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Note	From
Dear Editor, I am enclosing herewith a manuscript entitled "Analysis of wood ultimate composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bio-electrcity potency" for publication in the "Biodiversitas Journal of Biological Diversity" for possible evaluation. This finding will be the first report on the calculation of electricity production generated from *Eucalyptus pellita* wood according to its ultimate composition values. Furthermore, we also investigated the impact of the plant age. Submitted manuscript is a **Short Communication** type. With the submission of this manuscript, I would like to state that the above-mentioned manuscript has not been published elsewhere, accepted for publication elsewhere or under editorial review for publication elsewhere. Please kindly consider our manuscript to publish in the "Biodiversitas Journal of Biological Diversity". Thank you very much, Best regards, Prof. Rudianto Amirta, Ph.D. Faculty of Forestry, Mulawarman University, Jl. Penajam, Kampus Gn. Kelua, Samarinda 75119, East Kalimantan, Indonesia. Tel./Fax.: +62-541-748683. Email: ramirta@fahutan.unmul.ac.id	r_amirta 2022-04-11 07:14 AM

Short Communication:
Analysis of wood ultimate composition of a forest plantation species, *Eucalyptus pellita,* to estimate its bio-electricity potency

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ABSTRACT

Eucalyptus pellita F. Muell is one of the short rotation wood crop species widely planted in tropical countries, including Indonesia. Woody biomass obtained from this species is commonly utilized to produce fiber in the pulp and paper industry. Due to the growing interest in expanding *E. pellita* plantations, the potential application of *E. pellita* woody biomass to provide sustainable energy feedstock has been studied. Therefore, this study aimed to investigate the ultimate composition of *E. pellita* wood (carbon (C), hydrogen (H), and oxygen (O)) to estimate its higher heating value (HHV) and bio-electricity potency. The wood samples were harvested at different plant ages, from the first to the fifth year. The percentage of biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also calculated. The results demonstrated that lignin in the *E. pellita* wood increased in line with the increased plant age. Thus, this pattern was followed by significantly increased C content in the wood since lignin contained a primary source of C. Hence, this condition might contribute to enhancing the HHV and electricity potency. The ratio of H/C and O/C was found to be one of the most promising factors to improve HHV compared to the extractive/lignin ratio. The electricity potency of *E. pellita* at the fifth year showed the highest value (1.71 MWh ton^{-1}). Therefore, this study suggests that *E. pellita* possesses the potential to be one of the promising crops for green electricity production.

Key words: bio-electricity, carbon, *Eucalyptus pellita*, lignin, woody crop.

Running title: Analysis of ultimate composition of *Eucalyptus pellita* wood

INTRODUCTION

Nowadays, several countries have tried to initiate the transition from the use of non-renewable fossil fuels to the use of renewable resources. The application of biomass for energy production has received significant interest since it is abundantly available in the world. Its recent utilization is estimated to reach 13% of the total energy structure (Xing et al., 2019). It has offered direct and indirect advantages to human societies, including environmental and economic aspects (Nimmanterdwong et al., 2021). Also, biomass energy (BE) is becoming more important to mitigate the high level of carbon dioxide (CO_2) emission, which is one of the most crucial causes of climate change and environmental degradation (Zafar et al., 2021). Biomass is a renewable and sustainable organic source that stores energy through a photosynthesis process mainly produced by plants in the presence of sunlight (Demirbaş, 2001; McKendry, 2002; Sansaniwal et al., 2017; Islas et al., 2019). BE releases less CO_2 emissions and does not compete with global food supplies (Ashokkumar et al., 2022). Biomass can be converted through thermochemical, chemical, and biological processes into various forms, such as solid, liquid, and gas, which can be further utilized in heating, transportation, and electricity (Demirbaş, 2008; Konuk et al., 2021).

