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Evaluation of Four Lesser-Known Indonesian Hardwood Species for Paper Pulp Production Based on Fiber Quality and Specific Gravity

Evaluacija četiriju manje poznatih indonezijskih vrsta drva listača za proizvodnju papirne pulpe na temelju kvalitete vlakana i specifične gustoće

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ABSTRACT • *The effort to ensure raw material sustainability in the paper pulp industry needs to focus on finding substitutes for wood species. Raw materials for making paper pulp can be obtained from all species of wood, but they must meet specific criteria. We analyzed the specific gravity and maceration preparations of four lesser-known hardwood species that grow in West Sulawesi as potential raw materials for the paper pulp industry. The study indicated that three lesser-known hardwood species (palado, kambelu, and kanduruan) were potentially useful as raw material for pulp paper making.*

KEYWORDS: *fiber quality; specific gravity; lesser-known hardwoods; West Sulawesi*

SAŽETAK • *Napori usmjereni na osiguranje održivosti sirovina za pripremu papirne pulpe moraju se usredotočiti na pronalaženje zamjena za trenutačno upotrebljavane vrste drva. Svaka vrsta drva može biti sirovina za izradu papirne pulpe, ali mora ispunjavati određene kriterije. U radu je analizirana specifična gustoća i priprema macerata četiriju manje poznatih vrsta drva listača koje rastu u Zapadnom Sulawesiju kao potencijalne sirovine za pripremu papirne pulpe. Studija je pokazala da se tri manje poznate vrste drva listača (palado, kambelu, and kanduruan) mogu potencijalno iskorištavati kao sirovina za pripremu papirne pulpe.*

KLJUČNE RIJEČI: *kvaliteta vlakana; specifična gustoća; manje poznate vrste drva listača; Zapadni Sulawesi*

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1 INTRODUCTION
1. UVOD

The Southeast Asian Plant Resources Book categorizes wood species in Southeast Asia as major, minor, lesser-known, and least-known wood species. Due to intensive exploitation, the supply of commercial wood (major and minor wood species) is continuously declining and becoming scarcer. The increasing demand for wood from natural forests, as raw material for paper, can threaten forest sustainability. Today, the forest area is decreasing, but the global need for paper raw materials continues to increase (Deniz *et al.,* 2017). According to Jepri *et al*. (2016), the increasing of raw materials for the paper industry exceeded 100 million tons per year, and wood as a main paper industry raw material was obtained from hardwood and softwood (Bahri, 2015; Gülsoy and Şimşir, 2018).

The raw materials for making paper pulp in Indonesia commonly come from monoculture crops such as acacia, pine, albizia, and eucalyptus. Nowadays, there are some new raw materials used for pulp paper making. Some wood species are estimated to have good properties for making paper pulp other than acacia and pine (Sable *et al*., 2012). According to Jepri *et al.* (2016), the production of paper pulp from palm oil trunks is according to established standards. Industrial-scale pulp production using banana trunks has met standards with a cellulose content above 80 % (Bahri, 2015). On the other hand, harvesting monoculture crops is generally done by clear-cutting, resulting in forest damage. Taking into account the morphological characteristics of fruit tree wood left over from pruning and/or removal of orchards, as well as the pulp yields obtained in the laboratory, it has been noted that kiwi (Yaman and Gencer, 2005), white mulberry (Gençer *et al*., 2013), hazelnut (Gençer and Özgül, 2016), cherry (Gençer and Gül Türkmen, 2016), wild dogwood (Gençer and Aksoy, 2017) and avocado (Altunışık Bülbül and Gençer, 2021a) wood bear similarities to hardwoods used in industrial pulp production. While the current industrial use of fruit tree wood for pulp production may present some challenges, these resources should be considered to promote sustainability and reduce pressure on forests for wood production (Altunışık Bülbül and Gençer, 2021b).

