Perennial 2025
Vol. 21 No. 2: 61-70
p-ISSN: 1412-7784

Available Online:
https://doi.org/10.24259/perennial.v21i2.44044
e-ISSN: 2685-6859

EFFECT OF HOT WATER EXTRACTION ON CONTACT ANGLE OF *OCTOMELES SUMATRANA* AND *DUABANGA MOLUCCANA* WOODS AND ITS CORRELATION TO THE EXTRACTIVE CONTENT AND ANATOMICAL STRUCTURE

Pengaruh Hot Water Extraction terhadap Sudut Kontak Octomeles sumatrana dan Duabanga moluccana dan Kaitannya terhadap Zat Ekstraktif dan Struktur Anatomi Kayu

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ABSTRACT

Binuang bini (*Octomeles sumatrana*) and binuang laki (*Duabanga moluccana*) are fast growing species that have the potential to be developed as engineered wood products. However, previous studies have shown that both wood species have high contact angle values due to the extractive content and the high acidity. Therefore, this study aimed to examine the effect of hot water extraction (HWE) pretreatment to eliminate these limiting factors. The results proved that HWE pretreatment statistically significantly decreased the contact angle of binuang bini wood but not for binuang laki wood. HWE pretreatment resulted in a decrease in the levels of hot water-soluble extractive content and degradation of other wood chemical components. The different effectiveness of HWE pretreatment on binuang bini and binuang laki wood on improving the contact angle is influenced by differences in the quantity and quality of extractive substances as well as differences in the anatomical structure characteristics of these species.

Keywords: Binuang bini (*Octomeles sumatrana*); Binuang laki (*Duabanga moluccana*); Contact angle; Hot water extraction

ABSTRAK

Binuang bini (*Octomeles sumatrana*) dan binuang laki (*Duabanga moluccana*) merupakan jenis cepat tumbuh dan tumbuhan pioneer yang berpotensi dikembangkan sebagai *engineered wood products*. Akan tetapi, penelitian sebelumnya membuktikan bahwa kedua jenis kayu tersebut memiliki nilai sudut kontak yang tinggi dan diduga disebabkan karena kandungan zat ekstraktif serta Tingkat keasaman kayu yang tinggi. Oleh karena itu, penelitian ini bertujuan untuk mengkaji pengaruh pemberian perlakuan pendahuluan *hot water extraction* (HWE) untuk mengeliminasi faktor penghalang tersebut. Hasil penelitian membuktikan bahwa secara statistik perlakuan pendahuluan HWE signifikan menurunkan sudut kontak kayu binuang bini tetapi tidak untuk kayu binuang laki. Perlakuan pendahuluan HWE berdampak pada penurunan kadar zat ekstraktif larut air panas dan degradasi komponen kimia kayu lainnya. Efektivitas perlakuan pendahuluan HWE yang berbeda pada kayu binuang bini dan binuang laki terhadap penurunan sudut kontak kayu dipengaruhi oleh perbedaan kuantitas dan kualitas zat ekstraktif serta perbedaan karakteristik struktur anatomi kedua jenis kayu tersebut.

Kata kunci: Binuang bini (*Octomeles sumatrana*); Binuang laki (*Duabanga moluccana*); Ekstraksi air panas; Sudut kontak

Submitted: 5 May 2025; Accepted: 16 June 2025

A. INTRODUCTION

Binuang bini and binuang laki are categorized as lesser-used wood species (LUWS). In general, LUWS tends to exhibit lower quality characteristics compared to widely commercial ones (Marbun *et al.* 2019), which has limited their utilization and has received less attention in the timber industry. Yudohartono & Fambayun (2012) reported that binuang wood has a potential use, especially for applications that do not require high strength, such as moulding, veneer, chipboard, fibrebaord. Due to the decreasing quantity of commercial timber from natural forests, LUWS presents a promising alternative to be developed. These species are valuable assets with significant potential for forest product diversification.

Binuang bini (*Octmeles sumatrana)* (Bogidarmanti & Darwo 2019) and binuang laki (*Duabanga moluccana*) are pioneer species that naturally grown abundantly when land clearing occurs (Ogata *et al.* 2008). The International Tropical Timber Organization (ITTO 2025a; ITTO 2025b) confirmed that these species are abundant in natural forests. Moreover, ITTO (2021) published a report that mention these two species begun to be introduced as an export commodity in Indonesia. Increasing the utilization of these two species is expected to be a solution to the problem of timber raw material scarcity in the country. These woods are also expected to substitute commercial woods that have been used.