Combustion is the most widely applied process to produce the heat and electricity from biomass (Briones-Hidrovo et al., 2021). When the biomass burned, its chemical and physical structure are changed step by step due to drying, devolatilization, steam gasification, volatile matter burning, and char combustion process (Cui et al., 2006). Biomass is composed of carbon (C), hydrogen (H), and oxygen (O), which are desired properties for solid fuel (Nussbaumer, 2003). Nevertheless, the distribution of these organic constituents differs according to the type of biomasses. Herbaceous plants such as miscanthus, kenaf, straw, and switchgrass reportedly contained more nitrogen (N), sulfur (S), potassium (K), and chlorine (Cl), which potentially released dangerous emissions during the combustion process (Cui et al., 2006; Lee et al., 2021). Due to this limitation, the use of other biomass types, such as woody biomass, could be a great option for future sustainable energy feedstocks. Woody biomasses store C, H, and O in their macromolecular ingredients, such as cellulose, hemicellulose, and lignin. Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_n$ generally consist of polysaccharides, while lignin consists of aromatic polyphenols (Ozyuguran et al., 2018). The amount of C, H, and O significantly influences the biomass higher heating value (HHV) (Bounmanchar et al., 2019). Thus, this could be one of the important parameters to point out the energy-electricity potency of the woody biomass.

Eucalyptus pellita F. Muell is the most widely planted hardwood tree in Southeast Asia. This species is native to Indonesia, New South Wales, Queensland, Australia, and Papua New Guinea (Arisandi et al., 2020). The main utilization of this species is to provide raw material for pulp and paper production. However, *Eucalyptus* plants have been recently used for raw materials in various industries, such as perfumery, pharmaceuticals, nutraceuticals, and furniture (Salehi et al., 2019). *E. pellita* has been considered one of the most important fast-growing trees in Indonesia. Therefore, the government and cooperation are pursuing the tree breeding program to improve its sustainability in the forest plantation areas (Leksono et al., 2008). *E. pellita* is reportedly more resistant to pests and diseases than other crop species (Jang et al., 2020). It was one of the reasons why the plantation of *Acacia mangium* in both Sumatera (465,000 ha) and Kalimantan (225,500 ha) has been partially changed to *E. pellita* (Hardiyanto et al., 2021). Since there has been an increased demand for *E. pellita* plantations, it will provide the opportunity to use *E. pellita* woody biomass in a wide range of applications, such as heat and electricity production.

The aim of this study was to evaluate the ultimate composition of the *E. pellita* woody biomass in order to estimate its HHV and electricity potency. The wood samples harvested at the plant ages of first to fifth years were collected and were used for analysis. Its biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also measured in this study.

MATERIALS AND METHODS

Materials

The *E. pellita* wood used in this study was obtained from a forest plantation company, PT. Sumalindo Hutani Jaya II, which is located in Sei Mao District, Kutai Kartanegara, East Kalimantan Province, Indonesia. Five wood samples from different plant ages were harvested randomly from the forest sites. Each sample was debarked, hammer milled, and sieved to obtain wood powder with a size of 40 and 60 mesh for laboratory testing. All chemicals used in this study, such as sodium chlorite, glacial acetic acid, ethanol, benzene, and sulfuric acid, were analytical grade.

Biomass composition analysis

The dried wood powder with a size of 40 mesh was used as a sample to calculate the biomass composition (extractive, lignin, hemicellulose, and cellulose). Firstly, the sample was placed inside the filter paper. Then, the filter paper was placed inside the reflux containing mixed alcohol and benzene under heating conditions to remove extractives from the sample. The ratio of the alcohol-benzene solution used in this experiment was 1:2 (v/v). After that, the sample was filtered using a Whatman filter paper No. 1 and washed repeatedly with hot distilled water until the pH reached 7. The sample was air-dried to remove the moisture prior to the next experiments. The lignin content was determined by the Klason lignin protocol using a 72% sulfuric acid solution according to TAPPI T 222 om-88. The cellulose and hemicellulose contents were determined by a method adapted from Wise et al. (1946).

Ultimate composition analysis

The dried wood sample with a size of 60 mesh was used to analyze the ultimate composition, including carbon (C), hydrogen (H), and oxygen (O). It was determined by using an elemental analyzer according to ASTM D5373-02.

