	NR	40.33	MR
	Centre	80.30	NR	34.21	MR

	Average	55.91	NR	32.31	MR
Middle	Periphery	36.89	MR	16.44	R
	Intermediate	39.26	MR	33.91	MR
	Centre	81.09	NR	44.11	MR
	Average	52.41	NR	31.59	MR
Upper middle	Periphery	23.67	R	29.35	MR
	Intermediate	56.33	NR	50.57	NR
	Centre	43.36	MR	56.63	NR
	Average	41.12	MR	45.52	NR
Top	Periphery	18.49	R	26.53	MR
	Intermediate	62.35	NR	52.55	NR
	Centre	41.85	MR	49.42	NR
	Average	40.89	MR	42.83	NR

R- is resistant, MR-moderate resistant.

In relation to brown rot *Coniophora puteana*; the younger *C. manan* was classified as resistant except at the top portion, which was classified as moderately resistant. The periphery section (highly resistant and resistant) had a better resistance class compared to the intermediate and centre section (resistant and moderate resistant). *Calamus manan* aged 13 years was also classified as resistant to *C. puteana*, except at the top portion (moderate resistant). The resistant class of periphery section was increased from the basal portion (resistant) up to the upper portion (highly resistant) and then declined to moderate resistance at the top portion. Overall, the periphery section had the best resistance class. The difference of resistance class between the intermediate and centre sections was negligible along the stem height. The *C. manan* had a better resistance class to brown rot than those of white rot (Norul Hisham and Hale 2013). The average weight loss and decay resistance classes of the *C. manan* aged 10 and 13 years to white rot and brown rot fungi are tabulated in Tables 6 and 7.

Table 7. Average Percent Weight Loss and Decay Resistance Classes of *C. Manan* Aged 10- and 13-Years Decay by *C. puteana* According to ASTM D2017-81 (1986)

Portion	Section	Age (years)			
		10		13	
		Weight loss	Class	Weight loss	Class
Basal	Periphery	6.05	HR	17.54	R
	Intermediate	13.48	R	20.86	R
	Centre	17.42	R	20.02	R
	Average	12.31	R	19.50	R
Upper basal	Periphery	17.59	R	15.96	R
	Intermediate	18.99	R	25.51	MR
	Centre	34.66	MR	13.51	R
	Average	23.75	R	18.32	R
Middle	Periphery	23.66	R	9.12	HR
	Intermediate	44.40	MR	15.43	R
	Centre	24.82	MR	21.38	R
	Average	30.96	MR	15.31	R

Upper middle	Periphery	17.71	R	6.38	HR
	Intermediate	10.89	R	18.91	R
	Centre	14.55	R	16.62	R
	Average	14.38	R	13.97	R
Top	Periphery	20.09	R	33.86	MR
	Intermediate	10.20	HR	38.14	MR
	Centre	10.05	HR	22.77	R
	Average	13.45	R	31.50	MR

R- is resistant, MR-moderate resistant.

CONVENTIONAL COMPOSITES

Particleboard

The effect of alkaline treatment on the properties of rattan waste binderless particleboard was studied by Zuraida *et al*. (2017). The rattan waste was treated with 1% sodium hydroxide, and the board was pressed at 180 °C for 5 min. The MoR was 28.5 and 44.4 MPa for the untreated and treated respectively. Meanwhile, the IB was 0.26 and 0.44 MPa for the untreated and treated, respectively. The MoR of particleboard made from rattan skin and core using 12 % phenol formaldehyde (PF) and hot pressed at 150 °C for 10 min was 8.5 and 21 MPa, respectively. The MoE and IB were 0.19 and 0.47 GPa and 0.67 and 0.35 MPa for the rattan skin and rattan core, respectively (Astari and Akbar 2019).