A comprehensive understanding of the characteristics of binuang bini and binuang laki wood is essential for optimizing their processing and end-use applications. Wahyudi (2013) stated that there is a strong correlation between anatomical structure, its intrinsic properties, processing techniques, and intended application of wood. The anatomical structure of wood (defined by the arrangement and characteristics of its constituent cells) serves as a key indicator of wood quality and plays a critical role in determining its physical and mechanical behavior. Proper processing and end-use must be adjusted to the inherent properties of the wood. Therefore, a proper understanding of wood characteristics is necessary in order to optimize the processing and utilization. Some basic characteristics of binuang woods already published by (Marbun *et al.* 2019; Marbun *et al.* 2020a; Marbun *et al.* 2020b). However, the results showed that these species have an inferior quality and therefore an improvement is needed to increase their utilization.

One of the promising opportunities to enhance the utilization and added value of binuang bini and binuang laki wood is by converting the woods into engineered products through the application of adhesives. One of the critical factors in the successful manufacture of such composite products is the ability of wood to form a strong adhesive bond. It can be estimated by examining the wettability of the wood (Petrič & Oven 2015; Jankowska *et al.* 2018; Alia-Syahirah *et al.* 2019; Marbun *et al.* 2020b; Leggate *et al.* 2021). Wettability reflects the wood's capacity to be wetted, flowed, and penetrated by the adhesive (Wang *et al.* 2007). Previous research on wood anatomical structure and wettability properties of binuang bini and binuang laki wood has previously been conducted by (Marbun *et al.* 2019; Marbun *et al.* 2020a; Marbun *et al.* 2020b). These species are categorized into strength class III-IV, with a density of 0.38 g/cm^3 and 0.41 g/cm^3, respectively. The study revealed that both species exhibit low wettability and penetration of PF adhesive, that is indicated by high value of equilibrium contact angle because of the poor PF adhesive penetration (Marbun *et al.* 2020b). The low wettability is hypothesized to be influenced by the presence of extractive substances and the acidity of wood. Therefore, in considering the utilization of these two species as raw material for engineered products that involve adhesives bonding, it is necessary to explore the suitable pre-treatment aimed at eliminating these hindering factors.

Wood modification technology has been developed to overcome obstacles in wood processing, one of which involves heat treatment (Hill 2006). Heat can be applied with or without a medium. In this research, water is used as the medium for heat application at controlled temperature and duration, known as Hot Water Extraction (HWE). During the HWE process, thermochemical reactions occur as the applied heat induces chemical reaction within the wood substances (Pelaez-Samaniego *et al.* 2013). Previous researchers proved that immersion in hot water (80 °C) for 1 and 2 hours can reduce the levels of extractive substances and increase the wettability of castor fruit peels (Iswanto 2014). Furthermore, Fatrawana (2018), Pelaez-Samaniego *et al.* (2013), Paredes *et al.* (2009) and Varga *et al.* (2008) also confirmed that heat treatment using hot water or steam reduce the extractive content as well as increase the pH value and wettability of wood. Therefore, this study aims to examine the effect of HWE on increasing the wettability of binuang bini and binuang laki wood and explore its relationship with anatomical structure of wood. The results are expected to provide important information that will ultimately have an impact on increasing the utilization of wood from the lesser-used species group.

Therefore, this study specifically aims to evaluate the effectiveness of HWE treatment in improving the wettability of binuang bini and binuang laki wood surfaces as a first step in supporting their use in adhesive-based engineered products.

B. MATERIALS AND METHODS

Logs of ±150 cm long binuang bini (*Octomeles sumatrana*) and binuang laki (*Duabanga moluccana)* with a diameter of ±50 cm from the base of the tree trunk were used in this study. The logs came from the concession area of PT Sumalindo Lestari Jaya Global Timber Forest Utilization Permit (UIPHHK-HA), East Kalimantan. The main equipments were chainsaw, waterbath, microscope, oven, sliding microtome, and portable microscope camera. Chemicals and other supporting materials used in this study were H_2O_2, glacial acetic acid, distilled water, safranin, alcohol, glycerol, entellan, and phenol formaldehyde (PF) adhesive.

Preparation of Test Sample

The log was cut into two parts: a disk with a thickness of ±5 cm and the remaining portion processed into boards (live sawn cutting) with dimensions of 1 cm x 5 cm x 20 cm. These boards served as test samples for HWE-treated and control groups. Wood powder sized between 40-60 mesh was prepared to evaluate the extractive content both of control and HWE-treated samples. The wood disk was then further cut into smaller specimens measuring 2 cm x 2 cm x 2 cm, intended for anatomical structure observation. The detailed test sample preparation can be seen in the illustration of Figure 1.

