Comparison of the Wood Anatomy and Fibers Derived from Indonesian *Toona sinensis* Roem. and *Toona sureni* Merr.

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In terms of their anatomy, there is confusion in differentiating between *Toona sinensis* (Juss.) Roem. and *Toona sureni* (Blume) Merr. In order to validate the identification of both species, reconfirmation of the primary character differences is required. The objectives of this study are the reconfirmation of the anatomical properties to confirm their differences and the evaluation of the fiber morphology in terms of pulp and paper raw material quality. The results show that there were differences in the gross physical features of the bark and the color of the wood. The wood color of *T. sinensis* is red-brown and darker, while *T. sureni* is white-yellow, leading to the nomenclature red and white surian, respectively. An anatomical view of *T. sinensis* shows that the annual growth ring has indistinct boundaries as a primary distinguishing anatomical feature, while *T. sureni* shows that the annual growth ring boundaries are distinct. The annual growth ring allows the establishment of intra-annual past and present structure-function relationships as well as its sensitivity to environmental variability. Based on the results, both species have different anatomical properties, and both species are suitable to be used as a raw material for pulp and paper production.

Keywords: Fiber derivate; Fiber dimension; Toona wood; Red surian; White surian; Toona anatomy

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INTRODUCTION

Toona (surian) wood (family Meliaceae) is a wood species with the potential to be continuously developed, since it has a medium cycle of growth. Indonesia has developed surian wood through a social forestry program by the Ministry of Environment and Forestry (the Republic of Indonesia), using an agroforestry system in Java, Sumatera, and Sulawesi. The genus of *Toona* has the two most popular species developed in Indonesia, *i.e.*, *Toona sinensis* Roem. and *T. sureni* Merr. The two species have a difference in morphology and genetic characteristics (Li *et al*. 2015; Xing *et al*. 2016; Jayusman *et al*. 2017; Lin *et al*. 2018). However, the differences in their basic wood properties, especially their anatomical properties, have not been clarified. Wood identification through the observation of wood anatomy can be a beneficial tool for developing uses for *Toona* wood. In addition, the anatomical identification of wood is an important step in its use for legal timber commercial as well as forensic purposes (Wheeler *et al*. 1989; Wheeler and Bass 1998). The identification of wood is important because differences of wood properties can occur within trees, between trees and between species (Sharma *et al*. 2011; Sonsin *et al*. 2012;

Uetimane *et al.* 2018). The study focused on the differences in the properties of *T. sinensis* and *T. sureni* woods.

A description of the anatomy of *Toona* wood has been described by several researchers (Heinrich and Banks 2006; Indriyani 2014). However, such descriptions are still not specific, which results in confusion in differentiating between *T. sinensis* and *T. sureni*. The International Tropical Timber Organization (ITTO) has released information about the lesser-used species, *i.e.*, *T. sinensis* (ITTO 2016a) and *T. sureni* (ITTO 2016b) on their website in 2016. However, the anatomical data do not show a difference between the two species (ITTO 2016c). The macro and micro pictures of the anatomical features of *T. sinensis* and *T. sureni* were similar. Furthermore, this causes confusion in terms of how different the anatomical properties of the two species are. The confusion causes misidentification of *Toona* wood species and errors in citing in the bibliography. For this reason, it is necessary to have complete identification guidelines that have undergone anatomical scrutiny, especially in terms of the gross physical and anatomical features of the wood. This paper will clear up the mistakes and confusion that occur when distinguishing between *T. sinensis* and *T. sureni*. The objectives of this study are the reconfirmation of the anatomical properties of the two species to ensure their differences and the evaluation of the fiber morphology in terms of its quality for pulp and paper raw material usage.

