Anatomical comparison of branches and trunks of seven commercial wood species

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Abstract. Indonesia is a mega-biodiversity country that grows about 4000 timber producer tree species in tropical rain forest. The comprehensive information of wood properties and quality is important in managing the natural resources sustainably. However, stem in basic properties studies of wood from the natural forest is limited because of some difficulties in harvesting until the transportation process. Hence, study the wood branches becomes a solution, as sometimes wood core samples are not adequate. The question was whether the branch properties could represent the main stem properties? Wood anatomy is an important wood property that can predict the other properties, for instance, the physical and mechanical properties, that determine the effective use of this material. This paper aims to present the comparison of wood anatomical properties of branches and main stem of seven commercial wood species. Quantitative and qualitative anatomical structures were investigated according to the International Association of Wood Anatomist (IAWA) Committee. Result shows that the quantitative wood anatomy of four samples (Mimba, Leda, Jabon, and Bintangur) was statistically different, while only one parameter in Tusam, Mindi, and Khaya was different. Accordingly, it can be concluded that studying the wood properties could be carried out using branch effectively.

1. Introduction

Indonesia has around 4000 tree species, which can be used as timber for building, ships and others. However, until this time, only 400 species (10%) have economic value, and a smaller number, 260 species, have been classified as commercial timber [1] and the latest data update is 800 species classified as commercial timber [2]. Therefore, further research is needed on lesser-known species so that they can be used more optimally. Furthermore, in optimizing the use of wood, knowledge of the basic properties

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of wood is needed so that all parts of the wood can be used efficiently and, in the end, reduce excessive timber logging. One of the basic properties studies of wood can be identified by studying wood anatomy.

The use of trunk in basic properties studies of anatomical wood from natural forest is limited. There are some difficulties in harvesting until transportation process, mainly if the timber is collected from remote areas or the wood understudy is one of the rare and protected species. In some cases, the tree species is very limited in number, then use of whole trunk is impossible. Hence, study the wood branches becomes a solution, as sometimes wood core samples are not adequate. By studying the anatomical characteristics of the branches, logging activities to determine their basic properties can be reduced. The question was whether the nature of the branch could represent the nature of the main stem? Information regarding the comparison between branch and trunk properties is limited. Wood anatomy is one basic property of wood that can be used to predict the other properties, for instance, the physical and mechanical properties, that determine the effective use of this material. It does not contradict the science of wood anatomy because a study of wood anatomy focuses not only on the stem but also on the branches and roots [3]. However, currently, the data on wood anatomy mostly comes from the trunk. There is very poor information on wood anatomy data that comes from the branches or roots.

Research on comparing the anatomical characteristics of the trunk and branches has been carried out previously, among others by Samariha et al. [4] on Ailanthus altissima wood. In that research, it was known that there were differences between trunk and branches particularly in fibre dimension (length, diameter, lumen width) and its thickness. However, differences in fibre dimensions between trunk and branches were still within the normal range for hardwood. Yaman [3] also researched the anatomical properties of the trunk and branches of Ficus carica L. In that study, the anatomical properties of the trunk and branches of Ficus carica L had similar qualitative anatomical properties except for prismatic crystals in ray cells.

Based on the reasons above, this study aims to present the comparison of wood anatomical properties of branches and main stem of seven commercial wood species, namely Calophyllum tomentosum (Bintangur), Pinus merkusii (Tusam), Khaya anthotheca (Khaya/mahoni Afrika), Anthocepalus macrophyllus (Jabon), Eucalyptus sp. (Leda), Melia azedarach (Mindi) and Azadirachta indica (Mimba). By comparing the anatomical properties of branches and trunk, optimizing wood utilization can be carried out.

2. Materials and Methods

2.1. Raw material

Branches and primary-stem of seven commercial wood species: Calophyllum tomentosum Wight (Bintangur), Pinus merkusii Jungh. & de Vriese (Tusam), Khaya anthotheca C.DC. (Khaya/mahoni Afrika), Anthocepalus macrophyllus Havil. (Jabon), Eucalyptus sp. (Leda), Melia azedarach L. (Mindi), and Azadirachta indica A. Juss. (Mimba) were collected from the arboretum located at the Forest Research and Development Center, Bogor, Indonesia, in a 7 cm thick disc. Specimens for sectioning and cell maceration were prepared from each disc from three parts at heartwood, transition, and sapwood zones.

