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Secondary xylary features in proving truth/falsity of an alibi: Examples of three important Indian commercial woods

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ABSTRACT

Secondary xylary characters of wood are useful to identify a wood up to its generic or specific level and thus may prove or disprove the alibi of the retailers, i.e., a wood is genuine or not. In this study, 26 wood samples were collected from the local markets of Baruipur, Sealdah and Garia in Kolkata, West Bengal. Among them, 8 were sold as 'Sandal wood' (*Santalum album*), 4 as "Red Sanders" (*Pterocarpus santalinus*), and 14 as "Sal wood" (*Shorea robusta*). Results indicate that xylotomical features of most of the collected "sandal wood" and "red sander" samples did not match with the reference *S. album* and *P. santalinus* samples whereas most of the collected "Sal wood" samples from furniture shops matched with the reference samples of *S. robusta*. This study successfully indicates that xylotomical investigations of commercial wood may establish the authenticity of wood of commerce.

KEY WORDS: Adulteration, commercial wood, forensic xylotomy, India, provenance of alibi, secondary xylary characters

INTRODUCTION

Xylotomical features of wood may prove or challenge an alibi of wood traders and help identify the authenticity of the wood. Wood related evidences are rarely used in a criminal investigation and are often overlooked due to lack of awareness of its value, or lack of knowledge of how to properly collect and/or evaluate that evidence.

The main components of wood, i.e., tracheids, vessels, vascular rays, fibers, and axial parenchyma help to identify a wood up to its family and genus/species level. The identification and comparison of wood evidence have been proved useful in the investigation of earlier criminal cases (Graham, 1997; Schweingruber, 1988). Evidence from wood has proven an important resource in criminal and civil courts since 70's (Kerley and Ubelaker, 1978; Vanezis *et al*., 1978; Willey and Heilman, 1987; Schweingruber, 1988; Miller, 1994; Quatrehomme *et al*., 1997). Wood analysis played a crucial role in solving one earlier famous case, the kidnapping and murder of the infant son of aviator Charles Lindbergh from his New Jersey home in 1932 (Graham, 1997).

It is a common practice for wood traders to sell low-quality cheap woods with an alibi of genuine high-quality expensive ones. Thus, the analysis of microscopic xylotomical features of commercially important pricey woods and their counterfeits can be helpful to check the quality of the products. Keeping in view the usefulness of xylotomical study in forensic investigations this study was undertaken to check the authenticity of three economically important woody plants, i.e., Sandal wood (*Santalum album)*, red sanders (*Pterocarpus santalinus*), and Sal wood (*Shorea robusta*). Sandal wood (*S. album*) is a tree with a highly aromatic wood. It is economically and culturally important to many countries around the Pacific and Eastern Indian Ocean regions where it grows or is traded. It has been in use for at least 4,000 years and is prized for making furniture, ornaments, sacred objects, carvings, and joss sticks (incense). In India, these plants grow almost exclusively in the forests of Karnataka, followed by Tamil Nadu, Kerala, and Andhra Pradesh. *P. santalinus* (red sanders) is another economically important woody plant used for coloring, dyeing and also in religious purposes. Economical significance of *S. robusta* (local name "Sal") as a timber plant has been well established.

MATERIALS AND METHODS

About 12 samples were collected from markets of Baruipur (22° 22' N, 88° 26' E), Sealdah (22° 34' N, 88° 22' E), and Garia (22° 27' N, 88° 23' E) in Kolkata sold as "Sandal wood" and "Red sanders" and 14 samples were collected from different furniture shops at Garia and Baruipur in Kolkata sold as "Sal" wood. Details of sample numbers, collection sites and alibi of traders of the collected wood samples are presented in Table 1.

For xylotomical study solid, compact and uninfected wood samples were collected. The external features of the wood samples were described on the basis of color, texture, hardness, and presence/absence of growth rings. Identification of woods requires detailed observation of their internal features. This can be achieved through microscopic observations of fine sections of the wood samples. All the woods were sectioned along transverse (T.S.), tangential longitudinal (T.L.S) and radial longitudinal (R.L.S) planes with the help of fine razor, and permanent slides were prepared. For obtaining fine section of wood, samples were boiled 10-15 min and then kept in FAA (70% ethyl alcohol 90 cc, glacial acetic acid 5 cc, and formalin 5 cc) medium for 1-2 days for softening of the wood samples (Clavers, 1911). Fine wood sections were dehydrated with the help of different concentrations of ethyl alcohol solutions (30%, 50%, 70%, 90%, and absolute alcohol) and Safranin solution (2%). Finally, dehydrated wood sections were mounted in euperol and labeled accordingly. For the identification of prepared wood slides, the published records (Metcalfe and Chalk, 1950; Illic, 1987), photographs, index permanent slides kept at Herbarium cum Museum, Department of Botany, University of Calcutta were consulted.

