

Wood anatomy of *Shorea* of white meranti (Meranti Pa'ang) group of the Malay Peninsula

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The present communication deals with the variations in physical, macroscopic and microscopic anatomical features of different species of *Shorea* of white meranti group of the Malay Peninsula. Variance ratio (F) test indicated that inter-specific differences among wood element dimensions of *Shorea* were significant for fibre length, vessel element length, wall thickness and fibre diameter ($\alpha = 0.05$). However, intra-specific differences were non-significant for all the anatomical characters. Fibre diameter and vessel element length showed positive significant correlation. A dichotomous key for identification is presented on the basis of anatomical characters up to the species level. The dichotomous key is based on a pair of contrasting characters like ray height, ray width, fibre-wall thickness and dimensions of gum canal. Differences in quantitative characters were analysed using t -test for the mean. Hierarchical cluster analysis was carried out using qualitative and quantitative anatomical characters to understand the affinity of *Shorea* within the white meranti group. Members of white meranti showed similarity at 20% level, except *Shorea bentongensis* which showed no similarity with other members of this group. Furthermore, the member of the first cluster within the white meranti, *S. assamica* Dyer and *S. roxburghii* D. Don. also of Indian subcontinent, clustered together with *S. gratissima* Dyer, while other members formed another cluster.

Keywords: Cluster analysis, gum canals, Meranti Pa'ang, parenchyma, rays, silica bodies, wood identification.

WHITE meranti group forms a well-defined botanical section, *Anthoshorea*, genus *Shorea*¹. Representatives of the group are widely distributed from India in the north and west to the Philippines and Celebes in the east. It includes at least 30 species, among which about 20 have been botanically described. There are 11 species in the Malay Peninsula. The species included form a natural, homogeneous group, which corresponds botanically with the section *Anthoshorea*, genus *Shorea* as defined by Brandis². Several of peninsular species are widely distributed and well known outside the Peninsula, e.g. *Shorea roxburghii* G. Don. in southern India, a form of *S. assamica* Dyer in Assam, and *S. hypochra* Hance in Cambodia and Cochin China, representing the southernmost part of Vietnam. Other representatives of the group are *S. javanica* K. et V. and *S.*

virescens Parijs in the Netherlands Indies, *S. assamica* Dyer forma *Philippinensis* (Brandis) Sym. and *S. polita* Vidal in the Philippines, and *S. assamica* Dyer forma *Koordersii* (Brandis) Sym. in Celebes and Moluccas. Two species of the white meranti group occur in North Borneo. These timbers are known as Melapi. Species of the white meranti group are widely distributed in Indonesia. They are common in Sumatra, where seven species have been recorded, and in Indonesian Borneo where seven species have been recorded; *S. javanica* occurs in Java and *S. assamica* Dyer f. *koordersii* in Celebes and Moluccas¹.

At least ten and possibly 11 species of the white meranti group occur in Malaya, where for trade purposes the name white meranti has been adopted for its timbers³. Representatives of the group occur throughout the country and are locally common, but in general much less abundant than the species of the red meranti group. *S. bracteolata* Dyer is the most widely distributed and common species and *S. assamica* Dyer f. *globifera*, *S. hypochra* Hance, *S. dealbata* Foxw. and *S. bentongensis* Foxw. are also locally common.

At present, Malay *Shorea* contributes a significant amount in the timber import of India. Further, imported *Shorea* timbers have become a source to meet the deficits of timber requirement of various importing countries. Hence, identification to check adulteration or misuse has become important.

In this study, we considered nine out of 11 species of the Malay Peninsula. Wood samples of two species, viz. *S. farinosa* Fischer and *S. resinosa* Foxw. are not available in the xylarium of the Forest Research Institute (FRI), Dehradun. The identity of these species is doubtful and is closely related to *S. hypochra* Hance¹. Desch⁴ described ten species of white meranti as Meranti Pa'ang group. Variations at species level of wood anatomical characters of this group are not available. Hence, an attempt has been made here to describe the qualitative and quantitative intra- and inter-species physical and wood anatomical variations. A dichotomous key has also been prepared for identification of different species of *Shorea* of this group.

The studies were based on examination of authentic wood samples of nine species of *Shorea* of white meranti group housed in the xylarium of FRI. Samples were received through Edward Salisbury, then Director, Royal Botanical Gardens, Kew, UK dated 12 April 1956 (citation no. 6463/55, 2/ind/2/3) according to the record of the xylarium at FRI. Details of the specimens are given later in this communication along with their accession numbers.