The physical and mechanical properties of particleboard made from rattan were reported by Astari *et al*. (2018). The particleboard was fabricated with rattan and other materials wastes for a target density of 0.7 g/cm^3, blending with 10% phenol formaldehyde and cured with a hot-pressing at 150 °C for 10 minutes and pressure of 25 kgf/cm^2. The physical and mechanical properties of particleboard made from rattan met a minimum requirement to JIS A5908:2003, except for the thickness swelling. Additional use of wax and melamine urea formaldehyde could improve its thickness swelling. The maximum MoR, MoE, and screw withdrawal were 21.33, 0.47, and 159 MPa in particleboard made with rattan core or peeled rattan. The highest internal bond (0.67 MPa) was recorded in particleboard made of rattan skin.

Glue Laminated

The properties of square glue laminated rattan made from *C. manan* (Manau) using urea formaldehyde resin (UF) either as face to face or edge to edge bonding were reported by Norul Hisham *et al*. (2015). The water absorption, thickness swelling, and delimitation in either cold or hot water were not significantly different with the type on bonding and number of layers.

Table 8. Physical and Mechanical Properties of Glue Laminated Rattan by Type of Bonding

Properties	Type of Fabrication	
	Face to Face	Edge to Edge
Density (kg/m^3)	523.86	527.38
Water absorption (cold%)	64.33	67.08
Thickness swelling (cold%)	3.32	3.10
Water absorption (hot, %)	115.19	114.88
Delimitation	3.05	5.78
Modulus of Rupture (MPa)	50.41	52.21
Modulus of Elasticity (MPa)	1942.97	2342.52
Maximum load (MPa)	3.57	1.41

MPa – is mega pascal, % - is percent

Face to Face bonding

Edge to edge bonding

Fig. 7. The face to face (left) and edge to edge (right) bonding of glue laminated rattan

The modulus of elasticity (MoE) and maximum load (ML) were significantly different depending on the type of bonding, but not the modulus of rupture (MoR). The MoR and MoE were not significantly different as a function of the number of layers. The ML increased with increasing layers. Large diameter *C. manan* can be laminated with either type of bonding or number of layers. The properties of physical and mechanical properties of glue laminated *C. manan* are shown in Tables 8 and 9. The example of glue laminated rattan board is shown in Fig. 6.

Table 9. Physical and Mechanical Properties of Glue Laminated Rattan by Face to Face and Edge to Edge

Properties	Layer	Face to Face	Edge to Edge
Density	2	525.14	529.53
	3	508.79	546.05
	4	537.64	506.55
Water absorption (cold, %)	2	65.37	75.67
	3	64.91	61.22
	4	62.72	64.35
Water absorption (hot, %)	2	120.83	102.78
	3	104.86	128.34

	4	119.87	113.51
Delamination (cold, %)	2	4.25	6.67
	3	0	9.02
	4	4.89	1.67
Delamination (hot, %)	2	100	100
	3	100	100
	4	100	100
Modulus of rupture (MPa)	2	47.29	54.47
	3	49.22	53.8
	4	54.72	48.35
Modulus of elasticity (MPa)	2	1933.64	2347.24
	3	1967.8	2511.71
	4	1927.46	2168.6

MPa – is mega pascal, % - is percent

Rattan Fibre Reinforced Polymer Composite

The mechanical properties including tensile, flexural, density, and hardness of composite from rattan fibre and unsaturated polyester resin GP-7150 were investigated by Rachchh *et al.* (2014). The rattan fibers ranged from 5%, 7.5%, 10%, 12.5%, 15%, and 17.5% were reinforced in polyester, 2% cobalt as accelerator, and 3% MEKP (methylethyl-ketone-peroxide) as a hardener. The mixtures were allowed to air dry for 24 hours and cure at 70 °C for 2 hours in furnace. The study found that the optimum mechanical properties were achieved when 12.5 % of rattan fibre was used as a filler for the composite. The highest tensile, flexural and harness strengths of 20.4 MPa, 59 MPa, and 45 BHU were recorded.