2.2. Anatomical structure observation

The anatomical structure observation was conducted on sectioned specimens. The specimen was prepared following Sass [5]. After softening for three days, the samples were then sliced in 20-30 μm thick using a sliding microtome (American Optical AO 860) for cross-section, radial and tangential sections. Then the slices were stained in 2.5% safranin. Entellan was used for the permanent mounting of the slides [6]. Anatomical characteristics of wood were examined qualitatively and quantitatively according to hardwood list of the IAWA [7].
2.3. Measurement of cell dimensions

Every species is made small stick then put into the test tube, that contains of hydrogen peroxide (H$_2$O$_2$) and acetic acid glacial (CH$_3$COOH) in the ratio of 1:1 (v/v), heated on the water bath [8]. Then the measurement of dimension: length, diameter, and fiber lumen diameter using the conventional microscope was conducted using Zeis software. Measurements were also made for vessel length and diameter. The thickness of fiber wall was determined as the difference between fiber diameter and lumen width divided by two. For dimension, 30 fibers are measured randomly. From raw data, it was then averaged dimension and deviation was also measured. The following derivative indices were determined in the form of Muhlsteph, Flexibility, Runkel Ratios, Felting Power, and Coefficient of Rigidity. Fibre dimension derived values are calculated using Formula 1-5 according to Rahman and Siagian [9].

\[
\text{Runkel ratio} = \frac{2 (\text{Fibre wall thickness})}{\text{Lumen diameter}}
\]

\[
\text{Felting power} = \frac{\text{Fibre length}}{\text{Fibre diameter}}
\]

\[
\text{Flexibility ratio} = \frac{\text{Lumen diameter}}{\text{Fibre diameter}}
\]

\[
\text{Coefficient of rigidity} = \frac{\text{Fibre wall thickness}}{\text{Fibre diameter}}
\]

\[
\text{Muhlsteph ratio} = \frac{(\text{Fibre diameter}^2 - \text{Lumen diameter}^2)}{\text{Fibre diameter}^2} \times 100\%
\]

2.4. Data analysis

Anatomical structures were presented as figures and narrative descriptions, while fibre and vessel dimensions measured the averages and standard deviations. The difference in fibre and vessel dimension between main stem and branches was analysed using an independent t-test from SPSS Statistics version 19 published by IBM, New York, United States America. If the significance level at $\alpha > 0.05$, it meant that the average values are statistically not different.

3. Results and Discussion

The anatomical of trunk and branches from seven wood species are presented in Figure 1-7. The images of cross, radial, and tangential sections of the trunk and branches were juxtaposed to provide a direct comparison. The descriptions of wood anatomical characteristics are presented in Table 1. Number in brackets show the IAWA list of hardwood code except for P. merkusii, which is categorized into softwood.

*Pinus merkusii*: Growth ring boundaries indistinct or absent [41], gradual transition from earlywood to latewood [43], IT pitting (predominantly) uniseriate [44], LW LTs thin-walled (double wall thickness < radial lumen diameter) [54], pinoid [91], 1-3 pits per cross-field [98], average ray height medium (5 to 15 cells) [103], average ray height high (from 16 to 30 cells) [104], rays exclusively uniseriate [107], axial canals [109].

Qualitatively, the anatomical structures of each wood species observed from trunk and branch were similar. The result of the study supports the finding mentioned by Longui, Galao, Rajput, and de Melo [10], who reported that vessel grouping in *Inga laurina* trunk is similar to branch. Therefore, the branch can be used as a substitute for the trunk for identification.
**Table 1.** Descriptions of wood anatomical characteristics of stem and branch of seven wood species.

| Wood species             | Growth Ring | Vessels       | Fibres      | Parenchyma | Rays        | Crystal & Others |
|--------------------------|-------------|---------------|-------------|------------|-------------|------------------|
| *Calophyllum tomentosum* | 2           | 5, 7, 9, 13, 22, 42, 58 | 61, 69, 71, 72 | 85, 89 | 97, 115, 116 | 136, 137, 138, 141 |
| *Khaya anthotheca*       | 2           | 5, 13, 22, 24, 30, 42, 43, 46, 58 | 61, 65, 66, 68, 69 | 76, 79, 92, 93 | 97, 98, 106, 107, 115 | 136, 137, 141, 156 |
| *Anthocephalus macrophyllus* | 2           | 5, 10, 13, 22, 23, 25, 26, 29, 30, 42, 46, 47 | 61, 62, 66, 69 | 76, 77, 93, 94 | 97, 98, 102, 103, 106, 108, 115 | 153 |
| *Eucalyptus* sp.         | 1, 2        | 5, 7, 9, 13, 22, 26, 27, 29, 41, 42, 43, 46, 47, 56, 60 | 62, 69 | 76, 79, 80, 92, 93 | 96, 97, 104, 106, 115, 131 | 136, 142 |
| *Azadirachta indica*     | 2           | 5, 13, 22, 24, 25, 30, 40, 42, 46, 47, 49 | 61, 66, 69 | 79, 85, 89 | 97, 106, 107 | 136, 141 |
| *Melia azedarach*        | 1           | 3, 4, 6, 7, 8, 11, 12, 13, 22, 25, 30, 36, 37, 39, 58 | 61, 66 | 79, 89, 91, 92 | 98, 104, 106, 114, 122 | 136, 142 |
**Figure 1.** *Calophyllum tomentosum* Wight (Bintangur); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial-sections of the trunk (E) and branch (F).