Cross, radial and tangential sections (15–20 μ m thick) were cut on Reichert microtome for microscopic examination. The sections were stained in Heidenhain's haematoxylin and safranin and, mounted following standard laboratory procedure for making permanent slides.

Small radial chips were macerated for determination of fibre and vessel element length following Schultz's

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method (50% nitric acid and a pinch of potassium chlorate). Data on fibre length, vessel length, fibre diameter and lumen diameter were taken from macerated materials under the microscope.

Observation on microscopic features of various cell types such as vessel, parenchyma, rays and fibres were recorded. The average tangential diameter of the vessels was determined from 25 measurements from cross-section. Frequency of vessels was determined from the average of 10 counts per sq. mm area. The ray frequency (rays per mm) is based on an average of 10 counts per mm area in tangential sections. Maximum ray height and ray width were also determined from tangential sections. Physical features (colour, hardness, specific gravity, odour, lustre, grain, texture, etc.) were recorded directly from the wooden samples. Twenty-five counts were taken from macerated samples of each species for vessel element length, fibre length, vessel element diameter and fibre diameter. Collected data for vessel element length, fibre length, vessel element diameter, fibre diameter and wall thickness were statistically analysed for mean, standard deviation and variance ratio (*F*) test using analysis of variance (ANOVA) with replication.

Terminology and measurements were taken according to the IAWA Committee guidelines⁵.

The key was prepared using characters like ray height, ray width, ray seriation, patterns in gum canals, diameter of gum canal, fibre wall thickness, density of species and vessel diameter. Quantitative characters were used as mean maximum value on the basis of 25 counts from each sample. Species were separated on the basis of quantitative characters using statistical *t*-test for mean maximum value.

Specimen details are as follows. White meranti group: *S. assamica* Dyer, 5847, 7604, 7513, 7240, 6512; *S. bentongensis* Foxw., F 8013, F 8015, F 8016; *S. bracteolata* Dyer, F 8030, F 8034; *S. dealbata* Foxw., F 8071, F 8072, F 8073; *S. gratissima* Dyer, F 628, F 7139, F 6684; *S. hypochra* Hance, F 8126; *S. lamellata* Foxw., F 8137, F 8139, F 8140; *S. sericeiflora* Fisher et Hutch., F 6918, F 6753, F 8260, F 8259, and *S. roxburghii* G. Don. Syn. *S. talura* Roxb., 6211, 3895, 6185.

Details of ANOVA, general features, gross structure, minute structure and matrix for cluster analysis are given in Tables 1–5. Photomicrographs of cross-section (40×) of different species of white meranti group are shown in Figure 1 a–i.

General features: Sapwood colour ranges from white to light grey. Heartwood light yellow, yellowish-brown to reddish-brown. Wood soft to moderately hard to hard, light to moderately heavy to heavy, straight to usually interlocked grain, medium-to-coarse textured (Table 1).

Gross structure: Wood diffuse porous. Growth rings indistinct. Vessels medium-sized to moderately large; round to oval in outline; few to moderately numerous; solitary and in tangential multiples with radial multiples of 2 to 4

often reaching up to 5 or 6, sometimes in clusters, with some having the tendency of diagonal arrangement; tyloses few to abundant; vessel line conspicuous on longitudinal surface. Parenchyma indistinct to just visible to the naked eye, moderately abundant; aliform forming short extensions, confluent and sometimes forming irregular thin-to-thick, complete or incomplete bands often diffuse and diffuse in aggregates. Rays fine to moderately fine to moderately broad, more or less uniformly distributed. Inter-cellular canal solitary and also in the form of long and short tangential lines embedded in the parenchyma bands (Table 1).

