



# Anatomical and physical characteristics of some *Ficus* species of Meghalaya, NE India

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**Abstract** The study was conducted on seven *Ficus* species namely *F. drupacea* Thunb., *F. elmeri* Merr., *F. hispida* L.f., *F. microcarpa* L.f., *F. nervosa* B. Heyne ex Roth, *F. rumphii* Blume and *F. virens* Aiton collected from West Garo Hill district, Meghalaya with the aim to examine the detailed anatomical and physical characteristics of these species. The study revealed homogeneous structure among *Ficus* species. Diffuse porous wood with indistinct growth rings, vessels solitary, in radial multiple of 2–3, simple perforation plates, intervessel pits alternate, banded parenchyma, multiseriate, homocellular and heterocellular rays were common anatomical characteristics among species. However, some distinct features like vessel ray pits with much reduced border to apparently simple with vertical pits in *F. hispida*, scalariform pits in *F. virens*, thin to thick walled fibres in *F. virens*, *F. nervosa*, sheath cells in *F. elmeri* and *F. hispida* and horizontal laticifers in *F. virens* were observed. The fibre percentage was maximum in *F. elmeri* and parenchyma percentage was maximum in *F. rumphii*. Wood density was maximum in *F. elmeri* and moisture content was minimum in *F. rumphii*. There was significant variation in quantitative characteristics within and among species. Therefore, both qualitative and quantitative anatomical and physical characteristics can be used for reliable identification of *Ficus* species.

**Keywords** Anatomical characteristics · Diffuse porous · *Ficus* species · Laticifers · Physical characteristics · Tissue percentage

## Introduction

The family Moraceae is widely distributed in tropical and sub-tropical regions of the world and few species also occur in temperate zone (Raturi et al. 2001). It comprises of trees, shrubs, hemiepiphytes, climbers and herbs. The presence of milky latex in parenchymatous tissue, unisexual flowers, anatropous ovules, aggregated drupes or achene type of fruits are the diagnostic features of this family (Datwyler and Wieblen 2004). The members of this family are source of many timber species, edible fruits, rubber and dye etc. *Chlorophora excelsa*, *Brosimum oarensis*, *Piratinera guianensis* are some of durable timbers in the world. The species of *Artocarpus* and *Morus* are used for general carpentry works in India. The commercial rubber is obtained from *Ficus elastica*. The leaves of *Morus alba* are used for rearing silkworms (Raturi et al. 2001). The living bridges from the aerial roots of *Ficus elastica* in Khasi and Jaintia Hills of Meghalaya to cross the rivers represent an example of unique botanical architecture (Ludwig et al. 2019).

The family is divided into five tribes namely Artocarpeae, Dorstenieae, Castilleae, Ficeae and Moreae (Berg 1977, 2001). The tribe Ficeae is represented by a single genus *Ficus* L. It is the largest genus with 1000 species. Syconium inflorescence and obligate pollination mutualism with fig wasps are the diagnostic features of the genus *Ficus* (Datwyler and Wieblen 2004; Clement and Weiblen 2009). It is the most diversified genus with evergreen, semi-evergreen and deciduous in habit and represented by

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trees, shrubs, hemi epiphytes, climbers, creepers, rheophytes and lithophytes with wide distribution in tropical and sub-tropical regions of the world (Berg and Corner 2005; Chaudhary et al. 2012). *Ficus* species produce nutrient rich fruits throughout the year to attract most of frugivores and play a significant role in restoration of tropical ecosystem (Harrison 2006; Cotton-Jones et al. 2016). There are about 115 *Ficus* species in India. Among all states, Meghalaya is endowed with 43 *Ficus* species, and therefore, it is considered as a hot spot region for this genus (Chaudhary et al. 2012).

Wood anatomical characteristics are important to solve taxonomical problems for separation of species. They also help to study the relationship between tree growth and environmental factors. The available literature shows that few investigations have made on wood anatomy of *Ficus* species. Noorman et al. (1984) characterised *Ficus* species by abundant axial parenchyma in regular apotracheal bands and relatively wide vessels. Adeniyi et al. (2013) reported crystals, silica inclusions, size of rays, vessels and fibres as important features to distinguish seven *Ficus* species of Nigeria. A little information is available on wood anatomy of *Ficus* species in India (Gamble 1922; Purkayastha 1996). Raturi et al. (2001) studied the gross features of *Ficus* species under hand lens and separated in two groups on the presence or absence of ripple marks. Sharma et al. (2014) investigated 12 *Ficus* species collected from Mizoram. There is no information on anatomical investigations of *Ficus* species of Meghalaya despite of being a hot spot region for this genus. Therefore, the present study is an attempt to provide comprehensive account of anatomical and physical characteristics of seven *Ficus* species.

## Materials and methods

Seven *Ficus* species, namely *F. drupacea* Thunb., *F. elmeri* Merr., *F. hispida* L.f., *F. microcarpa* L.f., *F. nervosa* B. Heyne ex Roth, *F. rumphii* Blume and *F. virens* Aiton were selected from Tura and Rongram of West Garo Hills District, Meghalaya. The geographical coordinates of the sites were taken with the help of a GPS. The height and diameter of the selected trees were measured with Ravi altimeter and measuring tape (Table 1).

Five healthy trees with straight boles, uniform crown and with no visible defects were selected randomly for each species. Wood blocks of 5 cm × 5 cm × 5 cm size were extracted with the help of a hammer and a chisel at breast height. The wood samples were numbered, packed in polythene bags and brought to the laboratory for further investigations. For anatomical investigations, wood samples were cut into small blocks of 2 cm<sup>3</sup> size, fixed in FAA

for 24–48 h. and were transferred to 50% alcohol for further preservation.

The preserved blocks were sectioned 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 protocols were followed to prepare the permanent slides.

Thin splinters were taken from the radial side of selected wood species and were macerated with Franklin's solution at 60 °C for 24 h till they turn to soft and white in colour. Temporary slides were prepared with 50% glycerol for the measurement of all anatomical parameters and their dimensions were measured with the help of Scope image 9 software. Quantitative data of fibre, vessel and ray dimensions were based on random 30 measures for each replicate of selected species. While, for vessel frequency, rays per mm. and tissue proportion, 10 fields for each replicate were randomly selected. The percentage of fibre, vessel, ray and parenchyma were determined in the field of 1 mm<sup>2</sup> from cross-section. IAWA list of microscopic features for hardwoods identification (Wheeler et al. 1989) was followed for the anatomical descriptions of species. The photomicrographs were taken with the help of image analysis system at different magnifications to study detailed anatomical features of each species.

Water displacement method (Smith 1955) was used to determine the wood density. Moisture content was determined by oven drying method (IS 11215: 1991).

The data were analysed statistically by using SPSS 16 software. One way ANOVA was carried out to see the variation in anatomical characteristics within species. Tukey's test was performed to compare the means of selected anatomical characteristics among species.

