Comparing wood anatomy of root and stem of *Syzygium* sp from natural tropical forest of Papua

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Abstract. Root and stem wood anatomy of *Syzygium* sp from the natural tropical forest of Fakfak Districts, Papua Barat, Indonesia were studied. The study focused on vessel, fiber and parenchyma. Growth increments are not distinct, yet we observed that *Syzygium* sp has diffuse porosity and predominantly paratracheal with winged aliform of axial parenchyma in the wood of both root and stem. Many qualitative features were varying in the same way in both root and stem: simple perforation plates in vessel elements; large areas of axial parenchyma in both root and stem wood. Quantitative features differing between root and stem wood were evaluated using t-test, and vessel frequency, vessel element length, vessel diameter, percentage of tree wood’s tissues, and vulnerability are differed. Root wood had vessels density/frequency, narrower and longer vessel elements. We assumed that root wood is less vulnerability of embolism compared to the stem wood as the narrower of the vessel diameter and the higher percentage of parenchyma area. Roots seem to be more susceptible to water stress and the stain than the stem as seen in the percentage and the dimension of the vessel and parenchyma.

1. Introduction

Indonesia has a massive potential of unknown wood/lesser known species for local timber purposes. There are more than 4000 wood species identified in Indonesia [1,2] and only 400 of them had specific name in local and regional trading [1]. The other species then only known as borneo consisting of mixed wood timber and the other species are neglected or limited use.

The lack of utilization of lesser known species and the lack of technical information about these species as well as the possibility of exploiting them resulted in only fixated on the use of certain commercial species. For example, In Papua, two most favorable commercial timber species extracted, traded and used extensively in domestic and international market which are Merbau (*Instia* spp.) and Matoa (*Pometia* sp) respectively [3]. It is contrast to the facts, in Papua there are 28 commercial timbers have been identified and investigated their general utilization, comprising only a minor portion of 600 trees species known [4]. The rest of these timber species are neglected or even used in local and small scale or quantity. These timbers species are then known and grouped into less-used timber species or lesser-known species or even minor commercial species. In practices, however, these groups of timber have similar or even superior wood properties and natural durability with the existed-commercial timbers [5].

One of the endemics species of woody plant which is widely distributed in Indonesia is water gum (*Syzygium* sp.). This species is spread in Java Island which has nearly 52 species and in West Papua with nearly 132 species [6,7]. The availability of information about wood natural characteristics in...
Papua's natural forests in particular and Indonesia in general has not yet been completed. Much information can be obtained to support the use of wood species from natural forests in Indonesia. One of the objectives is to collect the anatomical characteristics of stem wood and root wood. Both of these aspects affect tree growth and wood quality.

Generally discussed, that root wood anatomy received less attention compared to stem wood anatomy [8]. Most of the studies [9-14] of root wood anatomy, showed that the vessels in root wood is wider that in the stem wood of a tree physiologically and anatomically. The earlier studied also showed that the rood wood has higher vulnerability of the embolisms process, since it is directly connected to the effect of the drought [15]. The aim of this study was to compare root and stem wood anatomy of Syzigium sp. qualitatively and quantitatively.

2. Materials and Methods

2.1. Materials

Samples were taken from natural tropical rain forest in Fakfak District. Fakfak lies in the Province of West Papua which has the highest rainfall occurring on January to May while the lowest rainfall is on September to December. The average air temperature recorded at the Meteorological, Climatology and Geophysics Station of Fakfak at normal temperatures is in the range of 20.70-32.50°C. The lowest air temperatures occur in August and the highest air temperatures occur in March and December. The average Air Humidity is 84.8 percent, the lowest air humidity occurred in December which was 79.0 percent and the highest occurred in August which was 90.0 percent. The highest air pressure occurred in May of 996.1 mb and the lowest in February of 898.8 mb [16].

2.2. Methods

Wood samples for anatomical observation of stem and main root were taken from adult tree. They were collected at 1.30 m (DBH) and 30 cm distal from root collar, respectively. Non embedding method was used to observe the cross-sectional feature of vessels, parenchyma and rays distribution [17]. The wood anatomical samples (root wood and stem wood) were cut and softened by immersing in a mixture of glycerol and alcohol in a ratio of 1:1 for 2 weeks [18,19].