The properties of rattan fibre and synthetic fibre glass fibre reinforced in polypropylene were reported by Nikmatan *et al*. (2017). The loading of both rattan and glass fibers used in the study was 5%. It was found that the PP/R5 gave the highest degree of crystallinity compared to PP and PP/FG5. Surface morphology of the PP/R5 was well distributed and hence better than the other materials. Although PP/FG5 demonstrated the greatest performance in terms of MoE and MoR, PP/R5 properties in terms of tensile modulus, tensile strength, and maximum elongation were akin to in the former. In addition, to a highest maximum strain in PP/R5, this property was correlated to a good energy absorption behaviour.

The mechanical, thermal, and morphology properties of rattan fibre reinforced in polyvinyl alcohol (PVA) were reported by Sahoo *et al*. (2021.) Maximum mechanical properties were obtained at optimum fibre loading of 24%. Maximum values of tensile strength, flexural strength, Young's modulus, and impact strength of 48.7 MPa, 45.7 MPa, 1.57 GPa, and 5.89 kJ/m^2, respectively, were recorded in this study. The thermogravimetric analysis (TGA) results implied that the thermal stability of the composites increased as compared to neat PVA matrix.

The rattan fibres used as reinforcement in thermoplastic polymer Acrylonitrile Butadiene Styrene (ABS) was reported by (Sahu *et al*. 2022). The rattan fibres were modified with NaOH followed by benzoylation and bleaching processes before being reinforced with ABS, at loading of at 0, 10, 20, 30, and 40%. The chemical treatment changed the surface texture of the fibres and improved the surface roughness and fiber–

matrix bonding. The maximum mechanical properties of the composites were obtained at 24% fiber loading. The maximum tensile strength, Young's modulus, flexural strength, and impact strength of 75.0 MPa, 4.80 GPa, 10 MPa, and 31.4 kJ/m^2 were obtained, respectively.

The mechanical and thermal properties of hybrid woven rattan/glass-fiber-reinforced epoxy composites were reported by Irawan *et al.* (2022). The six types of composites were fabricated using a hand lay-up technique followed by hydraulic press to the laminates. The hybrid woven composite comprised of glass fibre reinforced epoxy resin as both outer face layers laminated with three layers of rattan strips as a core inner layers (GF/RS/RS/RS/GF) gave the highest mechanical properties. The increase from one to three layers of RS in the core layer of GF hybrid composites gave a maximum flexural strength (200 MPa), impact strength (8 J), and tensile (100 MPa) strength. In addition, the hybrid comprised of both rattan and GF was more thermally stable. The GF/RS/RS/RS/GF composite only showed 0.6 % weight loss after heating at 700 °C. The woven RS and GF hybrid is a potential material for automotive applications such as car bumpers.

MODIFICATION

Resin Modification

The first rattan modification was made by using phenolic resin (Wan Tarmeze *et al.* 1993). The rattan was vacuum-impregnated with 12%, 25%, and 45% phenol formaldehyde resin. Overall, the 45% solids modified rattan gave the highest improvement for specific gravity (53.3%), hardness parallel to the grain (49.8%), nail pull resistance perpendicular (147%) and parallel (154%) to the fiber direction. The 24.5% solids modified rattan offered maximum improvement in MOR (24.7%), compression (35.4%), and shear (30.2%). Finally, rattan modified to 12% solids yielded a maximum improvement in MOE (15.3%).

The modification of rattan *C. manan* (manau cane) and *C. ornatus* (dok cane) using polymer impregnation was further reported by Norul Hisham *et al.* (2005). Polymethyl methacrylate solution was vacuum-impregnated for 20 and 30 minutes. This study found that polymer loading was influenced by species, cane diameter, and impregnation period. The performance of physical and mechanical properties in modified cane were also dependent to polymer loading. Greater polymer loading in dok cane significantly increased almost all of its mechanical properties, but this was not observed in manau cane. However, lower polymer loading in manau cane exhibited greater physical properties than the dok cane. Untreated dok cane was more durable than manau cane. The percentage weight loss following decay of modified cane was significantly reduced with higher polymer loading, which was obtained with a longer impregnation period. The properties of the manau and dok canes modified with polymethyl methacrylate are shown in Table 10.