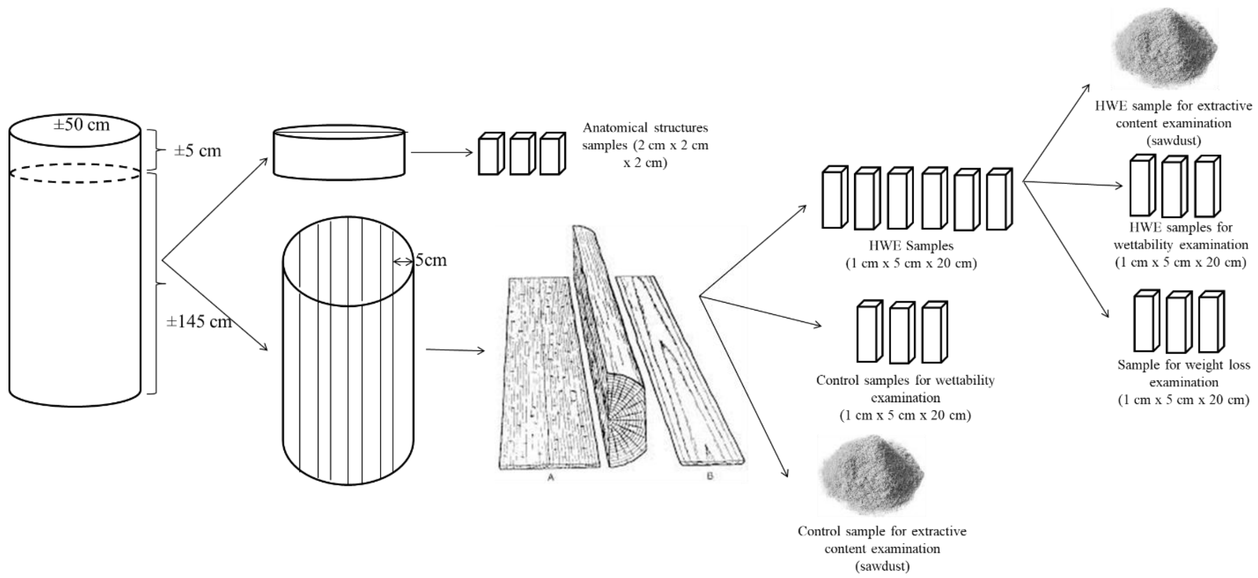

Figure 1. Test sample preparation procedure

Anatomical Structure Observation

Wood samples were softened by boiling in water for 2-3 days, then immersed in a container containing 30% glycerol solution. The samples were then sliced with a sliding microtome with a target thickness of 20-30 µm representing the transverse (X), radial (R), and tangential (T) planes. Selected slices were then soaked in safranin overnight, then washed with distilled water until clean, then dehydrated in stages with 30, 50, 70, 90 and 96% alcohol for 5-10 minutes each. The slices were then placed on a glass slide, glued with entellan, covered with a cover glass, labeled, and ready to be observed under a microscope and documented. Observations were made in the transverse, radial, and tangential planes of the growth rings, pores, fibers, axial parenchyma, rays, intercellular canal, and mineral inclusion in the wood. Wood anatomical features observed macro- and microscopically followed the IAWA List of Microscopic Features for Hardwood Identification (Wheeler *et al.* 1989).

Hot Water Extraction Treatment.

Test samples of 1 cm x 5 cm x 20 cm were used in the HWE process. The binuang bini and binuang laki wood samples were boiled at ±100 °C for 4 hours. During the boiling process, the test samples were ensured to be submerged in water. Each wood species was boiled separately. After the boiling process, the samples were air-dried and then oven-dried until they reached a moisture content (MC) of ±12%. The wood surface was then sanded using grid size 100 sandpaper in a circular direction for homogenization purposes.

Contact Angle Measurement

Contact angle measurement using the sessile drop method. An illustration depicting material wettability based on contact angle value can be seen in Figure 2. Tests were conducted on control and HWE samples, with PF adhesive as the reference liquid. The reason for the selection of PF adhesive is based on previous research conducted by (Marbun *et al.* 2020a: Marbun *et al.* 2020b). A 0.02 ml droplet of PF adhesive was dripped on the width wood surface and then recorded using a portable microscope camera and analyzed using GOM player software to obtain image segments every

10 seconds for 2 minutes. Contact angles from each captured image were then measured using Image-J Software. The test was carried out on three boards. Three measurement points were selected per board.