After two weeks approximately, the wood sample were sliced using a sliding microtome in 15-25 µm thickness. The slice included the three incisions of wood which are transversally, radially and tangentially. Good sections were stained with safranin 1% for 24 hours. The next step is dehydration process in succession with alcohol levels of 70%, 80%, 90% and absolute alcohol respectively for 10 minutes. Furthermore, the sections were dried by soaking the samples in alcohol and xylol for about 10 minutes. Wood descriptions follow the microscopic features definitions of IAWA Committee [20]. The obtained data from presented in the form of visual microscopy and descriptive analysis.

3. Results and Discussion

Certain qualitative anatomical features of Syzygium sp. vary between stem and root wood (Figure 1), differences between the organs were found only in quantitative features (Table 1). The vessel diameter, vessel area, and parenchyma area (Table 4) are the features that different between roots and stem of Syzygium sp. We also found that the diameter of stem wood vessel is wider than in the root wood, it has negative correlation with the vessel. It is contrast to the finding of the earlier study which said that root wood vessel is wider than the stem wood [9-14].

If we correlate the hydraulic architecture and the tradeoff principle between safety and efficiency in terms of vessel diameter of the root and the stem within a tree, we found that root of Syzygium sp is not efficient in transporting water because of the narrower vessel diameter compared to the vessel of the stem. The positives things regarding this finding, it is assumed that the root is less vulnerable to the embolism occurrence. This less vulnerability of the embolism is also confirmed with larger area of the parenchyma of the root wood (37.5%) compared to the stem wood (31%). The larger parenchyma area indicates the higher reserved of metabolites in the parenchyma which will lead to increase the water transportation in vessels and the removal of embolisms [21]. This assumption would be better
explained if we do further analysis on the pit membrane thickness as this data is not available at the moment. Since, the thickness of the pit membrane is known to be highly correlated to embolism resistance [22,23].

Table 1. Means and STDEV of quantitative anatomical features

| Sample | Varea (%) | Rayarea (%) | Parea (%) | Fibarea (%) | Vdens (n/mm²) | Vdiam (µm) | Flength (µm) | WT (µm) |
|--------|-----------|-------------|-----------|-------------|---------------|-------------|--------------|---------|
| STEM   | Mean      | 6.8         | 26.6      | 4.4         | 62.1          | 3.3         | 190.9        | 2935.5  |
|        | STDEV     | 7.7         | 12.6      | 0.6         | 14.9          | 1.0         | 23.2         | NA      |
| ROOT   | Mean      | 16.9        | 35.8      | 1.7         | 45.6          | 34.6        | 121.7        | 1790.2  |
|        | STDEV     | 2.9         | 9.6       | 1.0         | 10.1          | 10.3        | 13.4         | NA      |

Varea= Vessel area, Rayarea= Ray Area, Parea=Parenchyma area, Fibarea=Fiber area, Vdens=Vessel density, Vdiam=Vessel diameter, Flength= Fiber length and WT=fiber wall thickness

3.1. Growth rings
Both in root wood and stem wood, they have indistinct growth rings; the pattern is diffuse-porous wood, with no clear earlywood-latewood pore arrangement, and no significant difference in pore size (Figure 1a-b). In addition, the axial parenchyma pattern varied through the growth ring, predominantly paratracheal with winged aliform (Figure 2 a-b).

3.2. Vessels
Vessels exclusively solitary, almost 90% of the vessels are completely surrounded by other elements. It appears that every vessel is not to contact or connected one to another vessel, as viewed in Figure 1 and in multiples of 2-4 (7-9%) with the mean vessel diameter of stem wood is 190.9 mm and root wood 121.7, respectively; pit between vessel is alternately formed (Figure 2).

From earlier studies, root vessels are wider than stem vessels. Our study showed the opposite of the findings. It explains that the association of small vessel and low vessel density leads to the high mechanical stresses or strain and also affects the wood stiffness [24]. The existence of axial parenchyma (Figure 1 and 2) surrounding the narrow vessel in the root wood may influence the osmotic potential in the dry season and it will help the plants to refill the embolized vessel with water.