Correspondence and Cluster analyses were performed with the measurement data such as mean vessel diameter, vessel wall thickness, the frequency of vessels per sq mm, ray dimension (width and height), ray histology, and fiber characters (wall thickness, septation, etc.) of collected wood samples. Both analyses were employed to reduce the number of variables in the collection to a smaller set, revealing internal structure, group type variables, and detect covariance. For the Cluster analysis, Ward's method (Ward, 1963) was used, and the Euclidean distance with the variables rescaled to 0-1. Field photos were taken using a digital camera (Canon SX 120 IS), and photographs of thin sections of secondary wood structures were taken using a light compound microscope (Carl Zeiss Axioskop 2).

Table 1: Details of collected wood samples

Sample number	Location of sample collection	Alibi
SW-1	Baruipur	Sandal wood
SW-2	Baruipur	Sandal wood
SW-3	Baruipur	Sandal wood
SW-4	Sealdah	Sandal wood
SW-5	Baruipur	Sandal wood
SW-6	Sealdah	Sandal wood
SW-7	Garia	Sandal wood
SW-8	Baruipur	Sandal wood
RSW-9	Garia	Red Sanders
RSW-10	Sealdah	Red Sanders
RSW-11	Garia	Red Sanders
RSW-12	Baruipur	Red Sanders
SRW-1	Garia	Sal
SRW-2	Baruipur	Sal
SRW-3	Baruipur	Sal
SRW-4	Garia	Sal
SRW-5	Garia	Sal
SRW-6	Baruipur	Sal
SRW-7	Baruipur	Sal
SRW-8	Garia	Sal
SRW-9	Garia	Sal
SRW-10	Garia	Sal
SRW-11	Baruipur	Sal
SRW-12	Baruipur	Sal
SRW-13	Garia	Sal
SRW-14	Baruipur	Sal

RESULTS AND DISCUSSION

Among 12 collected wood samples (SW1-SW12) from Baruipur, Garia and Sealdah in Kolkata, 8 were sold as "Sandal wood" (Figure 1), and 4 were sold as "Red sanders" (Figure 2). Among 8 "sandal wood" samples (SW 1-8) only 2 samples (SW-2 and SW-7) proved to be real *S. album* but rest 6 samples (SW-1, SW-3, SW-4, SW-5, SW-6, and SW-8) did not resemble with the *S. album* reference samples. In the 6 "fake" sandal wood samples it was found that 4 were closely identical with *Aegle marmelos* (SW-1, SW-4, SW-5, and SW-8; Figure 1) and 2 resembled with species of *Santalum* other than *S. album* (SW-3 and SW-6; Figure 1). *Santalum* has 16 different species among which *S. album* and *S. spicatum* are used for aromatic and holy purposes. *S. spicatum* is commonly inhabitant of Australia and not growing in India. The secondary wood characters of SW-3 and SW-6 were similar with the genus *Santalum,* but not exactly with *S. album.*

For 4 "red sander" samples (RSW 9-12), it was evident that only one sample (RSW-10) was original *P. santalinus* (red sanders) but rest 3 (RSW-9, RSW-11, and RSW-12) were closely resembling with secondary wood characters observed in *Ceriops decandra* (Figure 2). *C. decandra* is commonly inhabitant of halophytic mangrove vegetation and found in the Indian Sundarbans regions. The Sundarbans is around 100 km away from the city of Kolkata. *Ceriops decandra* wood is morphologically closely identical with red sanders and is commonly adulterated as a red sander in the markets of Kolkata.

