

COMPARATIVE WOOD ANATOMICAL PROPERTIES OF GENUS SYZYGIUM (FAMILY MYRTACEAE) FROM MANIPUR, INDIA

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COMPARATIVE WOOD ANATOMICAL PROPERTIES OF GENUS SYZYGIUM (FAMILY MYRTACEAE) FROM MANIPUR, INDIA. *Syzygium* belongs to family Myrtaceae and comprises of mostly trees and a few shrubs. This paper studies the anatomical and physical characteristics of five *Syzygium* species, namely *Syzygium cumini*, *Syzygium fruticosum*, *Syzygium jambos*, *Syzygium nervosum* and *Syzygium praecox* and to see intra and inter-species variation among them. The wood samples were taken at breast-height from straight bole and uniform crowned trees. The present study showed that all the selected species shared common features like simple perforation plate, vested inter-vessel pits, disjunctive ray parenchyma cells, diffuse, diffuse-in-aggregate, vasicentric, aliform and confluent types of axial parenchyma, diffuse-porous and indistinct *fruticosum* were observed. The vessels were mostly barrel-shaped with small or long tails at one or both ends in all species except tube-shaped in *S. jambos* and drum-shaped in *S. fruticosum*. Spiral thickenings were present in the tails of *S. nervosum* and *S. fruticosum*. Fibres were thin-walled and non-septate. Occasional septate fibres and vasicentric tracheids were present in *S. nervosum* and *S. jambos*. Crystals in the ray of *S. nervosum* and *S. fruticosum* and silica bodies in axial parenchyma of *S. jambos* were observed. The fibre percentage and wood density were maximum in *S. jambos*, whereas moisture content was minimum in *S. jambos*. Principal Component Analysis revealed a close relationship among all species. Therefore, the qualitative characteristics and all quantitative anatomical characteristics can be used for reliable identification of *Syzygium* species.

Keywords: *Syzygium* species, anatomical characteristics, wood density, moisture content

PERBANDINGAN KARAKTERISTIK ANATOMI KAYU GENUS SYZYGIUM (FAMILY MYRTACEAE) YANG BERASAL DARI MANIPUR, INDIA. *Syzygium* merupakan Family Myrtaceae yang sebagian besar terdiri dari pohon dan semak. Tujuan penelitian ini adalah untuk mempelajari karakteristik anatomi dan sifat fisik dari lima spesies *Syzygium*, yaitu *Syzygium cumini*, *Syzygium fruticosum*, *Syzygium jambos*, *Syzygium nervosum*, dan *Syzygium praecox* dan untuk melihat variasi intra dan antar spesies. Contoh uji diambil dari batang lurus setinggi dada dengan kondisi pohon yang bertajuk relatif seragam. Hasil penelitian menunjukkan bahwa karakteristik anatomi semua spesies yang dipelajari berciri relatif sama, yaitu bidang perforasi sederhana, noktah antar-pembuluh berumbai, sel parenkim jari-jari disjungtif, difus, difus-in-agregat, vasicentric, aliform dan konfluen aksial parenkima, difus porus dan *fruticosum* tidak jelas. Pembuluh sebagian besar berbentuk silinder dengan ekor kecil atau panjang di satu atau kedua ujungnya di semua spesies kecuali berbentuk tabung di *S. jambos* dan berbentuk silinder di *S. fruticosum*. Penebalan spiral dijumpai di bagian ekor *S. nervosum* dan *S. fruticosum*. Serat ber dinding tipis dan tidak bersekat. Serabut bersekat sesekali dijumpai pada trakeid vasicentric jenis *S. nervosum* dan *S. jambos*. Sel kristal dalam jari-jari dijumpai pada jenis *S. nervosum* dan *S. fruticosum* dan badan silika di parenkima aksial jenis *S. jambos*. Persentase serat dan kepadatan kayu paling besar tercatat di *S. jambos*, sedangkan kadar air minimum tercatat di contoh uji *S. jambos*. Analisis komponen utama mengungkapkan hubungan yang erat di antara semua jenis. Oleh karena itu, karakteristik kualitatif bersama dengan karakteristik anatomi kuantitatif dapat digunakan sebagai dasar identifikasi jenis *Syzygium*.

Kata kunci: spesies *Syzygium*, karakteristik anatomi, kepadatan kayu, kadar air

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I. INTRODUCTION

The word *Syzygium* is derived from a Greek word ‘syzygos’ which means the presence of “paired/coupled” branches and leaves (Janick & Paull, 2008). It is one of the most abundant genera in family Myrtaceae with 1200 species. It is distributed from Africa eastwards to the Hawaiian Island, India, Southern China southwards to Australia and New Zealand (Parnell et al., 2007; Govaerts et al., 2008; Ahmad et al., 2016; Christenhusz et al., 2017). It ranks on 16th position among the 57 most abundant genera of flowering plants (Govaerts et al., 2018). Most of the workers have considered both *Syzygium* and *Eugenia* under genus *Eugenia* (Henderson, 1949) as there is no distinction between their morphological characters. Ingle and Dadswell (1953) divided *Eugenia* into two sections based on anatomical structure – ‘*Eugenia* A’ is comprised of the species having similarity with the new world species and ‘*Eugenia* B’ has *Syzygium* and other *Eugenia* species which are similar in their anatomy. The timbers of *Eugenia* A are characterized by the presence of vasicentric tracheids, solitary pores, apotracheal parenchyma, vessel ray pitting small and similar to inter vessel pits. The timbers of *Eugenia* B are characterized by absence of vasicentric tracheids, presence of multiple pores, paratracheal parenchyma, simple to scalariform vessel ray pitting. This grouping was also supported by Chattaway (1959) who observed substantial differences in bark structure between two groups. The separation of *Eugenia* and *Syzygium* as different lineage by Schimid (1972) is further confirmed with molecular studies by several workers (Wilson et al., 2001, 2005; Biffin et al., 2010).

In India, Genus *Syzygium* is represented by 91 species, of which most are trees and few shrubs (Arisdason & Lakshminarasimhan, 2017). *Syzygium aromaticum* is the essential spices with high commercial value. Species like *Syzygium cumini*, *Syzygium jambos* are being cultivated in several parts of India for their fruits. From timber point of view, *Syzygium cumini* is the most important species. Several other species

like *S. calophyllifolium*, *S. cerasoides*, *S. cavaran*, *S. densiflorum*, *S. grande* etc. also have good timber value and are being used for construction, furniture, flooring, telegraph poles, side props in mine shafts and galleries, railway sleepers, bottom boards of railway carriages, implements, packaging case, fibreboard, and veneer and plywood.

The anatomical characteristics of wood are valuable storehouse for environmental studies (Fonti et al., 2010) to determine additional and new ecological information and to see the relationship between tree growth and environmental factors. They also help to resolve taxonomical problems to separate the different species. Since there is no information on wood anatomical characteristics of selected *Syzygium* species, therefore, the present study was carried out (a) to study anatomical and physical features of *Syzygium* species and (b) to study intra- and inter-species variation in these characteristics.

II. MATERIAL AND METHOD

A. Study Site

Five straight trees with uniform crown and no visible defects of each species were randomly selected from Kakching and Imphal West districts of Manipur, India. The geographical coordinates, height and diameter of selected species were given in (Table 1).

B. Methods

Wood samples of 5 cm × 5 cm × 4 cm size at breast height were taken. The wood samples were packed in polythene bags and brought to the laboratory for further processing. Collected samples were cut into small blocks of 2 cm³ size. They were fixed in FAA (Formalin-acetoalcohol) for 24–48 hrs and preserved in 50% alcohol for anatomical studies. These blocks were cut in 3 planes namely Cross Section (C. S.), Tangential Longitudinal Section (T. L. S.) and Radial Longitudinal Section (R. L. S.) with the help of a sliding microtome (Leica SM 2000R). Standard methods were followed to prepare permanent slides.