Many lesser-known wood species are underutilized, despite their ecological abundance and potential as raw materials for paper pulp. Unfortunately, the suitability information of those species as raw material for pulp paper making is still lacking. According to Marbun *et al*. (2023), the decreasing availability of commercial woods may be substituted by lesser-known wood species. Unfortunately, in promoting their usage, most wood species lack essential information about their properties, and the paper and pulp industries, which use wood as raw material, do not yet have knowledge of the study. A study of physical and mechanical properties of some lesser-known wood species had been done in India, Nigeria, Bangladesh, Malaysia, and Indonesia (Hedge, 2019; Areo *et al*., 2021; Chowdhury *et al*., 2017; Hamdan *et al*., 2020; Siam *et al*., 2022; Damayanti *et al*., 2019; Marbun *et al*., 2019). A study on the properties of lesser-known wood species as pulp paper raw material needs to be done to substitute raw material from commercial wood species. Sama-sama (*Pouteria firma* Baehni), Palado (*Aglaia* sp.), Kambelu (*Buxus rolfie* Vidal), and Kanduruan (*Phoebe cuneata* Blume) are underutilized lesser-known wood species, many of which are growing in Sulawesi, Indonesia. To produce high-quality products from wood raw material, the exact information on wood species properties is needed (Wahyudi *et al*., 2014). In general, the use of wood is based on its basic properties (Hastuti *et al*., 2017), and these properties are varied among species, influencing commercial value and predicting how to precisely process the wood (Hidayat *et al*., 2017; Purusatama *et al*., 2018; Riki *et al*., 2019). The objectives of this study were (1) to determine the specific gravity of four lesser-known hardwood species from West Sulawesi, (2) to analyze their fiber dimensions and derived indices, and (3) to assess their potential suitability for pulp and paper production.

The process of fiber separation in pulp and paper pulping is conducted through mechanical, chemical, or semi-chemical means (Bahri, 2015). In producing high-quality products from wood raw material, the exact information on wood species properties is needed (Wahyudi *et al*., 2014). The search for alternative wood species is needed for paper pulp raw material. This study aims to evaluate the specific gravity and fiber characteristics of four lesser-known hardwood species from West Sulawesi to determine their suitability as alternative raw materials for paper pulp production. It is hoped that this study can provide information on some wood species that have potential as alternative raw materials for pulp paper making.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Research materials were collected from natural forests in West Sulawesi, Indonesia, with the geographical coordinates 2°38’50.82” N, 121°5’47.53.71 E. Confirmation of tree species names was based on herbarium tests. Four of the lesser-known hardwood species, i.e., sama-sama (*Pouteria firma* Baehni), palado (*Aglaia* sp.), kambelu (*Buxus rolfie* Vidal), and kanduruan (*Phoebe cuneata* Blume) were taken from a height of 1.30 m above ground level (chest height) or 30 cm above the buttress. Wood samples were shaped discs (5 cm in thickness) of each tree species collected from one mature tree, which was representative of multiple locations. Discs of wood samples were collected from the base, middle, and top of a standing tree with a diameter ranging from 40 to 45 cm. For specific gravity and maceration measurements, each wood species was divided into three parts, i.e., one part near the bark and the others in the middle and near the pith.

2.2 Methods
2.2. Metode

2.2.1 Specific gravity measurement
2.2.1. Mjerenje specifične gustoće

We used a total of 24 test samples (three replications) measuring 2 cm × 2 cm × 1 cm from four wood species to measure the specific gravity of wood, based on Hedge (2019). The specific gravity of wood is measured based on the comparison between the specific gravity of wood and the specific gravity of water at a temperature of 4 °C. The volume of air-dry wood in water is based on Kasmudjo (2012). The calculation of specific gravity is based on the weight of oven-dry wood (103 ± 2) °C and duration until constant weight. Equation for specific gravity is as follows:

$$SG = W / (1 + M/100)\ V,$$

Where SG – specific gravity; W – weight of air-dry wood (kg); M – moisture content of wood (%); V – volume of wood in water (cm^3). The classification of the specific gravity of wood was carried out based on the IAWA criteria (Wheeler *et al*., 2008).

2.2.2 Measurement of fiber dimensions
2.2.2. Mjerenje dimenzije vlakana

The wood samples of each species were obtained from the bottom, middle, and top of the tree. The maceration process was performed on wood pieces from four different directions on each disc, utilizing a modified version of the Franklin method (Rulliaty, 2014). The maceration was conducted by heating matchstick-sized pieces in a test tube that contained a 1:1 hydrogen peroxide solution with a glacial acetic acid solution.

The fibers were then washed using distilled water and immediately stained with safranin solution (for coloration: qualitative). After that, the fibers were covered with a cover glass for measuring. From this macerated material, 25 measurements of fiber length, fiber diameter, and fiber lumen diameter for each wood species were observed using an Olympus microscope CX 23LED. To calculate the thickness of the fiber wall, the formula $(a-b)/2$ is used, where a – fiber diameter and b – fiber lumen diameter. In order to categorize the quality class of wood fiber, the following properties were determined: the derived values of fiber dimension, namely the runkel ratio, felting power, muhlsteph ratio, flexibility ratio, and coefficient of rigidity, (Marbun *et al*., 2023). Fiber quality criteria are determined based on Abdurrahman *et al.* (2020) to obtain wood fiber quality. The fiber length dimension is measured with the help of a microscope with a magnification of 100x, while for measuring the fiber diameter and lumen, a magnification of 400x is used.

