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Characterization of Chemical Components in the Wood and Bark of *Anthocephalus cadamba* and *Anthocephalus macrophyllus* from Progeny Trial in Wonogiri, Indonesia

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Abstract. Jabon (*Anthocephalus* spp.) is a fast-growing species with considerable potential for pulp and paper production in Indonesia. This study aims to determine the chemical component in wood and bark of 10-year-old *Anthocephalus cadamba* (families 23, 11, and 6) and 5-year-old *Anthocephalus macrophyllus* (families 75, 85, and 2) in the bottom part of the trees. The results showed that chemical properties of *A. cadamba* in the wood and bark, i.e., holocellulose, α-cellulose, hemicellulose, and Klason lignin content ranged from 62.66 to 75.75%, 32.42 to 48.43%, 26.72 to 34.42%, and 22.80 to 35.10%, respectively. The levels of holocellulose and α-cellulose in these species are in the high class. High holocellulose and cellulose content indicates high pulp yield, which will benefit the pulp and paper industry, especially F6 and F2.

1 Introduction

Jabon (*Anthocephalus* ssp.) is a fast-growing species from the Rubiaceae family in Indonesia. There are two known species, namely the white jabon (*Anthocepalus cadamba*) and the red jabon (*Anthocepalus macrophyllus*). *A. cadamba* is native to Indonesia, Australia, China, India, Malaysia, Papua New Guinea, the Philippines, Singapore, and Vietnam [1]. In Indonesia includes Sumatra, West Java, East Java, East Kalimantan, South Kalimantan, South Kalimantan, Sulawesi, West Nusa Tenggara and Papua [2]. Meanwhile, *A. macrophyllus* is widespread in Maluku, North on the islands of Maluku, North Maluku, Sulawesi and Papua.

Jabon wood has a strength and durability class of III-IV and V, with a specific gravity of 0.42 g. cm^{-3} [3]. Krisnawati et al. [4] reported that this species has consistent quality and rapid growth, with mean diameter increasing from 1.2 to 11.6 cm at 5 years old.

The wood of *A. cadamba* and *A. macrophyllus* can be used as a raw material for plywood, in the furniture industry and in light-weight construction [2, 4]. Previous studies have also identified Jabon wood as a raw material for pulping and papermaking [5-7]. In Indonesia, species such as *Acacia mangium* and *Eucalyptus pellita* are developed in industrial forest plantations (HTI) for pulp and paper materials. However, these species often suffer from diseases and other problems.

A. mangium has reportedly suffered many mortalities due to *Ganoderma* and *Ceratocystis* fungal infections [8, 9]. In addition, many cases of damping-off of *Eucalyptus* sp. nurseries [10]. Therefore, jabon wood is one of the tree species with high potential and can be recommended for HTI development in Indonesia for pulp and paper materials.

The *A. cadamba* progeny test plots were established using genetic material from Banten, Lampung, and Kediri populations of about 76 families and planted in September 2010. Meanwhile, the genetic material in the *A. macrophyllus* progeny test was obtained from Konawe provenance, Southeast Sulawesi, which is the natural distribution of this species with a total of 55 families and planted in July 2011 [11]. Tree breeding for the development of superior seed sources has been carried out by establishing first-generation (F-1) progeny trial plots in Wonogiri, Central Java by the Forestry Standards and Instrument Testing Centre (BBPSIK). The trial was conducted to obtain the best progeny from several families that could be used as a source of superior seeds at the next level.

During the first year, average height, diameter at breast height (DBH), estimated volume, and growth for *A. macrophyllus* were 4.2 m, 5.7 cm 3.6 m^3/ha and 4.5 m/year, respectively. At the same age, the growth rates of *A. mangium* and *Falcataria moluccana* were 4.4 m/year and 3.91 m/year, respectively. Therefore, compared to both species, the growth rate of *A. macrophyllus* is significantly higher and faster. Meanwhile, the mean diameter for 5-year-old trees of *A. cadamba* was 21.4 cm, producing an average volume of 209.45 m^3/ha [12].