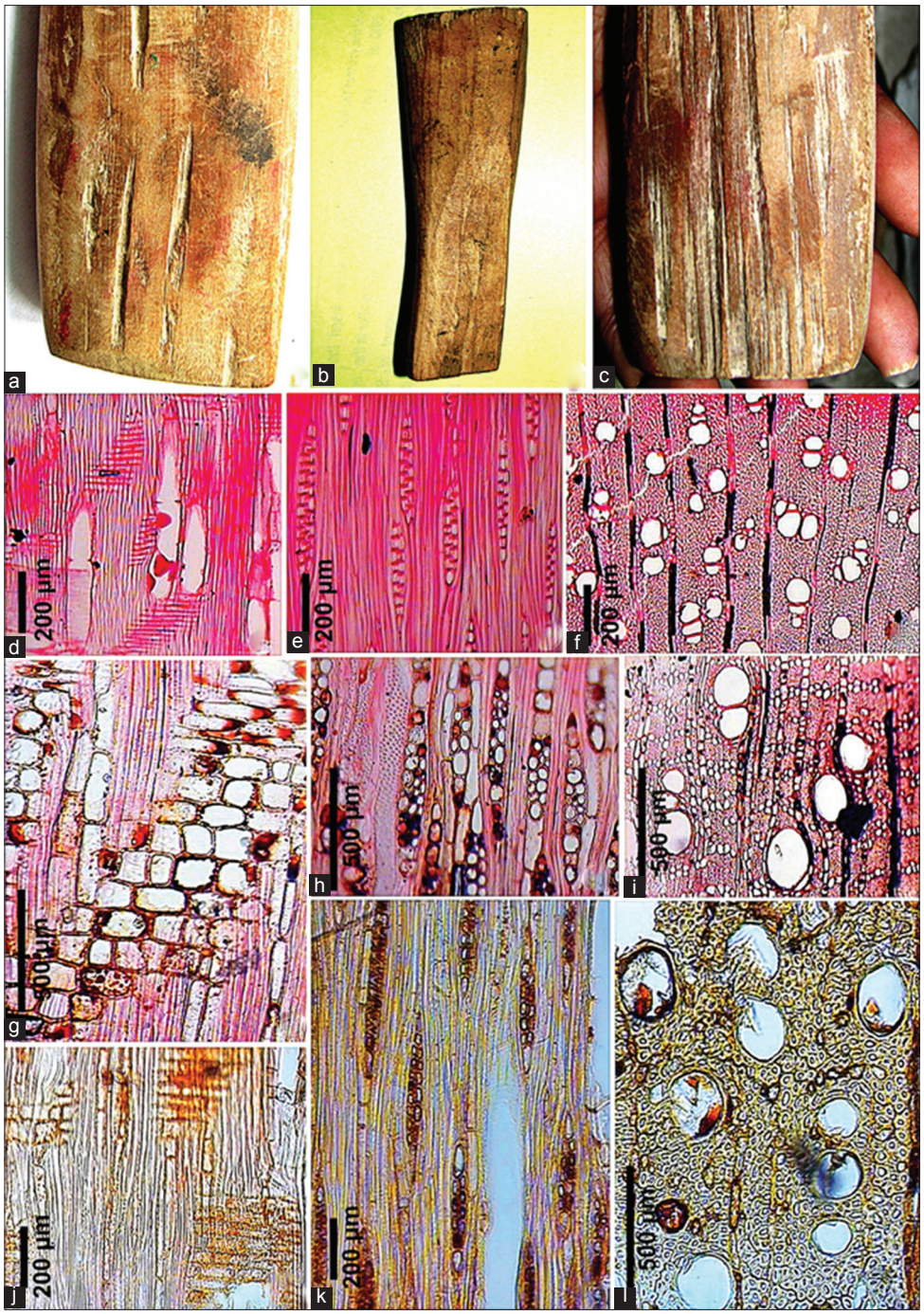

Figure 1: (a-c) Collected "sandal wood" samples, (d-f) radial longitudinal section (RLS), tangential longitudinal section (TLS), and transverse section (TS) of wood resembling *Aegle marmelos*, (g-i) RLS, TLS and TS of wood resembling *Santalum* spp., (j-l) RLS, TLS, and TS of wood resembling real *Santalum album*

Among 14 "Sal wood" samples, 12 (SRW 1-8, 10-12, 14) were found as authentic *S. robusta* wood. Amazingly, it was found that 2 (SRW-9 and SRW-13) sold as 'Sal wood' (*S. robusta*) were not similar in their anatomical features with reference wood samples of *S. robusta*. These two (SRW-9 and SRW-13) samples showed similarities with species of *Dalbergia* in their anatomical characters but not exactly with *Dalbergia sissoo* and thus considered here as *Dalbergia* sp. Type-I and *Dalbergia* sp. Type-II (Figure 3).

Salient xylotomical features of wood samples sold as "Sandal wood"

Samples Nos. SW-2 and SW-7

Wood diffuse porous; vessels medium to large, mostly solitary and in radial multiples of 2-3, evenly distributed 3-5 cells per sq mm, round to oval in cross section, thick walled 13-15 µm in thickness and 80-110 µm in diameter, long with truncate ends; perforation plate