Minute structure: Vessels range from 81 to 270 μm (*S. roxburghii* G. Don.–*S. assamica* Dyer, *S. gratissima* Dyer and *S. lamellata* Foxw.) in diameter (mean $179 \pm 32 \mu\text{m}$), perforation plate simple, inter-vessel pitting alternate, round to oval sometimes elliptical; frequency 2–20 per sq. mm, vestured, 3–16 μm in diameter and inter vesicular pits which leading to rays are larger than inter-vessel pitting, simple, and oval to round in shape with reduced border; vessel member 176–749 μm (*S. gratissima* Dyer–*S. assamica* Dyer; mean $425 \pm 83 \mu\text{m}$) in length, truncate or tailed at one or both ends; tyloses abundant in case of *S. lamellata* Foxw. (Figure 1 g) and scanty or few in case of *S. gratissima* Dyer (Figure 1 e) and *S. hypochra* Hance (Figure 1 f), while few to abundant in rest of the species. Vasicentric tracheids present, tracheids length (species mean) ranges from 454 ± 71 to $546 \pm 100 \mu\text{m}$ (*S. hypochra* Hance–*S. assamica* Dyer; mean $484 \pm 82 \mu\text{m}$) and species mean diameter ranges from 27.5 ± 2.4 to $35 \pm 4 \mu\text{m}$ (*S. roxburghii* G. Don.–*S. dealbata* Foxw.; mean $32 \pm 4.6 \mu\text{m}$), and wall thickness is 3.2. Parenchyma variable in amount and distribution mainly in the form of aliform to aliform confluent-type, sometimes observed as confluent-banded (Figure 1 a), often in the form of irregular complete or incomplete bands (*S. gratissima* Dyer, *S. lamellata* Foxw., *S. sericeiflora* Fisher et Hutch. and *S. roxburghii* G. Don.) and also diffuse and diffuse in aggregates (Figure 1 b, d and e) and rarely vasicentric; strands usually composed of 2–6 cells, sometimes up to 8 cells (e.g. *S. assamica* Dyer and *S. roxburghii* G. Don.; Figure 1 e, g–i); gummy infiltration present. Fibres angular, arranged in radial rows in cross-section, species mean diameter ranges from 18 ± 3 to $23 \pm 5 \mu\text{m}$ (*S. dealbata* Foxw.–*S. assamica* Dyer; mean $21 \pm 4 \mu\text{m}$) wall thickness 3.8–5.5 to 528–1712 μm (*S. gratissima* Dyer–*S. dealbata* Foxw.; mean $1035 \pm 157 \mu\text{m}$), non-septate, inter-fibre pits minute and simple. Rays 2–6 per mm (t), heterogeneous, uniseriate to multiseriate, up to five seriate and rarely six seriate in *S. assamica* Dyer, *S. bentongensis* Foxw., *S. dealbata* Foxw., *S. gratissima* Dyer, *S. lamellata* Foxw. and *S. sericeiflora* Fisher et Hutch., and 1–6 seriate reaching up to seven in *S. bracteolata* Dyer, *S. hypochra* Hance and *S. roxburghii* G. Don. (i) Uniseriate rays – maximum ray width ranges from 19 to 32 μm (*S. dealbata* Foxw.–*S. lamellata* Foxw.) and up to 13–26 cells or 278–749 μm (*S. sericeiflora* Fisher et

Table 1. Gross and physical features of white meranti group

Species	Physical features			Gross features (vessel/pores)					
	Colour of wood	Density (kg per cubic m)	Hardness	Weight	Diffuse porous	Solitary	Radial multiples	Clusters/tangential multiples	Tyloses
<i>Shorea assamica</i>	Light grey to pale brown	489–679	Soft to moderately hard	Light to moderately heavy	+	+	2–3 rarely up to 6	Few/+	Few to abundant
<i>S. bentongensis</i>	White to light yellow, brown to dark brown	578–769	Moderately hard to hard	Moderately heavy to heavy	+	+	2–4	Few/+	Few to abundant
<i>S. bracteolata</i>	White to light yellow or greyish-brown	669–679	Moderately hard	Moderately heavy	+	+	2–4	Few/+	Scant to few to abundant
<i>S. dealbata</i>	White to light yellow to brown	749–819	Moderately hard to hard	Moderately heavy to heavy	+	+	2–4 up to 6	Few/+	Few to abundant
<i>S. gratissima</i>	White or grey to light yellowish-brown	659	Moderately hard	Moderately heavy	+	+	2–3 rarely 4	Few/+	Scanty
<i>S. hypochra</i>	White to light yellow	657	Moderately hard	Moderately heavy	+	+	2–5	Few/+	Scanty
<i>S. lamellata</i>	White to light yellow	629–729	Moderately hard	Moderately heavy	+	+	2–3	+/+	Abundant
<i>S. sericeiflora</i>	White or grey to yellowish-brown	729–789	Moderately hard to hard	Moderately heavy to heavy	+	+	2–3	Few/few	Few to abundant
<i>S. roxburghii</i>	Light olive yellow to light yellowish or reddish-brown	729–789	Moderately hard to hard	Moderately heavy to heavy	+	+	2–4 up to 6	+/+	Few to abundant