Chemical composition is a relevant wood quality parameter. It is crucial for pulping suitability [13]. Cellulose, lignin and extractives are important in the interpretation of the pulping behavior as well as in the determination of the pulp quality [14]. Furthermore, the quantity and composition of the extractives can impact their use as raw materials to produce pulp and paper [15].

The wood industry generates large amounts of waste, particularly bark, which is typically removed from trees in factories and burned for energy. However, it can be an important renewable resource for high

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value-added applications [16, 17]. Bark is morphologically and chemically heterogeneous and varies considerably not only between hardwood and softwood trees, but also between species [18]. Although bark contains most of the same components as wood (cellulose, hemicellulose, pectin, lignin and extractives), they are present in very different proportions, e.g. higher extractives [19]. The bark is a source of a wide range of substances used in adhesives, pharmaceuticals and biocides [20].

Studies on the chemical composition of *A. cadamba* and *A. macrophyllus* are still limited to total cell wall chemical components, especially comparing wood and bark parts. Some previous studies related to the chemical composition of the cell walls of *A. cadamba* and *A. macrophyllus* have been reported [5, 7, 21-23]. However, the samples are generally not from genetic selection or selected individuals.

This study used the jabon family with the best phenotypic characteristics, including height and diameter. In a tree breeding program, these trees have undergone progeny trials. Therefore, this study aimed to evaluate the characterization of each family's chemical properties and provide information for the tree breeding process.

2 Materials and Methods

2.1 Sample collection

Samples of *A. cadamba* and *A. macrophyllus* were collected from the bottom of the trees at a height of 10–30 cm above the ground from a progeny trial established in Wonogiri, 7°47′S, 110°56′E (*A. cadamba)* and 7°80′S, 110°93′E (*A. macrophyllus*), Central Java, Indonesia. Each species had three single trees of different family numbers. Genetic material for *A. cadamba* was collected from Sobang, Pandeglang regency, Banten, Indonesia (76 families). Meanwhile, *A. macrophyllus* was collected from Konawe regency, Southeast Sulawesi, Indonesia (55 families). These three families were chosen because they had the best phenotypes (physical characteristics such as tree diameter and height) of all the families (76 families of *A. cadamba* and 55 families of *A. macrophyllus*). Despite the differing ages, the diameters of the two Jabon species were relatively similar at ± 20 cm. The sample tree descriptions are shown in Table 1.

After the trees were harvested into disk form (4 cm thick). The air-dried wood specimens were collected by drilling in cardinal directions and mixed. Samples for chemical analysis were then obtained at 1 cm from the bark-sapwood border. The drilled wood was separately milled to a powder and sieve-screened to pass a 1-mm sieve for chemical analysis.

Table 1. Description of six individual *A. cadamba* and *A. macrophyllus* samples

Species	Family numbers	Tree age (year)	Dbh (cm)	Total merchantable height (m)
A. cadamba	F23	10	24.2	18.0
	F6	10	20.1	18.8
	F11	10	19.3	18.8
A. macrophyllus	F75	5	21.3	16.6
	F85	5	20.0	16.0
	F2	5	20.0	17.0

2.2 Extraction and cell wall component determination

The 5 g powder (40-60 mesh size fractions) sample was successively extracted by *n*-hexane and methanol for 6 hours in a Soxhlet apparatus as well as hot water (refluxing in separated extraction for 3 hours). Further, the solvent was evaporated by a rotary evaporator. Then, the extract was dried in an oven (103±2°C), and the extractive content was quantified and expressed as a percentage of the oven dry weight. Furthermore, the determination of holocellulose was carried out according to the chlorite acid modification of the Wise method [24]. In addition, the determination of α-cellulose was carried out according to Rowell et al. [25]. Furthermore, the content of Klason lignin was measured by standards of TAPPI 222 om-02 [26]. Meanwhile, hemicellulose content was determined using an equation by Boonstra & Tjeerdsma [27].

