Chemical content and fiber dimension of agarwood branches
(*Aquilaria malaccensis* Lamk)

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Abstract. Potential utilization of agarwood residues from twigs and branches is supported by its chemical content and fiber quality. This study aimed to analyze the chemical content and fiber quality of agarwood branches (*Aquilaria malaccensis* Lamk). Parameters measured in this study were the chemical contents including extractives, holocellulose, alpha cellulose and lignin based on Technical Association of Pulp and Paper Industries (TAPPI) standard. Fibers were obtained after pulping and bleaching to determine its quality. Chemical analysis of the primary branch of agarwood revealed the composition of extractives which were soluble in cold water (2.71%), hot water (3.31%), ethanol benzene (3.81%), and 1% NaOH (10.03%). The proportion of holocellulose, alpha cellulose and lignin in the primary branch was 78.17%, 52.70% and 26.68%, respectively. In addition, the chemical analysis of the secondary branch of agarwood also revealed the soluble extractives in cold water (2.96%), hot water (3.49%), ethanol benzene (4.14%), and 1% NaOH (14.42%). The proportion of holocellulose, alpha cellulose and lignin in the secondary branch was 75.61%, 50.65% and 26.77%. Hence, the fiber quality of agarwood branches was categorized into class II.

1. Introduction
Tree felling and limbing are the beginning processes of logging to utilize timber from trees. During the processes, tree parts such as upper trunks, branches, twigs and defective trunks are considered as logging residues with suboptimal utilization and tend to be used directly as firewood [1]. Moreover, the majority of the residues were unprocessed and generally abandoned on-site then becoming a huge pile of wastes [2-4].

Efforts to maximize the functionality of wood are effectively achieved through the utilization of wood residues. To achieve an optimal utilization, some parts of the tree should be investigated first to obtain the data on their potential and availability, especially the cultivated trees. Important parameters such as chemical content and fiber dimensions of wood residues are defining factors to assess its potential utilization including as raw materials for pulp and paper industries. Based on the description above, a study was conducted to determine the chemical content and fiber dimensions of wood residue

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from plantation forests, especially the branch part, which will be a reference for further utilization of the wood residues, in order to improve the value of the stands.

Agarwood from Indonesia contains the main component of polycyclic organic compounds in the form of benzopyran derivative or chromone. Chromone is the chemical compound for fragrance when agarwood is combusted [5]. Agarwood is the final product obtained from the colonizing fungal species in *Aquilaria malaccensis* Lamk which is one of the non-timber forest product commodities with high economic value for industrial needs. Agarwood has been cultivated intensively and during the process until harvesting, some of the final products resulted in wood residues including agarwood branches. Crown pruning is an effort to optimize the tree by focusing all nutrients to the stem, resulting in larger stem and trunk growth. Therefore, the study will investigate the potential of agarwood branches based on the chemical content and fiber quality of the residues.

2. Materials and method

2.1. Study period and place
This study was conducted from September 2019 to November 2020. Agarwood samples were collected from Pekan Bahorok Village, Langkat Regency, North Sumatra. Chemical analysis was conducted in Wood Chemistry Laboratory, IPB University. Fiber quality was tested in Forest Products Technology Laboratory and Disease Laboratory, Universitas Sumatera Utara.

2.2. Sample preparation
Agarwood branches collected from the agarwood plantation in Bahorok District, Langkat Regency were pulverized into fine powders and dried in room temperature. Preparation of agarwood samples followed the technical procedure in TAPPI T 264 cm-07. The sample has been divided in two types of branch namely primary and secondary branch (Figure 1).

![Primary and secondary branches](image_url)

*Figure 1. Primary and secondary branches*

2.3. Determination of extractive levels
Analysis of extractive solubility in cold water, hot water, ethanol benzene (2:1, v/v), and 1% NaOH was based on TAPPI T 207 om-88, ASTM D 1110-80 [6], TAPPI T 204 om-88, and TAPPI 212 om -88, respectively.
2.4. Determination of holocellulose, alpha cellulose and lignin levels
Determination of holocellulose, alpha cellulose and lignin levels was based on chlorite method [7], TAPPI 203 om-88 and TAPPI T 222 om -88, respectively.