Table 1. List of *Syzygium* species collected from different sites of Manipur

Species	Latitude & Longitude	Height (m)	Diameter (cm)	Locality
<i>S. cumini</i>	24°29.938' N - 24°47.829' N 93°58.084'E - 93°55.463' E	5.2–8	32.48–38.85	Mahadevching, Kakching Sagolband, Imphal west
<i>S. fruticosum</i>	24°29.664' N - 24°29.679' N 93°57.860' E - 93°57.795' E	6.5–9.8	36–49	Mahadevching, Kakching
<i>S. jambos</i>	24°30.107' N - 24°30.329' N 93°58.737' E - 93°58.384' E	4.9–8.4	13.69–15.29	Chumnang, Kakching
<i>S. nervosum</i>	24°43'12"N - 24°44'09"N 93°55'47"E - 93°54'49"E	5.5–6.1	19.41–38.83	Lilong chajing, Imphal
<i>S. praecox</i>	24°29.938' N - 24°30.784' N 93°58.074' E - 93°58.116' E	5.8–7	19.10–23.57	Ashram ching, Kakching

Thin matchstick-size of wood was taken from the radial side of each sample of selected species and was macerated with Franklin's solution at 60°C for 24 hours till they become soft and white. The macerated material was washed with distilled water 2–3 times and gently shaken to get a fluffy mass of fibres. 2–3 drops of safranin were added, and temporary slides were prepared by using 50% glycerol. The dimensions of anatomical parameters of vessels, fibres and rays were taken with the help of Scopeimage 9.0 software at different magnifications. For each sample of selected species, 30 random fibres, vessels and rays were chosen for measurement of their various parameters. Ten fields per sample of each species were randomly selected for counting the number of vessels per mm² and ray per mm in cross-section. Thus, a total of 250 fields were observed for both parameters. Fibre, vessel, parenchyma and ray proportion were determined on cross-section by selecting ten fields.

The anatomical descriptions of species were given by following IAWA list of microscopic features for hardwoods identification (Wheeler et al., 1989). Different vessel shapes were identified as given by Helmling et al. (2018). The photomicrographs of selected species were taken with the help of image analysis system at different magnifications for their anatomical features.

Water displacement method (Smith, 1955) was used to determine the wood density. Moisture content was determined, as mentioned by Panshin and deZeeuw (1980).

C. Analysis

The data were statistically analysed by using SPSS 16 software. One way ANOVA followed by Tukey's test was performed to compare the differences in anatomical characteristics among species.

III. RESULT AND DISCUSSION

A. *Syzygium cumini* (L.) Skeels.

(Figure 1A-1F; Figure 6A-6D)

General features – Indistinct heartwood and sapwood; wood colour ranges from pale grey or greyish brown in the outermost region to dark brown or reddish-brown towards the centre; wood is moderately hard to hard and moderately dense to heavy; grain generally shallowly interlocked, sometimes wavy; medium to coarse-textured.

Anatomical features – A semi-ring porous, diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, circular in outline, barrel shape without the tail, with very long or small tail at one and/or both ends, 500–1200 µm (868.83 ± 147.66 µm) in length, 105.77–193.69 µm (146.02 ± 17.18 µm) in diameter, vessel frequency 6–20

(11 ± 3) per mm², simple perforation plate, inter-vessel pit alternate, vestured, small to medium $6.87\text{--}9.62\text{ }\mu\text{m}$ ($8.2 \pm 0.6\text{ }\mu\text{m}$) in size, vessel ray pits with much reduce borders to apparently simple: pits horizontal (scalariform, gash like) to vertical (palisade), tyloses present, vessel percentage 17.45%.

Fibres – Thin-walled, $1050\text{--}2300\text{ }\mu\text{m}$ ($1766.83 \pm 222.13\text{ }\mu\text{m}$) long, $18.28\text{--}35.89\text{ }\mu\text{m}$ ($25.13 \pm 3.64\text{ }\mu\text{m}$) and $11.08\text{--}28.05\text{ }\mu\text{m}$ ($18.62 \pm 3.32\text{ }\mu\text{m}$) in diameter and lumen diameter, $2.19\text{--}6.37\text{ }\mu\text{m}$ ($3.26 \pm 0.66\text{ }\mu\text{m}$) in wall thickness, fibre percentage 40.36%.

Parenchyma – Mostly scanty, diffuse, diffuse-in-aggregate and confluent, parenchyma strand 4-12 cells, vestured pits present, parenchyma percentage 14.55 %.

Ray – Uniseriate, biseriate and multiseriate, mean ray height and ray width $352.52\text{--}944.07\text{ }\mu\text{m}$ ($632.08 \pm 120.59\text{ }\mu\text{m}$) and $30\text{--}77.56\text{ }\mu\text{m}$ ($49.98 \pm 8.79\text{ }\mu\text{m}$), 1–3 cells wide, rays both homocellular and heterocellular, all homocellular rays of upright/square cells, heterocellular rays of body ray cells procumbent with one row of upright and/or marginal square cells, rays 5–10 (8 ± 2) per mm, disjunctive ray parenchyma cells present, ray percentage 27.64%.

B. *Syzygium fruticosum* DC.

(Figure 2A-2F; Figure 6E-6H)

General features – Indistinct heartwood and sapwood, wood pale grey to reddish-brown, moderately hard and moderately heavy; wavy rarely straight grain.

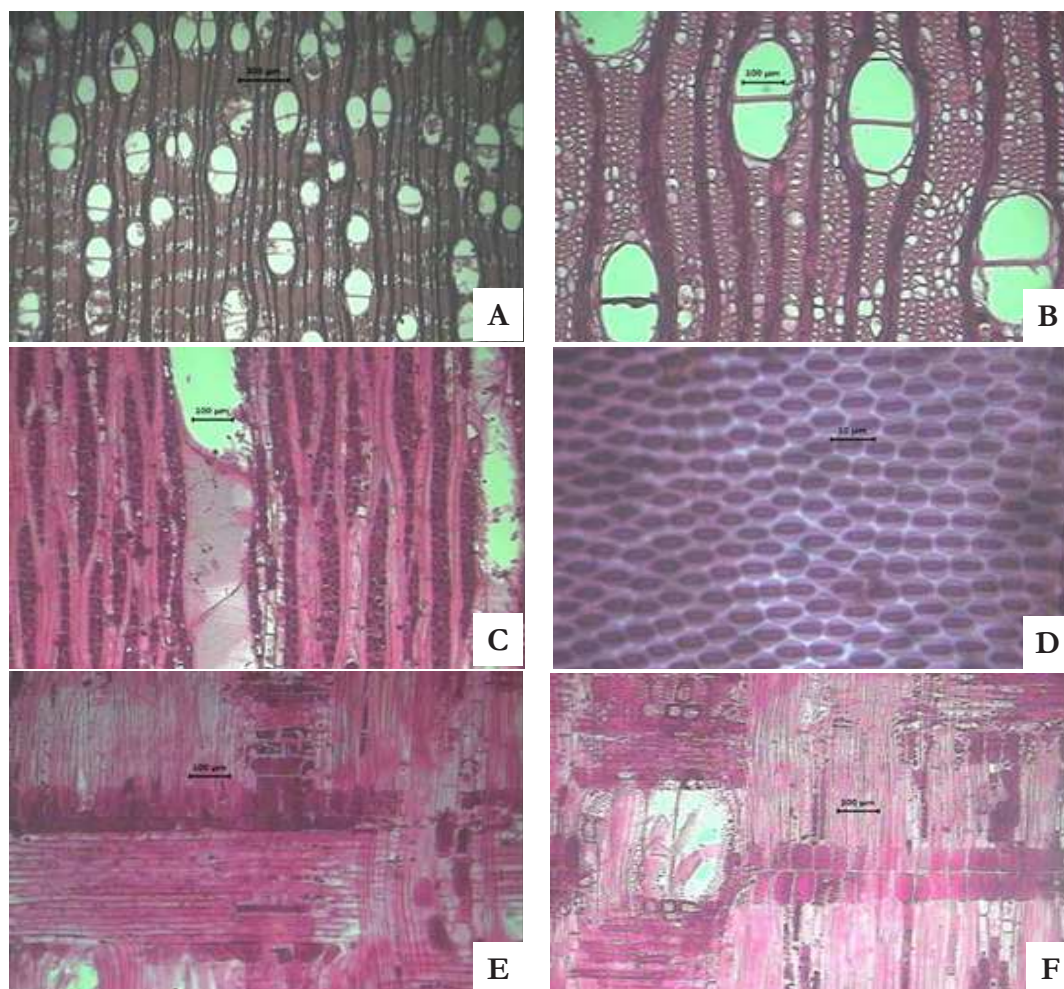


Figure 1. *Syzygium cumini*: C. S. - Wood diffuse-porous, parenchyma diffuse and confluent type (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate (C), vestured intervessel pits (D); R. L. S. - Heterocellular ray of procumbent and upright and/or marginal square cells (E); homocellular ray of upright/square cells (F)