3 Results and Discussion

3.1 Extractive content

In the wood parts, the highest values of *n*-hexane soluble extractive content (HEC), methanol (MEC), hot water (HWC), and total extractive content (TEC) were found in family 23 (*A. cadamba*). Meanwhile, in *A. macrophyllus*, the highest HEC and HWC values were found in family 75 and the highest MEC and TEC values in family 2. On the other hand, in the bark part, the highest HEC, MEC and TEC levels were observed in family 11, whereas the highest HWC value was obtained in family 6 (*A. cadamba*). Meanwhile, in *A. macrophyllus*, HEC value was highest in family 2, and MEC, HWC, and TEC levels were highest in family 85. Regarding the extractive content in these species, it has been reported in previous studies [28].

3.2 Holocellulose content

The holocellulose content in *A. cadamba* wood ranges from 73.63 to 75.75% (Fig. 1). These results were similar range as previous studies in *A. cadamba* wood [5, 7, 22]. On the other hand, the result of this study was lower than study in *A. cadamba* from Malaysia and Bangladesh [6, 29]. In addition, the content of holocellulose in this study was higher compared to previous studies [30, 31].

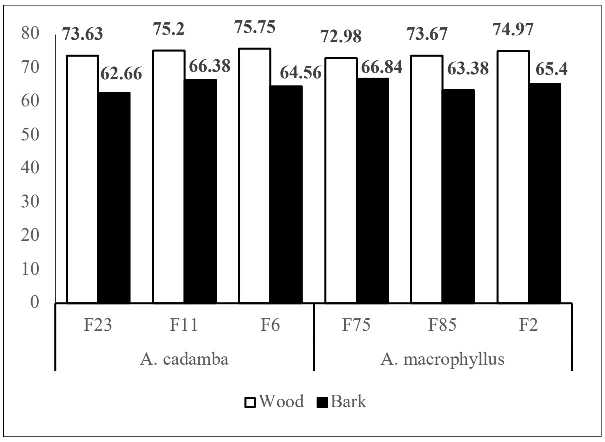

Fig. 1. Holocellulose content (%) in wood and bark of *A. cadamba* (10 years old) and *A. macrophyllus* (5 years old) from three different family numbers

The levels of holocellulose content in *A. macrophyllus* wood ranged from 72.98 to 74.97%. This result was larger than previous studies in 3-year-old *A. macrophyllus* [21]. The growing location and age of the trees may influence these differences. Then, when compared with other fast-growing species, the holocellulose content in *A. cadamba* and *A. macrophyllus* wood is relatively higher. Amirta et al. [30] reported that the holocellulose content in *Acacia mangium* wood ranged from 64.37% to 69.64% in sengon wood. Arisandi et al. [32] also reported that the holocellulose content in *Eucalyptus pellita* wood ranges from 63.37% to 70.57%. Meanwhile, the content of holocellulose in the bark part ranged from 62.66 to 66.38% (*A. cadamba)* and 63.38 to 66.84% (*A. macrophyllus).* This result was higher than in the bark part of the *E. globulus* species with a holocellulose content of 62.6% [33].

In general, the holocellulose substance in *A. cadamba* is still within the comparative range like *A. macrophyllus,* although it encompasses a different age. Subsequently, the content of holocellulose in the wood was higher compared to the bark portion in both *A. cadamba* and *A. macrophyllus.* The value of holocellulose content varies greatly depending on the family number both in *A. cadamba* and *A. macrophyllus*. In *A. cadamba*, the highest holocellulose content in the wood and bark was found in F6 (75.75%) and F11 (66.38%), respectively. Meanwhile, the lowest holocellulose content in the wood and bark part was observed in family numbers 23 (73.63%) and 23 (62.66%), respectively. In *A. macrophyllus,* the holocellulose content in the wood was highest in family number 2 (74.97 %) and the lowest levels was found in family number 75 (72.98 %). In addition, it was most elevated in family number 75 (66.84%) and least in family number 85 (63.38%) within the bark portion.