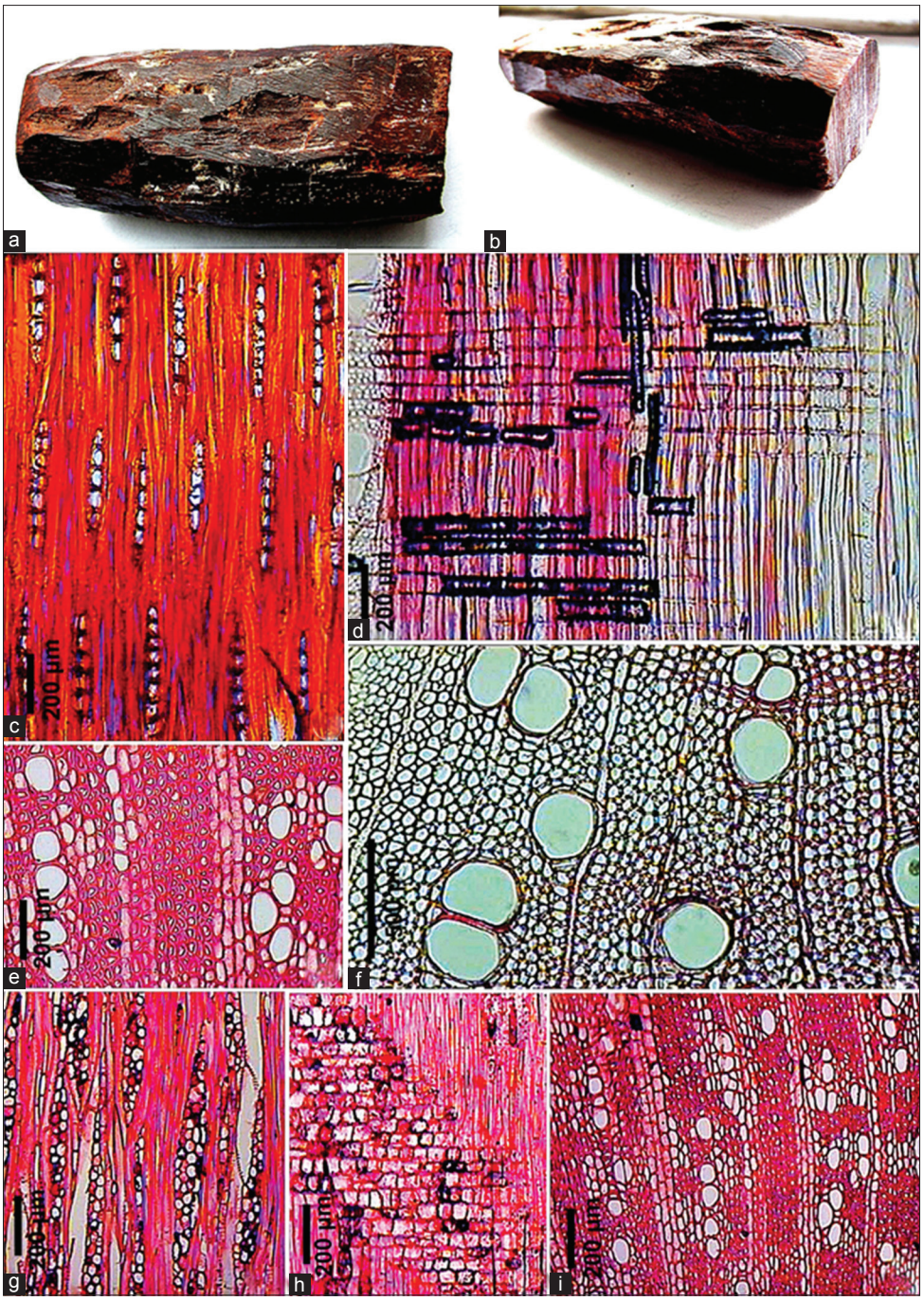

Figure 2: (a and b) Collected "red sanders" samples, (c, d and f) radial longitudinal section (RLS), tangential longitudinal section (TLS), and transverse section (TS) of wood resembling real *Pterocarpus santalinus*, (g, h, e and i) TLS, RLS, and TS of wood resembling *Ceriops decandra*

simple, intervessel pitting alternate; axial parenchyma paratracheal and apotracheal, parenchyma cells round to oval in cross section, 19 µm in diameter; xylem rays 1-2 seriate, 6-8 cells high; ray tissue heterocellular, made up of procumbent and upright cells; fibers in radial rows, thick walled, septate, circular in cross section, 16-18 µm in diameter. All the above-mentioned xylotomical features are closely similar with *S. album* L. (Santalaceae). Hence, the sold samples (SW-2, SW-7) are identified as 'authentic' Sandal wood samples.

Sample Nos. SW-3 and SW-6

Wood diffuse porous; vessel diameter moderate, 130-140 µm in diameter, mostly solitary and in radial multiples of 2-3, wall 15-17µm in thickness and 4-7 cells in per sq mm, vessels long, perforation plate simple, intervessel pitting alternate; axial parenchyma both