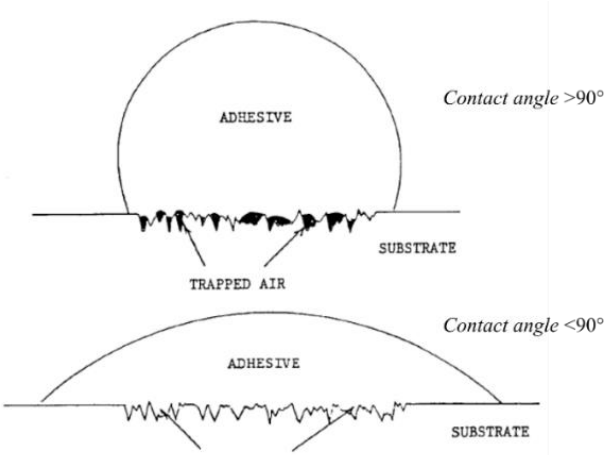

Figure 2. Illustration of hard-to-wet (top) and easy-to-wet (bottom) wood surfaces by adhesive (Petrie 2000)

Characterization of test samples after Hot Water Extraction treatment

Characterization of test samples after HWE treatment included the measurement of weight loss after HWE and measurement of hot-water soluble extractive content. Hot water-soluble extractive content measurement referred to the TAPPI T207 om-93 standard (TAPPI 1999). Wood powder with particles size of 40-60 mesh was used for the measurement. Measurements were carried out as many as 5 replicates. The hoot water-soluble extractive content (%) was calculated using the following equation:

$$\% \text{ Extractive content} = \frac{A-B}{A} \times 100 \quad (1)$$

where A is initial oven-dried weight of wood powder (g) and B is oven-dried weight of sawdust after extraction (g)

Weight loss measurement of HWE-treated samples was carried out using samples measuring 1 cm x 5 cm x 20 cm (thickness x width x length). Samples with a known moisture content were weighed to obtain the initial weight (BA_1), then boiled for 4 hours at 100 °C, then dried in an oven at 103±2 °C for 24 hours until the weight was constant and then weighed to obtain the oven-dried weight HWE-treated sample (BKO_2). The estimated oven-dried weight of untreated sample and the percentage weight loss after the HWE process were calculated by the equation:

$$BKO_{1est} = \frac{BA_1}{(MC/_{100}+1)} \quad (2)$$

$$\% \text{ Weight loss} = \frac{BKO_{1est} - BKO_2}{BKO_{1est}} \times 100 \quad (3)$$

where BA_1 is initial weight of sample before HWE (g), BKO_{1est} is estimated oven-dried weight of sample before HWE (g) and BKO_2 is oven-dried weight of sample after HWE (g), MC is moisture content.

Data Analysis

This study used statistical analysis of independent t-student test at 95% confidence level. It was performed using SAS 9.1 software. This was done to determine the significant level of difference in contact angle values, weight loss after HWE treatment, and hot water-soluble content between control and HWE test samples.

C. RESULTS AND DISCUSSION

The results showed that the HWE pretreatment effectively decreased contact angle value of binuang bini wood, but not for binuang laki wood. The evidence can be seen from the decrease in the size of the equilibrium contact angle of PF adhesive on binuang bini wood, from 71.62 ° to 62.29 ° (Table 1). Contact angles of PF liquid on the surface of both HWE-treated and control binuang bini and binuang laki woods are shown in Figures 3 and 4. Statistical analysis of the student's t-test revealed a significant difference in contact angles between control and HWE-treated binuang bini wood, while binuang laki exhibited no notable difference. Figures 5 and 6 show a clear time-based change in contact angle for PF liquid on control and treated binuang bini wood, but such a change was not evident in binuang laki wood. Previous study showed that the extractive content in ethanol-benzene, NaOH 1%, hot water, and cold water of these two species are different (Marbun *et al.* 2020b). This recent study showed that even though these two species got the same treatment, they had different results. Therefore, we presumed that the different effects in the effectiveness of HWE pretreatment on the two species are likely attributable to variations in the quantity and quality of extractive content of each species. Similar results were also reported by Iida *et al.* (2002). They conducted HWE treatment followed by cold water immersion on four softwood species. The result confirmed that the differences in the quantity and quality of wood extractives of each species had different effects of the treatment.