## Results

The qualitative anatomical features and tissue percentage of *Ficus* species were presented in Table 2 and Figs. 1, 2 and 3.

### 1. *Ficus drupacea* Thunb. (Fig. 1: a–d)

**Vernacular name:** Prap (Garo).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–3, oval in outline, barrel shaped with or without tails, 290.59–495.71 µm (Mean 393.65 ± 17 µm) in length, 81.82–250.83 µm (Mean 178.97 ± 30.46 µm) in diameter, vessel frequency 2–7 (Mean 3.82 ± 1.13) per mm<sup>2</sup>, simple perforation plates, intervessel pits alternate, 13–18.2 µm (Mean 15.34 ± 2.05 µm) in size, vessel-ray pits with much reduced border to apparently simple, pits rounded, tyloses present, vessel percentage 24.

**Table 1** Geographical co-ordinates, location and dimensions of selected *Ficus* species

Species	Latitude and longitude	Height (m)	Diameter (cm)	Locality
<i>F. drupacea</i>	25°31' 01.2" N–25°30' 57.6" N 90°13' 12.0" E–90°12' 57.6" E	28–32	620–870	Ringre, Tura,
<i>F. elmeri</i>	25°30' 21.0" N 90°13' 25.7" E	16–23	120–170	Akonggre, Tura
<i>F. hispida</i>	25°29' 54.5" N 90°10' 03.2" E	5–9	50–65	Danakgre, Tura
<i>F. microcarpa</i>	25°35' 52.8" N 90°15' 00.0" E	15–17	90–120	Rongchigre, Rongram
<i>F. nervosa</i>	25°35' 27.3" N 90°15' 39.7" E	9–12	120–200	Rongchigre, Rongram
<i>F. rumphii</i>	25°32' 45.6" N–25°35' 31.2" N 90°13' 19.2" E–90°14' 56.4" E	17–22	140–280	Megonggre, Tura
<i>F. virens</i>	25°35' 32.8" N 90°15' 53.2" E	23–27	280–350	Rongchigre, Rongram

**Fibres**—Thin walled, 1230.72–1931.55 µm (Mean 1544.72 ± 74.15 µm) long, 19.98–37.15 µm (Mean 25.30 ± 3.82 µm) and 13.17–30.08 µm (Mean 18.47 ± 3.90 µm) in diameter and lumen diameter, wall thickness 4.14–10.06 µm (Mean 6.84 ± 1.37 µm), fibres percentage 23.27.

**Parenchyma**—Fusiform, vasicentric, banded (both apotracheal and paratracheal bands), more than 3 cells wide, bands 4–12 cells wide (Mean 6.40 ± 2.50), 4–6 cells per parenchyma strand, parenchyma percentage 27.64.

**Rays**—Mostly multiseriate, uniseriate and biseriate rays also present, mean ray height and ray width 404.56–897.67 µm (Mean 564.30 ± 247.60 µm) and 4.14–88.81 µm (Mean 44.32 ± 24.88 µm), rays both homocellular and heterocellular, all homocellular rays of either procumbent cells or upright and/or square cells, heterocellular rays with procumbent, square and/or upright cells mixed throughout the ray. Rays 4–9 (Mean 5.52 ± 1.19) per mm, rays percentage 25.09.

**Mineral inclusions**—Prismatic crystals present in axial parenchyma and square cells.

**Laticifers**—Occasionally present among fibres.

2. *Ficus elmeri* Merr. (Fig. 1: e–h)

**Vernacular name:** Aminsep (Garó).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–3, oval in outline, barrel and drum shaped, 273.49–589.72 µm (Mean 400.77 ± 22.01) in length, 127.74–239.64 µm (Mean 181.83 ± 23.74 µm) in diameter, vessel frequency 3–12 (Mean 5.94 ± 1.77) per mm<sup>2</sup>, simple perforation plates, intervessel pits alternate, 10.4–15.6 µm (Mean 12.09 ± 2.56 µm) in size, vessel- ray pits with much reduced border to apparently simple, pits rounded, tyloses present, vessel percentage 25.09.

**Fibres**—Thin walled, 1239.27–2076.84 µm (Mean 1645.57 ± 57.82 µm) long, 13.84–25.58 µm (Mean 19.14 ± 2.33 µm) and 5.93–19.78 µm (Mean 11.56 ± 2.34 µm) in diameter and lumen diameter, wall thickness

4.97–10.23 µm (Mean 7.58 ± 1.25 µm), septate fibres and gelatinous fibres present, fibre percentage 29.45.

**Parenchyma**—Banded (paratracheal bands), more than 3 cells wide, bands 9–24 cells wide (Mean 13.00 ± 4.90), 4–6 cells per parenchyma strand, parenchyma percentage 24.55.

**Rays**—Multiseriate, mean ray height and ray width 512.10–468.90 µm (Mean 536.16 ± 101.82 µm) and 10.42–52.10 µm (Mean 105.56 ± 11.58 µm), both homocellular and heterocellular rays, all homocellular rays of procumbent cells, either square and/or upright cells, heterocellular rays of procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins. Rays 2–6 (Mean 3.76 ± 0.77) per mm, rays percentage 22.91.

**Mineral inclusions**—Prismatic crystals present in axial parenchyma and square ray cells.

3. *Ficus hispida* L. f. (Fig. 1: i–l)

**Vernacular name:** Pantap (Garó).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–3, oval in outline, barrel to oblong shaped with tail like extensions at one or both ends, 299.13–504.25 µm (Mean 413.65 ± 11.60 µm) in length, 106.11–233.38 µm (Mean 139.93 ± 24.57 µm) in diameter, vessel frequency 3–15 (Mean 7.74 ± 2.85) per mm<sup>2</sup>, simple perforation plates, intervessel pits alternate, 13–18.2 µm (Mean 13.91 ± 2.70 µm) in size, vessel—ray pits with much reduced border to apparently simple, pits vertical (palisade) present in outer 3–4 rows, vessel percentage 21.63.

**Fibres**—Thin walled, 1162.35–1871.72 µm (Mean 1431.22 ± 43.97 µm) long, 13.32–30.01 µm (Mean 21.11 ± 4.31 µm) and 9.03–25.05 µm (Mean 15.86 ± 4.12 µm) in diameter and lumen diameter, wall thickness 2.41–9.83 µm (Mean 5.24 ± 1.62 µm), fibre percentage 26.36.

**Parenchyma**—Banded (both apotracheal and paratracheal diagonal bands), more than 3 cells wide, bands 6–16 cells wide (Mean 9.30 ± 3.09), 3–6 cells per parenchyma strand, parenchyma percentage 26.91.