Anatomical features – A semi-ring porous, diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, oval in outline, drum and tube shape with spiral thickening in small and pointed tails, 275–925 μm ($526.50 \pm 124.327 \mu\text{m}$) in length, 63.19–152.47 μm ($113.76 \pm 17.63 \mu\text{m}$) in diameter, vessel frequency 6–10 (13 ± 3) per mm^2 , simple perforation plate, inter-vessel pit alternate, vestured, small to medium 7.83–10.85 μm ($9.30 \pm 0.67 \mu\text{m}$) in size, vessel ray pits with much reduce border to apparently simple pits horizontal (scalariform, gash like) to vertical

(palisade), tyloses present, vessel percentage 22.91%.

Fibres – Thin-walled, 900–1875 μm ($1286.83 \pm 186.96 \mu\text{m}$) long, 15.66–34.34 μm ($23.30 \pm 3.04 \mu\text{m}$) and 10.44–27.61 μm ($16.66 \pm 2.65 \mu\text{m}$) in diameter and lumen diameter, 2.06–5.22 μm ($3.32 \pm 0.61 \mu\text{m}$) in wall thickness, septate fibres present, fibre percentage 30.91%.

Parenchyma – Diffuse, diffuse-in-aggregate, aliform and confluent, parenchyma strand 4–12 cells, bordered pits present, parenchyma percentage 29.09%.

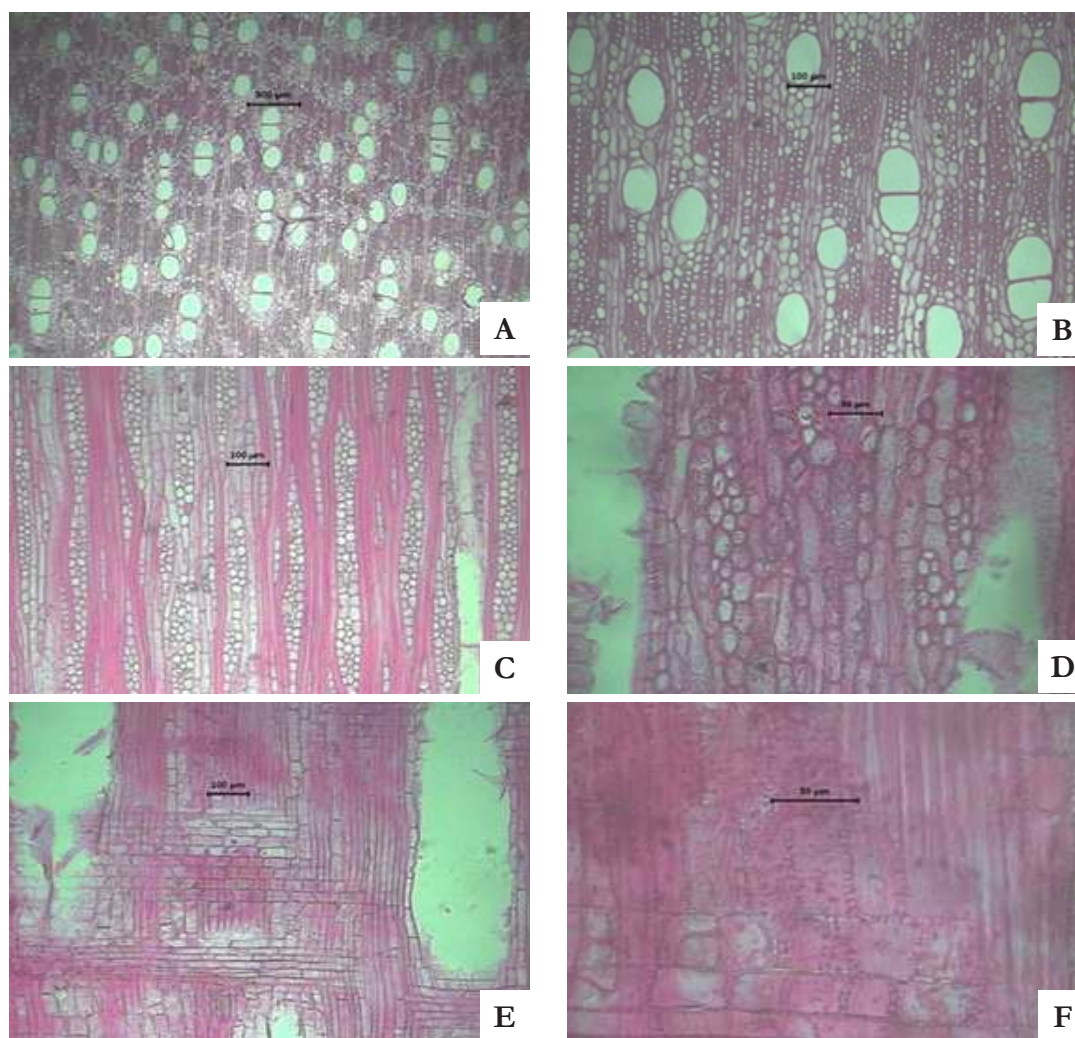


Figure 2. *Syzygium fruticosum*. C. S. - Wood diffuse-porous, vessels mostly solitary in radial multiple of 2 – 4, parenchyma diffuse, diffuse-in-aggregate, confluent type (A & B); T. L. S. - Rays multiseriate, parenchyma strand 4–12 celled (C), crystals in ray and parenchyma cell (D); R. L. S. - Heterocellular ray of procumbent and upright and/or marginal square cells (E); Disjunctive ray parenchyma cell walls (F)

Ray – Mostly multiseriate, mean ray height and ray width 226.09–946.21 μm (501.60 ± 158.41 μm) and 28.02–68.90 μm (47.71 ± 8.28 μm), 1–3 cells wide, rays both homocellular and heterocellular, all homocellular rays of square cells, heterocellular rays are consisting of body ray cells procumbent with 2–4 rows of upright and/or marginal square cells, rays 4–11 (7 ± 2) per mm, disjunctive ray parenchyma cells present, ray percentage 17.09%.

Mineral inclusions – Crystals and crystal sand present in ray and parenchyma, black streaks present among fibres.

C. *Syzygium jambos* (L.) Alston (Figure 3A-3F; Figure 6I-6L)

General features – Indistinct heartwood and sapwood, reddish grey to brown, wood slightly soft, moderately heavy, with a reasonably regular wavy grain.