Table 1. Wood characterization after hot water extraction pretreatment

Wood Species	(Contact Angle Equilibrium/°)			Weight Loss of HWE-treated samples (%)	Hot Water-soluble Extractive Content (%)		
	Control	HWE	Remarks		Control	HWE	Remarks
BN	71.62 (10.27)	62.29 (2.78)	**	4.39 (0.49)	5.61 (0.56)	4.32 (0.78)	**
DB	70.11 (3.32)	70.21 (5.58)	ns	3.49 (0.60)	-	-	-

where: numbers in parentheses are standard deviation values, BN = binuang bini, DB = binuang laki, ** = significantly different (p-value ≤0.01), and NS = not significantly different.

Although it was statistically confirmed that HWE treatment did not significantly affect the PF contact angle on the surface of binuang laki wood, an opposite effect was observed for binuang bini wood. Several previous studies also reported the same thing. Hakkou *et al.* (2005) reported the decreasing contact angle value of distilled water on the oven-pretreated beech wood at >120 °C. Similarly, Paredes *et al.* (2009) reported that the hot water extraction at 160 °C reduced the contact angle of maple wood strands when tested with distilled water. Moreover, Kaygin *et al.* (2014) also reported that steaming for 1 and 3 hours increased the surface roughness by 52-60% compared to the control. This increase was attributed to the swelling of the sample during the steaming. It led to the fiber separation and formed small voids in the wood structures. This morphological change enhanced the surface roughness and, consequently, increased the wettability wood.

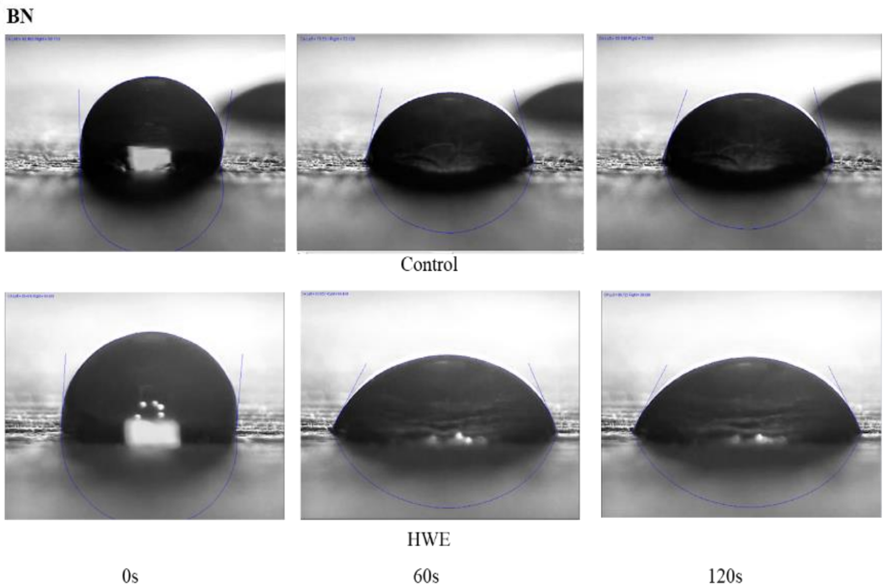

Figure 3. Contact angle of PF liquid on the surface of control and HWE binuang bini (BN) wood at 0, 60, and 120 seconds of observation

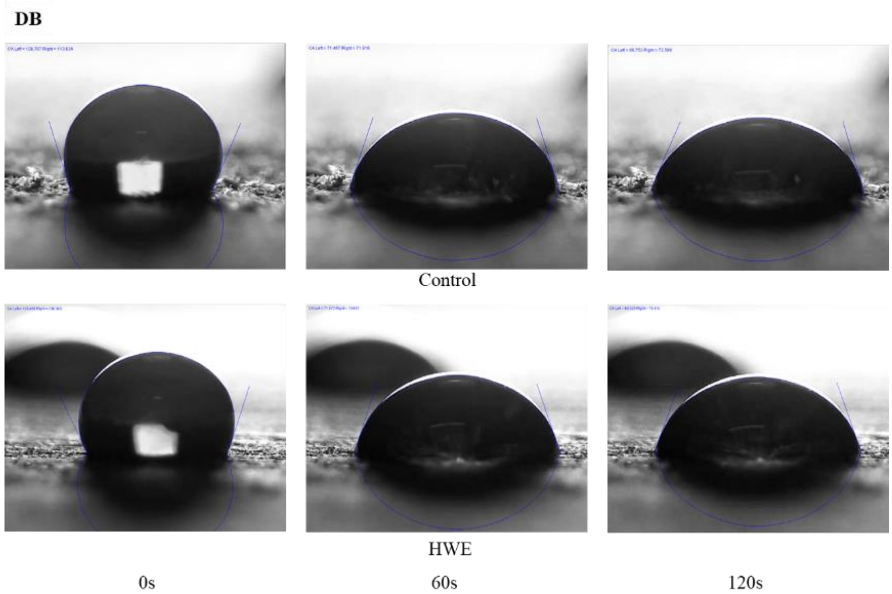

Figure 4. Contact angle of PF liquid on the surface of control and HWE binuang laki (DB) wood at 0, 60, and 120 seconds observation