Figure 1. (a) Transversal section of root wood and (b) stem wood of Syzygium sp. in 140 magnification
3.3. Parenchyma
The structure of axial parenchyma to the vessel both of root and stem is in predominantly paratracheal with winged aliform. Paratracheal parenchyma is parenchyma which is associated with pores while apotracheal is not associated with pores. Confluent paratracheal parenchyma consists of rows or diagonals. The axial parenchyma situated around the vessel. This will help plants on the water strain and stress [24].

3.4. Rays
In root and stem wood, the rays are heterogeneous because it consists of procumbent cells and 2-4(6) upright cells and or quadratic cells. Uniseriate and multiseriate types are seen in the rays’ formation with uniseriate portions. It has 1-3 series width, with an average width of 0.4482 mm. The perforation plates are in simple formation. It will help the water transported in the xylem.

![Figure 2](image)

**Figure 2.** (a) Sections in Transversal, (b) Tangential and (c) Radial of Syzygium in 140X magnification.

3.5. Statistical analysis
The correlation data by organ and the results of the t-test are summarized in Table 1 and 3. Vessel element parameters including length, diameter, and frequency, as well as ray height were significantly different between root and stem (Table 1) Root wood had higher vessel frequency and narrower vessel elements when compared to stem wood (Table 1).

The cross-sectional vessel area should be the product of vessel density and vessel diameter. Yet, in our observation (Table 3), the vessel area decreases with the vessel density and tends to increase with the vessel diameter, which is opposite to the expectations. This is probably because of the tradeoff between the vessel density and vessel diameter. The stem wood and root wood of Syzygium sp. shows us that there is positive correlative between Vessel area and Vessel diameter, cell wall thickness and fiber diameter, Lumen diameter and fiber diameter and between the area of parenchyma and Fiber area. This positive relation leads to the variation of wood density, water transportation and vulnerability to embolism.

The absence of growth rings in root wood in stem and root of Syzygium sp. is also found in most of the tropical forest tree species where the quantitative causes are not sufficiently studied. Yet, the rainfall seasonality is suspected has a high effect to the formation of the growth increment in the
tropical forest [11,25-27]. The presence of the growth ring is also correlated with the distribution pattern of the vessel. It its most like
ly that for the porous wood will form the growth ring distinctively.

Table 2. t test for VDiameter = Vessel diameter in μm, Vdens = Vessel density/ frequency (vessels/mm2), CWT = cell wall thickness of fibres in μm, Varea = Vessel Area in %, Rarea = Ray Area in %, Parea = parenchyma area in % Farea = Fiber area in %.

| VDiameter | 3.241 | .080 | 11.544 | 38 | .000 | 69.18700 | 5.99354 | 57.05371 | 81.32029 |
|-----------|-------|------|--------|----|------|-----------|---------|----------|----------|
| Vdens     | 36.174| .000 | 11.544 | 30.445 | .000 | 69.18700 | 5.99354 | 56.95406 | 81.41994 |
| Varea     | 14.408| .001 | 5.481 | 38 | .000 | 10.09200 | 1.84135 | 6.36439 | 13.18961 |
| Rarea     | 1.419 | .241 | 2.574 | 38 | .014 | 9.13800 | 3.55010 | 1.95121 | 16.32479 |
| Parea     | 8.516 | .006 | 8.796 | 35.478 | .014 | 9.13800 | 3.55010 | 1.93439 | 16.34161 |
| Farea     | 2.101 | .155 | -4.084 | 38 | .000 | -16.49700 | 4.03893 | -24.7338 | -8.32062 |
| CWT       | .000 | 1.000 | .000 | 38 | 1.000 | .00000 | .64967 | -1.31519 | 1.31519 |

In conclusion, Syzygium sp. root and stem wood were different in quantitative but not qualitative features. The root wood had higher frequency of vessels, with the higher percentage of axial parenchyma than the wood of the stem. It is assumed that with the narrower vessel diameter and the high percentage of axial parenchyma, the roots are suspected to be more susceptible to water stress than the stem.