Table 2. Anatomical features of white meranti group

Species	Vessels		Parenchyma ^b					Rays ^b				Other features					
	Frequency	Intervessel pitting (µm)	Diffuse	Diffuse in aggregates	Vasicentric ^c	Aliform	Confluent	Silica	Frequency	Seriation	Width of uniseriate µm	Height of uniseriate (µm/cells)	Width of multiseriate ^d (µm)	Height of multiseriate (µm/cells)	Silica	Gum canal ^d (µm)	Radial canal (µm)
<i>S. assamica</i>	4-15	4-16	+	+	R	+	+	-	2-6	1-6	27	428/17	70 (5)	1017/47	+	86 ± 22, +, +, +, +, +	-
<i>S. bentongensis</i>	3-11	5-8	+	+	-	+	+	-	2-6	1-5r7	27	449/17	86 (6)	803/39	+	77 ± 35 +, +	-
<i>S. bracteolata</i>	4-8	3-9	+	+	R	+	+	-	2-5	1-6	22	300/18	81 (7)	1220/54	+	103 ± 32, +, +, +, +	-
<i>S. dealbata</i>	3-9	3-8	+	+	R	+	+	-	2-6	1-5r6	19	642/26	59 (6)	1091/52	+	89 ± 26, +, +, +, +	-
<i>S. gratissima</i>	4-20	5-11	+	+	-	+	+	-	2-6	1-5r6	24	332/13	76 (6)	984/46	+	85 ± 37, +, +, +, +, +	-
<i>S. hypochra</i>	2-6	5-8	+	+	R	+	-	-	2-5	1-6r7	19	749/19	76 (6)	1070/51	+	59 ± 22, +, +, +, +	-
<i>S. lamellata</i>	2-13	3-8	+	+	-	+	+	-	2-4	1-4r7	32	428/16	95 (7)	1498/61	+	58 ± 22, +, +, +, +	-
<i>S. sericeiflora</i>	3-12	3-11	+	+	-	+	+	-	2-5	1-5r6	27	278/16	65 (6)	1017/49	+	110 ± 38, +, +, +, +, +	-
<i>S. roxburghii</i>	4-12	3-11	+	+	-	+	+	-	2-5	1-6	27	321/18	86 (6)	963/46	+	79 ± 25, +, +, +, +	-

^a +, +, +, Long tangential bands of gum canal; ++, Short tangential bands of gum canal; +, Solitary gum canal. ^b +, Presence and –, absence of silica in parenchyma and ray cells. ^c R, Rarely present; *Values in brackets show seriation.

Table 3. Quantitative anatomical features (μm) of white meranti group

Species	Vessel element dimensions				Fibres				Vasicentric trachieds		
	Length		Diameter		Length		Diameter (mean \pm SE)	Wall thick- ness	Length (mean \pm SE)	Diameter (mean \pm SE)	Wall thickness
	Range	Mean \pm SE	Range	Mean \pm SE	Range	Mean \pm SE					
<i>S. assamica</i>	267–749	457 \pm 85	95–270	176 \pm 33	706–1444	1079 \pm 148	23 \pm 5	5.5	546 \pm 100	32 \pm 6	4
<i>S. bentongensis</i>	214–663	432 \pm 96	108–248	180 \pm 32	706–1412	1031 \pm 159	21 \pm 4	4	487 \pm 127	34 \pm 6	4
<i>S. bracteolata</i>	246–588	403 \pm 79	97–243	182 \pm 27	642–1305	918 \pm 142	20 \pm 4	3.8	503 \pm 149	32 \pm 5	3.3
<i>S. dealbata</i>	214–588	400 \pm 81	97–256	177 \pm 32	856–1712	1305 \pm 204	18 \pm 3	4.6	477 \pm 53	35 \pm 4	4
<i>S. gratissima</i>	176–578	370 \pm 78	95–270	173 \pm 27	528–1254	912 \pm 152	22 \pm 4.4	4.8	460 \pm 88	32 \pm 6	3.1
<i>S. hypochra</i>	278–663	441 \pm 85	95–257	197 \pm 48	728–1551	1024 \pm 171	22 \pm 4	4.7	454 \pm 71	31 \pm 2.5	3
<i>S. lamellata</i>	332–663	477 \pm 90	108–270	177 \pm 31	749–1462	1041 \pm 177	22 \pm 4	4	496 \pm 148	34 \pm 5	4
<i>S. sericeiflora</i>	278–589	411 \pm 80	127–243	194 \pm 27	728–1220	936 \pm 126	21 \pm 3.8	4	470 \pm 118	32 \pm 4.5	3.6
<i>S. roxburghii</i>	246–738	437 \pm 76	81–257	152 \pm 31	738–1519	1071 \pm 164	22 \pm 4.5	5.4	461 \pm 91	27.5 \pm 2.4	3