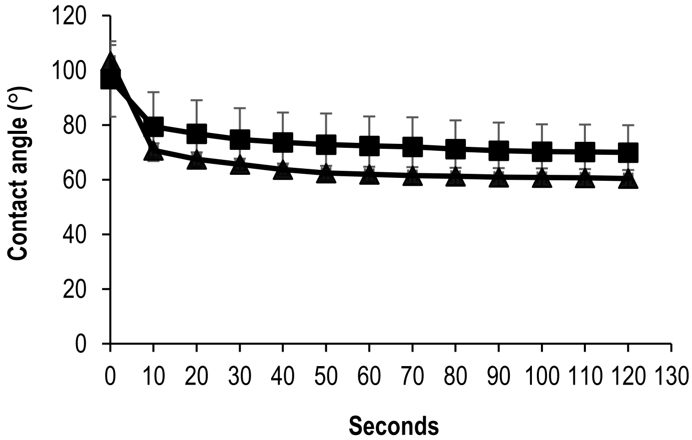

Figure 5. Change in contact angle value of PF liquid on the surface of control and HWE binuang bini (BN) wood as a function of time. ■ = control samples, ▲ = HWE samples

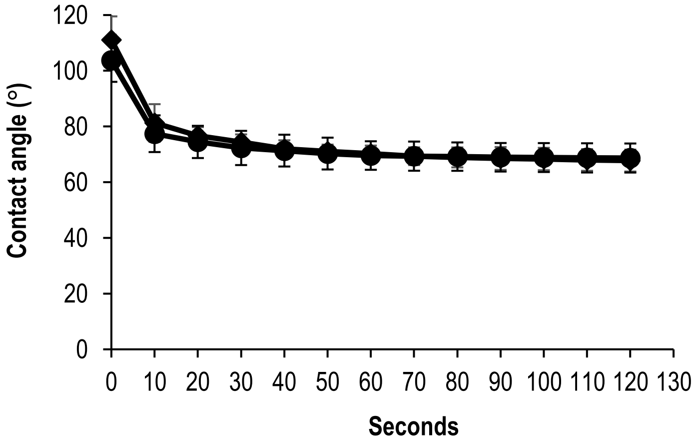

Figure 6. Change in contact angle value of PF liquid to the surface of control and HWE binuang laki (DB) wood as a function of time. ♦ = control samples, ● = HWE samples

Decreasing contact angle may be attributed to structural degradation of wood cell walls and the alterations of chemical composition due to heat (Sattler *et al.* 2008; Paredes *et al.* 2009). During heat treatment, the chemical components of wood can be degraded and dissolved to form voids and fissures. The degradation of chemical components during HWE of binuang bini and binuang laki is supported by the observed weight loss that listed in Table 1. The weight loss of HWE-treated binuang bini was 4.39%, while that of binuang laki wood was 3.49%. The different weight loss value between these species proved the weaker HWE response observed in binuang laki. The greater the weight loss, the greater void volume created on the treated wood, vice versa.The treated wood is presumed to have a greater void volume compared to the control wood, thereby increasing its permeability. Sattler *et al.* (2008) reported the similar thing. They found that HWE treatment at 120 °C for 20 minutes changed the physical characteristics of OSB wood flakes. In addition, the dissolution of extractive substances during hot water extraction treatment contributed to the opening wood pores and increased the permeability of the wood. Therefore, the degradation of chemical components and structural modifications is believed to improve the wettability of HWE-treated binuang bini wood compared to the control. However, the low weight loss observed in HWE-treated binuang laki wood resulted in the limited efficacy of the treatment in reducing the contact angle value for this species.