EXPERIMENTAL

Materials

Both wood species (*T. sinensis* and *T. sureni*) were harvested (at 12 years old) from an exsisting conservation area managed by an agroforestry system developed by PT. Perhutani in collaboration with local communities (Candiroto Village, District of Temanggung, Province of Central Java, Indonesia). Wood samples were taken from the middle (1.3 m from the bottom) of the stem in a disc shape that was 10 cm in thickness (as shown in Fig. 1).

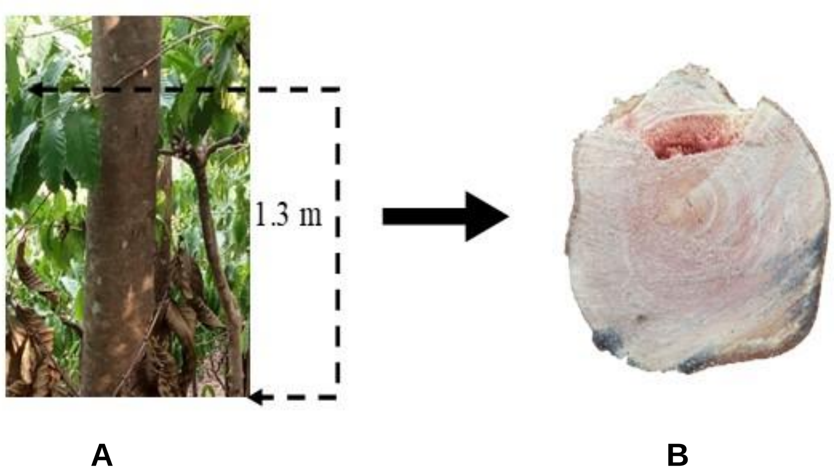

Fig. 1. Position of wood sample: (A) toona tree; and (B) wood sample

Observation of the Fundamental Properties

The preparation of the specimen for anatomical feature observation was based on the methods of Jansen *et al*. (1998). Woodblock samples (2 cm x 2 cm x 2 cm) were prepared and saturated in boiled water for 24 h. Then, the wood samples were immersed in a boiling solution of water and glycerin (2 to 1 volume ratio) for 24 h (two times), to soften the specimen. The samples were sliced *via* a sliding microtome with a metal knife to obtain a 10 µm to 20 µm thick sample. The best specimens were stained with safranin to highlight the anatomical features.

The observation of the fundamental properties of the two species covered their gross physical and anatomical features. The gross physical features, as observed on the surface of the wood sample, were as follows: the bark surface of the tree, the color of the wood surface, figure, texture, and odor. The anatomical features were observed based on those proposed by the IAWA committee (Wheeler *et al*. 1989). Three sections of each wood sample were observed, *i.e.*, cross-sections (transversal sections), radial, and tangential sections. The anatomical features, *i.e.*, anatomical features visible with a hand lens or unaided eye, which included the following: the porosity, vessel arrangement and grouping, axial parenchyma arrangement and abundance, ray size relative to vessel diameter, ray height, and the presence or absence of storied structures.

Fiber Analysis

Wood chips of both *Toona* species were macerated based on the method of Safdari and Devall (2012). The wood chips were immersed in a mixture of 30% hydrogen peroxide and glacial acetic acid (a 1 to 1 ratio) at a temperature of 60 to 80 °C for 24 h (two times) or until the wood chips became colorless and soft (making it easy to separate into individual fibers). The macerated fibers were washed with hot water (temperature greater than 70 °C) until they became acid-free and the acid odor was removed. Finally, the macerated fibers were stained with safranin to highlight the thickness of the cell wall and the lumen, *i.e.*, until both color contrasts could be seen clearly.

