Trachea features and fiber dimensions of fast-growing tree: A case study on wood samples from eastern Indonesia

A P Dewi*, E F Tihurua and T Y I Wulansari

Research Center for Biology, National Research and Innovation Agency (BRIN), Cibinong 16911, West Java, Indonesia

*Corresponding author e-mail: perwita09@gmail.com

Abstract. Fast-growing plant is one of the characteristics of pioneer plants. Commonly, the plants grow in areas that is exposed to sunlight such as open area and forest edges. Fast-growing plants have different anatomical and physical wood characteristics compare with slow-growing plants. Therefore, this study aims to examine the anatomical characteristics of fast-growing plants, especially trees, namely the fiber cells and trachea features. A total of 33 wood samples from 28 species were used in this study. We used wood samples from Eastern Indonesia deposited at Herbarium Bogoriense. Examined wood samples are taken from branches with 1-2 cm of diameter. The anatomical characters observed were focused on two types of cells, namely fiber cells (fiber length, fiber diameter, fiber cell wall thickness, lumen width, identification of septate fibers and fibers pit) and the trachea (perforation type, pit arrangement, and pit form). From the observations of all wood samples showed that the length of fiber cells are classified as short (18 species) and medium (10 species) fiber. There are two groups of fiber cell wall thickness viz. very thin (16 species) and thin to thick (12 species). Septate fibers only found in 7 species especially Chisocheton and Teijsmanniodendron. Fiber’s pit observed in Horsfieldia parviflora, Mallotus peltatus, dan Neuburgia corynocarpa. All species have simple tracheal perforation with alternate or opposite pit arrangement. Moreover, branch wood samples have polygonal pit shape, oval or combination of those two shapes were found in some species, such as Horsfieldia parviflora, Sandoricum koetjape and Teijsmanniodendron bogoreinse.

Keywords: Eastern Indonesia, fiber cell, pit, perforation, pioneer, trachea.

1. Introduction
Fast-growing trees are plants that have a short life cycle and generally are pioneer plants. Fast-growing species are commonly used in re plantation forests based on their growth speed [1,2]. Commonly, this tree grows in areas that are exposed to sunlight such as disturbed areas which is usually opened-areas [3]. In forestry, fast-growing species are characterized by high productivity in a short period. This productivity measure is not absolute because it relates to several combinations of aspects such as species, bioclimate, and management [4]. FAO [5] states that the range of productivity in tropical plantations varies widely with a maximum of 25-30 m³ ha⁻¹ yr⁻¹ in Eucalyptus and pines species.

Fast-growing trees have different anatomical and physical wood characteristics compare with slow-growing trees. Commonly, the fast-growing trees has low wood density [6] which is influenced by several anatomical structures such as fiber length, lumen diameter, fiber cell wall thickness, vessel, and parenchyma proportion. [7] and [8] showed that fiber length is related to wood density and mechanical properties of wood. Carillo et al. [9] on Eucalyptus globulus showed that cell wall thickness, fiber length, Runkel ratio, and coarseness were significantly superior in the high-density. Meanwhile, based on
qualitative anatomical observations, Hu et al. [2] stated that there are differences in fast-growing based on vessel size and type of perforation plates in native and exotic species related to water transport.

This study aims to determine the anatomical characteristics of 28 fast-growing species originating from Eastern Indonesia based on their tracheal features and fiber dimensions. A description of the anatomical characteristics of fast-growing tropical plants and species anatomy data that can be used to predict the suitability of unutilized tree both ecologically and industrially. This is supported by IUCN [10] (iucnredlist.org, 2021) and ITTO [11] (itto.int, 2021) data that most of the samples used are less concerned and unrestricted so their utilization can be optimized for the needs of local communities.

2. Materials and Methods

Thirty three of branch wood, belongs to 28 species of Herbarium Bogoriense collection collected from eastern part of Indonesia (such as Flores, Celebes, Moluccas and Papua) were used in this study. The determination of fast-growing species based on wood density from ICRAF [12]. We selected species with wood density of less than 0.55.