2.2.3 Data analysis
2.2.3. Analiza podataka

The measuring yield values were analyzed descriptively after obtaining the average yield from three replications. The calculation of the average fiber dimension uses the MINITAB 14 program.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Specific gravity
3.1. Specifična gustoća

Sama-sama, palado, kambelu, and kanduruan each have an SG of less than 0.7 (Table 1).

According to IAWA criteria (Wheeler *et al.*, 2008), the specific gravity (SG) is low if wood has an SG of < 0.40, moderate if it has an SG of 0.40-0.75, and high if it has an SG of > 0.75 (Wheeler *et al*., 2008). The variables that affect pulp cooking are age, moisture content, fiber dimensions, and specific gravity (Gallichsen and Paulapuro, 2000). The high pulp yield is produced by woods that have a high specific gravity; however, the woods with high specific gravity in the pulping process necessitate more chemical solvents. According to Carrillo *et al.* (2011), the quality of the final product for pulp paper depends on the specific gravity of wood. The fiber content of wood is important for pulp and paper making, and wood with a specific gravity of 0.55-0.65 is preferred (Wahyudi, 2013). According to Hedge (2019), the yield of pulp in a unit volume is influenced by the specific gravity of different wood species, and it will affect the pulp produced in the process of pulping (Haroen, 2016). The specific gravity also indirectly affects the yield of paper production. The gruffness and

Table 1 Specific gravity of four lesser-known hardwoods species
Tablica 1. Specifična gustoća četiriju manje poznatih vrsta drva listača

Species of wood *Vrsta drva*	Specific gravity *Specifična gustoća*	Categorization *Kategorizacija*
Sama-sama (*P. firma*)	0.60	Moderate
Palado (*Aglaia sp.*)	0.48	Moderate
Kambelu (*B. rolfie*)	0.62	Moderate
Kanduruan (*P. cuneata*)	0.63	Moderate

the spreading of fibers in pulp are also affected by specific gravity, and they are significant parameters for conformity use of pulp (Kasmudjo, 2012).

The wood requirement to produce one ton of pulp is called the specific wood consumption (*SWC*). *SWC* is affected by the specific gravity of wood, which significantly affects costs of production (Magaton *et al*., 2009). According to Kasmudjo (2012), the specific gravity as a pulp raw material is between 0.35 and 0.65; however, wood with a specific gravity of 0.40 to 0.60 can produce pulp and paper optimally. The conditions of more severe cooking in pulp processing happen at high specific gravity because more chemical components of the wood are degraded (Indrawan *et al*., 2015). The excellent pulp sheet physical properties, such as tear index, breaking length, crack index, and folding resistance, are obtained from wood with a specific gravity of less than 0.70, except that the high specific gravity results in a lower pulp maturity level (high Kappa/Permanganate number), and the pulp sheet has lower physical properties (Haroen, 2006).

3.2 Fiber dimensions and quality
3.2. Dimenzije i kvaliteta vlakana

The fiber dimensions, such as fiber length, fiber diameter, and fiber wall thickness, have variation between wood species, and they determine wood quality as raw material for pulp and paper (Gallichsen and Paulapuro, 2000; Listya and Supartini, 2017). The quality of the wood used in pulp production positively affects pulp yield, ease of cooking and sheet formation in paper production (Kasmudjo, 2012; Haroen, 2006). A strong felting power will be produced if the fiber wall is long and thin because the fiber wall will be flattened easily (Lempang and Asdar, 2012). The fiber dimension measurement of wood species is available in Table 2 below.

The dimensions of the fiber and its derivatives will influence the properties of the pulp product (Syafii and Siregar, 2016), with the length of the fiber being the main determinant factor (Hedge, 2019). The wood species must have a long fiber for raw material for paper pulp (Wahyudi, 2013). According to Kasmudjo (2012), the fiber length of hardwood species ranges from 800 to 1,500 µm, fiber diameter ranges from 8.0 to 60.0 µm, and thickness from 2.0 to 10.0 µm. Based on IAWA criteria (Wheeler *et al.,* 2008), the fiber length of sama-sama and palado was short to long (900-1,600 µm), and of kambelu and kanduruan very long (> 1,600 µm). Based on the criteria of fiber quality of Indonesian hardwood for pulp and paper raw materials (Abdurachman *et al*., 2020), the fiber length of all species in this research is classified as short-to-long. Paper strength, such as index of tear, index of tensile, and index of folding, is influenced by fiber length (Istikowati *et al*., 2019; Rizqiani *et al*., 2019). The tear resistance of the paper is higher if the fiber is longer (Walia, 2013). The crease resistance of the paper and the tensile strength are affected by fiber length (Rizqiani *et al*., 2019). The fiber length is an important factor in bonding between fibers because the tear strength of the paper will increase if the fiber is long (Syafii and Siregar, 2016).