The fiber dimensions were measured *via* light microscopy with a Zeiss instrument at 100 times magnification for the fiber length and 400 times magnification for the fiber diameter and fiber lumen diameter. The measurement of the fiber morphology was observed 50 times to ensure accuracy. The fiber cell wall thickness was measured based on the calculations of the cell diameter minus the lumen diameter and divided by 2. Furthermore, the fiber derivative was calculated based on the fiber morphology. The derived values were calculated based on Eqs. 1 to 4,

$$SR = \frac{Fiber\ length}{Fiber\ diameter} \tag{1}$$

$$FC = \frac{Fiber\ lumen\ diameter}{Fiber\ diameter} \times 100\% \tag{2}$$

$$RR = \frac{2 \times Fiber\ cell\ wall\ thickness}{Fiber\ lumen\ diameter} \tag{3}$$

$$LSF = \frac{FIber\ diameter^2 - Fiber\ lumen\ diameter^2}{Fiber\ diameter^2 + Fiber\ lumen\ diameter^2} \tag{4}$$

where SR is slenderness ratio, FC is flexibility coefficient, RR is Runkel ratio (RR), and LSF is Luce’s shape factor (Runkel 1949; Luce 1970; Malan and Gerisher 1987).

RESULTS AND DISCUSSION

Gross Physical Features

Figure 2 shows the difference between the gross physical features of *T. sinensis* and *T. sureni* based on what is visible to the naked eye. A difference could be seen between the two species before they were debarked, as the bark of *T. sinensis* was rougher compared to the bark of *T. sureni*. The bark of *T. sinensis* was cleaved and visibly thicker, while the bark of *T. sureni* was smoother and visibly thinner. The heartwood of *T. sinensis* was generally reddish-brown and darker in color compared to its sapwood. The wood color of *T. sureni* was brighter compared to *T. sinensis* and the white-yellow coloration was relatively similar between the heartwood and sapwood. The grain pattern of both species did not have a drastic difference between them, it generally was straight grain and partly looked interlocked. The color and grain pattern are the primary factors affecting the appearance and features of the wood. The color of a wood gives wood its aesthetic appearance and it is dependent on the type and chemical composition of the wood, especially its extractives and lignin content. Interestingly, the odor of *T. sinensis* had stronger aromatic properties, similar to red-cedar, while the odor of *T. sureni* was less aromatic, weak, and had no specific aroma. In addition, ITTO (2016a; 2016a) reported that the odor of both species aromatic profile was cedar-like. The texture of *T. sinensis* was rather slippery and lustrous, while *T. sureni* was coarse and rather lustrous.

A previous study by Heinrich and Banks (2006) about *T. sinensis* and *T. ciliate* described that the macroscopic features of both species are influenced by different environmental conditions. Based on the results of Henrich and Bank (2006), *T. sinensis* has a light-colored young tree, but recent research shows that the color is darker. Several previous studies that outlined a comparison of species within the same genus showed that different properties, *e.g.*, growth, phenology, physiology, and anatomy, were affected by the environmental conditions (Sint *et al*. 2013; Maiti *et al*. 2016; Beeckman 2016).

Fig. 2. Gross physical features of both Toona wood species: (A) bark surface of *T. sinensis*, which is cleaved, rough, and thicker; (B) transversal section of *T. sinensis*, which is red-brown and darker; (C) bark surface of *T. sureni*, which is smoother, and thinner; and (D) transversal section of *T. sureni*, which is white-yellow and brighter

Anatomical Features

The anatomical features of *T. sinensis* and *T. sureni* are shown in Fig. 3 and Table 1. The characteristics of *T. sinensis* can be explained by the unclear growth ring boundary between the earlywood and the latewood. The pattern of their vessels is diffuse-porous with frequency ranges of 8 per mm^2 and 77% solitary vessel with radial multiples 2 (2 to 3). The type of vessel was round to oval in shape with a vessel length of approximately 402 to 465 µm. The diameter of the tangential vessel was approximately 200 to 226 µm with a simple perforations plate. The pits on the wall of the vessels were alternate with a horizontal diameter of approximately 12 µm, while the vessel-ray pits were simple and pit rounded. There were tyloses clearly in some of the vessels. The type of parenchyma was a multilateral paratracheal, and there was not any apotracheal parenchyma with an axial parenchyma strand length of 3 cells to 17 cells.