Table 4. ANOVA for white meranti

Group	Source of variation	df	Mean sum of square					
			Fibre length	Fibre diameter	Wall thickness	Vessel element length	Vessel element diameter	Wood density
White meranti	Species	8	45,448**	8.7**	1.05*	3448.7*	509.5 ^{NS}	14,394.9**
	Replication	2	1292 ^{NS}	0.361 ^{NS}	0.463 ^{NS}	37.4 ^{NS}	584 ^{NS}	9657.4 ^{NS}
	Error MSS	16	2070	1.53	0.387	1225.5	272.5	3362.7

Note: $\alpha = 0.1^*$ and 0.05^{**} ; NS, not significant.

Table 5. Binary matrix for wood anatomical characters

Character
Colour: Light (0); dark (1)
Specific gravity: Light to moderately heavy (0); heavy (1)
Grain: Straight (0); interlocked (1)
Vessel frequency: Less than 10/mm (0); more than 10/mm (1)
Vessel length: Less 0.4 mm (0); more than 0.4 mm (1)
Vessel diameter: Less than 0.15 mm (0); more than 0.15 mm (1)
Fibre length: Less than 1 mm (0); more than 1 mm (1)
Fibre diameter: Less than 0.02 mm (0); more than 0.02 mm (1)
Wall thickness: Less than 5 μm (0); more than 5 μm (1)
Parenchyma apotracheal: Absent (0); present (1)
Vasicentric: Absent (0); present (1)
Scanty: Absent (0); present (1)
Aliform confluent: Absent (0); present (1)
Banded: Absent (0); present (1)
Idioblast: Absent (0); present (1)
Solitary: Absent (0); present (1)
Chambered maximum 10: Absent (0); present (1)
Chambered more than 10: Absent (0); present (1)
Ray frequency: Less than 5/cm (0); more than 5/cm (1)
Rays more than 1 mm: Absent (0); present (1)
Ray height more than 2 mm: Absent (0); present (1)
Rays more than 70 μm width: Absent (0); present (1)
Homocellular (0); heterocellular (1)
Crystals: Absent (0); present (1)
Silica bodies: Absent (0); present (1)
Radial canal: Absent (0); present (1)
Solitary gum canal: Absent (0); present (1)
Short tangential lines: Absent (0); present (1)
Long tangential: Absent (0); present (1)
Tyloses: Few to abundant (0); abundant (1)
Uniseriate rays 0.5 mm height: Absent (0); present (1)
Sheath cells: Absent (0); present (1)
Vessel arrangement diagonal: Absent (0); present (1)

Hutch.–*S. hypochra* Hance) in height, composed of upright and square cells. (ii) Multiseriate rays – maximum width 59–95 μm (*S. dealbata* Foxw.–*S. lamellata* Foxw.), and up to 39–61 cells or 803–1498 μm (*S. bentongensis* Foxw.–*S. lamellata* Foxw.) in height, body ray cells procumbent with one to two upright or square marginal ray cells. Fused rays are observed in most of the samples. Prismatic crystals are not observed. Silica bodies irregular and small in shape and size, observed in ray cells of all the species of the group. Normal axial inter-cellular canals solitary (Figure 1 c) and in the form of long and short tangential lines embedded in parenchyma bands (Figure 1 a, f–i), diameter (species mean) ranges from 58 \pm 22 to 110 \pm 38 μm (*S. lamellata* Foxw.–*S. sericeiflora* Fisher et Hutch.) and mean gum canal diameter is 84 \pm 29 μm (Tables 2 and 3).