Anatomical features – A diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, clusters, circular in outline, tube shape with short/long tail at one or both ends, 475–1700 μm (892 ± 186.66 μm) in length, 61.81–105.78 μm (83.85 ± 8.62 μm) in diameter, vessel frequency

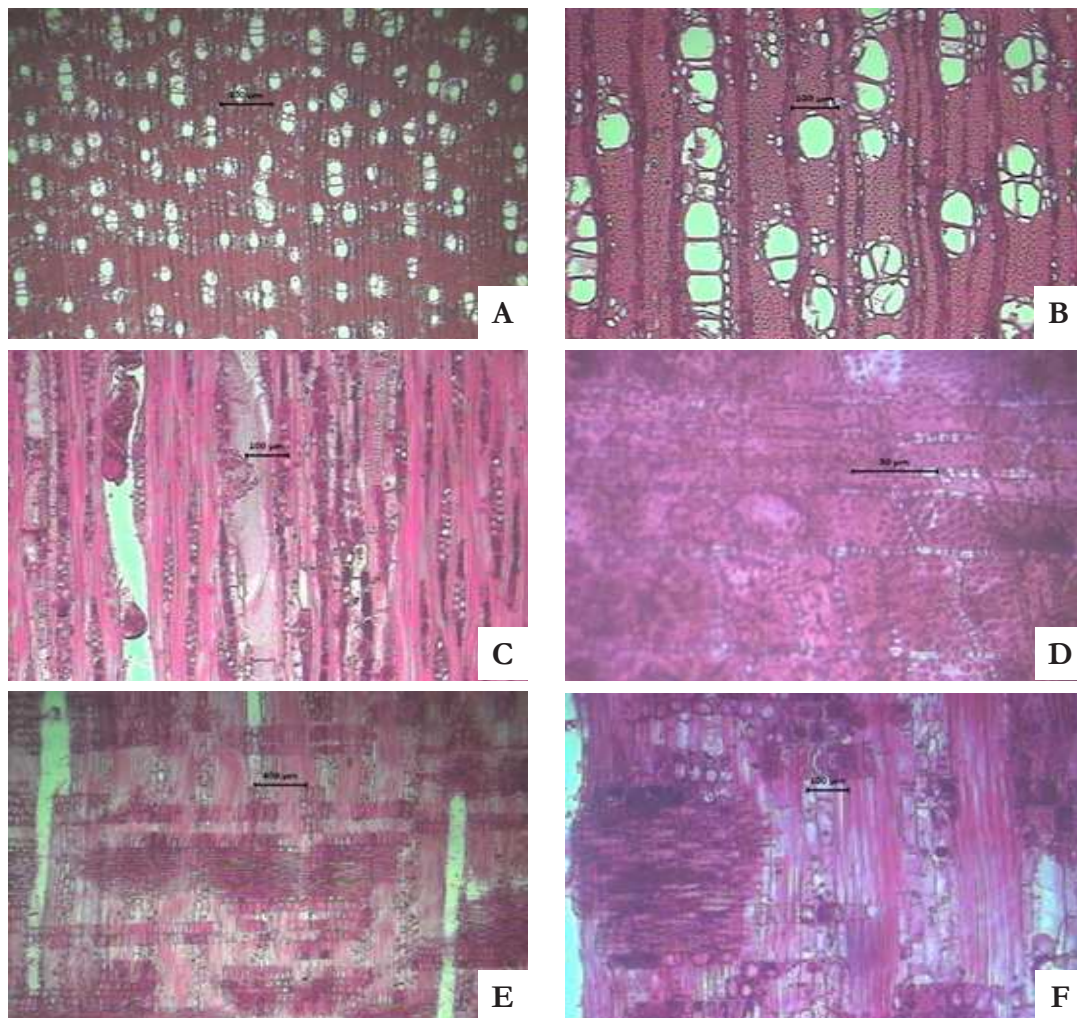


Figure 3. *Syzygium jambos*: C. S. - Wood diffuse-porous, vessels mostly solitary in radial multiple of 2–4 Parenchyma diffuse, diffuse-in-aggregate, aliform type (A & B); T. L. S. - Rays multiseriate, tyloses parenchyma strand 2–13 celled (C); R.L.S. - Vessel-ray pits with much-reduced border to simple pits rounded (D); heterocellular rays of procumbent and upright and/or marginal square cells (E), silica bodies in axial parenchyma cells (F)

14–30 (21 ± 4) per mm^2 , simple perforation plate, inter-vessel pit alternate, vested, small-medium $6.87\text{--}8.93\ \mu\text{m}$ ($7.72 \pm 0.45\ \mu\text{m}$) in size, vessel ray pits with much reduce borders to apparently simple: pits rounded, tyloses present, vessel percentage 14.91%.

Fibres – Thin - thick-walled, $1175\text{--}2425\ \mu\text{m}$ ($1657.83 \pm 237.30\ \mu\text{m}$) long, $17.52\text{--}28.81\ \mu\text{m}$ ($22.20 \pm 2.06\ \mu\text{m}$) and $7.20\text{--}17.35\ \mu\text{m}$ ($11.62 \pm 1.82\ \mu\text{m}$) in diameter and lumen diameter, $3.35\text{--}7.92\ \mu\text{m}$ ($5.29 \pm 1.02\ \mu\text{m}$) in wall thickness, vasicentric tracheid present, fibre percentage 44%.

Parenchyma – Diffuse, diffuse-in-aggregate, aliform, confluent and banded, parenchyma strand 4–12 cells, parenchyma percentage 20.36%.

Ray – Uniseriate and biseriate, mean ray height and ray width $369.16\text{--}870.23\ \mu\text{m}$ ($574.13 \pm 106.07\ \mu\text{m}$) and $33.08\text{--}56.90\ \mu\text{m}$ ($40.11 \pm 4.44\ \mu\text{m}$), 1–3 cells wide, rays both homocellular and heterocellular. Homocellular rays of upright and/or square cells, heterocellular rays consisting of body ray cells procumbent with 1–2 rows of upright and/or marginal square cells, rays 7–14 (10 ± 2) per mm, disjunctive ray parenchyma cells present, ray percentage 20.73%.

Mineral inclusions – Silica bodies present in the parenchyma.

D. *Syzygium nervosum* DC.

(Figure 4A–4F; Figure 6M–6P)

General features – Indistinct heartwood, wood reddish grey, hard, rough; moderately heavy – heavy; wavy grain to reasonably straight grain.

Anatomical features – A diffuse-porous wood.

Growth rings – Indistinct.

Vessels – Mostly solitary, in radial multiple of 2–3, circular in outline, barrel-shaped without and with spiral thickenings in very long/small tails at one or both ends, $375\text{--}825\ \mu\text{m}$ ($557.67 \pm 114.29\ \mu\text{m}$) in length, $103.02\text{--}181.32\ \mu\text{m}$ ($135.15 \pm 16.42\ \mu\text{m}$) in diameter, vessel frequency 11–21 (16 ± 3) per mm^2 , simple perforation plate, inter-vessel pit alternate

and also scalariform, vested, small-medium $7.08\text{--}10.27\ \mu\text{m}$ ($8.82 \pm 0.65\ \mu\text{m}$) in size, vessel ray pits with much reduce borders to simple: pits rounded, tyloses present, vessel percentage 20.36%.

Fibres – Thin-walled, $1025\text{--}1850\ \mu\text{m}$ ($1404.83 \pm 150.88\ \mu\text{m}$) long, $18.85\text{--}36.05\ \mu\text{m}$ ($24.04 \pm 3.21\ \mu\text{m}$) and $12.19\text{--}27.79\ \mu\text{m}$ ($17.91 \pm 2.96\ \mu\text{m}$) in diameter and lumen diameter, $2.21\text{--}4.50\ \mu\text{m}$ ($3.07 \pm 0.47\ \mu\text{m}$) in wall thickness, septate fibres present, fibre percentage 38.91%.

Parenchyma – Scanty, vasicentric, diffuse, diffuse-in-aggregate and aliform, parenchyma strands 2–13 cells, vested pits present in the parenchyma, parenchyma percentage 21.82%.

Ray – Multiseriate, mean ray height and ray width $393.01\text{--}843.77\ \mu\text{m}$ ($547.81 \pm 104.36\ \mu\text{m}$) and $30.34\text{--}71.48\ \mu\text{m}$ ($46.84 \pm 8.53\ \mu\text{m}$), rays both homocellular and heterocellular, all homocellular rays of square cells, heterocellular rays consisting of body ray cells of procumbent with one row of upright and/or marginal square cells, rays 4–9 (6 ± 1) per mm, disjunctive ray parenchyma cells present, ray percentage 18.91%.