Hot water-soluble extractive analysis in control and HWE-treated binuang bini was conducted in response to the statistically significant reduction in contact angle values. The results revealed that HWE treatment had a significant effect on reducing the levels of hot water-soluble extractive content in binuang bini wood by 1.29% (Table 1). This finding is consistent with the previous research by Marbun *et al.* (2020b), which indicated that the high contact angle of binuang bini wood is partially due to the extractive content of the wood. Extractives are responsible for the low wettability of wood because they can form a 'weak boundary layer' on the wood surface. This 'weak boundary layer' inhibits the interaction between the adhesive and the lignocellulosic material (Nussbaum & Sterley 2002; Nzokou & Kamdem 2004; Kamke & Lee 2007). In contrast to binuang bini wood, HWE treatment did not significantly affect the contact angle of PF on binuang laki wood. Therefore, at this stage of the study, the evaluation of hot water-soluble extractive content both control and HWE-treated binuang laki was not conducted.

Table 1 indicated that the percentage of weight loss in binuang bini wood exceeded the reduction of hot water-soluble content by about 3.1%. This showed that HWE treatment at 100 °C for 4 hours not only degraded extractive substances but also degraded other chemical components. Sattler *et al.* (2008) previously reported that HWE treatment at 120 °C for 40 minutes degraded hemicellulose (mannose), and at 140 °C for 40 minutes degraded cellobiose. Esteves & Pereira (2009) mentioned that weight loss due to the degradation of wood chemical components during heat treatment is influenced by wood species, heating medium, temperature, and exposure duration. During the HWE treatment, water can break acetyl groups from hemicellulose, producing acetic acid and uronic acid (Pelaez-Samaniego *et al.* 2013). These acids concentrated on the solution and acted as catalyst accelerating the hydrolysis of hemicellulose, and under more severe conditions, even initiating cellulose hydrolysis. However, the degradation of wood chemical components – cellulose, hemicellulose, lignin, and extractives – due to the thermal treatment depends on the processing parameters. Among these, extractives – especially the volatile ones – are the most readily degraded. For the structural component of wood, hemicellulose is the most thermally susceptible due to its amorphous nature. Moreover, the lack of heat-resistant acetyl groups of hemicellulose is also an important factor in its susceptibility to heat. Hill (2006) reported some weight loss of heat-treated wood at a temperature of 100 °C from the decreasing of hardwood xylan which is less thermally stable than softwood hemicellulose. However, the result showed that weight loss percentage of binuang bini and binuang laki wood is different, despite undergoing identical treatment conditions. It suggests the inherent differences in their chemical characteristics and composition. It is supported by Hill (2006). He mentioned that the content and composition of hemicellulose of each species do not have the same result to the different response of each species to the same heat treatment. This study showed that both binuang bini and binuang laki had same HWE treatment, but these species gave different responses of weight loss.

In addition to variations in the chemical characteristics, differences in the anatomical structure of wood have also been reported to affect the surface properties of wood and hence the wettability of wood. Wang (2019) and Frihart & Hunt (2021) reported that wettability and bond ability of wood are complex phenomena. There are at least three factors that affect the penetration of adhesives in wood: wood characteristics, adhesive characteristics, and production factors (Kamke & Lee 2007). Among the wood-related factors, wood species, chemical properties, anatomical structures, and surface roughness properties play critical roles in affecting wood wettability. In line with this, Jankowska *et al.* (2018) previously reported that axial parenchyma type affects the contact angle value of a liquid on a wood surface. The more complex the axial parenchyma type, the higher the contact angle. Similarly, Laskowska & Kozakiewicz (2017) found that ring-porous wood has lower wettability than diffuse-porous wood. Furthermore, Alia-Syahirah *et al.* (2019) reported strong correlation between fiber-wall thickness to contact angle, as well as wood density to contact angle (R^2 >70%). This further strengthens the evidence that wood anatomical structure affects the wettability properties of wood.

Marbun *et al.* (2020b) reported that binuang bini and binuang laki woods are classified as low-density wood species with porosities of 77.2 and 74.7%, respectively. The images of anatomical structures of these species can be seen in our previous publication (Marbun *et al.* 2019). The study also reported that binuang laki wood has a larger average vessel diameter (279.51 µm) compared to binuang bini wood (182.29 µm). Although binuang laki wood exhibited a larger average vessel diameter compared to binuang bini, its vessel frequency per per mm^2 is lower (2.70) than binuang bini (5.40), resulting in reduced overall porosity. Furthermore, the fiber diameter of binuang bini was reported to be smaller (29.38 μm) than that in binuang laki (35.55 μm), while the fiber wall thickness in binuang bini wood (3.06 μm) was slightly thinner than that of binuang laki wood (3.13 μm). Both species exhibited the same ray frequency of 4.90 rays per mm; however, the ray height was substantially greater in binuang bini (738.10 μm) compared to binuang laki wood (210.81 μm). Anatomical features of binuang bini dan binuang laki are listed in Table 2. Based on these data, it can be concluded that binuang bini wood possesses a higher overall porosity than binuang laki wood.