Differences among different wood elements, viz. vessel element length and diameter, fibre length and diameter, and wall thickness are analysed using multivariate analysis. Variance ratio (F) test indicated that inter-species differences of *Shorea* of white meranti group are significant for fibre length, vessel element length, wall thickness and fibre diameter ($\alpha = 0.05$) and intra-species differences were non-significant. Variations as SD in different wood elements are shown in Table 3. Inter-specific variations in wood elements of plantation-grown meranti timbers (*S. leprosula*, *S. parvifolia* and *S. pauciflora*) have also been reported^{6,7}. Pande *et al.*^{8–10} reported significant inter-species variation and non-significant intra-species variation in red meranti and balau group of the Malay Peninsula. These wood elements are also correlated to each other for

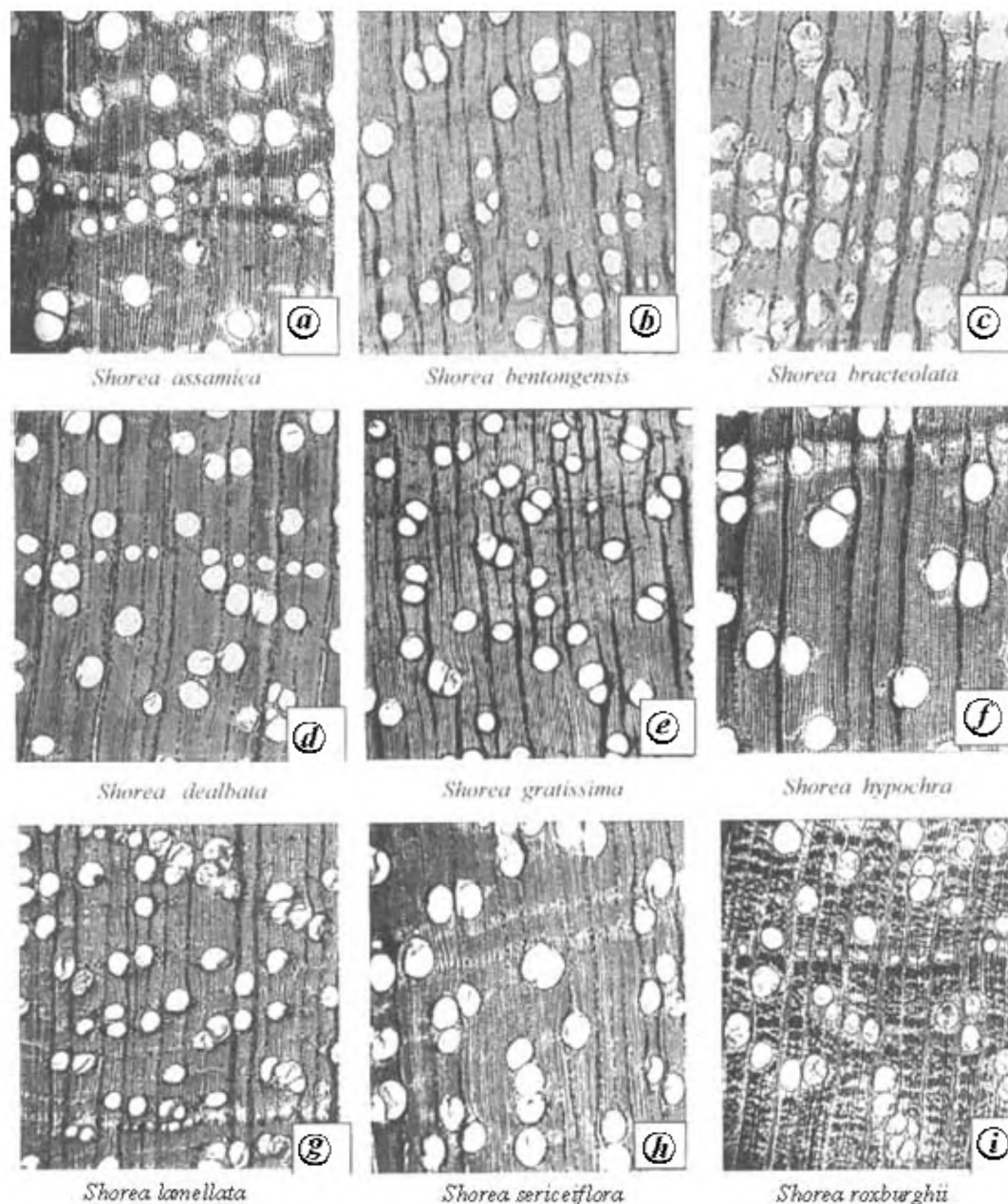


Figure 1 a-i. Photomicrographs of cross-section (40 \times) of different species of white meranti.

few characters. Fibre diameter and vessel element length are positively correlated. Correlation in different wood elements was also obtained by Pande and Singh^{11,12} for *Dalbergia sissoo* and *Eucalyptus tereticornis*. It showed that these characters influence each other up to some extent and clearly indicates that the species of white meranti group of Malay *Shorea* can also be differentiated on the basis of significant quantitative variations in dimensions of the wood elements.