Mineral inclusions – Crystal in fibre and parenchyma, black streaks present among fibres.

E. *Syzygium praecox* (Roxb.) Rathakr. & N.C.Nair (Figure 5A–5F; Figure 6Q–6T)

General features – Heartwood and sapwood not clearly demarcated, wood pale grey or greyish brown in the outermost region and gradually grading into dark brown or reddish-brown towards the centre, moderately hard to hard and moderately heavy to heavy, usually interlocked sometimes wavy grains.

Anatomical features – A diffuse-porous wood.

Growth rings – Indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, oval or circular in outline, barrel-shaped without and with very long or small tail at one or both ends, $325\text{--}975\ \mu\text{m}$ ($652.50 \pm 134.23\ \mu\text{m}$) in length, $61.81\text{--}204.67\ \mu\text{m}$ ($112.58 \pm 29.89\ \mu\text{m}$) in diameter, vessel frequency 10–22 (15 ± 3) per

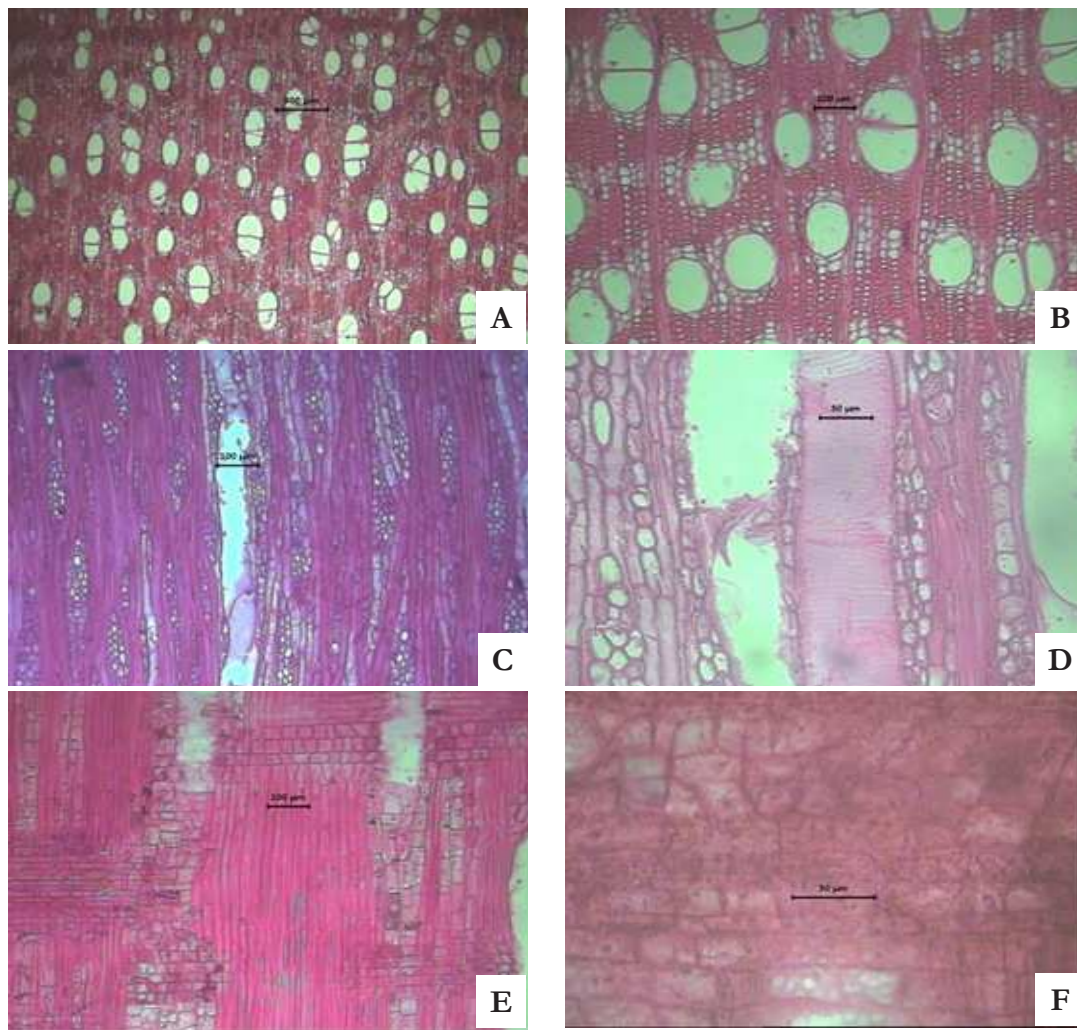


Figure 4. *Syzygium nervosum*. C. S. - Wood diffuse-porous, vessels mostly solitary and in radial multiple of 2–3, banded Parenchyma (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate; parenchyma strand 2–13 celled, crystals in fibre and parenchyma cells (C); scalariform vestured intervessel pits (D); R. L. S. - With a homocellular ray of square cells and heterocellular rays of procumbent body ray cells with 1 row of upright and/or marginal square cells, the crystal in fibre and parenchyma cells (E) and Vessel-ray pits with much-reduced border to simple pits rounded pits (F)

mm², simple perforation plate, inter-vessel pit alternate, vestured, small-medium 6.05–8.79 μm ($7.61 \pm 0.51 \mu\text{m}$) in size, vessel ray pits with much reduce borders to apparently simple: pits rounded, tyloses present, vessel percentage 16.73%.

Fibres – Thin-walled, 975–1875 μm ($1362.5 \pm 179.5 \mu\text{m}$) long, 16.07–26.59 μm ($20.76 \pm 2.07 \mu\text{m}$) and 10.53–19.39 μm ($14.39 \pm 1.95 \mu\text{m}$) in diameter and lumen diameter, 1.99–4.76 μm ($3.18 \pm 0.64 \mu\text{m}$) in wall thickness, fibre percentage 38.36%.

Parenchyma – Diffuse, diffuse-in-aggregate, vasicentric, confluent and banded, 4–16 cells per parenchyma strand, vestured pits present in the parenchyma, parenchyma percentage 26.55%.

Ray – Uniseriate, biseriate and multiseriate, mean ray height and ray width 348.60–737.42 μm ($533.75 \pm 80.13 \mu\text{m}$) and 25.03–52.36 μm ($36.46 \pm 5.45 \mu\text{m}$), rays both homocellular and heterocellular, all homocellular rays of upright and/or square cells, heterocellular rays consisting of body ray cells procumbent with