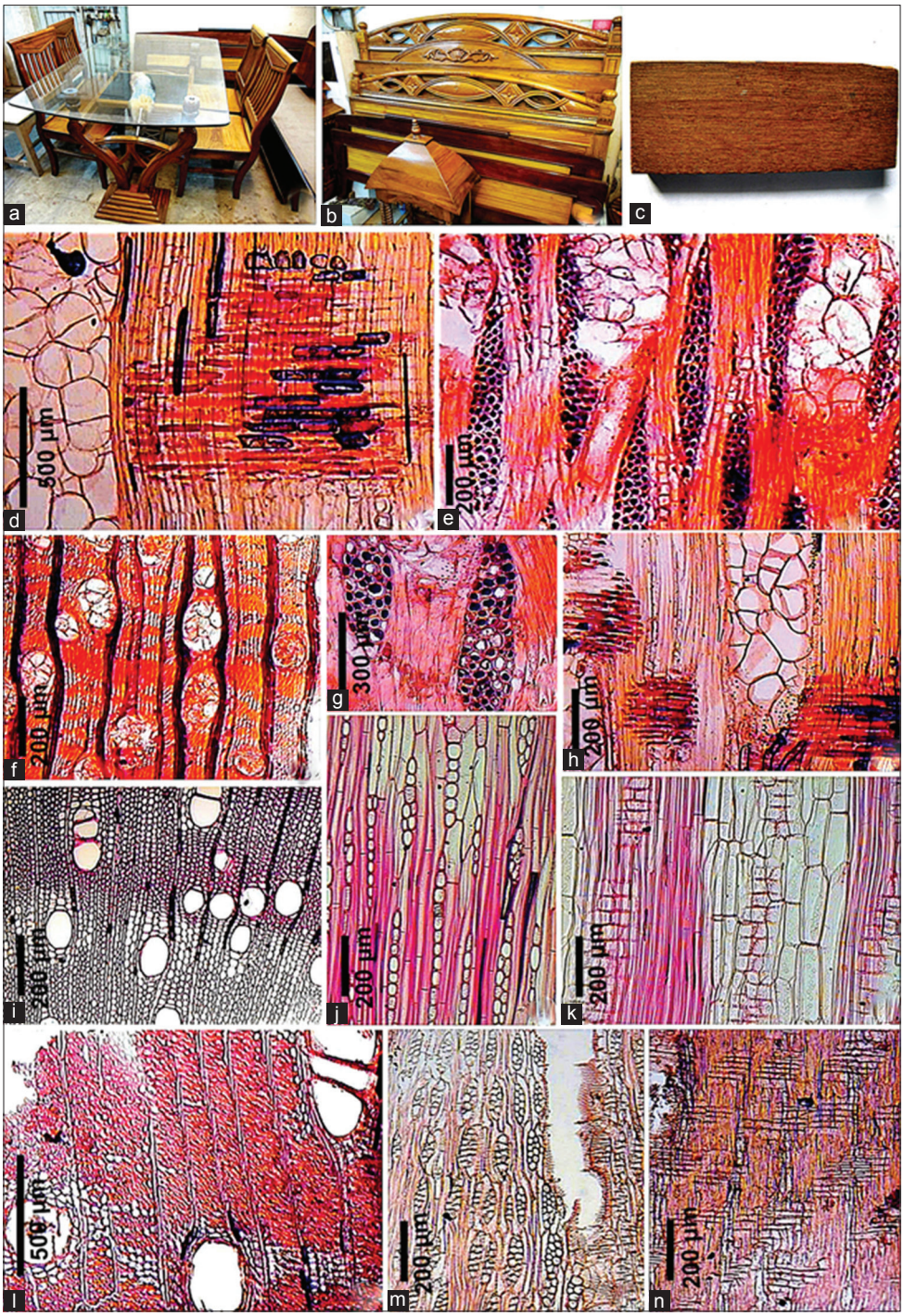

Figure 3: (a-c) Collected "Sal wood" samples from furniture shops, (d and h, e and g, f) radial longitudinal section (RLS), tangential longitudinal section (TLS), and transverse section (TS) of wood resembling real *Shorea robusta*, (i-k) TS, TLS, and RLS of wood resembling *Dalbergia* sp. Type-I, (l-n) TS, TLS and RLS of wood resembling *Dalbergia* sp. Type-II.

paratracheal and apotracheal, thick walled oval in cross section, 17.5 µm in diameter; ray cells mostly 2-3 seriate, in some cases uniseriate, multiseriate rays with long uniseriate wings, 8-10 cells high; fibers aligned in radial rows, thick walled, septate, oval in cross section, 11-13 µm in diameter; ray tissue heterocellular, made up of procumbent and upright cells, some cells are square. On the basis of vessel diameter, vessel wall thickness, vessel frequency, diameter of parenchyma, ray tissue width and ray tissue height, it seems that the wood samples were related with the genus *Santalum* of the family Santalaceae but not exactly with *S. album*. Many of the species of the genus *Santalum* do not have any commercial value, and present wood may represent any of these non-commercial

species of *Santalum*. The other commercial species *S. spicatum* has not been considered as it does not grow in India. Hence, the supplied samples (SW-3, SW-6) were identified as 'fake' Sandal wood samples.

Sample Nos. SW-1, SW-4, SW-5, and SW-8

Wood diffuse porous; vessel diameter moderate, 100-120 µm in diameter, mostly multiple of 2-3 and in some cases solitary, round to oval in cross section, thin walled 12-14 µm in thickness, long, perforation plate simple, intervessel pitting opposite; axial parenchyma abundant and apotracheal (paratracheal condition scanty), forms single layer concentric ring, thick walled, mostly oval in cross section, 16-17 µm in diameter; ray cells 3-4 seriate, 8-11 cells high; fibers aligned in radial rows, thick walled nonseptate, 7-10 µm in diameter; ray tissue mostly homocellular mostly made up of procumbent cells, rarely with upright cells.

All the above mentioned microscopic characters were more similar to *A. marmelos* (L) Corr. Serr. (Rutaceae) rather than *S. album* L. In *S. album*, intervessel pitting is an alternate, axial parenchyma is apotracheal and paratracheal, ray tissue heterogeneous, ray cell type procumbent and upright, fibers thick walled and septate. Hence, the samples (SW-1, SW-4, SW-5, and SW-8) were identified as 'fake' sandal wood. Comparative account of salient xylotomical characters of *S. album*, *Santalum* sp., and *A. marmelos* are presented in Table 2.

