Assessment of Wood Biomass Productivity from Anthocephalus macrophyllus Forest Plantation for Energy Production

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Assessment of Wood Biomass Productivity from *Anthocephalus macrophyllus* Forest Plantation for Energy Production

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ABSTRACT

Antocephalus macrophyllus is one of the fast-growing species widely planted in an industrial forest plantation in Indonesia. Since its cultivation has been mainly expanded, the interest to explore *A. macrophyllus* wood for further utilization to produce various valuable products is also growing. Nevertheless, there was no available information about energy production generated from *A. macrophyllus* forest plantation in recent times. Therefore, this work assessed its suitability for energy purposes. The result showed that the harvest cycle of *A. macrophyllus* plantation in third year demonstrated the most appropriate energy feedstock since it could obtain the highest wood productivity (43.20 ton/ha) with high annual energy potential (211.97 GJ/ha/year). According to the wood physicochemical properties, we found that higher lignin content contributed to an increase in calorific value. Meanwhile, the high presence of moisture had a converse effect. Finally, we suggested that the forest plantation of *A. macrophyllus* was promising for developing renewable and sustainable energy production in the future.

Keywords: *Anthocephalus macrophyllus, Energy, Forest Plantation, Woody Biomass.*

1. INTRODUCTION

Industrial development is the primary reason for releasing high greenhouse gas (GHG) emissions into the atmosphere [1]. It strongly contributes to severe climate change. On the other hand, the human population is growing exponentially, causing an increase in energy demand. However, the most utilized energy source is still dominated by non-renewable fossil fuels (80%) [2]. Hence, developing alternative energy sources is necessary to improve energy security and reduce adverse problems because of conventional fuels.

Lignocellulosic biomass is one of the most popular bioenergy sources used in many countries in the world. This type of biomass accounts for more than 80% of the total biomass used in renewable energy sectors [3]. Biomass-based energy has great potential to minimize the environmental impact due to GHG emission. Its sustainable production has been reported to constitute the pillar of socioeconomic growth and reduces some wastes [4]. A lignocellulosic crop with a shorter growing ability and without compromising food production will fit sustainable green energy generation requirements. Some countries geographically located in the tropical region receive significant benefits to obtain high biomass yield since plants can grow faster than other areas on the earth. Several works have been performed to evaluate some tropical woody species [5-8].

Anthocephalus macrophyllus (red jabon) is a woody non-food crop. It is well known as one of the fast-growing species widely planted in Indonesia's industrial forest plantation. *A. macrophyllus* wood is commonly utilized to supply needs in the pulp and paper industry. Although its cultivation has been expanded largely, there was still no available information about its potential application in energy purposes in recent times.

Therefore, this work aims to point out A. macrophyllus forest plantation's suitability for sustainable feedstock of energy production. The wood productivity of *A. macrophyllus* at different ages was assessed to obtain the most appropriate time for its harvest cycle. Furthermore, its wood physicochemical properties produced at the optimized harvest cycle time were also reported.

2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted at permanent sampling plots (PSP) in an industrial forest plantation company, PT Intraca Lestari, located at Malinau district, North Kalimantan Province, Indonesia.

2.2. Determination of Wood Biomass Productivity

The data of plant height, diameter, and quantity (different plant age) at PSP were collected to estimate the availability of wood volume per hectare. Furthermore, the wood density of *A. macrophyllus* was measured according to the protocol previously reported by Henry et al. [9]. The biomass productivity was calculated based on the multiplication between volume per hectare (m^3) and its wood density (kg/m^3).

2.3. Wood Energy Potency Analysis

The wood calorific value was measured using a bomb calorimeter according to the EN-ISO 15400:2011. The all-wood physicochemical properties obtained from the optimized harvest cycle time of *A. macrophyllus* forest plantation was further investigated. The content of ash, volatile matter and fixed carbon was determined following the ASTM D 7582-12. The elemental compositions such as carbon (C), hydrogen (H), and oxygen (O) was estimated by using an Equation introduced by Parikh et al. [10]. Other compositions, including extractive, holocellulose, α-cellulose, and klason lignin, were carried out based on the standard of TAPPI T 222 om-98.