The woods were prepared in semi-permanent maceration. The maceration slides were prepared through modification of the Schultze method [13], boiled with the HNO₃ 1:3 solution until the wood component separated. The slides then coloring with 1% safranin solution. Anatomical slides were observed using an optical microscope Nikon Eclipse 80i and Betaview programme. Photographs were taken with XCAM Indomicro 1080 PHB camera with magnification 2.4 x 2.4 pixels and Beta View application.

The observation of fiber cells and trachea components are following the IAWA guidelines for wood microscopic identification [14], includes quantitative and qualitative cell characters of fiber cells and trachea. As many as 150 fiber cells were measured from each number collection of each species for quantitative characters.

3. Results and Discussion

The anatomical character of cells, especially in fiber cells and tracheal cells, is influenced by several factors including stem part, age of the stem, and the position of stem sample (at the base of the root, as high as the diameter of breast high, or at the end of stem). Wood components that are quite diverse and have complex variations are also an obstacle in finding definite patterns of anatomical variations, especially in relation to physiological and ecological conditions of wood growth. In this study, we tried to reveal the trend of several anatomical characters in fiber cells and tracheal cells of fast-growing plants.

3.1 Characterization of fast-growing plant fiber cells

According to taxonomical characters, the qualitative characters of fiber cells are the presence of septate fibers and pit [15]. Mostly, the septum fibers are very rare to find, so it can be an anatomical key character of some species. In this study, septate fibers were found in Chisocheton ceramicus, Chisocheton koordesii, Macaranga hispida, Neuburgia corynocarpa, Nothaphoebe umbelliflora, Teijsmanniodendron bogoriense, and Teijsmanniodendron hollrungii. Number of septate in one cell is up to 5 septate. Sometimes, the thickness of the septate were difficult to observe. But in some species it can be seen very clearly such us in Neuburgia corynocarpa (Figure 1). The septum that appears in fiber cells occurs during the process of mitotic cell division, especially at the telophase stage during the cells elongation [16]. [17] also stated that the septum in fiber cells is formed from renewed wall formation after late division of the fiber cytoplasm. The appearance of septate fibers is not limited to certain parts, but it can appear in secondary wood during single growing season [16] within phloem and xylem [18]. The number of septate appears in each cells is not clearly observed, but it is suspected with the relation of the wood sampling position to the growth ring and the annual increment of height growth [17]. Septate fibers have the same function as the axial parenchyma, namely as storage system such as starch [19,20].
Table 1. The fiber dimensions of the 30 species of fast-growing wood from eastern Indonesia.