**Table 2** Qualitative features of selected *Ficus* species

Sl. No	Features	<i>F. drupacea</i>	<i>F. elmeri</i>	<i>F. hispida</i>	<i>F. microcarpa</i>	<i>F. nervosa</i>	<i>F. rumphii</i>	<i>F. virens</i>
1	Growth rings	Indistinct	Indistinct	Indistinct	Indistinct and Distinct	Indistinct	Indistinct	Indistinct
2	Porosity	Diffuse-porous	Diffuse-porous	Diffuse-porous	Diffuse-porous	Diffuse-porous	Diffuse-porous	Diffuse-porous
3	Vessel grouping	Solitary, radial multiples of 2–3	Solitary, radial multiples of 2–3	Solitary, radial multiples of 2–3	Solitary, radial multiples of 2	Solitary, radial multiples of 2–4	Solitary, radial multiples of 2–3	Solitary, radial multiples of 2–4
4	Vessel shape	Barrel shape with or without tails	Barrel and drum shape	Barrel to oblong shaped with tail like extensions at one or both ends	Barrel and drum shaped	Barrel to oblong shape	Barrel shape	Barrel and drum shaped
5	Solitary vessel outline	Oval	Oval	Oval	Oval	Oval	Oval	Oval
6	Perforation plate	Simple	Simple	Simple	Simple	Simple	Simple	Simple
7	Intervessel pits arrangements	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate	Alternate
8	Vessel-ray pitting	Much reduced to apparently simple, pits rounded	Much reduced to apparently simple, pits rounded	Much reduced to apparently simple, pits vertical (palisade)	Much reduced to apparently simple, pits rounded	Much reduced to apparently simple, pits vertical (palisade)	Much reduced to apparently simple, pits vertical (palisade)	Much reduced to apparently simple, pits scalariform (gash like)
9	Septate fibres	Absent	Present	Absent	Present	Absent	Present	Present
10	Fibres	Thin walled	Thin walled	Thin walled	Thin walled	Thin to thick walled	Thin walled	Thin to thick walled
11	Axial parenchyma	Fusiform, vasicentric, banded (both paratracheal and apotracheal bands)	Banded (paratracheal bands)	Banded (both apotracheal and paratracheal diagonal bands)	Banded (both apotracheal and paratracheal wavy bands)	Banded (Both apotracheal and paratracheal bands)	Banded (paratracheal bands),	Banded (both apotracheal and paratracheal bands)
12	Ray width	Uniseriate, biseriate and multiseriate	Multiseriate	Multiseriate	Uniseriate, biseriate and multiseriate	Mostly multiseriate, rarely uniseriate	Uniseriate, biseriate and multiseriate	Mostly multiseriate, rarely biseriate
13	Ray composition	Homocellular rays—All ray cells procumbent, upright and/or square	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins procumbent, square and / or upright cells mixed throughout the ray	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins	Homocellular rays—All ray cells procumbent, upright and/or square Heterocellular rays—procumbent body ray cells with 1–2 rows of upright and/or square ray cells on the margins

Table 2 continued

Sl. No	Features	<i>F. drupacea</i>	<i>F. elmeri</i>	<i>F. hispida</i>	<i>F. microcarpa</i>	<i>F. nervosa</i>	<i>F. rumphii</i>	<i>F. virens</i>
14	Sheath cells	Absent	Absent	Present	Absent	Absent	Absent	Absent
	Laticifers	Present among fibres	Absent	Present among fibres	Present among fibres	Absent	Present among fibres	Present in rays
15	Prismatic crystals	Present in axial parenchyma and square cells	Present in axial parenchyma and square cells	Absent	Present in axial parenchyma, fibres, square and procumbent cells	Present in axial parenchyma	Present in axial parenchyma square and/or upright ray cells	Present in square cells

**Rays**—Multiseriate, mean ray height and ray width 361.55–887.40 µm (Mean 579.55 ± 131.10 µm) and 38.50–93.07 µm (Mean 62.78 ± 12.72 µm), rays both homocellular and heterocellular, homocellular rays of either procumbent cells or square cells, heterocellular ray either procumbent body ray cells with marginal 1–2 rows of upright and/or square cells or mixed throughout the ray, body ray cells procumbent. Rays 3–6 (Mean 4.4 ± 0.83) per mm, sheath cells present, ray percentage 25.09.

**Laticifers**—Occasionally present among fibres.

4. *Ficus microcarpa* L. f (Fig. 2: a–c)

**Vernacular name:** Prapsi, tapsi (Garo).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Both indistinct and distinct and marked by radially flattened thick walled fibres.

**Vessels**—Mostly solitary, in radial multiples of 2, oval in outline, barrel and drum shaped, 341.87–495.71 µm (Mean 417.932 ± 7.79 µm) in length, 152.18–289.44 µm (Mean 211.30 ± 28.51 µm) in diameter, vessel frequency 4–10 (Mean 6.68 ± 1.73) per mm<sup>2</sup>, simple perforation plate, intervessel pits alternate in size, 13–20.8 µm (Mean 15.73 ± 2.98 µm) polygonal in outline, vessel -ray pits with much reduced border to apparently simple, pits rounded or tyloses present, vessel percentage 27.64.

**Fibres**—Thin walled, 1282–2128.12 µm (Mean 1661.98 ± 56.31 µm) long, 11–31.52 µm (Mean 20.34 ± 5.04 µm) and 7.81–24.28 µm (Mean 15.20 ± 4.04 µm) in diameter and lumen diameter, 2.62–7.55 µm (Mean 5.14 ± 1.34 µm) in wall thickness, septate fibres and gelatinous fibres present, fibre percentage 26.

**Parenchyma**—Banded (both apotracheal and paratracheal wavy bands) more than 3 cells wide, bands 4–8 cells wide (Mean 5.70 ± 1.57), 4–7 cells per parenchyma strand, parenchyma percentage 24.91.

**Rays**—Uniseriate, biseriate and multiseriate, mean ray height and ray width 310.72–537.79 µm (Mean 421.45 ± 57.33 µm) and 30.25–56.06 µm (Mean 42.49 ± 6.49 µm), rays both homocellular and heterocellular, body ray cells procumbent in homocellular rays and in heterocellular rays procumbent body ray cells with marginal rows of upright and/or square cells. Rays 4–8 (Mean 5.8 ± 1.19) per mm, rays percentage 21.45.