3. RESULTS AND DISCUSSION

3.1. Wood Productivity and Energy Potency

The diameter at breast height (DBH) increment of *A. macrophyllus* was measured. Figure 1 showed the wood samples harvested randomly from PSP at different age from the 1st to 4th year. It was observed that DBH was highly increased at 1st, 2nd, and 3rd-year plant age with the mean value of 7.44, 12.32, and 15.58 cm, respectively. It was found that an increase in DBH from 3rd to 4th year was relatively low, showed by the fact that the DBH increment was less than 2 cm. In line with this, the plant height also demonstrated a similar pattern. The plant height at 1st year (1.50 m) increased dramatically to 5.43 m at 2nd year, followed by 8.83 and 10.58 m at 3rd and 4th year, respectively. However, these results were still lower than those of *Acacia mangium*, and *Eucalyptus pellita* previously reported [11,12].

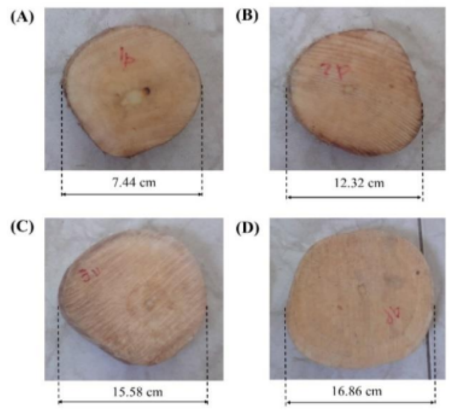

Figure 1 The appearance with each average DBH of *A. macrophyllus* wood collected from different plant age: (A) 1st year, (B) 2nd year, (C) 3rd year, and (D) 4th year.

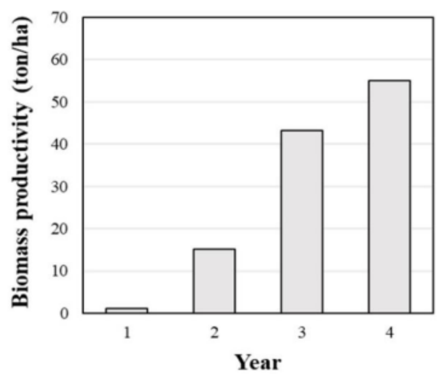

Figure 2 Wood biomass productivity obtained from *A. macrophyllus* forest plantation at different plant age.

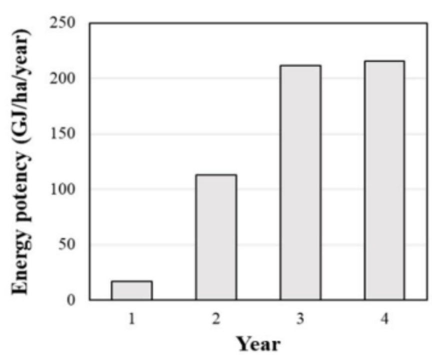

Figure 3 The annual increment of energy potency obtained from *A. macrophyllus* forest plantation.

The biomass productivity of *A. macrophyllus* forest plantation has been displayed in Figure 2. It could be observed that the values were also rising in line with the age of the plant. It could produce 1.17 tons of biomass per hectare in 1st year. While, in the 2nd year, the biomass productivity achieved 15.10 ton/ha. This value was also increased in the 3rd year (43.20 ton/ha). *A. macrophyllus* achieved 55.11 ton/ha biomass at the 4th plant age. To point out the energy potency, the calorific value should be determined. The obtained value was further converted according to wood biomass availability. Figure 3 demonstrated the results of energy potency obtained from *A. macrophyllus* forest plantation. It could be seen that the value in the 4th year was not significantly higher than that of the 3rd year. Hence, the 3rd plant age indicated the most appropriate harvest time, producing 211.97 GJ/ha/year energy potential. It was interesting to know that the normal harvest cycle time of *A. macrophyllus* was reportedly between 8-12 year [13]. In this study, the optimized harvest period could become faster than the common *A. macrophyllus* forest plantation to provide wood for the pulp and paper industry.

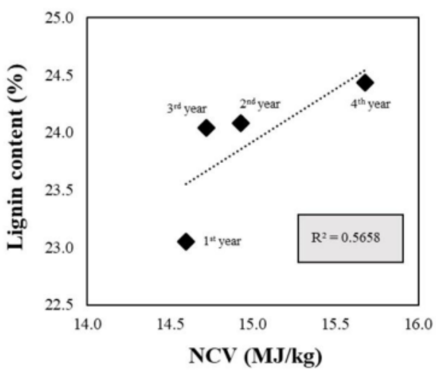

Figure 4 A correlation between lignin content and calorific value of *A. macrophyllus* wood.