**Figure 2.** *Pinus merkusii* Jungh. & de Vriese (Tusam); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial sections of the trunk (E) and branch (F).
Figure 3 *Khaya anthotheca* C. DC. (Khaya/mahoni Afrika); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial-sections of the trunk (E) and branch (F).
Figure 4. *Anthocephalus macrophyllus* Havil. (Jabon); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial sections of the trunk (E) and branch (F).

Figure 5. *Eucalyptus* sp. (Leda); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial sections of trunk (E) and branch (F).
**Figure 6.** *Melia azedarach* L. (mindi); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial sections of the trunk (E) and branch (F).
Figure 7. *Azadirachta indica* A. Juss. (Mimba); cross-sections of the trunk (A) and branch (B), D: tangential sections of the trunk (C) and branch (D), and radial sections of the trunk (E) and branch (F).

The wood anatomical structures of the trunk and branch of seven wood species studied similar to those described in [11-15]. Furthermore, the independent t-test of fibre and vessel dimension of the main stem (trunk) and branch and the calculation of fibre derivative values of each species are presented in Table 2 and 3.

### Table 2. Independent t-test of fiber length, cell wall thickness and vessel diameter of trunks and branches.

| Wood species          | Fiber length (µm) | Cell wall thickness (µm) | Vessel Diameter (µm) |
|-----------------------|-------------------|--------------------------|----------------------|
|                       | Trunk             | Branch                   | Trunk                | Branch               | Trunk                | Branch               |
| *Calophyllum tomentosum* | 1243.2a          | 1188.1a                  | 4.5a                 | 4.8a                 | 232.9a               | 205.7a               |
| *Pinus merkusii*       | 5003.3a          | 3698.4b                  | 7.9a                 | 6.1a                 | -                    | -                    |
| *Khaya anthotheca*     | 1566.3a          | 1506.4a                  | 4.7a                 | 5.1a                 | 189.5a               | 186.5b               |
| *Anthocephalus macrophyllus* | 1606.2a    | 1321.0a                  | 4.5a                 | 4.2a                 | 170.4a               | 159.9a               |
| *Eucalyptus sp.*       | 1155.6a          | 9215.7a                  | 5.2a                 | 5.0a                 | 146.3a               | 127.2a               |
| *Azadirachta indica*   | 1516.5a          | 1277.9a                  | 3.9a                 | 4.2a                 | 192.5a               | 178.5a               |
| *Melia azedarach*      | 1059.0a          | 1071.2a                  | 3.6a                 | 4.1a                 | 172.9a               | 205.0a               |

Remarks: The letters in the same column indicate levels of significance among the treatments (different sample source: stem or branch) at α = 0.05; the same letters in one column mean the average values are statistically not different.

The results from Table 2 show that majority of tree species have similar cell dimensions in the stems and their branches except for *P. merkusii* and *M. azedarach* for fibre length and *K. anthotheca* for vessel diameter. However, the fibre derivative values of *P. merkusii* and *M. azedarach* resulted in the same pulp and paper quality class, namely quality class II for *P. merkusii*’s stem and branch and quality class III for *M. azedarach*’s stem and branch. Therefore, it can be concluded that the main stem and branch have similar wood properties. Furthermore, analysis confirmed that the trunk anatomical structure was similar with branch and for wood density, although trunk and branch have a different size [16].
Table 3. Fiber dimensions derived values of trunks and branch.