**Mineral inclusions**—Prismatic crystals present in axial parenchyma, fibres, square and procumbent ray cells.

**Laticifers**—Present among fibres.

5. *Ficus nervosa* B. Heyne ex Roth (Fig. 2: d–h)

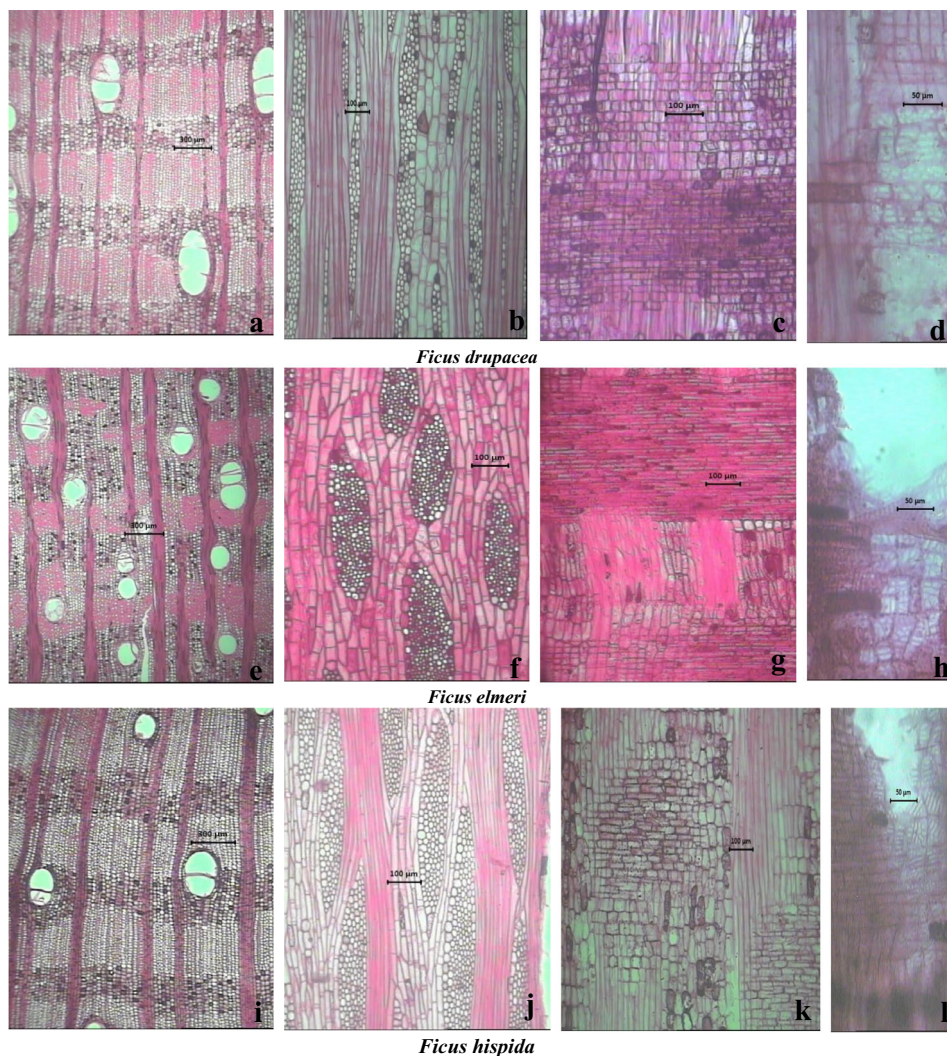
**Vernacular name:** Bolchap (Garo).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–4, oval in outline, barrel to oblong shaped, 341.87–512.80 µm (Mean 422.37 ± 8.55 µm) in length, 114.09–259.32 µm

**Fig.1** *Ficus spp.* Cross-section showing wood diffuse-porous, vessels mostly solitary and in radial multiples of 2–3, parenchyma banded and bands more than 3 cells wide, fibres thin walled (a,e,i). Tangential longitudinal section showing rays multiseriate, parenchyma strands 4–6 celled (c,j,k); fusiform parenchyma (c); crystals in parenchyma (f) and sheath cells in rays (j). Radial longitudinal section showing heterocellular rays made up of procumbent body ray cells with marginal over 4 rows of upright and/or squares cells (c–k) and with marginal over 1–2 rows of upright and/or squares cells (g); crystals present in rays (e); vessel ray pits with much reduced border to apparently simple, pits rounded (d–h) and vertical (palisade) (l)



(Mean  $179.75 \pm 31.45 \mu\text{m}$ ) in diameter, vessel frequency 2–14 (Mean  $5.68 \pm 2.77$ ) per  $\text{mm}^2$ , simple perforation plates, intervessel pits alternate,  $10.4\text{--}18.2 \mu\text{m}$  (Mean  $14.3 \pm 2.98 \mu\text{m}$ ) in size, vessel-ray pits with much reduced border to apparently simple, pits rounded, vessels percentage 20.90.

**Fibres**—Thin to thick walled,  $1247.81\text{--}2017.01 \mu\text{m}$  (Mean  $1621.47 \pm 29.35 \mu\text{m}$ ) long,  $27.05\text{--}43.80 \mu\text{m}$  (Mean  $34.76 \pm 4.42 \mu\text{m}$ ) and  $19.59\text{--}37.71 \mu\text{m}$  (Mean  $27.65 \pm 4.37 \mu\text{m}$ ) in diameter and lumen diameter, wall thickness  $4.69\text{--}9.41 \mu\text{m}$  (Mean  $7.11 \pm 0.92 \mu\text{m}$ ), fibre percentage 29.09.

**Parenchyma**—Banded (Both apotracheal and paratracheal bands), more than 3 cells wide, bands 6–12 cells wide (Mean  $8.70 \pm 2.31$ ), 4–9 cells per parenchyma strand, parenchyma percentage 27.09.

**Rays**—Mostly multiseriate, rarely uniseriate, mean ray height and ray width  $517.28\text{--}954.61 \mu\text{m}$  (Mean  $684.32 \pm 115.46 \mu\text{m}$ ) and  $50.13\text{--}102.57 \mu\text{m}$

(Mean  $73.01 \pm 11.9 \mu\text{m}$ ), multiseriate rays with long tail, rays both homocellular and heterocellular, body ray cells of upright and/or square cells in homocellular ray, body ray cells of procumbent with marginal 1–2 rows of upright and/or square cells in heterocellular rays. Rays 3–7 (Mean  $4.78 \pm 1.03$ ) per mm, rays percentage 22.91.