| No. | Species / collection number | Fiber length (µm) | Score | Criteria | Fiber diameter (µ) | Lumen diameter (µ) | Fiber wall thickness (µ) | Criteria | Fiber septate | Fiber pit | Perforation type | Pit arrangement | Pit form |
|-----|-----------------------------|-------------------|-------|----------|------------------|------------------|----------------------|----------|--------------|----------|----------------|----------------|---------|
| 1   | *Alangium chinense* (xm-874), | 1000.47           | 50    | Medium   | 17.63           | 6.29             | 5.665933             | Thin to thick walled   | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| 2   | *Albizia chinensis* (xm-805) | 742.77            | 25    | Short    | 16.72           | 7.50             | 4.608667             | Thin to thick walled   | Absent       | Absent     | simple   | alternate          | oval           |         |
| 3   | *Andisia purpurea* (xm-735)  | 904.91            | 25    | Short    | 26.85           | 18.06            | 4.395867             | Thin walled            | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| 4   | *Buchanania arborescens* (xm-728) | 714.35         | 25    | Short    | 17.03           | 8.29             | 4.368933             | Thin walled            | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| 5   | *Cerbera manghas* (xm-473)   | 913.67            | 25    | Short    | 20.89           | 12.65            | 4.120267             | Thin walled            | Absent       | Absent     | simple   | alternate          | oval           |         |
| 6   | *Chisocheton ceramicus* (xm-504) | 1173.73       | 50    | Medium   | 18.61           | 7.92             | 5.349067             | Thin to thick walled   | Present, inconspicuous | Absent     | Absent     | simple   | alternate          | poligonal       |         |
| 7   | *Chisocheton koordersii* (xm-845) | 1217.11      | 50    | Medium   | 19.72           | 12.08            | 3.818867             | Thin walled            | Present, inconspicuous | Absent     | Absent     | simple   | alternate          | poligonal       |         |
| 8   | *Croton oblongus* (xm-696)    | 744.91            | 25    | Short    | 16.29           | 8.14             | 4.0756               | Thin to thick walled   | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| 9   | *Elaeocarpus angustifolius* (xm-780) | 759.53       | 25    | Short    | 16.22           | 8.03             | 4.0948               | Thin to thick walled   | Absent       | Absent     | simple   | alternate and opposite |               |         |
| 10  | *Ficus ampelos* (xm-865)      | 864.35            | 25    | Short    | 17.59           | 10.94            | 3.3258               | Thin walled            | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| 11  | *Ficus benjamina* (xm-929)    | 776.25            | 25    | Short    | 16.58           | 9.43             | 3.573267             | Thin walled            | Absent       | Absent     | simple   | alternate          | poligonal       |         |
| No. | Species / collection number | Fiber length (µm) | Score | Criteria | Fiber diameter (µ) | Lumen diameter (µm) | Fiber cell wall thickness (µm) | Criteria | Fiber septate | Fiber pit perforation type | Pit arrangement | Pit form |
|-----|-----------------------------|-------------------|-------|----------|-------------------|-------------------|-----------------------------|----------|--------------|---------------------------|----------------|---------|
| 12  | Ficus magnolifolia (xm-703) | 778.41            | 25    | Short    | 18.93            | 10.57             | 4.182333                    | Thin walled | Absent        | Absent, simple            | alternate      | polygonal |
| 13  | Ficus magnolifolia (xm-807) | 749.43            | 25    | Short    | 19.54            | 11.50             | 4.0212                      | Thin walled | Absent        | Absent, simple            | alternate      | polygonal |
| 14  | Horsfieldia parviflora (xm-496) | 1034.47          | 50    | Medium   | 17.46            | 10.75             | 3.351133                    | Thin walled | Present, few & tend to absent | simple          | alternate | oval & polygonal |
| 15  | Horsfieldia sylvetris (xm-478) | 1006.68          | 50    | Medium   | 18.10            | 8.75              | 4.672667                    | Thin to thick walled | Absent       | Absent, simple            | alternate      | polygonal |
| 16  | Macaranga tanarius (xm-902) | 923.41            | 25    | Short    | 17.19            | 7.10              | 5.045467                    | Thin to thick walled | Absent       | Absent, simple            | alternating    | polygonal |
| 17  | Macaranga hispida (xm-980)  | 1076.02           | 50    | Medium   | 20.00            | 11.15             | 4.426                       | Thin walled | Present, inconspicuous   | simple          | alternate | oval |