Salient xylotomical features of wood samples sold as "red sanders"

Sample No. RSW-10

Wood diffuse porous; vessels diameter moderate, 90-100 µm in diameter, solitary, multiples of 2-3, round to oval in cross section, thick walled 13-15 µm in thickness, long, perforation plate simple, intervessel pitting alternate; ray cells uniseriate (biserite condition very rare), 4-10 cells high; ray tissue heterocellular, mostly procumbent, some are upright; fibers radial in alignment, nonseptate, thick walled, 16-18 µm in diameter. Xylotomical features are closely comparable with *P. santalinus* L.f. of the family Fabaceae. Hence, the sold sample (RSW-10) is proved to be authentic red sanders wood.

Sample Nos. RSW-9, RSW-11, and RSW-12

Wood diffuse porous; vessels mostly solitary, 80-90 µm in diameter, long, perforation plate simple, intervessel pitting opposite; axial parenchyma apotracheal with crystals, round to oval in cross section, 23-27 µm in diameter; ray cells 2-4 seriate, 16-20 cells height; fibers radial in alignment, nonseptate, thick walled, 18-20 µm in diameter; ray tissue heterocellular, mostly procumbent and sometimes upright. On the basis of intervessel pitting, axial parenchyma, diameter of parenchyma and ray cell type, and ray tissue width and height, the characters are analogs to xylotomical features of *Ceriops decandra* (Griffith) Ding Hou. of the family Rhizophoraceae and hence the samples (RSW-9, RSW-11, and RSW-12) are proved to be fake red sanders wood. Comparative account of detailed xylotomical characters of *P. santalinus* and *Ceriops decandra* are presented in Table 3.

Salient xylotomical features of wood samples sold as "Sal wood"

Samples Nos. SRW 1, SRW 2, SRW 3, SRW 4, SRW 5, SRW 6, SRW 7, SRW 8, SRW 10, SRW 12, and SRW 14

Wood diffuse porous; vessel mostly solitary and in some cases radial multiple of 2, medium sized, oval in cross section, thick walled, 12-14 µm in thickness, 180-205 µm in diameter, 6-8 cells per sq mm, long with truncate or tailed ends, perforation simple, intervessel pits alternate, sometimes blocked with gummy substances and tylosoids, axial parenchyma paratracheal as well as

Table 2: Numerical data of secondary wood characters of *Santalum album*, *Santalum* sp., and *Aegle marmelos*

Wood characters	*Santalum album*	*Santalum* spp.	*Aegle marmelos*
Diffuse porous	Present	Present	Present
Growth ring	Absent	Absent	Absent
Vessel diameter in µm	80-110	130-140	100-120
Vessel wall thickness µm	13	17.5	14
Vessel frequency/sq mm	3-5	4-7	4-6
Inter-vessel pitting	Alternate	Alternate	Opposite
Axial parenchyma	Apotracheal and paratracheal	Apotracheal and paratracheal	Apotracheal
Diameter of parenchyma in µm	13-15	15-17	16-17
Ray tissue	Heterogeneous	Heterogeneous	Homogenous
Ray cell types	Procumbent and upright	Procumbent and upright	Procumbent
Ray tissue width	1-2	2-3	3-4
Ray tissue height	6-8	12-18	8-11
Fiber	Thick walled, septate, 16-17 µm in diameter	Thick walled, septate, 11-13 µm in diameter	Nonseptate, 6-7 µm in diameter

apotracheal, apotracheal diffuse, scattered and in some places aggregated, paratracheal parenchyma scanty, parenchyma cells thin walled, 13-17 µm in diameter; xylem rays 4-5 seriate, 25-28 cells high; rays heterocellular composed of procumbent and upright cells; fibers thick walled, nonseptate and 17-19 µm in diameter; gum canals longitudinal, mostly solitary, 70-78 µm in diameter. The above-mentioned characters are similar with real *S. robusta* Roth. of the family Dipterocarpaceae. Thus, the supplied samples (SRW 1, SRW 2, SRW 3, SRW 4, SRW 5, SRW 6, SRW 7, SRW 8, SRW 10, SRW 12, and SRW 14) are identified as 'authentic' Sal wood.

Sample No. SRW-9

Wood diffuse porous; vessels mostly solitary, 180-190 µm in diameter, 5-9 cells per sq mm, long with truncate ends, perforation simple, intervessel pits opposite, large, oval in cross-section, wall 5-8 µm in thickness; axial parenchyma apotracheal and paratracheal, paratracheal parenchyma form sheath; parenchyma oval in cross section, 30-35 µm in diameter; xylem rays fine, uniseriate and 6-13 cells high; rays heterocellular composed of procumbent and upright cells; fibers thick walled, non-septate, 19-21 µm in diameter. All the wood characters closely resemble with the genus *Dalbergia* of the family Fabaceae but not exactly with *D. sissoo*. Thus, the wood is identified as *Dalbergia* sp. Type I and proved to be "fake" Sal wood.