3.3 α-cellulose content

The value of *α* -cellulose content in *A. cadamba* wood ranged from 46.91 to 48.43% (Fig. 2). These results were higher than those found in previous studies [5, 6, 22, 30, 34, 35]. Meanwhile, the amount of *α*-cellulose content in *A. macrophyllus* wood ranged from 46.12 to 47.94%. This result was smaller than the study by Lempang [23], but larger than the study by Mukhdlor et al. [21]. Furthermore, the content of *α*-cellulose in *A. cadamba* and *A. macrophyllus* bark ranged from 33.20 to 35.16% and 32.42 to 33.93%, respectively.

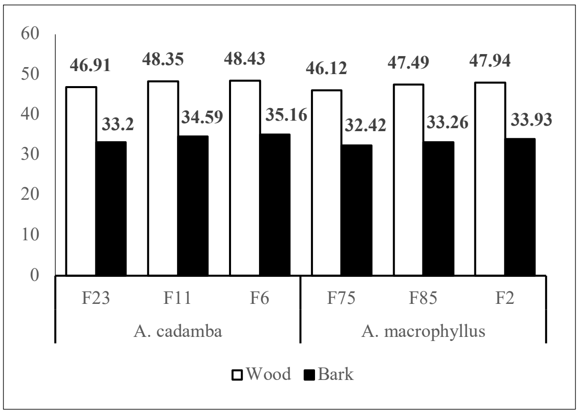

Fig. 2. α-cellulose content (%) in wood and bark of *A. cadamba* (10 years old) and *A. macrophyllus* (5 years old) from three different family numbers

Compared to other fast-growing species, the amount of *α*-cellulose in *A. cadamba* and *A. macrophyllus* wood was higher compared to *A. mangium* wood (38.94%) and lower than in sengon wood (51.41%) [30]. Meanwhile, the content of α-cellulose in this study was in the same range of values in *E. pellita* wood with α-cellulose content ranging from 42.55 to 50.97% [32].

In general, *A. cadamba* and *A. macrophyllus* have similar levels of α-cellulose. Subsequently, the amount of α cellulose in the wood (>45%) was larger than the bark (<40%) parts in both *A. cadamba* and *A. macrophyllus* species. This may be due to the extractive content of the bark, which contains a lot of suberin and requires harsh conditions to isolate the cellulose, so the cellulose content is usually low, and the cellulose is degraded during the isolation process [25].

The α-cellulose content in both *A. cadamba* and *A. macrophyllus* wood from all families is included in the high class. This is because this species has an α-cellulose content of >45%, based on the classification of hardwood chemical components [36]. High levels of cellulose contained by a wood species are desirable in manufacturing pulp for paper.

In *A. cadamba,* the highest α-cellulose content was found in F6 (48.43% in wood and 35.16% in bark). The lowest was obtained in F23 (46.91% in wood and 33.20% in bark). In *A. macrophyllus,* the highest α-cellulose content was observed in F2 (47.94% in wood and 33.93% in bark). Meanwhile, the lowest content was investigated in F75 (46.12% in wood and 32.42% in bark).

The high cellulose in *Anthocephalus* spp., is not only potential as a raw material for pulp and paper, but also cellulose can be used as the main ingredient in the production of second-generation bioethanol [37]. High cellulose content indicates that the wood has the potential to be further processed into bioethanol. Amin et al. [22] also stated that cellulose can also be hydrolysed into reducing sugars, which are then fermented into bioethanol. High α-cellulose content generally has a positive effect on reducing sugar yield.

3.4 Hemicellulose content

The levels of hemicellulose content in *A. cadamba* wood ranged from 26.72 to 27.32% (Fig. 3).