Table 1. Comparison of the Wood Anatomical Features between *T. sinensis* and *T. sureni*

Anatomical Characteristics	*T. sinensis*	*T. sureni*
Growth ring boundaries vessel		
Boundaries	Indistinct	Distinct
Solitary vessel (%)	77%	78%
Multiple vessel	2 (2 to 3)	2 (2 to 4)
Diameter (µm)	213 ± 13	243 ± 21
Frequency per mm^2	8	14
Length (µm)	432 ± 33	502 ± 28
Inter-vessel pith		
Arrangement	Alternate	Alternate
Diameter (µm)	12	12
Vessel-ray pitting	With much reduced border to apparently simple: pith rounded	With much reduced border to apparently simple: pith rounded
Parenchyma		
Paratracheal axial	multilateral paratracheal	multilateral paratracheal
Apotracheal axial	-	-
Strand length, cell	3 to 17	4 to >20
Rays		
Width (seriete)	1 to 4	1 to 4
Height (µm)	547	612
Max height (µm)	894	873
Frequency per mm	16	17
Fibers		
Pith type	simple	simple
Cell wall thickness (µm)	2.4	2.2
Diameter (µm)	23	38
Lumen diameter (µm)	20	35
Length (µm)	1322	1642
Note: Bold sections denote sub-categories of anatomical characteristics		

The rays were unicellular and heterocellular (1 seriate to 4 seriate) with a frequency of 16 per mm and a height of approximately 547 µm. The fibers were simple bordered pits with a fiber length of approximately 1322 µm, a fiber diameter of 23 µm (tangential), a fiber wall thickness of 2.4 µm, and a lumen diameter of 20 µm.