**Mineral inclusions**—Prismatic crystals present in axial parenchyma.

6. *Ficus rumphii* Blume: (Fig. 3: i–l)

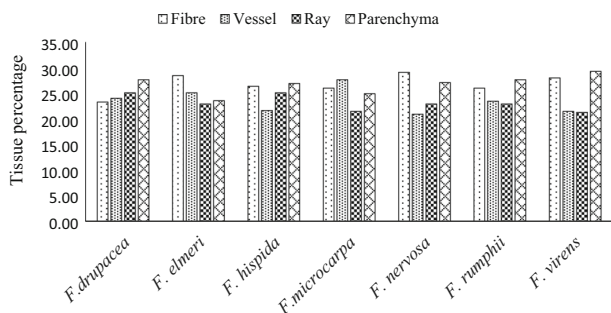
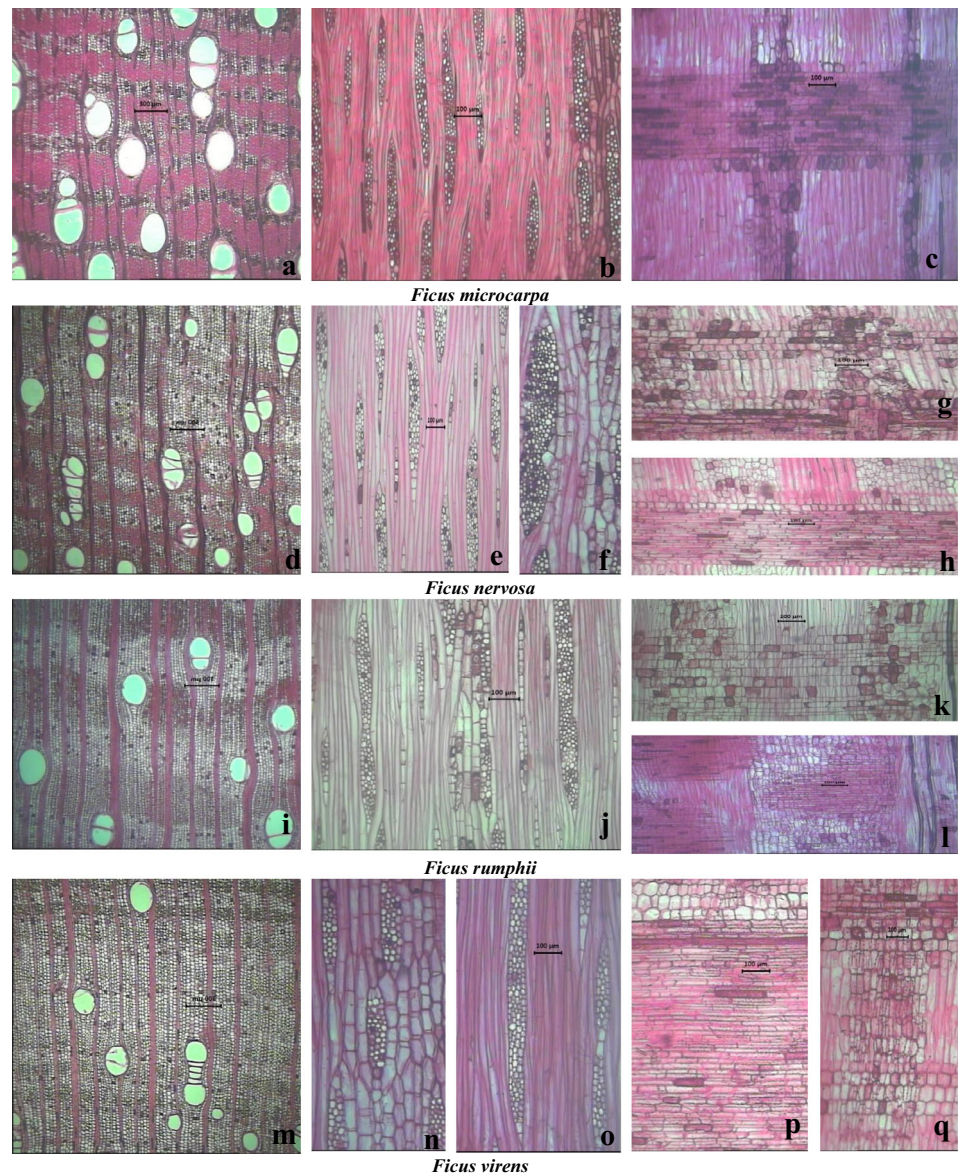
**Vernacular name:** Prap rakseng (Garo).

**Anatomical features**—A diffuse-porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–3, oval in outline, barrel shaped,  $282.04\text{--}529.89 \mu\text{m}$  (Mean  $376.73 \pm 12 \mu\text{m}$ ) in length,  $112.95\text{--}231.51 \mu\text{m}$  (Mean  $159.55 \pm 22.35 \mu\text{m}$ ) in diameter, vessel frequency 3–10 (Mean  $5.54 \pm 1.66$ ) per  $\text{mm}^2$ , simple perforation plates, intervessel pits alternate in size,  $13\text{--}18.2 \mu\text{m}$  (Mean  $15.34 \pm 1.86 \mu\text{m}$ ) vessel—ray pits with much reduced

**Fig. 2** *Ficus spp.* Cross-section showing wood diffuse-porous, vessels mostly solitary and in radial multiples of 2–3, parenchyma banded and bands more than 3 cells wide (a,d,i,m) fibres thin to walled (a,d,m); fibres thin walled (i). Tangential longitudinal section showing rays mostly multiseriate and parenchyma strands, (b, e, f, j, n and o); rays with long tail and septate fibres present (e). Radial longitudinal section showing homocellular rays of procumbent cells(p); heterocellular rays made up of procumbent body ray cells with marginal 1–2 rows of upright and/or squares cells (c, g,h,k,l,and q); axial laticifers among fibres (l) and horizontal laticifers in rays (p) present



**Fig. 3** Tissue percentage of selected *Ficus* species

border to apparently simple, pits vertical (palisade), vessel percentage 22.45.

**Fibres**—Thin walled, 307.68–1820.44  $\mu\text{m}$  (Mean 1492.07  $\pm$  22.14  $\mu\text{m}$ ) long, 14.01–25.95  $\mu\text{m}$  (Mean

20.08  $\pm$  2.58  $\mu\text{m}$ ) and 9.51–18.58  $\mu\text{m}$  (Mean 13.54  $\pm$  2.14  $\mu\text{m}$ ) in diameter and lumen diameter, wall thickness 3.63–8.73  $\mu\text{m}$  (Mean 6.54  $\pm$  1.08  $\mu\text{m}$ ), septate fibres present, fibre percentage 23.50.

**Parenchyma**—Banded (paratracheal bands), more than 3 cells wide, bands 8–32 cells wide (Mean 16.80  $\pm$  4.32), 5–8 cells per parenchyma strand, parenchyma percentage 30.27.

**Rays**—Uniseriate, biseriate and multiseriate, mean ray height and ray width 331.22–331.22  $\mu\text{m}$  (Mean 562.83  $\pm$  118.55  $\mu\text{m}$ ) and 17.46–26.71  $\mu\text{m}$  (Mean 55.73  $\pm$  17.46  $\mu\text{m}$ ), both homocellular and heterocellular rays, homocellular rays of either procumbent cells or of square and/or upright cells, heterocellular rays of procumbent body ray cells with 1–2 marginal rows of

upright and/or square cells. Rays 3–7 (Mean  $4.7 \pm 0.86$ ) per mm, rays percentage 23.78.