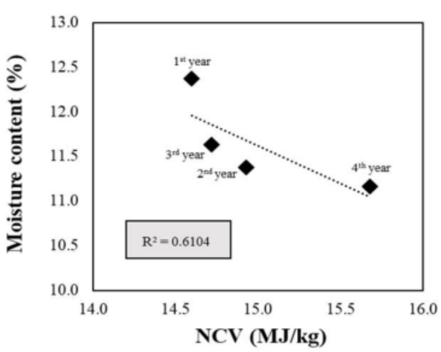

Figure 5 A correlation between moisture content and calorific value of *A. macrophyllus* wood.

Determination of several factors affecting the *A. macrophyllus* net calorific value (NCV) was conducted. Figure 1 showed how a high lignin content on the wood of *A. macrophyllus* affected its increased NCV. It was noted that the relationship between lignin and heating value was also available in the literature. Demirbas et al. reported that lignin's heat content is generally higher than other lignocellulosic components due to its richness in carbon content [14]. Lignin contains alkylphenol structures that make it potential for carbon sources, thus increasing its obtained NCV in biomasses. The heating value of lignin has been reported previously (27.0 MJ/kg), and this value was significantly higher in comparison to cellulose (17.5 MJ/kg) and hemicellulose (16.0 MJ/kg) [15]. Another property reportedly causing high calorific value is extractive. Although the previous work proved that extractive presence had a considerable increase in obtained calorific value [16], we found a contrary result (data was not shown).

Figure 2 showed an influence of moisture content on *A. macrophyllus* on its decreased NCV. A decrease in NVC was due to the heat of vaporization of water content [17]. The presence of moisture that played a negative role in the calorific value in biomass has been reported by several authors [18,19]. In general, we observed that as an increase in plant age of *A. macrophyllus*, lignin content was increased, and moisture content was decreased. Thus, it contributed to an enhancement of the obtained NCV.

3.2. Wood Physicochemical Properties at the Optimized Plant Age

The wood physicochemical properties of *A. macrophyllus* harvested in the third year was further assessed since it was the most desired wood for feedstock of biomass-based energy production. The wood characteristic was classified as proximate content, ultimate content, and biomass composition (Table 1).

Table 1. The wood physicochemical properties of *A. macrophyllus* obtained at the 3rd year of plant age.

No	Property	Percentage (%)
1	Ash	0.65 ± 0.03
2	Volatile matter	73.22 ± 0.07
3	Fixed carbon	17.41 ± 0.06
4	C	47.78 ± 0.01
5	H	5.10 ± 0.01
6	O	47.02 ± 0.01
7	Extractive	3.13 ± 0.30
8	Holocellulose	68.67 ± 0.33
9	α-cellulose	36.06 ± 0.50
10	Klason lignin	24.04 ± 0.17

Data were presented as mean value ± standard deviation (n=3).

The proximate content of *A. macrophyllus* wood included ash (0.65%), volatile matter (73.22%), and fixed carbon (17.41%). Since the ash content was low, it indicated great suitability for energy feedstock via thermochemical process [20]. A previous study reported that ash content in biomass could significantly affect decreased calorific value [21]. The volatile matter represents the mass evolved at the temperature between 100°C and 550°C. The high volatile content in biomass indicated better combustion and gasification rates [22]. Furthermore, a sensible fixed carbon also one of the parameters of ideal energy produced from biomass [23]. The ultimate content of *A. macrophyllus* wood, including C, H, and O, was also analyzed. As shown in Table 1, the proportion of C and O was comparable with the value of 47.78 and 47.02%, respectively, while the percentage of H was 5.10%. When heated at 200-400°C, the cellulose and hemicellulose in biomass were decomposed to produce synthetic gases [24]. On the other hand, lignin was reported to possess higher fixed carbon [25]. In this study, *A. macrophyllus* wood contained 68.67% holocellulose, 36.06% α-cellulose, and 24.04% klason lignin.

4. CONCLUSIONS

In summary, the biomass productivity and energy potency of *A. macrophyllus* increased annually from the first to fourth year. The third plant age was the most desired harvest circle time since it produced the highest wood productivity and energy potency value. Moreover, the increase in plant age was also linked with the enhance of lignin content. On the other hand, we found that moisture content decreased, affecting the significant enhancement on NCV value. The low proportion of ash indicated that wood of *A. macrophyllus* was acceptable for energy feedstock. Finally, we concluded that *A. macrophyllus* forest plantation was promising for future development in biomass-based energy production.

AUTHORS' CONTRIBUTIONS

AM: Methodology, Writing – original draft. **MTH**: Conceptualization, Writing – review & editing. **MTT**: Resources. **RA**: Conceptualization, Funding acquisition, review and Supervision.

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