| 18  | Mallotus mollissimus (xm-978) | 959.13            | 25    | Short    | 20.64            | 10.13             | 5.256333                    | Thin to thick walled | Absent       | Absent, simple            | alternate      | polygonal |
| 19  | Mallotus mollissimus (xm-846) | 923.08            | 25    | Short    | 24.67            | 18.18             | 3.247533                    | Thin to thick walled | Absent       | Absent, simple            | alternate      | polygonal |
| 20  | Aleurites moluccanus (xm-842) | 860.45            | 25    | Short    | 21.32            | 14.00             | 3.66                        | Thin to thick walled | Absent       | Absent, simple            | alternate      | polygonal |
| 21  | Mallotus peltatus (xm-498)  | 685.58            | 25    | Short    | 14.77            | 5.68              | 4.542933                    | Thin to thick walled | Absent       | Present, simple            | alternate      | polygonal |
| 22  | Mallotus peltatus (xm-698)  | 917.20            | 25    | Short    | 16.02            | 6.67              | 4.674933                    | Thin to thick walled | Absent       | Present, simple            | alternate      | polygonal |
| 23  | Neuburgia corynocarpa (xm-476) | 1296.10           | 50    | Medium   | 28.40            | 19.24             | 4.582133                    | Thin walled | Present, thick          | Present, simple | alternate | polygonal |
| No. | Species / collection number | Fiber length (µm) | Score | Criteria | Fiber diameter (µm) | Lumen diameter (µm) | Fiber cell wall thickness (µm) | Criteria | Fiber septate | Fiber pit perforation type | Pit arrangement | Pit form |
|-----|-----------------------------|-------------------|-------|----------|---------------------|----------------------|-----------------------------|----------|---------------|--------------------------|----------------|---------|
| 24  | *Nothaphoebe umbelliflora* (xm-870) | 921.94            | 25    | Short    | 22.20               | 12.45                | 4.87267                     | Thin-walled | Present        | Absent                  | simple          | alternate poligonal & oval |
| 25  | *Ormosia calavensis* (xm-889)   | 1171.52           | 50    | Medium   | 20.32               | 9.04                 | 5.6362                      | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal         |
| 26  | *Polyscias nodosa* (xm-924)     | 1029.98           | 50    | Medium   | 23.12               | 14.63                | 4.2448                      | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal       |
| 27  | *Prunus arboarea* (xm-618)      | 712.91            | 25    | Short    | 17.04               | 7.79                 | 4.626467                    | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal       |
| 28  | *Prunus arboarea* (xm-702)      | 827.41            | 25    | Short    | 17.76               | 9.75                 | 4.006133                    | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal       |
| 29  | *Sandoricum koetjape* (xm-926)  | 650.98            | 25    | Short    | 17.17               | 8.68                 | 4.2476                      | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal       |
| 30  | *Sandoricum koetjape* (xm-594)  | 722.04            | 25    | Short    | 18.07               | 10.26                | 3.906067                    | Thin-walled | Absent         | Absent                  | simple          | alternate oval poligonal  |
| 31  | *Spondias dulcis* (xm-449)      | 717.34            | 25    | Short    | 22.23               | 15.87                | 3.182067                    | Thin-walled | Absent         | Absent                  | simple          | alternate poligonal       |
| 32  | *Teijsmanniodendron hollrungi* (xm-565) | 1015.57         | 50    | Medium   | 23.16               | 14.62                | 4.267667                    | Thin-walled | Present        | Inconspicuous           | alternate poligonal & oval |
| 33  | *Teijsmanniodendron hollrungi* (xm-622) | 680.31           | 25    | Short    | 17.32               | 8.83                 | 4.2468                      | Thin-walled | Absent         | Inconspicuous           | Simple          | alternate poligonal       |
The presence of pit in fiber cells is not really common. But some species observed in this study showed that the fibers have pits such as *Horsfieldia parviflora*, *Mallotus peltatus*, and *Neuburgia corynocarpa* (Table 1). It is suspected that the existence of this pit is also related to water transport among cells. However, the presence of septate and pit on the fibers need to be further investigated to ensure the relation between the fast-growing and the function mechanism of the structure.