2.5. Analysis of fiber quality
The analyzed fiber was obtained after pulping process. The pulping process used soda while the bleaching process used hydrogen peroxide. The fiber was stained to improve the test result. Measurement on fiber dimension included fiber length, fiber diameter, lumen diameter, and cell wall thickness while its derivatives were runkel’s ratio, felting power, mahlsteph ratio, coefficient of rigidity, and flexibility ratio. During the measurement of fiber dimension, the selected fiber (n = 100) must be intact while showing no indication of damage and folded [8].

3. Results and discussion

3.1. Chemical content
Chemical components of agarwood branch (Aquilaria malaccensis Lamk) which were soluble extractives in cold water, hot water, ethanol benzene, and 1% NaOH is presented in Table 1. In this study, we tested two types of branch namely primary and secondary branch. The chemical component of agarwood branch was higher in the primary branch although not significant than the secondary branch which was still classified from moderate to high class (Table 2). The highest extractive substances were the ones that soluble in ethanol benzene for secondary branch and in 1% NaOH for primary and secondary branch.

| Parameter         | Chemical content (%) | Primary branch | Secondary branch |
|-------------------|----------------------|----------------|------------------|
| Water content     | 12.64 ± 0.34         | 10.32 ± 0.32   |
| Cold water extractive | 2.71 ± 0.49   | 2.96 ± 0.84    |
| Hot water extractive  | 3.31 ± 0.18 | 3.49 ± 0.38    |
| Ethanol benzene   | 3.81 ± 0.34         | 4.14 ± 0.22    |
| 1% NaOH           | 10.03 ± 0.31        | 13.42 ± 0.65   |
| Holocellulose     | 78.17 ± 1.01        | 75.61 ± 1.71   |
| Alpha cellulose   | 52.70 ± 0.53        | 50.65 ± 0.38   |
| Lignin            | 26.68 ± 0.99        | 26.77 ± 1.91   |

Table 2. Classification of hardwood type based on wood chemical components [9]

| Chemical compounds | Component class |
|--------------------|-----------------|
|                    | High | Moderate | Low  |
| Cellulose          | >45  | 40-45    | <40  |
| Lignin             | >33  | 18-33    | <18  |
| Pentosan           | >24  | 21-24    | <21  |
| Extractive         | >4   | 2-4      | <2   |
| Ash                | >6   | 0.2-6    | <0.2 |

Wood extractives that were soluble in cold water and hot water in agarwood branch, were similar to those in Eucalyptus urophylla, a common species utilized as raw material in pulp and paper production with proportion of 2.32% and 3.37%. Other wood species as an example, Acacia mangium, was also commonly utilized as raw material with a higher extractive content namely 11.39% for cold water extractive and 14.06% for hot water extractive [10].

In this study, we obtained high results of extractive solubility in NaOH. Solubility of wood extractives in 1% NaOH indicated the damage intensity caused by fungi, heat, sunlight, and oxidation [11]. The higher the level of physical damage or rot intensity, the higher the solubility of wood
extractives in NaOH [12]. The solubility of wood extractive in ethanol benzene was higher in the secondary branch than primary branch. The extractives contribute to the hardness of wood as to protect its integrity towards microbial colonization [13].

Quantitatively, the content of extractive substances in wood was in smaller portion when compared to cellulose and lignin. However, wood extractives play a significant role on the wood properties and its processing. For example, the effect of extractives during the pulping process may cause pitch problems or the occurrence of spots on the resulting pulp sheet due to the high content of extractives [14].

The chemical component in the secondary branch was similar to the primary branch of agarwood classified as medium class. High lignin content was not required in the paper pulp processing because it may increase the need for chemicals thus increasing the cost of production [10]. Hardwood lignin is composed of guiaacyl and syringyl units with different ratios [15].