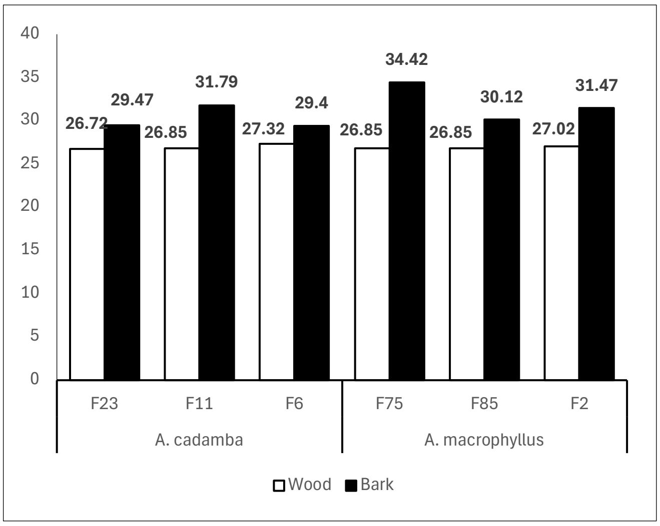

Fig. 3. Hemicellulose content (%) in wood and bark of *A. cadamba* (10 years old) and *A. macrophyllus* (5 years old) from three different family numbers

These results were lower than those of previous studies [5, 22, 35] but higher than reported by Lal et al. [34]. Meanwhile, the amount of hemicellulose content in *A. macrophyllus* wood ranged from 26.85 to 27.02%. The hemicellulose content of *A. cadamba* and *A. macrophyllus* bark ranged from 29.40 to 31.79% and 30.12 to 34.42%, respectively.

Compared to other fast-growing species, the hemicellulose content in *A. cadamba* and *A. macrophyllus* wood was higher than *A. mangium* wood (around 20.7%) and is still in the same range as *E. pellita* wood (around 26.8%) [38]. Meanwhile, the value of hemicellulose content in this study was smaller than *A. mangium* and *Leucaena leucocephala* (31.54 to 36.14% %) [39].

In general, the hemicellulose content of *A. cadamba* wood was in the same range as that of *A. macrophyllus.* However, the bark of *A. macrophyllus* was higher than that of *A. cadamba.* Furthermore, the hemicellulose content was different from holocellulose and α-cellulose. The hemicellulose content of the bark was larger compared to the wood part. In almost all cases, the hemicellulose found in the bark is the same as that found in the wood, with some variations in the composition [25].

The highest hemicellulose content in *A. cadamba* wood was found in F6 (27.32%) and the lowest in F23 (26.73%). Meanwhile, in the bark portion, the highest hemicellulose content was found in F11 (31.79%), and the lowest was obtained in F6 (29.40%). In *A. macrophyllus,* the highest hemicellulose content in wood was found in F2 (34.42%), and the lowest was detected in F85 (26.85%). Furthermore, the highest hemicellulose content in the bark part was detected in F75 (34.42%), and the lowest was observed in F85 (30.12%).

3.5 Klason lignin content

A. cadamba wood had a Klason lignin content ranged from 22.80 to 23.89% (Fig. 4). This result was lower than previous studies [5, 6, 22, 29-31], but higher than the study by Lal et al. [34]. Meanwhile, the amount of lignin content in *A. macrophyllus* wood ranged from 25.68 to 31.71%. This result agrees with those found by Lempang [23]. However, it was higher than those found by Mukhdlor et al. [21].

The Klason lignin content of both *A. cadamba* and *A. macrophyllus* wood was low compared to other fast-growing species. Amirta et al. [30] reported that the lignin content in *A. mangium* wood was around 27.8%. Arisandi et al. [32] also reported that lignin content in *E. pellita* wood had values ranged from 28.8 to 32.94%.

However, the amount of lignin content was lower than *Eucalyptus* (from 29 to 32%) [40]. In agro-industrial applications, lignin has a negative impact on the utilisation of plant biomass in both biofuels and the paper industry. Although *Eucalyptus* is the most important hardwood fibre crop species in tropical and subtropical regions [41], *A. cadamba* may be a suitable alternative tree species due to future demands for biomass utilisation. Meanwhile, the amount of Klason lignin content in *A. cadamba* and *A. macrophyllus* bark ranged from 29.62 to 31.71% and 33.70 to 35.10%, respectively. This result was larger than the bark of *E. globulus* (26.6%) [33].