The cell wall thickness of sama-sama, kambelu, and kanduruan wood is classified as very thin, whereas palado is thin to thick. According to Tutus *et al*. (2010) and Kassim *et al*. (2016), there is a complex relationship between fiber dimensions that can influence the physical properties of pulp paper. The long fibers can produce strong weaving power as the walls of thin fiber are easily flattened in milling (Kassim *et al*., 2016). Fiber quality of wood species in this research is presented in Table 3.

Fiber dimensions and their derivatives are important wood properties for estimating pulp paper products. The comparison/ratio between twice the fiber wall thickness and the lumen diameter is a derivative of the fiber dimensions called the Runkel ratio. The best value of the Runkel ratio is fibers with low Runkel. The low Runkel ratio means the that fibers have thin walls and wide lumen diameters, which are easily flattened, and that the fibers have high tensile strength and breaking strength (Wahyudi, 2013; Syafii and Siregar, 2016; Akgul and Tozluoglu, 2009). High Runkel ratio values lead to reduced tensile strength and breaking strength in pulp sheets. The thick-walled and small diameter of fibers can maintain the shape of the pipe in milling. Kambelu and Kanduruan have a very low Runkel ratio (< 0.25), Palado has a low Runkel ratio (0.25-0.50), and Sama-sama has a high Runkel ratio (0.51-0.75).

Table 2 Fiber dimensions of four lesser-known hardwoods species
Tablica 2. Dimenzije vlakana četiriju manje poznatih vrsta drva listača

Wood species *Vrsta drva*	**Fiber dimensions** / *Dimenzije vlakana,* mm			
	Length of fiber *Duljina vlakana*	**Diameter of fiber** *Promjer vlakana*	**Diameter of fiber lumen** *Promjer lumena vlakana*	**Thickness of fiber wall** *Debljina stijenke vlakana*
Sama-sama (*P. firma*)	1,138	16.63	10.83	2.90
Palado (*Aglaia sp.*)	1,132	25.61	17.39	4.11
Kambelu (*B. rolfie*)	1,934	39.17	34.00	2.49
Kanduruan (*P. cuneata*)	1,777	36.00	31.36	2.32

Table 3 Fiber quality and dimension derivative values of four lesser-known hardwoods species
Tablica 3. Kvaliteta vlakana i vrijednosti izvedenih dimenzija za četiri manje poznate vrste drva listača

Species of wood/ Scoring *Vrsta drva/bodovanje*	Length of fiber, μm *Duljina vlakana,* mm	Derivative value					Total score *Ukupni rezultat*	Fiber quality *Kvaliteta vlakana*
		Runkel ratio *Runkelov omjer*	**Felting power** *Brzina filcanja*	**Muhlsteph ratio, %** *Muhlstephov omjer, %*	**Flexibility ratio** *Omjer fleksibilnosti*	**Coeffisient of rigidity** *Koeficijent krutosti*		
Sama-sama (*P. firma*)	1,138	0.54	68.43	57.59	0.65	0.17		
Score	50	50	50	75	75	50	350	III
Palado (*Aglaia sp*)	1,132	0.47	44.20	53.89	0.68	0.16		
Score	50	75	50	75	75	50	375	II
Kambelu (*B. rolfie*)	1,934	0.15	49.39	23.77	0.87	0.06		
Score	75	100	50	100	100	100	525	I
Kanduruan (*P. cuneata*)	1,777	0.15	49.37	24.12	0.87	0.06		
Score / *Rezultat*	75	100	50	100	100	100	525	I

The four wood species have a low felting power (40-70). According to Akgul and Tozluoglu (2009), the value of the felting power of hardwoods is between 40 and 60. The higher the felting power value, the more flexible and the higher the tear strength of fibers produced because the tear will be divided into larger areas (Syafii and Siregar, 2016).

Pulp strength is influenced by the multistep ratio, which reflects the value of the pulp sheet density. Muhlsteph ratios of kambelu and kanduruan are classified as very low (< 30%), and low (30-60%) for sama-sama and palado. The fiber wall is thin, making the fiber more compatible for paper pulp making (Akgul and Tozluoglu, 2009). It is stated that a lower Muhlsteph ratio results in higher density and strength pulp sheets. In contrast, a high Muhlsteph ratio results in low-density pulp sheets, so the pulp sheet is weaker.