On the basis of wood anatomical features, *Shorea* showed two distinct clusters: (i) white meranti and (ii) yellow meranti, red meranti and balau. The second cluster is fur-

ther subdivided into: (i) balau and red meranti, and (ii) yellow meranti¹³. Desch^{4,14} had shown that groups, based primarily on gross timber characters, correspond closely to the botanical subdivisions^{2,15}. On the basis of *PgiC* gene tree from representative *Shorea* species showed two distinct clades: (i) white meranti and (ii) yellow meranti, balau and red meranti. Further, in II clade *PgiC* gene tree showed the relationship of these timber groups (yellow meranti – balau + red meranti)¹⁶. These groups, viz. balau, red, yellow and white meranti form distinct economic units. Therefore, they have been treated separately as if each were a distinct genus². Rath *et al.*¹⁷ used RAPD analysis on

species of Malay *Shorea* and showed that the species belonging to white meranti (*S. bracteolata* Dyer and *S. roxburghii* G. Don.), light red meranti (*S. leprosula* Miq., *S. macroptera* Dyer and *S. palembanica* Miq.) and *Isoptera* sub group of balau (*S. seminis* and *S. sumatrana* Sym.) are closely related to the respective groups of Symington¹⁵ and Seibert¹⁸. Maury¹⁹ also divided *Shorea* into two tribes, viz. *Shoreae* and *Anthoshorinae*. The first categorized three groups of Symington¹⁵, viz. balau, yellow meranti and red meranti. The paraphyly of genus *Shorea* and the sister relationship of *Parashorea* to second group white meranti of *Shorea* in the *PgiC* tree correspond to the phylogeny of Kajita *et al.*²⁰. The *PgiC* tree could identify three distinct lineages that are concordant with the wood anatomical characters¹⁶. These views are well supported by the grouping of *Shorea* species on the basis of wood anatomy¹².

Hierarchical cluster analysis was carried out using qualitative and quantitative wood anatomical characters to understand the affinity or closeness of different species of white meranti of *Shorea* of the Malay Peninsula (Table 5, Figure 2). Members of white meranti showed similarity at 20% level except for *S. bentongensis*, which separated from the base of the cluster from the other members of this group (Figure 2). Further, members of the first cluster within white meranti, *S. assamica* Dyer and *S. roxburghii* D. Don. (both from the Indian subcontinent) clustered together with *S. gratissima* Dyer, while other members formed another cluster on the basis of wood anatomical characters. *S. roxburghii*, other members of white meranti and *Neobalanocarpus heimii* showed three subclades of clade I of white meranti on the basis of *PgiC* gene¹⁶. *S. roxburghii* has wide distribution from the Indian subcontinent to Malaysia, and is a typical member of white meranti²¹. In the present study, it forms a cluster with *S. assamica*, another species showing wide distribution from India to Malaysia. *S. hypochra* and *S. lamellata* showed 98% similarity. These two species showed 65% similarity with *S. bracteolata*. *S. hypochra*, *S. lamellata*, *S. bracteolata* and *S. bracteolata* and are grouped together at 50% similarity level, whereas *S. sericeiflora* showed 42% similarity with these species.

The dichotomy is based on a pair of contrasting characters, e.g. ray height, ray width, diameter of gum canal and

fibre wall thickness. Differences in quantitative characters are analysed using *t*-test for the mean.