Estimation of higher heating value and electricity potency

The higher heating value (HHV) was calculated based on the amount of C using an equation introduced by Sheng and Azevedo (2005), while the bio-electricity was calculated using an equation modified from Xue et al. (2016):

$$\text{HHV} = (0.3295 \times \text{C}) + 3.4597 \quad (1)$$

$$\text{Electricity} = (\text{HHV} \times 0.35 \times 10^3) / 3600 \quad (2)$$

Statistical analysis

The analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at the level of $p < 0.05$ using IBM SPSS Statistic 22 Software (IBM Corp., Armonk, NY) was used to compare any significant differences among the mean values.

RESULTS AND DISCUSSION

Biomass composition

Woody biomass is a complex organic material in nature, produced by lignocellulosic plants through photosynthesis. Therefore, information about its composition, including extractive, lignin, cellulose, and hemicellulose, is considered the basic knowledge for converting the woody biomass into various value-added products. The results of the biomass composition measurement of *E. pellita* at different plant ages are displayed in Table 1. It was found that increased plant age significantly contributed to a decline in the percentage of extractive and cellulose. It could be observed that hemicellulose content was not influenced by plant age. On the other hand, the opposite pattern could be seen from the amount of lignin content. The lignin percentage of *E. pellita* harvested in the first year was 25.35%, and it was significantly enhanced to reach 29.90% after being grown in the fifth year. Although *E. pellita* was reportedly grown worldwide in the plantation forest, its constituents differed, depending on the clone and site. For instance, Menucelli et al. (2019) reported that 31-year-old *E. pellita* collected from Selviria, Brazil had 15.88% extractive, 38.86% lignin, and 45.24% holocellulose (cellulose and hemicellulose). *E. pellita* grown in Sabah, Malaysia had low extractive (1.4%) with high lignin content (37.3%) (Fiskari and Kilpeläinen, 2021). In this study, the average values of extractive, lignin, cellulose, and hemicellulose among all age classes of *E. pellita* grown in East Kalimantan, Indonesia were 8.26%, 28.14%, 39.96%, and 26.41%, respectively.

Ultimate composition

The ultimate composition of *E. pellita* wood, including C, H, and O, measured at different plant ages can be seen from Figure 1. It was clearly observed that plant age strongly influenced the amount of C and O, whereas H was not affected. The increased C of *E. pellita* might have a relationship with the significant enhancement of lignin content (Table 1). As previously reported by Ma et al. (2019), lignin contained a higher content of C in comparison with hemicellulose and cellulose. Woody biomass with a high content of C could be desirable for solid fuel purposes since it has been reported to generate a significantly higher energy content (Poddar et al., 2014). Hence, to improve biomass energy, Chen et al. (2018) demonstrated that it could be achieved by improving of C-C and C-H bonds and reducing C-O and O-H bonds in the biomass. Generally, the average values of C, H, and O of the *E. pellita* in this study were 42.82%, 5.30%, and 39.17%.

Table 1. Biomass composition of *E. pellita* wood at different plant ages.

Plant age (year)	Extractive (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
1	10.11 ± 0.17^{a}	25.35 ± 0.42^{c}	41.86 ± 1.24^{a}	26.68 ± 1.13^{ns}
2	8.85 ± 0.09^{b}	28.12 ± 1.15^{b}	40.08 ± 0.04^{b}	26.52 ± 0.88^{ns}
3	8.15 ± 0.15^{c}	28.47 ± 0.94^{b}	40.37 ± 0.21^{b}	26.47 ± 0.79^{ns}
4	7.41 ± 0.11^{d}	28.87 ± 0.31^{b}	39.79 ± 0.25^{c}	26.23 ± 1.23^{ns}
5	7.08 ± 0.05^{e}	29.90 ± 0.78^{a}	37.70 ± 0.46^{d}	26.17 ± 0.15^{ns}
Average	**8.26 ± 1.06**	**28.14 ± 1.52**	**39.96 ± 1.37**	**26.41 ± 0.19**

Different superscript letters (a-e) demonstrated a significant different value at $p < 0.05$; ns = not significant.