Table 10. Physical and Mechanical Properties of Wild *C. manan* and *C. ornatus* Modified with PMMA

Properties	Time	*C. manan*	*C. ornatus*
Polymer loading (%)	Control	-	-
	20	23.7	31.5
	35	34.1	57.7
	Mean	28.9	44.6
Water absorption (%)	Control	-	-
	20	26.6	50.5
	35	21.4	38.9
	Mean	24	44.7
Anti swelling efficiency (%)	Control	-	-
	20	53.7	48.6
	35	66.0	61.4
	Mean	59.9	55
Static bending (MOR) (MPa)	Control	87.4	43.9
	20	106.7	60.1
	35	101.0	50.5
	Mean	98.37	51.5
Static bending (MOE) (MPa)	Control	116.9	43.6
	20	138.7	74.7
	35	125.1	73.7
	Mean	126.9	64
Compression (MPa)	Control	28.9	16.2
	20	38.1	19.4
	35	39.2	22.7
	Mean	35.4	19.43
Shear (MPa)	Control	8.5	6.2
	20	10.0	7.0
	35	10.3	6.1
	Mean	9.6	6.4
Weight loss following decay	Control	28.5	16.9
by *Coriolus versicolor* (%)	20	14.1	6.6
	35	10.3	5.3
	Mean	17.63	9.6

MPa – is mega pascal, % - is percent, MOR – is modulus of rupture, MOE – is modulus of elasticity

Acetylation

Unlike modification using polymers, which are mostly deposited in the cell lumens, acetylation involves the reaction between acetic anhydride and accessible OH groups in the cell walls. Thus, it is possible to improve the low quality *C. manan* by acetylation without adding excessive weight. The reactivity of acetic anhydride to rattan is dependent on the stem age, portions, sections as well as the specimen size. The reactivity is fastest at the juvenile top and then gradually becomes slower when proceeding to the more mature basal portion of both ages.

Cross-wise, the reactivity is fastest at the periphery section and then proceeded towards the centre section of the younger rattan aged 10 yrs, but the order was the inverse for the older rattan. This trend may be a result of a higher hemicellulose content in the top portion of older rattan. The reactivity was higher in the strip rattan than the block rattan. In the block rattans, the maximum WPG was higher in the older rattan aged 13 years (13.5%) than the younger rattan aged 10 years (15.0%).

In the strip rattans, the maximum WPG was almost similar for both ages (18.1% and 17.9% respectively). This clearly indicates that the weight added by acetylation was much lower compared with polymer modification. In the younger block rattan aged 10 years, the reaction amount or Weight Percent Gain (WPG) levelled-off at 10 hours, whereas it levelled-off after 15 hours with the older rattan aged 13 years. This is probably an attribute of the higher lignin content in the younger rattan (lignin content 19.4% and 17.3% in 10-year-old and 13-year-old rattan, respectively). Lignin has been reported to react faster with the acetic anhydride than hemicellulose and α-cellulose and it may increase the accessibility when reacted. In strip rattan of either age, the levelling-off WPG is achieved at the same reaction period (10 h). The higher WPG in strip rattans was possibly caused by its greater specific gravity (Norul Hisham *et al.* 2014).

In the moisture adsorption test (Table 11), the untreated younger rattan aged 10 years adsorbed more moisture than the untreated older rattan aged 13 years, which was probably due to its higher hemicellulose content. The acetylated older rattan has lower equilibrium moisture content reduced (EMC_R) than the younger rattan at similar levelling-off WPG, except for 55% RH. The bulking coefficient has a strong relationship with the lower EMC_R values derived from experimental for both ages. The moisture exclusion of acetylated older rattan is better (Table 12). It has higher MEE than the younger rattan at 33% RH and higher. The optimum MEE values at all the RH levels are achieved at the levelling-off WPG for both ages. Regardless of reaction periods, the MEE ranged from 73.5% to 110% and from 72.6% to 89.2% for 10- and 13-year-old rattan, respectively (Norul Hisham *et al*. 2014).