Observation of the quantitative characters of fiber cells showed the fiber length is short to medium. There are more than half of examined species is classified as short fiber with less than 1000 µm (Figure 2). These results indicate that fast-growing wood species have an average fiber cell length range of less than 1000 µm. However, the previous study recorded that there are also fast-growing species having long fiber length, such as *Endospermum diadenum*, *Adinandra dumosa*, and *Nauclea junghuhnii* [21] with fiber length reaching 2000 µm.

![Figure 1. The septate fiber in *Neuburgia corynocarpa* with the septate. Scale bar 50 µm.](image)

**Figure 1.** The septate fiber in *Neuburgia corynocarpa* with the septate. Scale bar 50 µm.

The fiber wall thickness showed about more than half examined species have thin wall, 4-5 µm (Table 1). This size is still in the range of cell wall thickness of other fast-growing species such as *Macaranga gigantea* (4.4 µm) and *Endospermum malaccense* (5.1 µm) that observed in previous study [22]. In addition, there is also another species of fast-growing trees with very thin wall thicknesses such as *Shorea leprosula* (2.02 µm) and *Shorea parvifolia* (2.00 µm) [23].

Kojima *et al.* [24] stated that fiber dimension depends on maturity of the wood. The examined wood used in this study are branch woods (diameter of 1-2 cm) which are not mature enough, therefore it could be understood that this study obtained wood fiber which are short and thin wall. In addition, our
wood samples are fast-growing species with low wood density which affect the fiber dimension such as short fiber length and thin wall fiber. This is found by Sulistyo et al. [23] that recorded the relation between wood density and fiber dimensions on Shorea leprosula and S. parvifolia. Their founding agreed to Spurr and Hyvärinen [25] which stated that branch fiber shorter than stem fiber.

3.2 Tracheal cell characterization of fast-growing plants
Observation on the trachea cells showed that all species has vessel with simple perforation and pits are arranged alternate in almost all species except Elaeocarpus sphaericus which is arranged alternate and opposite (Figure 3). According to Dickinson [26], about 20% of wood with simple perforations have alternate or opposite pits. Simple perforation is considered more advantageous in terms of water distribution than scalariform perforation for water transport [20]. Therefore, simple perforation of fast-growing species that commonly present in the opened-area has environment with water and nutrients limitation is an advantage.

There are two pit forms viz. polygonal and oval (Figure 3). Examined species are dominantly polygonal, three species with oval pit form, and mixed of these two forms present in H. bivalvis, O. calensis, S. koetjape and T. bogoreinse. [27] suggested that the elliptical pit form has a better level of resistance to the risk of cavitation in habitat with limited water sources. Meanwhile, [28] also found that there is relation between pit size and cavitation risk based on the size of the pit in the trachea. In this study, the types of plants that have oval pit, i.e. Albizia chinensis, Cerbera manghas, and Macaranga hispida, have been studied previously and showed that they were able to adapt as fast growing trees and other functions such as heavy metal accumulators. A. chinensis is a species that has a role in maintaining soil fertility [29] and the function of revegetation of ex-mining land [30]. C. manghas which is often used as an ornamental plant, planted in the parks and able to absorb the CO₂ [31] and lead [32]. This species also has a hydrological function that can withstand water loss through the canopy and stem architecture so it can be reduce the destruction of the soil grains causes from the rainfall [33]. M. hispida along with other species within same genus are known as fast-growing plants with the regeneration comes from their seed banks that are abundant in the forest floor [34].

3.3 Relation between wood density and fiber wood dimension
In this study, we tried to find a possible relationship between wood density values and fiber dimension factors, i.e. fiber length, fiber diameter, and fiber cell wall thickness. However, based on simple regression analysis, we find slightly linear regression between certain quantities in density values and certain sizes in wood dimensions. Fiber length and fiber diameter showed a negative regression function on wood density, while cell wall thickness indicated positive regression value on wood density. This is presumably because of different resources of wood density and branch wood that we used. Wood density data, which is obtained from the ICRAF [12] database, is measured from primary stems, meanwhile the fiber dimension data used of this study is collected from the branch wood. Therefore, the measured
regression pattern cannot reflect the desired pattern. Several relationships between wood density to the fiber dimension were proposed by Hamdan et al. [22]. The long fiber cells and thick fiber walls were related to the high wood density, while the short, thin fiber walls and also large diameter of the vessel were related to the low wood density. Density was positively correlated to the fiber length with the correlation is moderate to strong, in other hand density is positively correlated to the fiber wall thickness with weak to moderate correlation.

\[ y = 1.0832x + 9.4125 \quad R^2 = 0.0019 \]

\[ y = -10.317x + 29.237 \quad R^2 = 0.0033 \]

\[ y = 1.5212x + 3.6415 \quad R^2 = 0.0055 \]

**Figure 4.** Regression analysis were not shown any specific pattern between certain number of wood density and the measure of the fiber dimension.

4. Conclusion
Tracing the anatomical characters of fast-growing wood species in fiber cells and trachea did not show a significant pattern, especially on quantitative characters. The selection of wood samples from branch wood allows the type of wood to still develop into mature wood, so it might be possible that the cells will still grow elongated until its reach the level of cell maturity. Several qualitative characters such as the type of tracheal perforation and the shape of the pit vessel reflect characters related to resistance to water stress, but it is not yet certain whether these characters have a functional mechanism related to the fast-growing habit. Further research to clarify the anatomical evidence with the growth mechanism of fast-growing species is recommended.

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