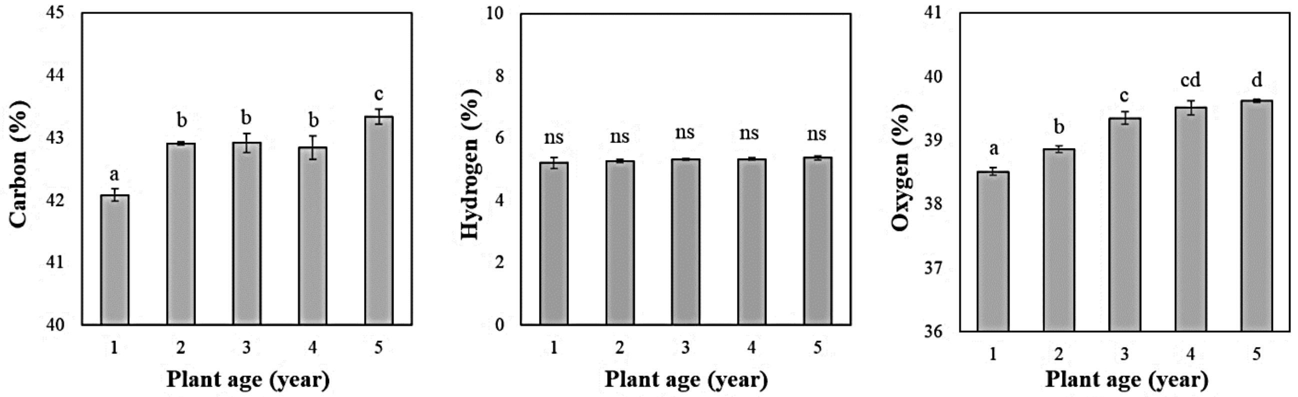

Figure 1. Ultimate composition of *E. pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant.

Higher heating value and energy potency

The higher heating value (HHV) is an important indicator to assess the suitability of woody biomass to produce heat and electricity. Hence, its excessive value is preferable. The information about the HHV of *E. pellita* calculated from all age classes is illustrated on Table 2. It was found that increasing plant age significantly influenced the obtained HHV. The average value of all of them reached 17.41 MJ kg^{-1}. According to Ghugare et al. (2014), this value was characterized as being in the mid-range (16-25 MJ kg^{-1}). It was in line with the study from Telmo and Lousada, who reported that hardwood had HHV ranged from 17.38 to 23.05 MJ kg^{-1}. Nevertheless, the HHV value of *E. pellita* in this study was still higher than that of another forest plantation crop, *Anthocephalus macrophyllus*, reported by Mukhdlor et al. (2021). We stated that it might have a relationship with the high presence of lignin since this macromolecule could be a primary source of C in the lignocellulosic biomass. Besides lignin, Telmo and Lousada (2011) reported that extractives also had a significant role in achieving better HHV. Therefore, we further evaluated the correlation of ultimate composition, lignin, and extractive to the obtained HHV of *E. pellita* (Figure 2). We found that the combination of H/C ratio and O/C ratio contributed to a significant correlation ($r^2 = 0.966$) compared to lignin and extractive ($r^2 = 0.872$). This condition was in agreement with the previous work reported by Nhucchen and Afzal (2017).

The bioelectricity potency of *E. pellita,* calculated from all age classes, is shown on Table 2. It is noticeable that the trend was similar to the HHV results in which plant age significantly affected the electricity potency. In general, the average values were 1.69 MWh ton^{-1}. As it was reported by Amirta et al. (2016b; 2019), fast growing tree species, such as *E. pellita* and *Acacia mangium* (1.35 MWh ton^{-1}), commonly produced lower energy potency than those of low growing tree species, such as *Shorea balangeran.* (3.00 MWh ton^{-1}). This phenomenon might be probably due to the high lignin content of the Dipterocarpaceae family. Amirta et al. (2016a) reported that *Shorea* sp. contained 31.5% of lignin, while this study revealed the lower lignin content of *E. pellita* (28.14%) as shown on Table 1.

Table 2. HHV and Electricity Potency of *E. Pellita* Wood at Different Plant Ages.