With respect to mechanical properties (Table 13), the reaction of rattan with acetic anhydride for prolonged reaction periods did not significantly influence the MoR and MoE of acetylated rattan for both ages. The MoR and MoE of acetylated younger rattan were not significantly different to the untreated rattan. However, the acetylated older rattan had the highest MoR when reacted for four hours. The improvement in MoR was about 48% for the older rattan. Similarly, the MoE of acetylated rattan was not significantly different to the untreated rattan for both ages. The improvement of strength (MoR and MoE) in acetylated rattan had a strong relationship with increase of specific gravity following modification (Norul Hisham and Hale 2013a).

Table 11. Mean Values of Equilibrium Moisture Content at Different Relative Humidity

Age (years)	WPG	RH (%)						
		12	23	33	44	55	76	93
10	0	2.70	14.01	13.3	14.94	17.03	26.26	52.22
	5.4	0.65	7.62	7.18	8.24	9.91	15.17	44.42
	5.4	1.92	6.21	6.53	7.66	9.00	14.06	29.46
	7.0	0.31	2.60	2.50	3.82	4.17	7.48	25.69
	9.7	2.56	9.23	8.33	9.45	10.75	15.38	34.30
	13.5	2.26	1.45	1.82	2.04	2.74	5.43	12.61
	13.8	0.04	4.44	4.15	5.11	5.76	10.14	22.36
	13.7	0.57	2.90	3.49	3.81	4.71	9.52	17.16
	Average	1.38	6.06	5.92	6.88	8.01	12.93	29.13
13	0	3.40	4.83	10.17	10.61	13.30	18.40	31.52
	9.0	1.03	1.90	1.87	2.69	4.13	6.48	11.21
	6.6	0.94	2.68	2.36	3.27	4.12	6.53	11.29
	11.1	1.29	1.70	1.79	2.59	3.49	6.14	11.11
	9.4	1.12	1.64	1.68	2.36	3.46	5.45	9.15
	10.3	1.02	1.12	1.07	1.70	2.83	4.58	7.54
	10.7	1.05	0.99	1.16	1.76	2.83	4.19	8.31
	10.9	0.58	1.91	1.61	2.20	3.39	5.23	9.46
	Average	1.30	2.10	2.71	3.40	4.69	7.13	12.45

WPG -is weight percent gain, % - is percent.

Table 12. Mean Values of Moisture Excluding Efficiency (MEE)

Age (yrs)	WPG	RH (%)						
		12	23	33	44	55	76	93
10	5.4	73.04	29.04	31.42	31.56	41.48	31.89	28.66
	5.4	73.10	66.50	66.17	64.65	63.08	61.88	59.19
	7.0	90.58	74.27	74.75	70.49	67.69	61.97	69.18
	9.7	94.65	70.19	74.21	71.23	69.78	67.11	60.23
	13.5	110.45	84.38	80.95	81.29	79.08	73.89	73.54
	13.8	99.00	80.64	78.47	75.51	76.85	72.97	71.90
	13.7	76.96	89.84	82.12	81.98	79.65	70.01	75.02
	Average	88.87	73.17	70.11	68.60	69.06	63.10	63.15
13	9.0	73.02	56.00	80.14	72.83	68.27	64.29	65.23
	6.6	73.69	38.08	78.09	70.27	70.47	66.02	65.40
	11.1	66.18	67.67	80.40	74.44	73.62	67.35	66.50
	9.4	69.04	66.42	83.01	77.81	74.73	71.64	72.27
	10.3	72.62	74.28	89.15	83.76	79.40	76.24	77.26
	10.7	73.29	77.58	89.06	84.06	80.76	76.01	76.25
	10.9	81.49	59.87	91.21	88.39	83.25	77.14	76.1
	Average	72.69	63.33	84.49	78.82	75.85	71.40	71.48

WPG -is weight percent gain, % - is percent.