In general, the Klason lignin content in *A. cadamba* was smaller than that of *A. macrophyllus.* This trend differed from the holocellulose, α-cellulose, and hemicellulose levels where *A. macrophyllus* and *A. cadamba* were in the same range. It can be concluded that only the levels of Klason lignin are affected by differences in species and age. Subsequently, the content of Klason lignin in the bark was higher than in the wood.

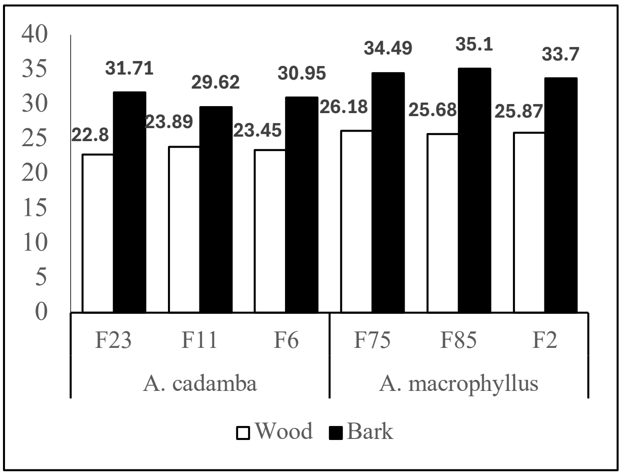

Fig. 4. Klason lignin content in wood and bark of *A. cadamba* (10 years old) and *A. macrophyllus* (5 years old) from three different family numbers

In *A. cadamba,* the highest lignin content in wood was found in F11 (23.89%) and the lowest in F23 (22.80%). While in the bark, the highest content was found in F23 (31.71%) and the lowest in F11 (29.62%). Furthermore, the highest lignin content of *A. macrophyllus* wood was detected in F75 (26.18%) and the lowest in F85 (25.68%). Meanwhile, the largest lignin content was found in F85 (35.10%), and the lowest in F2 (33.70%) was observed in the bark of *A. macropyllus*.

In general, *A. cadamba* and *A. macrophyllus* trees in this study had a lower lignin content than in *Acacia* wood [30] and eucalyptus wood [32]. *Acacia* and *Eucalyptus* are commonly used as pulp and paper raw materials. Therefore, the *A. cadamba* and *A. macrophyllus* wood in this study have good potential as pulp and paper raw materials because their relatively low lignin content. The lignin content in *A. cadamba* and *A. macrophyllus* wood from all families is the medium class (from 18 to 33%), based on the classification of chemical components of hardwood species [36].

3.6 Potential family as raw material for pulp and paper

Chemical properties such as holocellulose, α-cellulose, hemicellulose, and Klason lignin are important factors in determining the quality of raw materials for pulp and paper. Based on the evaluation, F6 (*A. cadamba*) and F2 (*A. macrophyllus*) have the potential to be developed into HTI for pulp and paper raw materials because they have high cellulose and hemicellulose content with relatively low lignin content. However, it should be noted that it is not enough to evaluate the properties of cell wall components, but also other parameters such as basic density, fibre dimensions and derived values [42]. However, extractive parameters and lipophilic compounds have been reported in previous studies [28, 43]. Therefore, further research is needed to evaluate its properties (basic density, fibre dimensions and their derived values).

4 Conclusions

The levels of holocellulose, α-cellulose, hemicellulose, and Klason lignin content in both of *A. cadamba* and *A. macrophyllus* ranged from 62.66 to 75.75%, 32.42 to 48.43%, 26.72 to 34.42%, and 22.80 to 35.10%, respectively. The content of holocellulose and a-cellulose in the wood was larger than the bark parts in both *A. cadamba* and *A. macrophyllus.* The reverse trend was found for hemicellulose and Klason lignin. Furthermore, these species have great potential as alternative raw materials for the pulp and paper industry in Indonesia, especially F6 and F2, which have high levels of polysaccharide fractions and relatively low lignin content. Therefore, these families can be developed for HTI as raw material for pulp and paper.

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