Secondly, in this study we found that in the wood stem with high percentage of parenchyma tends to have a positives correlation with the wider vessel diameter and the parenchyma placed around the vessels. This leads us to the fact regarding the independent function of axial parenchyma.
Table 3. Pearson correlation of the organs between root and stem measurements. **. Correlation is significant at the 0.01*. Correlation is significant at the 0.05. VHeight = Vessel Height in µm, Vdems= Vesel density/ frequency (vessels/mm²), CWT = cellwall thickness of fibres in µm., Rwidth = rays height in µm, Rdens = ray density (n/mm²), Varea = Vessel Area in %, Rarea= Ray Area in %, Parea=parenchyma area in % Farea = Fiber area in %, Flenght – Fiber length in µm, Fdiameter = Fiber diameter in µm, LumDiam = Lumen diameter in µm.

|             | Vdiameter | VHeight | Vdems | Rheight | Rwidth | Rdens | Rarea | Rarea | Parea | Farea | Flenght | Fdiameter | LumDiam | CW T |
|-------------|-----------|---------|-------|---------|--------|-------|-------|-------|-------|-------|----------|-----------|---------|------|
| Vdiameter   | 1         | - .192  | -.827 | .141    | .095   | .105  | .638  | .281  | -.723 | -.467 | .363     | .246      | -.013   | .162 |
| Vheight     | -.192     | 1       | .221  | .104    | -.256  | .047  | -.030 | -.001 | -.190 | .025  | .033     | -.109     | -.108   | -.024 |
| Vdems       | -.827     | -.221   | 1     | -.142   | -.396  | .319  | .597  | -.340 | .708  | .495  | .022     | -.274     | -.262   | -.023 |
| Rheight     | .141      | .104    | -.142 | 1       | -.132  | .288  | .228  | .137  | -.056 | -.230 | .253     | .046      | .009    | .060 |
| Rwidth      | .095      | -.256   | -.396 | -.132  | 1      | -.590 | -.161 | -.157 | -.468 | .235  | .069     | -.093     | .112    | -.290 |
| Rdens       | .105      | .047    | .319  | .288    | -.590  | 1     | .107  | .140  | .310  | -.186 | .033     | .123      | .070    | .097 |
| Varea       | .638      | -.030   | -.597 | .228    | -.161  | .107  | 1     | -.294 | -.494 | -.687 | -.227    | .369      | .355    | .116 |
| Rarea       | .281      | -.001   | .340  | .137    | -.157  | .140  | .294  | 1     | -.469 | -.891 | .114     | -.178     | .003    | -.216 |
| Parea       | .723      | -.190   | .708  | -.056   | -.468  | .310  | .494  | -.469 | 1     | .512  | .043     | -.026     | -.195   | .021 |
| Farea       | .467      | .025    | .495  | -.230   | -.235  | -.186 | .687  | -.891 | .512  | 1     | .019     | -.039     | -.177   | .110 |
| Flenght     | .363      | .033    | .022  | .253    | .069   | .033  | -.227 | .114  | .043  | .019  | 1        | -.385     | -.381   | -.091 |
| Fdiameter   | .246      | -.109   | -.274 | .046    | -.093  | .123  | .369  | -.178 | -.026 | -.039 | -.385    | 1         | .764    | .533 |
| LumDiam     | -.013     | -.108   | -.262 | .009    | .112   | .070  | .355  | .003  | -.195 | -.177 | -.381    | .764      | 1       | -.138 |
| CWT         | .162      | -.024   | -.023 | .060    | -.290  | .097  | .116  | -.216 | .021  | .110  | -.091    | .533      | -.138   | 1     |

**. Correlation is significant at the 0.01*. Correlation is significant at the 0.05.

Table 4. Summary of Anova test for quatitative feature of VDiameter= Vessel diameter in µm, VHeight = VWT = cellwall thickness of fibres in µm, Varea = Vessel Area in %, Rarea = Ray Area in %, Parea=parenchyma area in % Farea = Fiber area in %.

|                | Sum of Squares | df | Mean Square | F     | Sig. |
|----------------|----------------|----|-------------|-------|------|
| TreePart * Vdiameter | 9.333          | 16 | .583       | 20.125 | .000 |
| TreePart * Varea    | 9.500          | 32 | .297       | 4.156  | .028 |
| TreePart * Rarea    | 7.200          | 24 | .300       | 1.607  | .172 |
| TreePart * Parea    | 9.333          | 19 | .491       | 14.737 | .000 |
| TreePart * Farea    | 8.500          | 36 | .236       | .472   | .885 |
| TreePart * CWT      | .000           | 6  | .000       | .000   | 1.000 |
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