In terms of fungal colonisation (Table 14), the white rot fungus (*T. versicolor*) was more aggressive in colonisation of both untreated and acetylated rattan than those of the brown rot fungus (*C. puteana*) for both ages of rattan. With both fungi, the colonisation was more aggressive in untreated rattan than acetylated rattan for both ages of rattan. The inhibition of hyphal colonisation against *T. versicolor* was apparent at the shorter reaction periods, 0.5 (5.4% weight gain) and 0.25 hours (8.9% weight gain) for 10- and 13-year-old rattan, respectively. The inhibition of hyphal colonisation against *C.*

puteana was initiated at 0.5 hours reaction period (5% weight gain) for both ages. The untreated rattan was more susceptible to attack by *T. versicolor* than either untreated Scots pine sapwood or beech wood, and the woods were more susceptible to *C. puteana*. Acetylated rattan at the levelling-off WPG exhibited the lowest percent weight loss decayed by both white rot and brown rot fungi. Generally, the increases WPG gave less decay by both fungi. The decay protection thresholds of 13.4 and 9.0 WPG were sufficient to protect for 10- and 13-year-old rattans, respectively, against *T. versicolor*. In the case of *C. puteana*, 13.5 and 10.3 WPG (respectively) are necessary for protection. Acetylated rattan at these decay protection thresholds are classified as durability class 1 in accordance with EN 350-1 (Norul Hisham and Hale 2012).

Table 13. Mean Values of the Static Bending Properties

Properties	10 years		13 years	
Modulus of rupture	WPG	MPa	WPG	MPa
	0	40.94	0	23.00
	12.7	45.88	15.8	20.49
	12.7	37.41	12.1	30.07
	14.3	38.75	14.1	31.01
	15.4	37.88	14.5	34.02
	16.2	36.40	17.2	31.32
	16.9	43.51	18.0	28.85
	16.1	34.87	18.0	28.55
	15.4	40.28	15.9	28.35
Modulus of elasticity	0	1353.14	0	909.29
	12.7	1452.00	15.8	833.14
	12.7	1120.00	12.1	958.00
	14.3	1114.71	14.1	1015.29
	15.4	1168.29	14.5	1043.71
	16.2	1131.00	17.2	973.86
	16.9	1287.86	18.0	928.57
	16.1	1091.00	18.0	870.86
	15.4	1139.57	15.9	897.71
Static bending	0	0.07	0	0.05
(Maximum load, kN)	12.7	0.11	15.8	0.04
	12.7	0.09	12.1	0.07
	14.3	0.11	14.1	0.07
	15.4	0.09	14.5	0.08
	16.2	0.09	17.2	0.08
	16.9	0.12	18.0	0.07
	16.1	0.09	18.0	0.08
	15.4	0.01	15.9	0.06

WPG -is weight percent gain, MPa- is mega pascal, kN – is kilo newton

The untreated rattan was the most susceptible decay in a soil bed test, *i.e.* against soft rot and other micro-organisms, and this was followed by beech wood and Scots pine sapwood (Table 15). The resistance of acetylated rattan in this test was achieved at the decay protection threshold of 15.38 and 16.16 WPG for 10- and 13-year-old rattan, respectively. Similarly, the acetylated rattan at the decay protection threshold is classified as durability class 1 for both ages. The WPG of acetylated rattan and untreated rattan has a strong relationship with the moisture content following decay. The appearance of untreated rattan was heavily stained and had a dark colour and tapered and eroded ends, while it was not obviously changed for the acetylated rattan. However, a minor discoloration appeared on the rattan acetylated for short reaction periods (Norul Hisham and Hale 2013b).