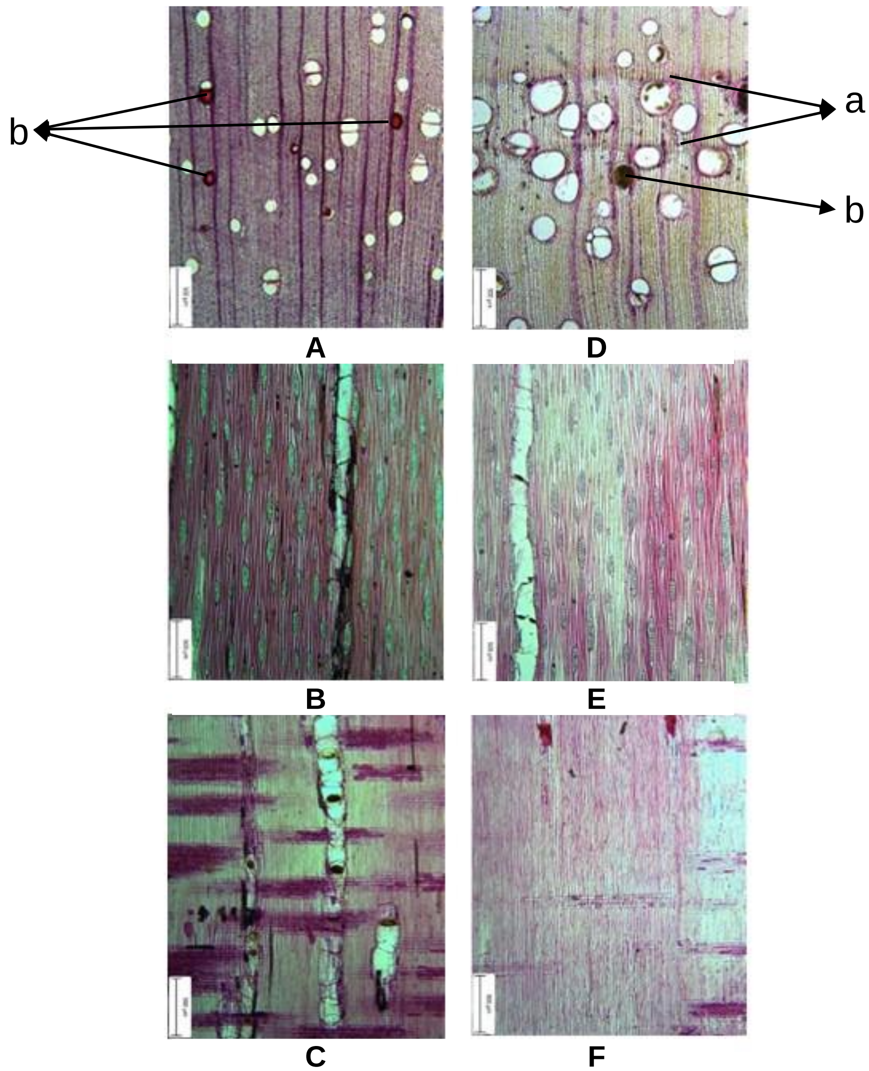

Fig. 3. Anatomical features of both *Toona* wood species: (A) transversal section of *T. sinensis*; (B) tangential section of *T. sinensis*; (C) radial section of *T. sinensis*; (D) transversal section of *T. sureni*; (E) tangential section of *T. sureni*; (F) radial section of *T. sureni;* (a) growth ring; (b) tyloses

The characteristics of *T. sureni* can be described as having growth ring boundaries between the earlywood and latewood. The vessels in the earlywood are wider in tangential diameter compared to the tangential diameter of the vessels in the latewood. The pattern of their vessels is diffuse-porous with frequency ranges of 14 per mm^2 and 78% solitary vessel with radial multiples 2 (2 to 4). The type of vessel is relatively round in shape except multiple radial vessels are oval shaped. The average vessel length was approximately 474 µm to 530 µm. The vessel tangential diameter was approximately 222 µm to 264 µm with a simple perforations plate. The vessel pits on the cell wall were alternate with a horizontal diameter of approximately 12 µm, while the vessel-ray pits are simple and pit rounded. The tyloses were clearly detected in several vessels. The type of parenchyma is multilateral paratracheal and there was not apotracheal parenchyma with an axial parenchyma strand length of 4 cells to greater than 20 cells. The rays are unicellular and heterocellular (1 seriate to 4 seriate) with a frequency of 17 per mm and a height of approximately 612 µm. The fibers are simple bordered pits with a fiber length of approximately 1462 µm, a fiber diameter of 38 µm (tangential), a fiber wall thickness of 2.2 µm, and a lumen diameter of 35 µm.

Based on this recent research, there is a difference in the growth ring boundaries between the two *Toona* species. This was similar to the findings of Heinrich and Bank (2006), who described *T. sinensis* as missing a growth ring under several environmental conditions. Furthermore, this research establishes that there is a difference between *T. sinensis* and *T. sureni*, which was previously stated by ITTO that the wood identification markers of both species are similar (ITTO 2016a,b). Based on the observations in this study, it can be concluded that there is clear evidence of differences in the anatomical structures of *T. sinensis* and *T. sureni*.

Characteristics of Fibers Derived from *Toona* Wood

The characteristics of fibers derived from *Toona* wood are comparable to those of fibers currently in use as pulp and paper raw material. The fiber characteristics, *e.g.*, slenderness ratio, flexibility coefficient, Runkel ratio, and Luce's shape factor, have been recognized as important traits in terms of pulp and paper properties (Ohshima *et al*. 2005; Takeuchi *et al.* 2016). The characteristic of fibers derived from *T. sinensis* and *T. sureni* are shown in Table 2.