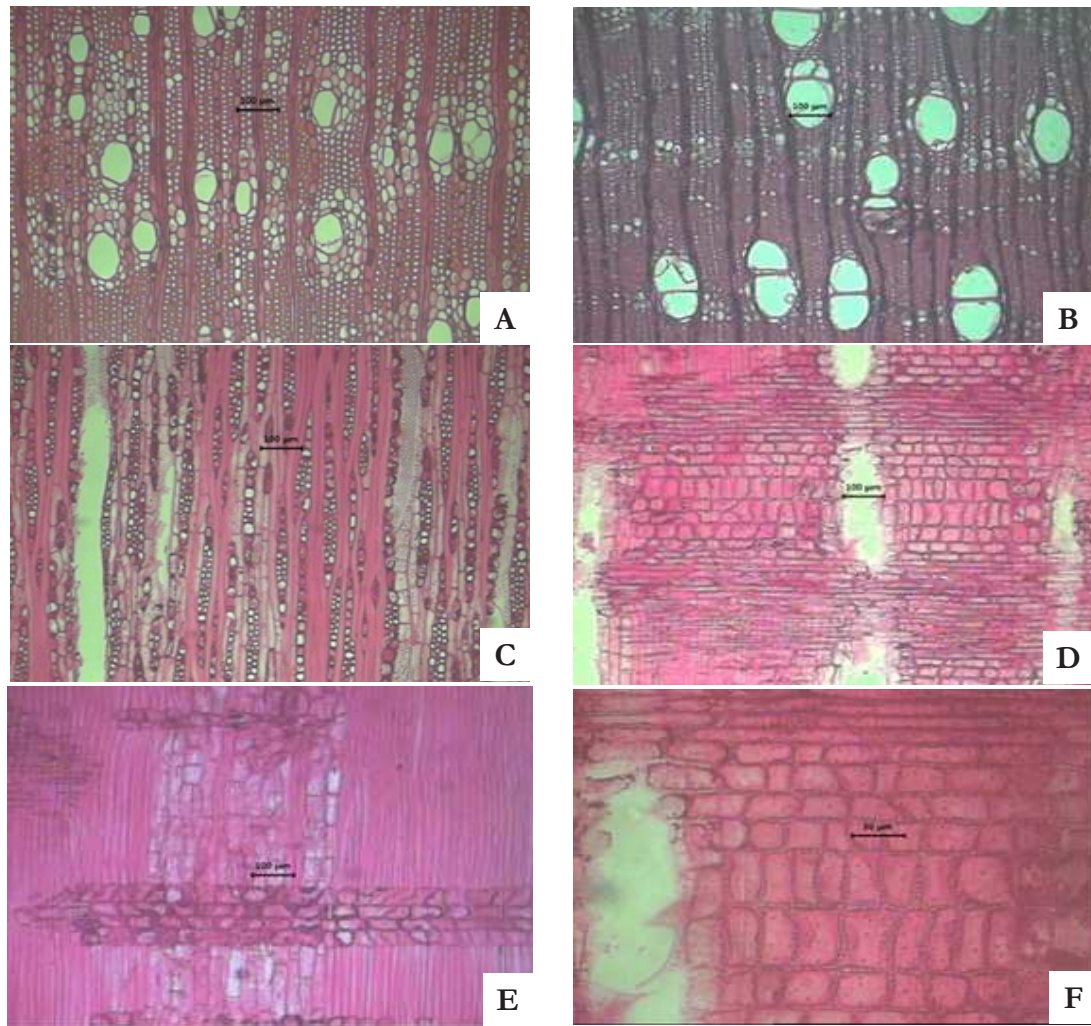


Figure 5. *Syzygium praecox*: C. S. - Wood diffuse-porous, vessels mostly solitary and in radial multiple of 2–4, diffuse, diffuse-in-aggregate and confluent type of parenchyma (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate, parenchyma strand 4–16 celled (C); R. L. S. - Heterocellular ray with procumbent square and upright cells mixed throughout the ray (D), a homocellular ray of upright and/or square cells (E); disjunctive ray parenchyma cell walls (F)

mostly 2–4 rows of upright and/or marginal square cells, rays 6–15 (9 ± 2) per mm, disjunctive ray parenchyma cells present, ray percentage 18.18%.

The results given in Table 2 show that the anatomical parameters exhibiting significant variation within species were vessel diameter in *S. cumini* and *S. jambos*, vessel length and vessel frequency in *S. nervosum*, fibre wall thickness in *S. cumini*, fibre diameter in *S. jambos*, fibre lumen diameter, ray height and width in *S. praecox*, number of cells in parenchyma strand and ray per mm in all species.

The vessel, fibre and ray characteristics exhibited significant variation among species except for several cells in parenchyma strand. Vessels were significantly longer in *S. cumini* and *S. jambos* than other species. Vessel diameter was substantially larger in *S. cumini* whereas inter-vessel pits were larger in *S. fruticosum*. Vessel frequency was significantly more in *S. jambos* than other species. Fibre length, fibre diameter and fibre lumen diameter were substantially higher in *S. cumini*, and fibre wall thickness was more in *S. jambos* than other species. Ray heights were significantly longer in *S. cumini* and

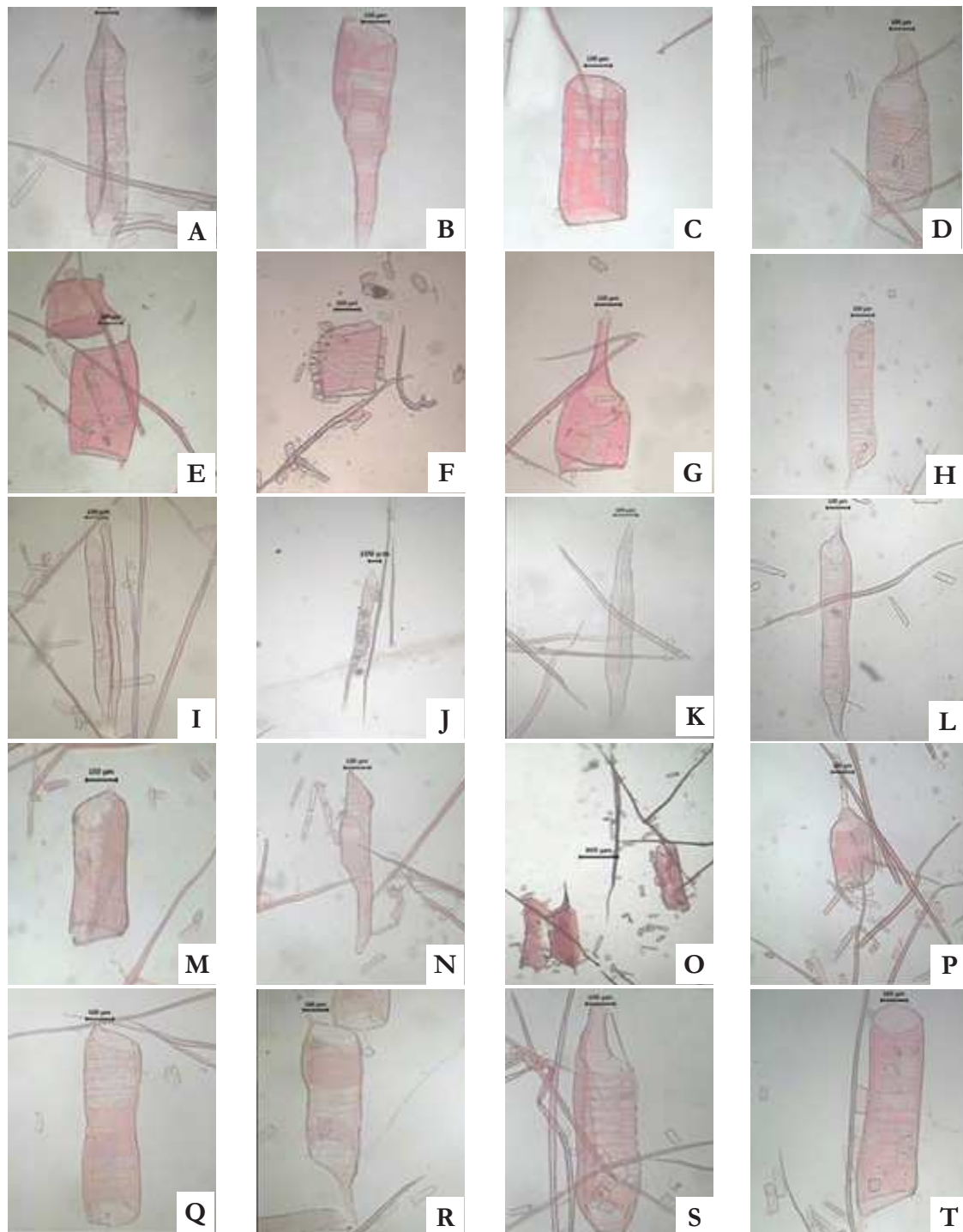


Figure 6. Vessel elements shape: *Syzygium cumini* – Tube shaped (A), barrel-shaped with and without tails (B - D); *Syzygium fruticosum* – Barrel-shaped with a small and pointed tail (E - F), spiral thickenings in the tail (G), tube-shaped (H); *Syzygium jambos* – Vasicentric tracheid with the vessel (I), tube-shaped vessels (J - L); *Syzygium nervosum* – Barrel-shaped with small, pointed and long-tail (M - O), spiral thickenings in the tail (P); *Syzygium praecox*- Barrel-shaped vessels with a small and long-tail (Q – T)