Table 14. Mean Values of Percent Weight Loss Against Fungi

Age (years)	Percent weight loss					
	Trametes versicolor			*Coniophora puteana*		
	Control	WPG	Acetylated	Control	WPG	Acetylated
10	82.72	0	77.39	45.48	0	68.47
	76.50	3.3	23.52	32.05	5.0	50.27
	75.13	5.4	19.80	37.18	5.0	57.37
	67.36	8.5	5.56	32.07	7.0	17.91
	85.64	10.5	1.30	35.37	10.2	2.70
	89.29	13.4	0.38	48.57	13.5	-2.56
	83.39	13.4	0.95	47.07	13.3	-0.12
	84.35	14.0	2.64	32.32	11.6	-0.24
	80.25		-	38.26		-
13	82.98	0	62.97	50.15	0	64.74
	83.95	8.9	2.14	33.89	8.1	7.21
	77.93	5.9	1.78	42.63	5.0	25.85
	81.10	8.4	1.61	40.67	8.0	11.78
	92.85	7.6	1.19	28.06	7.8	0.69
	77.56	9.0	0.07	28.95	10.3	-0.59
	73.17	15.8	3.22	35.83	10.8	-0.59
	77.32	10.2	0.76	59.61	11.3	-0.73
	80.88		-	39.97		-
Pine	40.30			65.31		
Beech	74.44			57.49		

WPG -is weight percent gain

Table 15. Mean Values of Percent Weight Loss Against Soft Rot at the End of Exposure Period (32 Weeks)

Reaction (hour)	10 years	13 years
0	54.14	43.56
0.25	-0.22	5.03
0.5	1.74	2.37
1	0.16	-2.40
4	-0.14	-1.31
10	-0.10	0.90
15	-0.00	-1.46
24	0.19	-6.51
30	-1.89	-34.58
Average	5.46	-4.18
Pine	28.51	
Beech	48.93	

CONCLUSIONS

Almost all the rattan properties that involve anatomical, physical, chemical, mechanical, and biological resistance have been shown to vary with individual species, with and within the stem of each species, as well as the site origin where they have been grown. However, a general agreement could be made with all the species assessed in this review:

1. The vascular bundle diameter increases with the stem diameter and it size tends to be smaller with increases in frequency.
2. The vascular bundle diameter also is smaller at the outer section and gradually becomes bigger towards the inner section, as well as gradually bigger from the basal portion toward the top portion.
3. The metaxylem vessel diameter varies with species and diameter.
4. The fibre wall thickness decreases from the periphery towards the centre section as well as decrease from the basal towards the top portion.
5. The fibre percentage decreases from the outer section towards the centre section as well as from the basal portion towards the top portion.
6. The cellulose content decrease from the outer section towards the centre section as well as from the basal portion towards the top portion.
7. The alcohol-toluene and cold-water soluble extractives increase from basal portion towards the middle portion.
8. The hot-water soluble extractive decreases from the basal portion towards the top portion.
9. The density increases with the centre section towards the outer section as well as from the basal portion towards the top portion.
10. The modulus of rupture and tensile strength decreases from the periphery section towards the centre section as well as from the basal portion towards the top portion.
11. The modulus of rupture and modulus of elasticity are also increased with the stem ageing.
12. The *C. manan* stem is mostly classified as resistant to brown rot fungi (*C. puteana*) and moderately resistant or resistant to white rot fungus (*T. versicolor*).
13. The large rattan (*C. manan*) could be glue laminated either by face to face or edge to edge bondings as well as with any number of layers.
14. Particleboard made from rattan using either resin or without resin can meet the requirements in JIS A509:2003, with the exception of the thickness swelling.
15. The mechanical properties are highest in polyester resin reinforced with 12.5% rattan fibre.
16. The mechanical properties are maximum in polyvinyl alcohol (PVA) or acrylonitrile butadiene styrene (ABS) reinforces with 24% of rattan fibre.

17. The acetylated rattan at the maximum weight percent gain (WPG) of levelled of WPG gave the lowest equilibrium moisture content, highest moisture excluding efficiency, 0% weight loss after 16 weeks decayed by white rot (*T. versicolor*), brown rot (*C. puteana*) and soft rot. The static bending of acetylated rattan is unaffected after prolong reaction with acetic anhydride.
18. The acetylated rattan at the maximum weight percent gain (WPG) of levelled of WPG is classified as durability class 1.

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