The flexibility ratio is the ratio between the lumen diameter and the fiber diameter. The fiber that has high flexibility is the fiber that has a thin wall, with the result that it is easily deformed (Syafii and Siregar, 2016; Akgul and Tozluoglu, 2009). The change of the fiber shape causes the fiber to be more flexible in contact among the fiber surfaces, so the fiber bonds are better in sheets of pulp products that make a good strength of pulp. Sama-sama and palado have high flexibility ratios (0.60 to 0.80), and kambelu and kanduruan have very high flexibility ratios (>0.80). The low-flexibility fiber has a diameter with a narrow lumen, so it can produce thicker sheets of pulp and paper, uneven paper surfaces, and lower breaking strength.

The ratio between fiber wall thickness and fiber diameter is called the coefficient of rigidity. Sama-sama and palado have high coefficients of rigidity (0.15-0.20), whereas kambelu and kanduruan have very low coefficients of rigidity (<0.10). The tensile strength of paper is inversely proportional to the rigidity coefficient value. The lower the coefficient of rigidity, the higher the tensile strength of the paper produced (Syafii and Siregar, 2016; Akgul and Tozluoglu, 2009).

3.3 Potential use of paper pulp
3.3. Potencijalna primjena papirne pulpe

Specific gravity of sama-sama, palado, kambelu, and kanduruan is between 0.48 and 0.63. Such specific gravity is classified as moderate. As well known, mangium (*Acacia mangium*) is a wood species that is commonly used for paper pulp products. According to Arsad (2011), mangium (*Acacia mangium*) from South Kalimantan has a specific gravity of 0.6. The four wood species in this research have different specific gravity each. The specific gravity of palado is 0.48; it is lower than that of mangium. Sama-sama, kambelu, and kanduruan each have relatively the same specific gravity as mangium, namely 0.60, 0.62, and 0.63.

Fiber length of Kambelu and Kanduruan is 1,934 µm and 1,777 µm, and such fibers are classified as very long fibers. Fiber length of sama-sama and palado is 1,138 µm and 1,132 µm, and such fibers are classified as long fibers. The fibers of these four species are longer than the fibers of mangum (1,019 µm) researched by Mulyawati (2013).

The Runkel ratio of these four hardwoods varies from 0.15 to 0.54. According to Syafii and Siregar (2016), these Runkel ratios are classified as very low to moderate. The Runkel ratio of *Acacia mangium* is between these values (0.41). The Runkel ratios of kambelu (0.15) and kanduruan (0.15) are categorized as very low and lower than the Runkel ratio of A. mangium. Wood species with a long fiber and a low Runkel value can be obtained from wood species that have a specific gravity of 0.55 to 0.65, and such wood species are a proper raw material for pulp paper making (Wahyudi, 2013).

Table 3 presents the scores for fiber quality based on derivative values, which are classified into three ranges: classes I to III. The fibers in classes I to II have short to very long fibers, narrow to very wide lumen diameters, and very thin to thick walls. These fibers will range from difficult to relatively easy to flatten during milling, and the fiber bond will be sufficiently strong. The fibers classified in class II will exhibit low to high levels of cracking, tearing, and tensile strength. Of the four species of lesser-known hardwood studied, only three are potentially useful as raw material for pulp paper making, namely palado, kambelu, and kanduruan, with kambelu and kanduruan being more appropriate as raw material for pulp paper making because these two species not only have higher specific gravity but also good fiber quality.

4 CONCLUSIONS
4. ZAKLJUČAK

This research offers the first systematic fiber-quality assessment of four lesser-known Indonesian hardwood species, i.e., Sama-sama (*Pouteria firma* Baehni), Palado (*Aglaia* sp.), Kambelu (*Buxus rolfie* Vidal), and Kanduruan (*Phoebe cuneata* Blume), with specific gravity that is appropriate as raw material for pulp paper making. However, based on the analysis of fiber quality and dimension derivative value, only Palado, Kambelu, and Kanduruan have potential as raw material for paper pulp. Kambelu and Kanduruan were identified as the most promising species, referring specifically to their advantageous fiber properties–such as long fiber length (1,934 and 1,777 mm), low Runkel ratio (< 0.25), and moderate specific gravity (0.60–0.63), which together indicate high pulpability and strong bonding potential and make their specific gravity appropriate as raw material for pulp paper making. This paper has some limitations in pulping testing, meaning that further research is required. It is necessary to conduct pilot pulping experiments, analyze the chemical composition, and evaluate the paper strength.

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