**Mineral inclusions**—Prismatic crystals present in axial parenchyma square and/or upright ray cells.

**Laticifers**—Occasionally present among fibres.

7. *Ficus virens* Aiton: (Fig. 3: m–q)

**Vernacular name:** Dieng- sohoklaw (Khasi).

**Anatomical features**—A diffuse- porous wood.

**Growth rings**—Indistinct.

**Vessels**—Mostly solitary, in radial multiples of 2–4, oval in outline, barrel and drum shaped, 324.77–487.16  $\mu\text{m}$  (Mean  $421.52 \pm 9.20$   $\mu\text{m}$ ) in length, 108.55–319.86  $\mu\text{m}$  (Mean  $180.49 \pm 52.37$   $\mu\text{m}$ ) in diameter, vessel frequency 3–11 (Mean  $5.94 \pm 1.77$ ) per  $\text{mm}^2$ , simple perforation plates, intervessel pits alternate, 10.4–15.6  $\mu\text{m}$  (Mean  $13.13 \pm 1.98$   $\mu\text{m}$ ) in size, vessel- ray pits with much reduced border to apparently simple, pits scalariform (gash like), vessels percentage 23.45.

**Fibres**—Thin to thick walled, 1290.55–2179.40  $\mu\text{m}$  (Mean  $1637.71 \pm 69.16$   $\mu\text{m}$ ) long,

23.15–41.18  $\mu\text{m}$  (Mean  $33.29 \pm 4.04$   $\mu\text{m}$ ) and 15.64–35.72  $\mu\text{m}$  (Mean  $26.20 \pm 4.47$   $\mu\text{m}$ ) in diameter and lumen diameter, wall thickness 4.7–11  $\mu\text{m}$  (Mean  $7.09 \pm 1.45$   $\mu\text{m}$ ), septate fibres present, fibres percentage 26.

**Parenchyma**—Banded (both apotracheal and paratracheal bands), more than 3 cells wide, bands 4–15 cells wide (Mean  $8.20 \pm 3.79$ ), 4–6 cells per parenchyma strand, parenchyma percentage 27.64.

**Rays**—Mostly multiseriate, rarely biseriate, mean ray height and ray width 612.10–1037.78  $\mu\text{m}$  (Mean  $778.90 \pm 107.83$   $\mu\text{m}$ ) and 36.65–82.83  $\mu\text{m}$  (Mean  $62.41 \pm 8.89$   $\mu\text{m}$ ), both homocellular and heterocellular rays present, all homocellular rays of either procumbent or upright and/or square cells, heterocellular rays of procumbent body ray cells with marginal 1–3 rows of square and/or upright cells. Rays 3–7 (Mean  $5.12 \pm 1.15$ ) per mm, rays percentage 22.91.

**Mineral inclusions**—Prismatic crystals present in square ray cells.

**Laticifers**—Present in rays.

The results given in Table 3 showed highly significant variations in most of the anatomical characteristics within species. A non-significant variation was observed for ray frequency and intervessel pit size for all *Ficus* species. The other few anatomical characteristics exhibiting non-significant variation were vessel length (*F. microcarpa* and *F. virens*), vessel diameter (*F. rumphii*) and fibre diameter and fibre lumen diameter (*F. elmeri* and *F. rumphii*), fibre wall thickness (*F. nervosa* and *F. rumphii*), ray height (*F. microcarpa*, *F. rumphii* and *F. virens*) and ray width (*F. hispida*).

Tukey's HSD test was performed to see the significant differences in anatomical characteristics of selected *Ficus* species (Table 4). Vessels were significantly longer in *F. nervosa* and *F. virens* than other species. Vessel diameter was significantly larger in *F. microcarpa* and vessel frequency was higher in *F. hispida* than other species. Fibres were substantially longer in *F. microcarpa*, *F. elmeri*, *F. virens* and *F. nervosa* whereas fibre diameter and fibre lumen diameter were significantly greater in *F. nervosa* and *F. virens*. *F. elmeri* had maximum wall thickness among selected species. Rays were significantly longer and wider in *F. virens* and *F. nervosa*. On the other hand, the number of rays per mm was maximum in *F. microcarpa* and *F. drupacea*. Parenchyma strands were longer in *F. rumphii* where as parenchyma bands were significantly wider in *F. rumphii* and *F. elmeri*.

Coded descriptions based on IAWA list of microscopic features of *Ficus* species presented in Table 5 showed similarity in most of the anatomical characteristics.

Maximum wood density and minimum moisture content were recorded in *F. elmeri* among species. On the other hand, *F. rumphii* showed minimum wood density with maximum moisture content (Table 6).

## Identification key

1. Banded parenchyma, both apotracheal and paratracheal bands with more than 3 cells wide...4
  - 1a. Banded parenchyma, paratracheal bands with more than 3 cells wide ...2
2. Fibre length 900–1600  $\mu\text{m}$ , laticifers among fibres present ...3
  - 2a. Fibre length  $\geq 1600$   $\mu\text{m}$ , laticifers among fibres absent ...*F. elmeri*.
3. Vessel frequency 5–20, vessel ray pits vertical, multiseriate rays with sheath cell ...*F. hispida*.
  - 3a. Vessel frequency 5–20, vessel ray pits vertical, multiseriate rays without sheath. Cells ...*F. rumphii*.
4. Ray frequency  $\geq 4$ , fusiform and vascicentric parenchyma present...*F. drupacea*.
  - 4a. Ray frequency  $\leq 4$ , fusiform and vascicentric parenchyma absent ...5.
5. Vessel diameter 100–200  $\mu\text{m}$ , vessel ray pits rounded and laticifers absent in fibres ...6.



**Table 3** Analysis of variance for anatomical characteristics within species

Parameters ( <i>F</i> value)	<i>F. drupacea</i>	<i>F. elmeri</i>	<i>F. hispida</i>	<i>F. microcarpa</i>	<i>F. nervosa</i>	<i>F. umphii</i>	<i>F. virens</i>
Vessel length	10.722**	13.832**	7.701**	1.695 <sup>ns</sup>	5.226**	15.113**	1.038 <sup>ns</sup>
Vessel diameter	5.070**	5.411**	4.009**	5.727**	4.405**	2.111 <sup>ns</sup>	7.264**
Vessel frequency	7.080**	2.058 <sup>ns</sup>	9.382**	1.100 <sup>ns</sup>	20.510**	8.970**	1.935 <sup>ns</sup>
Inter vessel pit size	0.882 <sup>ns</sup>	0.762 <sup>ns</sup>	2.334 <sup>ns</sup>	1.340 <sup>ns</sup>	0.033 <sup>ns</sup>	0.066 <sup>ns</sup>	0.060 <sup>ns</sup>
Fibre length	5.317**	9.450**	12.108**	4.803**	13.910**	33.047**	9.580**
Fibre diameter	3.595*	1.092 <sup>ns</sup>	4.062**	14.952**	20.503**	0.686 <sup>ns</sup>	4.749**
Fibre lumen diameter	6.027**	1.851 <sup>ns</sup>	3.701*	17.195**	22.082**	0.555 <sup>ns</sup>	10.155**
Fibre wall thickness	5.030**	3.505*	14.122**	3.989**	0.313 <sup>ns</sup>	1.540 <sup>ns</sup>	8.091**
Ray height	3.559*	4.898**	3.710*	0.683 <sup>ns</sup>	5.161**	1.917 <sup>ns</sup>	2.463 <sup>ns</sup>
Ray width	11.788**	3.364*	2.014 <sup>ns</sup>	4.310**	4.087**	8.108**	0.802 <sup>ns</sup>
Ray frequency	1.539 <sup>ns</sup>	2.067 <sup>ns</sup>	2.411 <sup>ns</sup>	2.566 <sup>ns</sup>	1.362 <sup>ns</sup>	2.125 <sup>ns</sup>	1.634 <sup>ns</sup>