Table 2. Anatomical features of binuang bini and binuang laki

Type of cell	Anatomical Features	Binuang bini	Binuang laki
Vessel	Growth rings	Indistinct or absent	Indistinct or absent
	Porosity	Diffuse-porous	Diffuse-porous
	Vessel grouping	Mostly solitary vessel	Mostly solitary vessel
	Vessel arrangement	Radial pattern	Radial pattern
	Solitary vessel outline	Rounded	Rounded
	Perforation plates	Simple	Simple
	Intervessel pits	Alternate	Alternate
	Shape of alternate pits	polygonal	Polygonal
	Vessel frequency per mm^2	5 (4–6)	3 (2–4)
	Tyloses and deposits	-	-
Fiber	Fiber length (μm)	1565.61 (844.75–2561.5)	1599.39 (763.00–2670.50)
	Fiber wall thickness (μm)	3.06	3.13
	Pits	Simple to minutely bordered pits	Simple to minutely bordered pits
	Septate fibers	present	present
Axial Parenchyma	Banded Parenchyma	1–4 cells	> 3 cells
	Strand length	> 8 cells	> 8 cells
	Apotracheal axial parenchyma	diffuse	diffuse
	Paratracheal axial parenchyma	Scanty and vasicentric narrow sheath	Complete to oval narrow and broad sheath of vasicentric axial parenchyma, confluent
	Mineral inclusions	-	Present
Rays	Ray width	Mostly is 2–5 series	Mostly is uniseriate
	Ray height (μm)	738.10 (309.91–1414.47)	210.81 (79.03–336.29)
	Rays per mm	5 (4–6)	5 (4–6)
	Cellular composition	Body ray cells procumbent with mostly 2 – 4 rows of square marginal cells	Body ray cells procumbent with mostly 1 – 2 rows of upright marginal cells Sel
	Deposits	Present	Present
	Mineral inclusion	-	Present

Observations of the anatomical structure of wood in this study revealed that binuang laki wood has a more complex axial parenchyma arrangement (Table 2). This species possesses wide and long axial parenchyma, including complete and incomplete circular axial parenchyma vasicentric, either broad or narrow sheath, as well as confluent axial parenchyma. Meanwhile, the axial parenchyma of binuang bini wood is simpler, characterized mainly by scanty parenchyma with and sometimes narrow sheaths. Moreover, mineral deposits were observed within the rays and axial parenchyma of binuang laki but were absent in binuang bini (Table 2). These findings suggest that the anatomical structure of binuang bini is less complex than that of binuang laki, hence resulting in higher permeability for binuang bini than that of binuang laki. The difference in wood permeability characteristics between binuang bini and binuang laki affects the effectiveness of the HWE process. During the HWE treatment, water can more easily penetrate the wood structure of binuang bini and consequently dissolves more extractive substances than in binuang laki wood (Table 1). Therefore, differences in the anatomical characteristics of wood contribute to the success of the HWE pretreatment in increasing wood wettability.

D. CONCLUSION

The research showed that HWE pretreatment effectively decreased in the contact angle of phenol-formaldehyde (PF) adhesive of binuang bini wood. In contrast, no significant improvement was observed in binuang laki wood. The effectiveness of the HWE pretreatment on binuang bini wood can be attributed to the reduction of hot water-soluble extractives and the simpler anatomical characteristics that increased the wood's permeability. The differences in chemical substances, particularly in quantity and quality of wood extractive, and anatomical features such as vessel frequency, porosity, and axial parenchyma arrangement, played critical roles in determining the success of the treatment. Based on the data of hot water-soluble extractive content and weight loss of HWE-treated sample, it was suggested that there was a partial degradation of chemical components beyond extractives. The impact of HWE treatment on the chemical composition degradation was more pronounced in binuang bini wood due to its higher porosity and simpler anatomical structure. These findings underline the importance of wood species selection in pretreatment processes aimed at improving wood surface properties and bonding performance. Further studies investigating more severe or alternative pretreatment conditions may provide additional insights into optimizing wettability enhancement for woods with more complex anatomical structures like binuang laki.

AUTHOR'S DECLARATION

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- No potentially identified images or data are present in the manuscript.

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