Table 2. Analysis of variance of anatomical characteristics within the selected *Syzygium* species

Parameters	<i>Syzygium cumini</i>	<i>Syzygium fruticosum</i>	<i>Syzygium jambos</i>	<i>Syzygium nervosum</i>	<i>Syzygium praecox</i>
	(F value)				
Vessel length	8.809**	13.337**	7.405**	2.216 ^{ns}	26.323**
Vessel diameter	2.003 ^{ns}	22.055**	2.268 ^{ns}	18.078**	115.225**
Vessel frequency	3.706*	15.869**	3.282*	1.220 ^{ns}	5.025**
Inter vessel pit size	28.636*	5.866**	2.259 ^{ns}	10.014**	7.774**
Fibre length	3.465*	14.768**	16.208**	2.773*	20.630*
Fibre diameter	13.921**	7.397**	1.248 ^{ns}	8.726**	4.649**
Fibre lumen diameter	15.550**	11.003**	8.098**	6.276**	1.193 ^{ns}
Fibre wall thickness	1.249 ^{ns}	5.571**	16.253**	9.777**	24.789**
Ray height	8.397**	16.364**	13.622**	3.847**	1.424 ^{ns}
Ray width	15.196**	11.799**	3.707*	36.183**	15.811**
Ray frequency	1.911 ^{ns}	2.122 ^{ns}	1.826 ^{ns}	0.785 ^{ns}	4.986**

Remarks: The levels of significance used are: ns = Not-significant, * = Significant at $P \leq 0.05$ level, ** = Highly significant at $P \leq 0.01$ level

Table 3. Anatomical characteristics variation among *Syzygium* species

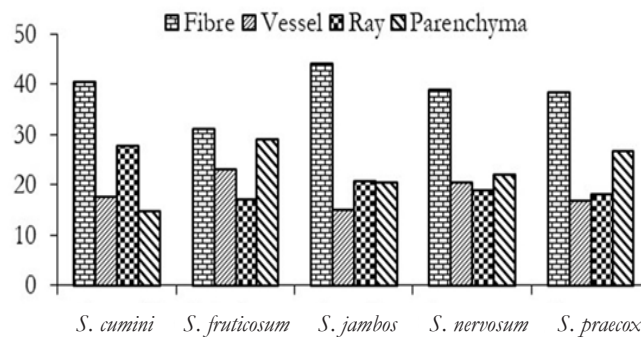
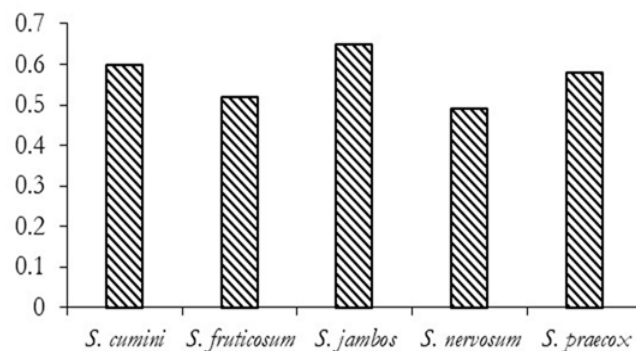
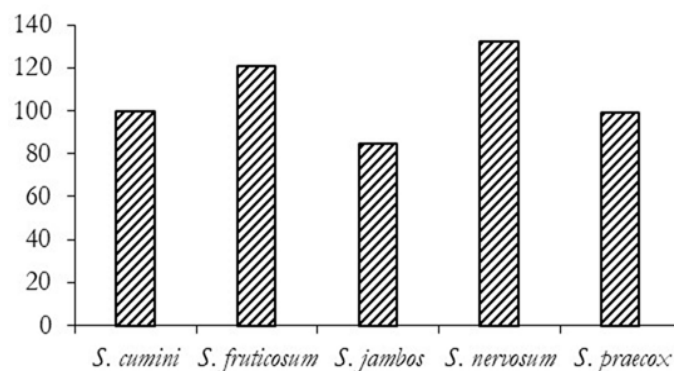
Parameters	<i>Syzygium cumini</i>	<i>Syzygium fruticosum</i>	<i>Syzygium jambos</i>	<i>Syzygium nervosum</i>	<i>Syzygium praecox</i>
	(Mean $\pm$ SD)				
Vessel length (μm)	868.83 $\pm$ 147.66 ^c	526.50 $\pm$ 124.327 ^a	892.00 $\pm$ 186.66 ^c	557.67 $\pm$ 114.29 ^a	652.50 $\pm$ 134.23 ^b
Vessel diameter (μm)	146.02 $\pm$ 17.18 ^d	113.76 $\pm$ 17.63 ^b	83.85 $\pm$ 8.62 ^a	135.15 $\pm$ 16.42 ^c	112.58 $\pm$ 29.89 ^b
Inter vessel pit size (μm)	8.20 $\pm$ 0.60 ^b	9.30 $\pm$ 0.67 ^d	7.72 $\pm$ 0.45 ^a	8.82 $\pm$ 0.65 ^c	7.61 $\pm$ 0.51 ^a
Vessel frequency (no./mm ²)	11.00 $\pm$ 3.00 ^a	13.00 $\pm$ 3.00 ^a	21.00 $\pm$ 4.00 ^c	16.00 $\pm$ 3.00 ^b	15.00 $\pm$ 3.00 ^b
Fibre length (μm)	1766.83 $\pm$ 222.13 ^d	1286.83 $\pm$ 186.96 ^a	1657.83 $\pm$ 237.30 ^c	1404.83 $\pm$ 150.88 ^b	1362.50 $\pm$ 179.50 ^{bc}
Fibre diameter (μm)	25.13 $\pm$ 3.64 ^d	23.30 $\pm$ 3.04 ^{bc}	22.20 $\pm$ 2.06 ^b	24.04 $\pm$ 3.21 ^{cd}	20.76 $\pm$ 2.07 ^a
Fibre lumen diameter (μm)	18.62 $\pm$ 3.32 ^d	16.66 $\pm$ 2.65 ^c	11.62 $\pm$ 1.82 ^a	17.91 $\pm$ 2.96 ^d	14.39 $\pm$ 1.95 ^b
Fibre wall thickness (μm)	3.26 $\pm$ 0.66 ^a	3.32 $\pm$ 0.61 ^a	5.29 $\pm$ 1.02 ^b	3.07 $\pm$ 0.47 ^a	3.18 $\pm$ 0.64 ^a
Ray height (μm)	632.08 $\pm$ 120.59 ^c	501.60 $\pm$ 158.41 ^a	574.13 $\pm$ 106.07 ^b	547.81 $\pm$ 104.36 ^{bc}	533.75 $\pm$ 80.13 ^{ab}
Ray width (μm)	49.98 $\pm$ 8.79 ^d	47.71 $\pm$ 8.28 ^{cd}	40.11 $\pm$ 4.44 ^b	46.84 $\pm$ 8.53 ^c	36.46 $\pm$ 5.45 ^a
Ray frequency	8 $\pm$ 2 ^b	7 $\pm$ 2 ^{ab}	10 $\pm$ 2 ^c	6 $\pm$ 1 ^a	9 $\pm$ 2 ^c

Remarks: Values with the same letter in the same row are not significantly different at the 0.05 probability level

S. nervosum. On the other hand, *S. cumini* and *S. fruticosum* had wider rays as compared to other species. The number of rays per mm was higher in *S. jambos* than other species (Table 3).