1. Maximum ray width between (59 and 65 μ m) (mean max. 48.5 \pm 4.6 μ m) **2**
1. Maximum ray width between (70 and 95 μ m) (mean max. 63 \pm 6.4 μ m) **3**
2. Maximum diameter of gum canal up to 297 μ m (mean max. 226 \pm 37 μ m) *S. sericeiflora*
2. Maximum diameter of gum canal up to 176 μ m (mean max. 129 \pm 21 μ m) *S. dealbata*
3. Maximum diameter of gum canal (mean max. 154 \pm 29 μ m, sample mean range 126 \pm 31–182 \pm 27 μ m) **4**
3. Maximum diameter of gum canal (mean max. 91 \pm 26 μ m, sample mean range 76 \pm 20–104 \pm 3 μ m) **5**
4. Fibre wall thickness 3.7–4 μ m; density between 669 and 679 kg per cubic m *S. bracteolata*
4. Fibre wall thickness 4.5–6 μ m; density between 729 and 789 kg per cubic m *S. roxburghii*
5. Maximum ray height more than 1498 μ m (mean max. 965 \pm 124 μ m) *S. lamellata*
5. Maximum ray height less than 803–1220 μ m (mean max. 746 \pm 69 μ m) **6**
6. Maximum ray width up to 86 μ m (mean max. 65 \pm 6 μ m) **7**
6. Maximum ray width more than 76 μ m (mean max. 58.5 \pm 4.5 μ m) **8**
7. Uniseriate rays up to 449 μ m high (mean max. 324 \pm 36 μ m, sample mean range 303 \pm 32–360 \pm 56 μ m); tyloses few to abundant *S. bentongensis*
7. Uniseriate rays up to 749 μ m high (mean max. 565 \pm 71 μ m); tyloses scanty *S. hypochra*
8. Maximum ray height more than 1000 μ m (mean max. 764 \pm 7.5); tyloses few to abundant *S. assamica*
8. Maximum ray height less than 1000 μ m (mean max. 608 \pm 66); tyloses scanty *S. gratissima*.

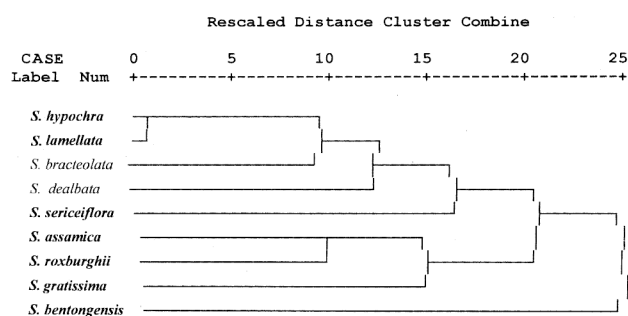


Figure 2. Dendrogram of different species of *Shorea* of white meranti.

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Phytoliths as indicators of monsoonal variability during mid–late Holocene in mainland Gujarat, western India

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Phytolith studies were carried out on a 7.8 m profile of mid–late Holocene succession located at Itola, Dhadhar river basin that lies in the sub-humid belt bordering the semi-arid zone of western India. The exposed sediment succession consists of alternating sand, silt and clay with thin layers of terrigenous charcoal partings dated to 3960 ± 510 cal yrs BP and pottery pieces at the basal-most part. Since grasses respond readily to precipitation, the ratio of characteristic cool and moist to warm and humid phytolith associations was used to reconstruct the mid–late Holocene monsoonal variability in this region. The study indicates weakening of the SW monsoon during mid–late Holocene. Winter precipitation, known to have commenced during early–mid Holocene, was still persistent around 3960 cal yrs BP, leading to cool and moist climatic conditions. Following a brief phase of dry climatic conditions, winter precipitation also gradually died out resulting in a dry climate. The SW monsoon regained its strength during the later part of late Holocene. The presence of vast archeological sites of the Indus Valley Civilization in Gujarat region during mid Holocene and their subsequent decline from this region during late Holocene raises questions regarding its relationship with the monsoonal variability during that time-span. The phytolith studies of a late Holocene sequence in mainland Gujarat has provided evidence of extremely weak winter as well as SW monsoonal activity resulting into dry climatic conditions during mid Holocene, a possible cause in the decline of the Indus Valley Civilization.

Keywords: Late Holocene, mainland Gujarat, phytoliths, SW monsoon, winter precipitation.

PHYTOLITHS are microscopic bodies of opaline silica produced in and between the vegetal cells of living plant tissues. They occur in many plant families, but are distinctive and abundant in grasses^{1–3}. They also have an advantage over the pollen due to their resistance to decay in highly oxidizing environmental conditions. Owing to the morphological distinctiveness and ecological preferences of grasses, grass phytolith assemblages are now being used for identification of crops in archaeobotany⁴ and palaeoclimatic interpretations. Grasses follow two photosynthetic pathways: C₃ (Calvin–Benson cycle) and C₄ (Hatch–

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