| Species                        | Derived values of fiber dimensions |
|--------------------------------|-----------------------------------|
|                                | Rankel ratio | Felting power | Flexibility ratio | Coef. of Rigidity | Multishep Ratio | Quality Class | Rankel ratio | Felting power | Flexibility ratio | Coef. of Rigidity | Multishep Ratio | Quality Class |
| Calophyllum tomentosum (Bintangur) | 0.57         | 53.52         | 0.64             | 0.18              | 58.87            | III           | 0.70         | 58.33         | 0.59             | 0.20             | 64.59           | III           |
| Quality class                  | 25           | 50            | 50               | 25                | 25               | 175           | 25           | 50            | 50               | 25               | 25              | 175           |
| Pinus merkusii (Tusam)         | 0.56         | 111.66        | 0.65             | 0.18              | 57.59            | II            | 0.26         | 79.36         | 0.79             | 0.10             | 36.75           | II            |
| Quality class                  | 25           | 100           | 50               | 25                | 50               | 250           | 50           | 50            | 50               | 50               | 50              | 250           |
| Khaya anthotheca (Khaya/mahoni Afrika) | 0.71       | 69.04         | 0.59             | 0.21              | 65.11            | III           | 0.74         | 53.39         | 0.58             | 0.21             | 66.13           | III           |
| Quality class                  | 25           | 50            | 50               | 25                | 25               | 175           | 25           | 50            | 50               | 25               | 25              | 175           |
| Anthocephalus macrophyllus (Jabon) | 0.26       | 40.00         | 0.79             | 0.10              | 37.09            | II            | 0.33         | 31.01         | 0.75             | 0.12             | 42.79           | II            |
| Quality class                  | 50           | 25            | 50               | 50                | 50               | 225           | 50           | 25            | 50               | 50               | 50              | 225           |
| Eucalyptus sp. (Leda)          | 0.70         | 53.85         | 0.59             | 0.20              | 64.74            | III           | 0.66         | 40.74         | 0.61             | 0.20             | 63.03           | III           |
| Quality class                  | 25           | 50            | 50               | 25                | 25               | 175           | 25           | 25            | 50               | 25               | 25              | 175           |
| Melia azedarach (Mindi)        | 0.49         | 36.19         | 0.67             | 0.16              | 54.61            | III           | 0.51         | 40.83         | 0.66             | 0.17             | 55.78           | III           |
| Quality class                  | 50           | 25            | 50               | 25                | 50               | 200           | 25           | 25            | 50               | 25               | 50              | 175           |
| Azadirachta indica (Mimba)     | 0.37         | 36.95         | 0.73             | 0.13              | 46.40            | II            | 0.47         | 41.49         | 0.68             | 0.16             | 53.17           | III           |
| Quality class                  | 50           | 25            | 50               | 50                | 50               | 225           | 50           | 25            | 50               | 25               | 50              | 200           |

From Table 3, it can be seen that even though the fibre length and cell wall thickness of A. indica were not significantly different, the fibre derivative values resulted in different quality classes. A. indica stem had a score of 225 that makes the fibre belong to class II for quality of pulp and paper, while the branch had a score of 200, which causes the fibre to fall into class quality III. According to Rahman and Siagian [9], timber in Quality Class II has moderate low to medium-heavy density (strength class III/IV) with thin to a medium wall and moderate lumen; during sheet forming, fibers flatten easily, and felting, as well as bonding characteristics, are fairly good. Sheet produced has a fairly high tear, burst and tensile strength. Furthermore, timber in Quality Class III has moderate to heavy density (strength class I/II) with a thick wall and narrow lumen. During sheet forming, fibers do not flatten easily, and felting and bending among fibers are poor, producing low quality in tear, burst and its tensile strength. The difference of the stem and branch was in the Coefficient of Rigidity value. It is calculated from the fibre wall thickness divided by fibre diameter. Thus, the fibre diameter of A. indica seems different statistically.

4. Conclusion
The result showed quantitative wood anatomy, specifically fibre dimensions of length, thickness, and vessel diameter of four samples, Azadirachta indica A. Juss. (Mimba), Eucalyptus sp. (Leda), Anthocephalus macrophyllus Havil. (Jabon), and Calophyllum tomentosum Wight (Bintangur) were not statistically different, while only one parameter in Pinus merkusii Jungh. & de Vriese (Tusam), Khaya anthotheca C.DC. (Khaya/mahoni Afrika), and Melia azedarach L. (Mindi) were different, namely fibre
length in Tusam and Mindi, and vessel diameter in Khaya wood. In general, the main stem and branch have similar wood properties. Accordingly, it can be concluded that the study of wood properties could be carried out in branch effectively, and the branch can be used as a substitute for the trunk for identification.

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