Plant age (year)	HHV (MJ kg^{-1})	Electricity Potency (MWh ton^{-1})
1	17.17 ± 0.03^a	1.67 ± 0.00^a
2	17.44 ± 0.01^b	1.69 ± 0.00^b
3	17.45 ± 0.05^b	1.69 ± 0.00^b
4	17.42 ± 0.06^b	1.69 ± 0.01^b
5	17.58 ± 0.04^c	1.71 ± 0.00^c
Average	**17.41 ± 0.15**	**1.69 ± 0.01**

Different superscript letters (a-c) demonstrated a significant different value at $p < 0.05$; ns = not significant.

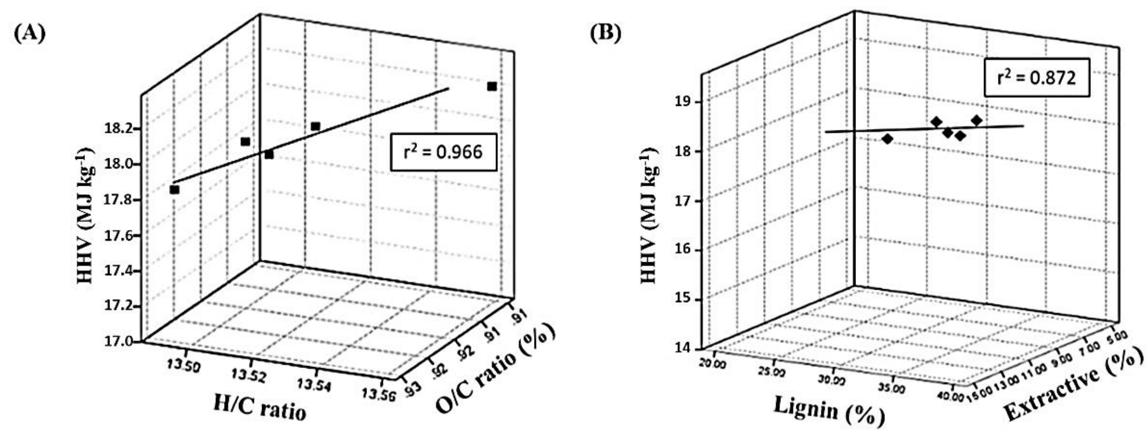

Figure 2. High influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *E. pellita* wood.

A recent study points out the suitability of *E. pellita* wood to be used as an energy feedstock (wood chip) for biomass-based electricity production. Our previous work demonstrated that East Kalimantan Province has abundant natural resources from forest plant diversity, which is promising for future energy feedstock (Amirta et al., 2016b; 2019; Haqiqi et al., 2018; Yuliansyah et al., 2019). It could be one of the viable options for development of bio-electricity to increase the economy of local society in this province due to its high availability (see Figure 3). Thus, future work about the biomass yield of the *E. pellita* under different planting distances will be necessary to be carried out.