Sample No. SRW-13

Wood diffuse porous; vessels diameter large, 310-340 µm in diameter, mostly solitary and in radial multiple of 2-3, thick walled, 17.5 µm in thickness, 14-19 cells per sq mm, long with truncate ends, perforation simple, intervessel pits opposite; axial parenchyma apotracheal and paratracheal; parenchyma oval in cross section, 31-32 µm in diameter; xylem rays biseriate and 4-5 cells high; rays homocellular, composed of procumbent cells; fibers thick walled, nonseptate, 16-18 µm in diameter. Again the secondary xylary characters closely resemble with the genus *Dalbergia* of the family Fabaceae but not exactly with *D. sissoo* and *Dalbergia* sp. Type-I. Thus, the wood is identified as *Dalbergia* sp. Type II and proved to be "fake" Sal wood sample. Comparative account of detailed xylotomical characters of *S. robusta*, *Dalbergia* sp. Type-I and *Dalbergia* sp. Type-II are presented in Table 4.

Correspondence analysis (CA) was applied to the numerical data (Table 2) of 8 sandal wood (*S. album*) samples using the statistical program Statistica 6 (Figure 4). In the biplot with a variance of 91.51% and 8.487% in axis 1 and 2, respectively, *S. album*, *Santalum* sp. and *A. marmelos* occupied three different positions in the correspondence biplot

Table 3: Numerical data of secondary wood characters of *Pterocarpus santalinus* and *Ceriops decandra*

Wood characters	*Pterocarpus santalinus*	*Ceriops decandra*
Diffuse-porous	Present	Present
Growth ring	Absent	Absent
Vessel diameter in µm	110-120	90-100
Vessel wall thickness µm	13-15	8-10
Vessel frequency/sq mm	4-6	7-9
Inter-vessel pitting	Alternate	Opposite
Axial parenchyma	Apotracheal	Apotracheal, crystaloferous
Diameter of parenchyma in µm	25-27	39-43
Ray tissue	Heterocellular	Heterocellular
Ray cell types	Procumbent and upright	Procumbent and square
Ray tissue width in cells	1	2-3
Ray tissue height in cells	8-10	16-18
Fiber	Nonseptate, 16-18 µm in diameter	Nonseptate, 16-18 µm in diameter
Gum canal	Absent	Absent

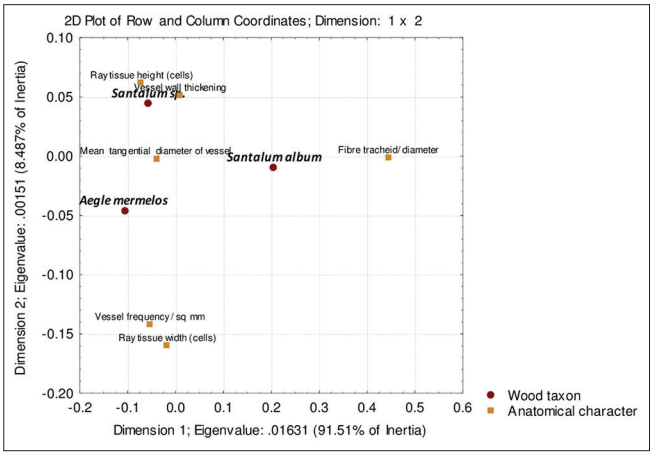

Figure 4: Biplot showing the results of correspondence analysis of collected Sandal woods and their xylotomical characters

due to the difference in the secondary xylem characters of the three different types of plant taxa (Figure 4). Tree diagram of hierarchical cluster analysis of *Santalum* wood samples was also performed using the Ward's method. The Euclidean distance in the hierarchical cluster shows the significant difference between *S. album*, *Santalum* sp. and *A. marmelos* wood samples by their numerical characters (Figure 5). It was not possible to perform correspondence analysis and hierarchical cluster analysis for the numerical data (Table 3) of *P. santalinus* (Red Sanders) as for their analysis at least three taxa are needed.

Correspondence analysis was also applied to the numerical data (Table 4) of 14 Sal (*S. robusta*) wood samples using the statistical program Statistica 6 (Figure 6). In the biplot with a variance of 89.65% and 10.35% in axis 1 and 2, respectively, *S. robusta*, *Dalbergia* sp. Type- I and *Dalbergia* sp. Type-II took again three different positions in the

Table 4: Numerical data of secondary wood characters of *Shorea robusta*, *Dalbergia* Sp. Type-I and *Dalbergia* sp. Type-II