The portion of holocellulose and alpha cellulose was obtained in high amount for both primary and secondary branch of agarwood. Holocellulose is the total fraction of carbohydrate consisted of cellulose and hemicellulose [16]. Cellulose is one of the sustainable and abundant biomass resources in Indonesia [17]. Cellulose can be processed into Carboxymethyl cellulose (CMC), Nanocellulose, and nanocrystalline cellulose (NCC) materials and others [18].

3.2. Fiber quality
Fiber dimension is an important feature or key determinant for choosing wood species which is suitable for pulp and paper production. Fiber dimension measured in this study namely fiber length, fiber diameter, cell wall thickness, and lumen diameter from agarwood branch (*A. malaccensis* Lamk) is presented in Table 3.

| Sources          | Fiber length (µm) | Fiber diameter (µm) | Lumen diameter (µm) | Cell wall thickness (µm) |
|------------------|-------------------|--------------------|---------------------|-------------------------|
| Primary branch   | 601.86 ± 87.30    | 28.33 ± 6.00       | 20.71 ± 10.56       | 2.56 ± 1.07             |
| Secondary branch | 481.3 ± 115.12    | 18.17 ± 4.29       | 11.85 ± 1.60        | 2.22 ± 1.12             |

In Table 3, the average fiber length of agarwood branch (*A. malaccensis* Lamk) in the primary branch was higher than the secondary branch. Mature cells were longer than immature cells due to the rapid division of immature length preventing the cellular enlargement. In addition, the vacuole, as the largest cellular compartment also contributed to the cellular size of mature cells [19]. Based on the fiber length, it can be concluded that agarwood branch was still classified as having short fibres (481–600 µm). The fiber diameter in the primary branch was also larger than the secondary branch as a consequence of its fiber length. The fiber diameter of primary branch was classified as wide (26–40 µm) while in the secondary branch, the fiber diameter was classified as moderate (11–25 µm) [20].

The cell wall thickness of the primary agarwood branch was thicker than the secondary branch. Hence, it was classified as having profuse cell walls and narrow lumens. Thin-walled fibers are easier to flatten, resulting in denser pulp and paper sheets and improved bursting strength than thick-walled fibers. In contrast, thick-walled fibers produce sheets with higher tear strength but low burst strength. In order to obtain high fracture and tear strength, thick-walled fibers are blended with thin-walled fiber plants, for example pines, spruces and firs or ground. The composites were ground after the pulp production in some weeks to decimate the cell walls. The lumen diameter also followed the trend result of other parameters which also indicated the dominant immature cells in the tissue. Fiber dimension is one of the anatomical variables that determine wood quality. Based on our observation, the agarwood branches would still potent as raw materials for paper and low-grade lumbers.
In Table 4, the runkel’s ratio agarwood branch ranged between 0.39 and 0.45. Runkel’s ratio is the ratio of cell wall thickness to lumen diameter which correlate in line with the cell wall thickness. Based on the runkel’s ratio, the agarwood branch could meet the criteria of fiber characteristics for pulp with quality class III. Suitable wood for pulping has a smaller runkel’s ratio (<0.25) and wide lumens to support the flattening and improved bonds among fibers. Based on the felting power, agarwood branches were also classified into quality class III. Felting power is the ratio of fiber length to fiber diameter. The greater the ratio, the higher the tear strength and the better the felting power of the fiber. A higher tear strength indicated that the fiber can withstand the tension and become longer due to the interweaving between the fibers thus the tearing force will be scattered into a larger area [14]. Based on the muhlsteph ratio, agarwood branches were classified into quality class II. The magnitude of muhlsteph ratio determined the density and strength of the pulp sheets produced. The smaller the muhlsteph ratio, the denser of the resulting pulp sheet will be and vice versa [21].

Based on the coefficient of rigidity, agarwood branches were classified into quality class II. Coefficient of rigidity is the ratio of cell wall thickness to fiber diameter. The ratio showed a negative correlation to the tensile strength of a material. For industry, the raw material should possess a low coefficient of rigidity [14]. Flexibility ratio is the ratio of lumen diameter to fiber diameter. Based on the result, agarwood branches were also classified into class II. A high flexibility ratio produces pulp sheets with good strength due to the more bonds among thin fibers.