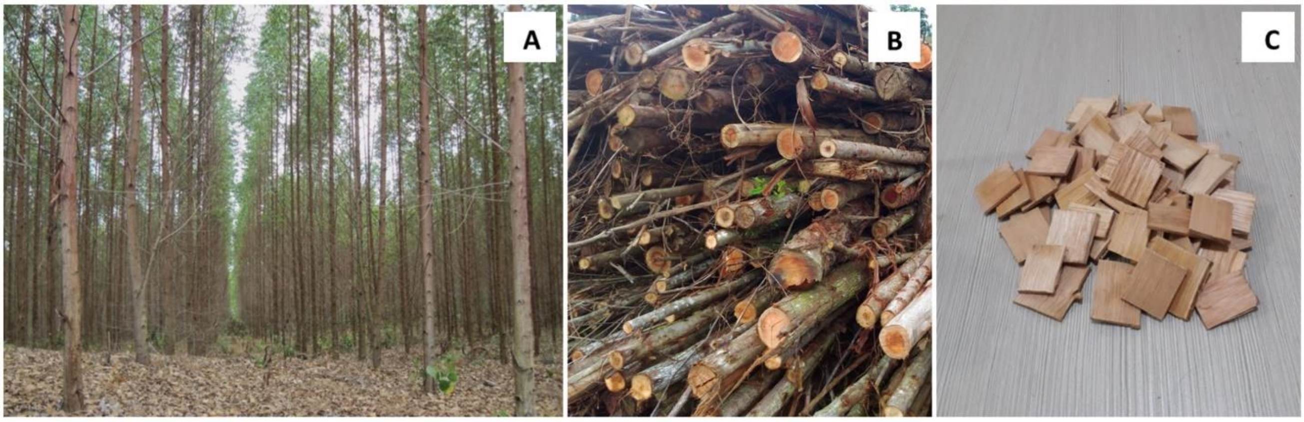

Figure 3. Forest plantation (A), harvested wood (B), and wood chip (C) of *E. pellita*.

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[biodiv] Submission Acknowledgement

From: Ahmad Dwi Setyawan (smujo.id@gmail.com)

To: r_amirta@yahoo.com

Date: Monday, April 11, 2022 at 03:31 PM GMT+8

Rudianto AMIRTA:

Thank you for submitting the manuscript, "Analysis of wood ultimate composition of a forest plantation species, Eucalyptus pellita, to estimate its bio-electricity potency" to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/10967
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Ahmad Dwi Setyawan

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Notifications

[biodiv] Editor Decision

2022-04-13 07:40 AM

Rudianto AMIRTA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Analysis of wood ultimate composition of a forest plantation species, Eucalyptus pellita, to estimate its bio-electricity potency".

Our decision is: Revisions Required

Reviewer A:

Dear author(s),

The paper entitled 'Short Communication: Analysis of wood ultimate composition of a forest plantation species, *Eucalyptus pellita,* to estimate its bio-electricity potency' is too brief to be published in Biodiversitas journal. For a short-communication paper, a minimum of 2000 words is required.

Best regards

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

Notifications

[biodiv] Editor Decision

2022-04-20 03:23 AM

Rudianto AMIRTA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Analysis of wood ultimate composition of a forest plantation species, Eucalyptus pellita, to estimate its bio-electricity potency".

Our decision is: Revisions Required

Reviewer A:

Recommendation: -

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Biodiversitas Journal of Biological Diversity

Short Communication:
Analysis of the ~~wood ultimate~~ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency

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ABSTRACT

Eucalyptus pellita F. Muell is one of the short rotation wood crop species widely planted in tropical countries, including Indonesia. Woody biomass obtained from this species is commonly utilized to produce fiber in the pulp and paper industry. Due to the growing interest in expanding *E. pellita* plantations, the potential application of *E. pellita* woody biomass to provide sustainable energy feedstock has been studied. Therefore, this study aimed to investigate the ultimate composition of *E. pellita* wood (carbon (C), hydrogen (H), and oxygen (O)) to estimate its higher heating value (HHV) and bioelectricity potency. The wood samples were harvested at different plant ages, from the first to the fifth year. The percentage of biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also calculated. The results demonstrated that lignin in the *E. pellita* wood increased to a~~in ~~li~~n~~gne with the increased plant age. Thus, this pattern was followed by significantly increased C content in the wood since lignin contained a primary source of C. Hence, this condition might ~~contribute to enhancing~~enhance the HHV and electricity potency. The ratio of H/C and O/C was found to be one of the most promising factors to improve HHV compared to the extractive/lignin ratio. In the fifth year, the electricity potency of E. pellita ~~The electricity potency of *E. pellita* at the fifth year~~ showed the highest value (1.71 MWh ton^{-1}). Therefore, this study suggests that *E. pellita* possesses the potential to be one of the promising crops for green electricity production.

~~Key words~~Keywords: bioelectricity, carbon, *Eucalyptus pellita*, lignin, woody crop.