The maximum fibre percentage was in *S.*

jambos (44%) and the minimum in *S. fruticosum* (30.91%). Likewise, highest vessel percentage, ray percentage and parenchyma percentage were observed in *S. fruticosum* (22.91%), *S. cumini* (27.64%) and *S. fruticosum* (29.09%) respectively

Figure 7. Tissue percentage of the selected *Syzygium* speciesFigure 8. Wood density of selected *Syzygium* speciesFigure 9. The moisture content of selected *Syzygium* species

(Figure 7). The results presented in Figure 10 revealed that *S. cumini* was closely related to *S. praecox*. There was a more close relationship between *S. fruticosum* and *S. nervosum*. Though *S. jambos* was also in the same axis, but it forms a separate group.

The result given in Figures 8 showed maximum wood density in *S. jambos* and minimum in *S. nervosum*. On the contrary to it, the maximum wood moisture content was in

S. nervosum and minimum in *S. jambos* (Figure 9).

The wood structure in *Syzygium* species is uniform as reported in other genera of family Myrtaceae (Dias-Leme et al., 1995). All the selected species were diffuse-porous with indistinct rings except both diffuse-porous and semi-ring porous in *S. cumini* and *S. fruticosum*. The vessels were mostly barrel-shaped with small or long tails at one or both ends in all species except tube-shaped in *S. jambos* and

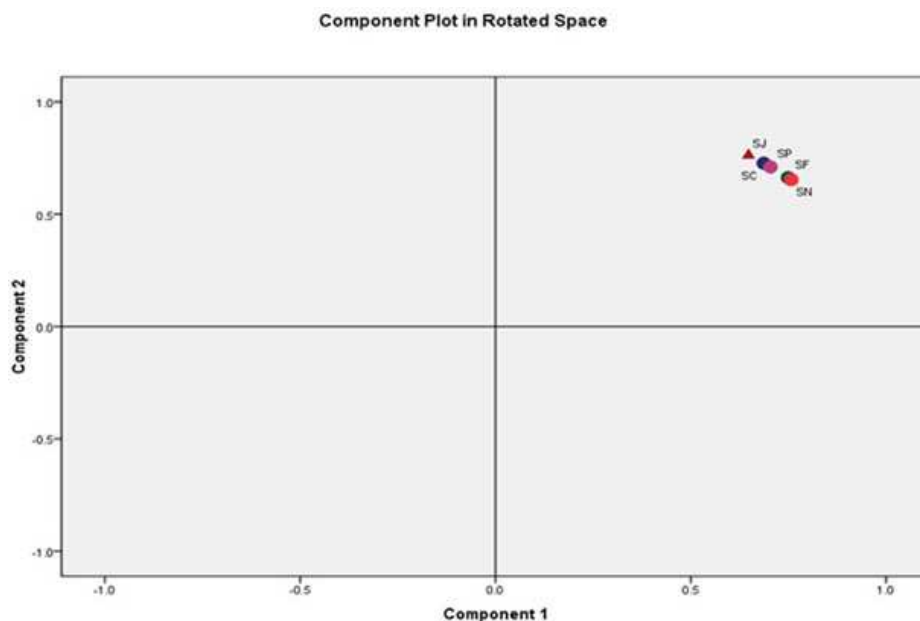


Figure 10. Scattered plot for principal component analysis of selected *Syzygium* species

drum-shaped in *S. fruticosum*. Spiral thickenings were present in the tails of *S. nervosum* and *S. fruticosum*. Presence of spiral thickenings in vessel elements and simple perforation plate, small to medium-sized vestured pits and tyloses were common features in all selected species. Similar observations are reported in other genera of family Myrtaceae by Metcalfe and Chalk (1950); Schmid and Baas (1984) and Patel (1995). In *S. nervosum*, scalariform inter-vessel pits were seen in some parts of vessels which may be due to fusion of adjacent pits.

Fibres were thin-walled and non-septate in all species. Occasional septate fibres and vasicentric tracheids were observed in *S. nervosum* and *S. jambos*. Vasicentric tracheids play an essential role in xylem conduction efficiency and decrease the chances of embolism in vessels (Barotto et al., 2016). The presence of septate fibres in *S. jambos* and *S. nervosum* may be due to presence of less percentage of parenchyma in these species as septate fibres are liable for transportation and also storage of photo-assimilates in plants with less parenchyma (Evert, 2006).

The axial parenchyma was diffuse, diffuse in aggregate, vasicentric, aliform and confluent

types. Hence, there was no variation in types of axial parenchyma. Vestured bordered pits were seen in *S. cumini*, *S. fruticosum*, *S. nervosum* and *S. praecox*. In the present study, disjunctive ray parenchyma cells were present in all species and corroborated the findings of Patel (1995).

Mineral inclusions are also important features for identification of wood. In the present study, prismatic shaped crystals were found in fibres and axial parenchyma of *S. nervosum* and even in ray and axial parenchyma of *S. fruticosum*. Silica bodies were observed in axial parenchyma of *S. jambos* in radial section. The present investigation is in agreement with the findings of van Vilet and Bass (1984) who reported crystals in genus *Lophomyrtus*.

Most of the anatomical characteristics existed significant variation within species which may be due to the collection of samples from unknown age of selected trees. On the contrary to it, Pande et al. (2005, 2007) reported non-significant variation in wood elements within species. The highly significant difference in anatomical parameters among species confirms the findings of other workers (Sharma et al., 2011a, 2011b; Singh et al., 2013) who reported the similar results in other hardwood

species. Thus, the present study indicates that *Syzygium* species can be differentiated based on quantitative anatomical characteristics.

The present investigation reveals a close relationship among selected species. Though *S. jambos* was also in the same axis, but it forms a separate cluster. There was a close relationship between *S. fruticosum* - *S. nervosum* and *S. cumini* - *S. praecox*. The present study is in agreement with the findings of Biffin et al. (2006) who reported *S. cumini*, *S. jambos* and *S. nervosum* in the same group by using cpDNA sequence from matK and ndhF genes and rpl16 intron.

The wood density and moisture content of *Syzygium* species showed maximum density and minimum moisture content in *S. jambos* as compared to other species. Higher fibre percentage with thick-walled fibres in *S. jambos* may be the probable reason for its highest density and lowest moisture content.

The identification key for investigated species is given below:

1. Homocellular and heterocellular rays, vessels barrel to tube-shaped without spiral thickenings in tail 2
 - 1a. Homocellular and heterocellular rays, vessels barrel to tube-shaped without spiral thickenings in tail 3
2. Vessel diameter more than 100 µm, vasicentric tracheids and silica bodies absent 4
 - 2a. Vessel diameter was less than 100 µm, vasicentric tracheids and silica bodies present *S. jambos*.
3. Uniseriate, biseriate and multiseriate rays, diffuse, diffuse-in-aggregate and confluent parenchyma, vessel-ray pits horizontal to vertical *S. cumini*.
 - 3a. Uniseriate, biseriate and multiseriate rays, diffuse, diffuse-in-aggregate and confluent parenchyma, vessel-ray pits simple and rounded *S. praecox*.
4. Multiseriate rays present, aliform, confluent parenchyma and crystals present in rays *S. fruticosum*.

- 4a. Multiseriate rays present, vasicentric parenchyma and crystals present in fibres *S. nervosum*.

IV. CONCLUSION

The detailed anatomical characteristics of five *Syzygium* species of Manipur, India revealed that both qualitative features and quantitative anatomical characteristics could be used for identification. Diffuse porous and indistinct growth rings were present in all selected species except *Syzygium cumini* and *Syzygium fruticosum* (semi-ring porous and distinct). Vasicentric tracheids were present in *Syzygium jambos*, and septate fibres were observed in *Syzygium nervosum* and *Syzygium fruticosum*. Silica bodies were present in axial parenchyma of *Syzygium jambos* whereas crystals were observed in the ray of *Syzygium nervosum* and *Syzygium fruticosum*. *Syzygium jambos* had maximum fibre percentage, wood density and minimum moisture content. All the selected species showed significant variations in their quantitative anatomical and physical characteristics. Identification key was prepared for investigated species.

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