Table 2. Comparison Characteristics of Fibers from *T. sinensis* and *T. sureni*

Derivative Fibers	*T. sinensis*	*T. sureni*
Slenderness ratio	44.6	53.1
Flexibility coefficient	79.7	85.3
Runkel ratio	0.1	0.2
Luce's shape factor	0.2	0.16

Slenderness ratio (SR)

The slenderness ratio (felting power) is an important factor that has a positive effect on the strength, tear, burst, tensile breaking force, and double folding resistance, according to physical test results of a paper (Ekhuemelo and Udo 2016). The SR values of *T. sinensis* and *T. sureni* were 44.60 and 53.11, respectively. Furthermore, this value is appropriate for usage as a pulp and paper raw material. The value required for good paper quality is a value of 70 to 90 for softwood and 40 to 60 for hardwood. The values of these two species are higher compared to the SR value of *Acacia mangium* (Andianto *et al*. 2020). However, the values are almost the same compared to *Eucalyptus* (Oshima *et al*. 2005; Morais *et al*. 2019), the values are lower than *Moringa oleifera* (Ekhuemelo and Udo 2016); and the values are lower than the other lesser-known species in Indonesia (*Saurauia bracteosa* DC., *Saurauia capitulata* Smith., and *Saurauia nudiflora* DC) that were reported by Damayanti and Dewi (2019).

Flexibility coefficient (FC)

Bektas *et al*. (1999) determined that there are four groups of fibers, *i.e.*, high elastic fibers (FC is greater than 75%), elastic fibers (FC equals 50% to 75%), rigid fibers (FC equals 30% to 50%), and highly rigid fibers (FC is less than 30%). The FC value of *T.*

sinensis and *T. sureni* obtained for this study were 79.7% and 85.1%, respectively. Based on the classification of fiber elasticity, the FC values for both species indicated their fibers had high elasticity. Furthermore, the virgin fibers usually have a flexible fiber, which results in better bonding ability and softness compared to secondary fibers or recycled fibers (Assis *et al*. 2018). The high flexibility coefficient value also implies that the fibers can easily be flattened and yield good paper with high strength properties (Sadiku and Abdukareem 2019).

Runkel ratio (RR)

The Runkel ratio of fiber is one of the features that has been recognized as an important trait for pulp and paper properties, since it is related to paper conformity, pulp yield, and digestibility (Ohshima *et al*. 2005). The RR value of *T. sinensis* and *T. sureni* were 0.1 and 0.2, respectively. A RR value of less than 1.0 in hardwoods is desirable to obtain great conformability and interphase bonding fiber to fiber in a paper (Oshima *et al*. 2005; Ekhuemelo and Udo 2016; Sadiku and Abdukareem 2019). Based on the results of both species, the Runkel ratio denotes they are qualified as a pulp and paper raw material. A high Runkel ratio value indicates that the fiber is stiffer, while a low Runkel ratio value indicates that the fibers easily collapse, which will form paper with good strength properties (Ashori and Nourbakhsh 2009; Istikowati *et al*. 2016).

Luce's shape factor (LSF)

Luce's shape factor is an index for the resistance beating of a pulp. A low Luce's shape factor value indicates a decreased resistance to beating during the papermaking process (Luce 1970). Takaeuchi *et al*. (2016) reported that the Luce's shape factor value of *Macaranga bancana* and *Macaranga pearsonii* wood was approximately 0.08 to 0.09. The Luce's shape factor value of *Eucalyptus* ranged from 0.37 to 0.42 (Ohshima *et al.* 2005). The mean value of the Luce's shape factors for *T. sinensis* and *T. sureni* were 0.2 and 0.1, respectively. This suggested that the fibers from both species would produce a good quality paper.

CONCLUSIONS

1. This research has provided observation of the anatomical features of *T. sinensis* and *T. sureni*, which can be used to distinguish between the two species. A comparative analysis of the anatomical features showed that both species have different growth ring boundaries vessels, *i.e.*, *T. sinensis* is indistinct and *T. sureni* is distinct.
2. The fibers from Toona wood (*T. sinensis* and *T. sureni*) species could produce paper with higher quality properties compared to the paper currently developed from fast-growing tree species.

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