The level of significance used are:

n s = non-significant

\* = significant at  $P \leq 0.05$  level and \*\* = highly significant at  $P \leq 0.01$  level

5a.

Vessel diameter  $\geq 200$   $\mu\text{m}$ , vessel ray pits rounded and laticifers present ...*F. microcarpa*.

6. Prismatic crystals in axial parenchyma, septate fibres absent ...*F. nervosa*.

6a. Prismatic crystals in ray cells, septate fibres present ...*F. virens*.

## Discussion

Most of the anatomical characteristics are similar in *Ficus* species. Diffuse-porous woods with indistinct growth rings, vessels solitary and in radial multiples of 2–3 were present in all species except *F. microcarpa* in which distinct rings due to presence of radially flattened fibres were observed. The vessels were barrel shaped except drum shaped in *F. elmeri* and *F. microcarpa*. The tangential diameters of vessels were in the range of 100–200  $\mu\text{m}$  except *F. microcarpa* and the range of vessel frequency was 5–20 per square millimetre in all species except *F. drupacea*. Other common features of vessels were simple perforation plate and intervessel pits alternate. Vessel ray pits were with much reduced border to apparently simple with rounded pits in all species except vertical (palisade) in *F. hispida* and *F. rumphii* and scalariform (gash like) in *F. virens*. Fibres were thin to thick walled in *F. nervosa* and *F. virens*. Whereas, these were thin walled in other selected species. Septate fibres were present in *F. drupacea* and *F. hispida*. The present study on qualitative and quantitative features of fibres and vessels confirms the findings of

Noorman et al. (1984) and Adeniyi et al. (2013) who reported similar features of vessel and fibres in Neotropical, African and Nigerian species of *Ficus*.

Axial parenchyma was abundant, banded and present in both apotracheal and paratracheal bands. On contrary to it, Sharma et al. (2014) reported other forms of parenchyma like lozenge aliform and diffuse in *F. hispida* and *F. variegata*, diffuse-in-aggregate in *F. racemosa* and *F. rumphii* in addition to banded parenchyma. Raturi et al. (2001) divided Indian *Ficus* species into two groups on the basis of ripple marks which may be due to storied rays, fibres or parenchyma. In this study, storied (fusiform) parenchyma was observed in *F. drupacea* only. Rays were mostly multiseriate in all species. Uniseriate and biseriate rays along with multiseriate rays were also observed in *F. drupacea*, *F. microcarpa* and *F. rumphii*. The presence of sheath cells in *F. elmeri* and *F. hispida* corroborates the findings of Sharma et al. (2014). Rays were homocellular and heterocellular in all species and confirm the findings of other workers (Noorman et al. 1984; Adeniyi et al. 2013; Sharma et al. 2014). Crystals were present in axial parenchyma cells, square and upright ray cells of *Ficus* species whereas Yaman (2014) reported prismatic crystals in axial parenchyma cells of *F. carica* subsp. *carica*.

Laticifers act as a defense system in plants and prevent pest invasion by secretion of latex. Axial/longitudinal laticifers were present in the form of streaks among fibres in *F. hispida*, *F. rumphii*, *F. microcarpa* and occasionally in *F. virens* also. Horizontal laticifers were observed in rays of *F. virens* only. The study corroborates the findings of Kaji et al. (2014) who reported the frequent occurrence

**Table 4** Quantitative anatomical characteristics of selected *Ficus* species

Parameters (Mean ± SD)	<i>F. drupacea</i>	<i>F. elmeri</i>	<i>F. hispida</i>	<i>F. microcarpa</i>	<i>F. nervosa</i>	<i>F. rumpffii</i>	<i>F. virens</i>
Vessel length (µm)	393.65 ± 17.00 <sup>ab</sup>	400.77 ± 22.01 <sup>ab</sup>	413.65 ± 11.60 <sup>b</sup>	417.932 ± 7.79 <sup>b</sup>	422.37 ± 8.55 <sup>b</sup>	376.73 ± 12 <sup>a</sup>	421.52 ± 9.20 <sup>b</sup>
Vessel diameter (µm)	178.97 ± 30.46 <sup>c</sup>	181.83 ± 23.74 <sup>c</sup>	139.93 ± 24.57 <sup>a</sup>	211.30 ± 28.51 <sup>d</sup>	179.75 ± 24.41 <sup>c</sup>	159.55 ± 22.35 <sup>b</sup>	180.49 ± 21.33 <sup>c</sup>
Vessel frequency	3.82 ± 1.13 <sup>a</sup>	5.94 ± 1.77 <sup>b</sup>	7.74 ± 2.85 <sup>c</sup>	6.68 ± 1.73 <sup>bc</sup>	5.68 ± 2.77 <sup>b</sup>	5.54 ± 1.66 <sup>b</sup>	5.94 ± 1.77 <sup>b</sup>
Inter vessel pit size(µm)	15.34 ± 2.05 <sup>bc</sup>	12.09 ± 2.56 <sup>a</sup>	13.91 ± 2.70 <sup>ab</sup>	15.73 ± 2.98 <sup>c</sup>	14.30 ± 2.98 <sup>ab</sup>	15.34 ± 1.86 <sup>bc</sup>	13.13 ± 1.98 <sup>ab</sup>
Fibre length (µm)	1544.72 ± 74.15 <sup>bc</sup>	1645.57 ± 57.82 <sup>c</sup>	1431.22 ± 43.97 <sup>ab</sup>	1661.98 ± 56.31 <sup>c</sup>	1621.47 ± 29.35 <sup>c</sup>	1492.07 ± 22.14 <sup>a</sup>	1637.71 ± 69.16 <sup>c</sup>
Fibre diameter (µm)	25.30 ± 3.82 <sup>b</sup>	19.14 ± 2.33 <sup>a</sup>	21.11 ± 4.31 <sup>a</sup>	20.34 ± 5.04 <sup>a</sup>	34.76 ± 4.49 <sup>c</sup>	20.08 ± 2.58 <sup>a</sup>	33.29 ± 2.85 <sup>c</sup>
Fibre lumen diameter (µm)	18.47 ± 3.90 <sup>d</sup>	11.56 ± 2.34 <sup>a</sup>	15.86 ± 4.12 <sup>c</sup>	15.20 ± 4.04 <sup>bc</sup>	27.64 ± 3.39 <sup>e</sup>	13.54 ± 2.14 <sup>ab</sup>	26.20 ± 2.79 <sup>e</sup>
Fibre wall thickness (µm)	6.84 ± 1.37 <sup>bc</sup>	7.58 ± 1.25 <sup>c</sup>	5.24 ± 1.62 <sup>a</sup>	5.14 ± 1.34 <sup>a</sup>	7.12 ± 1.39 <sup>bc</sup>	6.54 ± 1.08 <sup>b</sup>	7.09 ± 1.01 <sup>bc</sup>
Ray height (µm)	564.39 ± 247.60 <sup>b</sup>	536.16 ± 101.82 <sup>b</sup>	579.55 ± 131.10 <sup>b</sup>	421.45 ± 57.33 <sup>a</sup>	684.32 ± 65.55 <sup>c</sup>	562.83 ± 118.55 <sup>b</sup>	778.90 ± 87.09 <sup>d</sup>
Ray width (µm)	44.32 ± 24.88 <sup>b</sup>	105.56 ± 11.58 <sup>c</sup>	62.78 ± 12.72 <sup>c</sup>	42.49 ± 6.49 <sup>a</sup>	73.01 ± 12.07 <sup>d</sup>	55.73 ± 17.46 <sup>bc</sup>	62.41 ± 13.98 <sup>c</sup>
Ray frequency	5.52 ± 1.19 <sup>de</sup>	3.76 ± 0.77 <sup>a</sup>	4.4 ± 0.83 <sup>b</sup>	5.8 ± 1.19 <sup>e</sup>	4.78 ± 1.03 <sup>bc</sup>	4.7 ± 0.86 <sup>bc</sup>	5.12 ± 1.15 <sup>cd</sup>
Parenchyma bands	6.40 ± 2.50 <sup>a</sup>	13.00 ± 4.90 <sup>b</sup>	9.30 ± 3.09 <sup>ab</sup>	5.70 ± 1.57 <sup>a</sup>	8.70 ± 2.31 <sup>a</sup>	16.80 ± 4.32 <sup>c</sup>	8.20 ± 3.79 <sup>a</sup>