### Table 4. Wood fiber derivative values of agarwood branches (A. malaccensis Lamk)

| Fiber derivative values     | Primary Branch | Secondary Branch |
|-----------------------------|----------------|------------------|
| Runkel’s ratio              | 0.39 ± 0.32    | 0.45 ± 0.34      |
| Felting power               | 33.92 ± 38.30  | 32.03 ± 26.57    |
| Muhlsteph ratio             | 42.58 ± 18.45  | 46.15 ± 19.67    |
| Coefficient of rigidity     | 0.13 ± 0.07    | 0.14 ± 0.07      |
| Flexibility ratio           | 0.75 ± 0.13    | 0.72 ± 0.14      |

4. Conclusion

Chemical content in agarwood (Aquilaria malaccensis Lamk) branches for extractives was categorized as moderate-to-high levels. The branches also contained a high portion of holocellulose and alpha cellulose with a medium portion of lignin. Based on the fiber dimension and its derivative values, agarwood branches were qualified into class II.

### References

[1] Syahidah, Hikmah and Yunianti A D 2006 Jurnal Perennial 3 11
[2] Budiaman A, Mubarak F M and Lismaya W 2020 Jurnal Ilmu Pertanian Indonesia 25 145
[3] Suwarna U, Mantangaran J R and Morizon 2013 Jurnal Ilmu Pertanian Indonesia 18 61
[4] Soenarno, Dulsalam and Yuniawati 2020 Jurnal Penelitian Hasil Hutan 38 105
[5] Nasution A A, Siregar U J, Miftahudin and Turjaman M 2019 J. For. Res. 31 1371
[6] American Society for Testing Materials 2002 Annual Book of ASTM Standards (Baltimore: ASTM International)
[7] Browning B L 1967 Methods of Wood Chemistry (New York: Interscience Publishers)
[8] Nuryawan A 2016 Teknologi Papan Partikel dan Papan Serat (Medan: Universitas Sumatera Utara)
[9] Kementerian Lingkungan Hidup dan Kehutanan 2020 Vademecum Kehutanan Indonesia (Jakarta: Badan Penelitian Pengembangan dan Inovasi Kementerian Lingkungan Hidup dan Kehutanan)
[10] Herlina, Istikowati W T and Fatriani 2018 Jurnal Riset Industri Hasil Hutan 10 21
[11] Júnior G B and Moreschi J C 2003 Bioresour. Technol. 87 231
[12] Shang J, Yan S and Wang Q 2013 *BioResources* **8** 6066
[13] Munir M T, Pailhories H, Eveillard M, Irle M, Aviat F, Dubreil L, Federighi M and Belloncle C 2020 *Antibiotics* **9** 225
[14] Syafii W and Siregar IZ 2006 *Journal of Tropical Wood Science & Technology* **4** 28
[15] Nawawi D S, Rahayu I S, Wistara N J, Sari R K and Syafii W 2019 *Jurnal Ilmu Kehutanan* **13** 70
[16] Lukmandaru G, Susanti D and Widyorini R 2018 *Jurnal Penelitian Kehutanan Wallacea* **7** 37
[17] Mulyadi I 2019 *Jurnal Saintika UNPAM* **1** 177
[18] Batubara R, Wirjosentono B, Siregar A H, Tamrin and Harahap U 2021 AIP Conf. Proceedings 2342 080004
[19] Tan X, Li K, Wang Z, Zhu K, Tan X and Cao J 2019 *Plants* **8** 327
[20] Kasmudjo 1994 *Cara Penentuan Proporsi Tipe Sel dan Dimensi Sel Kayu* (Indonesia: Fakultas Kehutanan Universitas Gadjah Mada)
[21] Aprianis Y and Rahmayanti S 2008 *Jurnal Penelitian Hasil Hutan* **27** 11