Wood characters	*Shorea robusta*	*Dalbergia* sp. Type-I	*Dalbergia* sp. Type-II
Diffuse porous	Present	Present	Present
Growth ring	Absent	Absent	Absent
Vessel diameter in μm	180-200	180-190	320-340
Vessel wall thickness in μm	12-14	5-8	14-18
Vessel frequency/sq mm	6-8	5-9	14-19
Inter-vessel pitting	Alternate	Opposite	Opposite
Axial parenchyma	Paratracheal and apotracheal	Paratracheal and apotracheal	Paratracheal and apotracheal
Diameter of parenchyma	27-30	33-35	31-32
Ray tissue	Heterocellular	Heterocellular	Homocellular
Ray cell types	Procumbent and upright	Procumbent and upright	Procumbent
Ray tissue width	4-6	1	2
Ray tissue height	24-29	8-10	6-6
Fiber	Thick walled nonseptate, 18-20 μm in diameter	Thick walled nonseptate, 19-21 μm in diameter	Thick walled nonseptate, 16-18 μm in diameter
Gum canal	Present, 78-83 μm in diameter	Absent	Absent

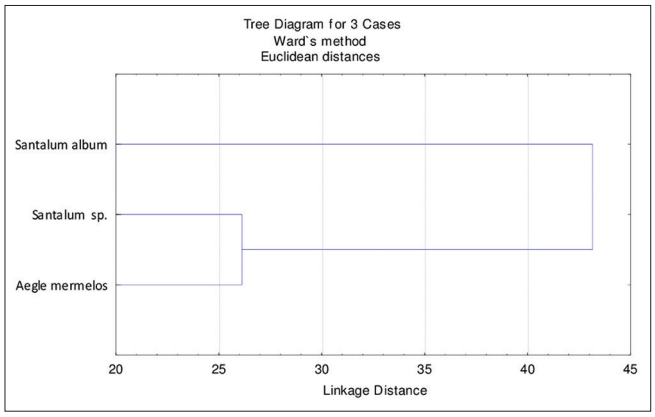

Figure 5: Tree diagram of hierarchical cluster analysis of Sandal woods

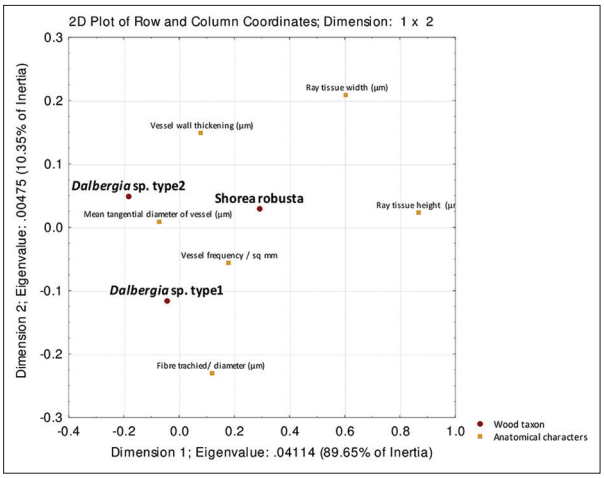

Figure 6: Biplot showing the results of correspondence analysis of collected Sal woods and their xylotomical characters

correspondence biplot due to the significant difference in their secondary xylem characters (Figure 6).

Hierarchical cluster analysis of collected Sal wood samples was also performed applying the Ward's method. The Euclidean distance in the hierarchical cluster shows that *S. robusta* is significantly different from the *Dalbergia* sp. Types I and II, but some ancestral linkage were found between the *Dalbergia* sp. Type-I and *Dalbergia* sp. Type-II. It clearly indicates that both samples are species of the same genus, i.e. *Dalbergia* (Figure 7).

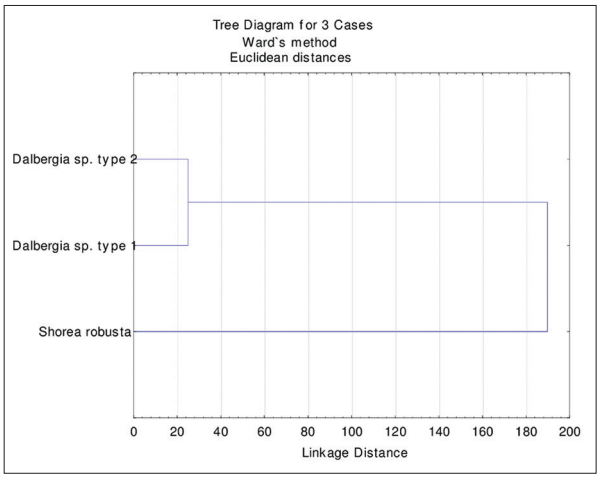

Figure 7: Tree diagram of hierarchical cluster analysis of Sal woods

CONCLUSIONS

This study clearly demonstrates that xylotomical study of commercially used woods can play a significant role for the provenance of their authenticity. Secondary xylem structures of plants are very efficient to identify a plant up to its family, generic or specific level. It was found that furniture, carvings and other commercially sold wooden products made by Sandal, Red sander, and Sal woods were faked by the local manufacturers in Kolkata. Thus, this study indicates that sometimes it is also possible to trace an illegal transport of wood having high medicinal properties or importance as expensive timber and the identification of wood may trap the traders and stop such illegal trading of wood. It is not always possible to identify

a tree species from this kind of fragmentary examination. However, comparison with known samples may provide an idea of the type of timber involved. Thus, xylotomical features may be utilized as an effective tool to measure the authenticity of a wood of commerce.

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