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

**Table 5** Coded description based on IAWA list microscopic features of *Ficus* species

SL. No	Species	IAWA list of coded features
1	<i>F. drupacea</i>	2,5,9,10,13,22,27,31,42,46,53,56,68,72,79,85,90,93,98,104,105,109,115,132,137,141
2	<i>F. elmeri</i>	2,5,9,10,13,22,27,31,42,46,53,56,65,68,73,85,93,98,104,105,106,114,137,141
3	<i>F. hispida</i>	2,5,9,10,13,22,27,31,42,46,53,68,72,85,93,98,105,106,109,110,115,132
4	<i>F. microcarpa</i>	1,2,5,9,10,13,22,27,31,43,47,53,69,73,85,93,98,105,106,115,122
5	<i>F. nervosa</i>	2,5,9,10,13,22,27,31,42,47,53,69,73,85,93,98,105,106,115,142
6	<i>F. rumphii</i>	2,5,9,10,13,22,27,32,42,47,53,65,68,72,85,93,98,104,105,106,115,132,137,141
7	<i>F. virens</i>	2,5,9,10,13,22,27,32,42,47,53,65,69,73,85,93,98,104,105,106,107,115,132,137

**Table 6** Wood density and moisture content of selected *Ficus* species

Species	Wood density (gm/cc) (Mean ± SD)	Moisture content (%) (Mean ± SD)
<i>F. drupacea</i>	0.34 ± 0.04 <sup>a</sup>	223.86 ± 37.27 <sup>d</sup>
<i>F. elmeri</i>	0.45 ± 0.05 <sup>d</sup>	157.06 ± 31.63 <sup>a</sup>
<i>F. hispida</i>	0.35 ± 0.02 <sup>ab</sup>	214.20 ± 17.37 <sup>cd</sup>
<i>F. microcarpa</i>	0.40 ± 0.06 <sup>c</sup>	182.98 ± 41.77 <sup>b</sup>
<i>F. nervosa</i>	0.37 ± 0.06 <sup>b</sup>	200.83 ± 36.17 <sup>bc</sup>
<i>F. rumphii</i>	0.34 ± 0.04 <sup>a</sup>	228.38 ± 42.16 <sup>d</sup>
<i>F. virens</i>	0.37 ± 0.04 <sup>b</sup>	225.04 ± 40.63 <sup>d</sup>

Values with same letter in the same column are not significantly different at 0.05 probability level

of both longitudinal and horizontal laticifers in secondary phloem and secondary xylem of *F. carica*.

Anatomical characteristics are highly variable within a tree, among trees of same or different species (Zobel and Talbert 1984). Pande et al. (2007, 2009) reported non-significant intra-species variation in anatomical features. On contrary to it, the conflicting results have been found in the present study. Most of the anatomical characteristics show highly significant variations while other features are non-significant. Hence, *Ficus* species can be differentiated on the basis of both qualitative and quantitative anatomical characteristics.

In *Ficus* species, the percentage of fibres, vessels, rays and parenchyma are more or less uniform. *F. elmeri* had maximum fibre and vessel percentage. Ray percentage was maximum in *F. drupacea* and *F. hispida* whereas, maximum parenchyma percentage was observed in *F. rumphii*. The banded parenchyma may be the reason of less percentage of fibres in most of species.

The present study reveals maximum wood density and minimum moisture content in *F. elmeri*. On the other hand, *F. rumphii* has minimum wood density with maximum moisture content. The higher percentage of fibres with maximum wall thickness and low percentage of parenchyma may attribute to maximum wood density with minimum moisture content in *F. elmeri*. On the other hand, maximum width of parenchyma bands (16 cells wide) may

be the possible reason for maximum moisture content in *F. rumphii*.

### Conclusions

The wood structure of *Ficus* species is uniform. Storied (fusiform) parenchyma in *F. drupacea*, vessel ray pits with much reduced border to apparently simple with vertical pits in *F. rumphii*, scalariform pits and laticifers in rays of *F. virens*, both distinct and indistinct growth rings, presence of septate and gelatinous fibres in *F. microcarpa* and absence of laticifers among fibres and rays in *F. elmeri* and *F. nervosa* are the diagnostic features for identification among species. Also, the selected species showed significant variation in most of the anatomical characteristics. Both qualitative and quantitative anatomical characteristics are used for preparation of identification key and are important to differentiate *Ficus* species.

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