Running title: Analysis of the ultimate composition of *Eucalyptus pellita* wood

INTRODUCTION

Nowadays, several countries have tried to initiate the transition from ~~the use of~~using non-renewable fossil fuels to the use of renewable resources. The application of biomass for energy production has received significant interest since it is abundantly available ~~in the world~~worldwide. Its recent utilization is estimated to reach 13% of the ~~total~~ entire energy structure (Xing et al., 2019). It has offered direct and indirect advantages to human societies, including environmental and economic aspects (Nimmanterdwong et al., 2021). Also, biomass energy (BE) is becoming more important to mitigate the high level of carbon dioxide (CO_2) emission, which is one of the most crucial causes of climate change and environmental degradation (Zafar et al., 2021). Biomass is a renewable and sustainable organic source that stores energy through a photosynthesis process mainly produced by plants in the presence of sunlight (Demirbaş, 2001; McKendry, 2002; Sansaniwal et al., 2017; Islas et al., 2019). BE releases less CO_2 emissions and does not compete with global food supplies (Ashokkumar et al., 2022). Biomass can be converted through thermochemical, chemical, and biological processes into various forms, such as solid, liquid, and gas, which can be further utilized in heating, transportation, and electricity (Demirbaş, 2008; Konuk et al., 2021).

Combustion is the most widely applied process to produce ~~the~~ heat and electricity from biomass (Briones-Hidrovo et al., 2021). When the biomass is burned, its chemical and physical structure ~~are~~ changes~~changed~~ step by step due to drying, devolatilization, steam gasification, volatile matter burning, and char combustion process (Cui et al., 2006). Biomass is composed of carbon (C), hydrogen (H), and oxygen (O), which are desired properties for solid fuel (Nussbaumer, 2003).

Nevertheless, the distribution of these organic constituents differs according to the type of biomasses. Herbaceous plants such as miscanthus, kenaf, straw, and switchgrass reportedly contained more nitrogen (N), sulfur (S), potassium (K), and chlorine (Cl), which potentially released dangerous emissions during the combustion process (Cui et al., 2006; Lee et al., 2021). Due to this limitation, ~~the use of~~using other biomass types, such as woody biomass, could be a great option for future sustainable energy feedstocks. Woody biomasses store C, H, and O in their macromolecular ingredients, such as cellulose, hemicellulose, and lignin. Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_n$ generally consist of polysaccharides, while lignin consists of aromatic polyphenols (Ozyuguran et al., 2018). The amount of C, H, and O significantly influences the ~~biomass~~ biomass's higher heating value (HHV) (Bounmanchar et al., 2019). Thus, this could be one of the important parameters to point out the energy-electricity potency of the woody biomass.

Eucalyptus pellita F. Muell is the most widely planted hardwood tree in Southeast Asia. This species is native to Indonesia, New South Wales, Queensland, Australia, and Papua New Guinea (Arisandi et al., 2020). The main utilization of this species is to provide the raw material for pulp and paper production. However, *Eucalyptus* plants have been recently used for raw materials in various industries, such as perfumery, pharmaceuticals, nutraceuticals, and furniture (Salehi et al., 2019). *E. pellita* has been considered one of Indonesia's most important fast-growing trees~~the most important fast-growing trees in Indonesia~~. Therefore, the government and cooperation are pursuing the tree breeding program to improve its sustainability in the forest plantation areas (Leksono et al., 2008). *E. pellita* is reportedly more resistant to pests and diseases than other crop species (Jang et al., 2020). This could be one of the reasons why the plantation of *Acacia mangium* in both Sumatera (465,000 ha) and Kalimantan (225,500 ha) has been partially changed to *E. pellita* (Hardiyanto et al., 2021). Since there has been an increased demand for *E. pellita* plantations, it will ~~provide the opportunity to use~~allow the use of *E. pellita* woody biomass in ~~a wide range of~~various applications, such as heat and electricity production.

The aim of this study was to evaluate the ultimate composition of the *E. pellita* woody biomass in order to estimate its HHV and electricity potency. The wood samples harvested at the plant ages of first to fifth years were collected and were used for analysis. This study also measured its biomass composition, including cellulose, hemicellulose, lignin, and extractives~~Its biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also measured in this study~~.

MATERIALS AND METHODS

Materials

The *E. pellita* wood used in this study was obtained from a forest plantation company, PT. Sumalindo Hutani Jaya II, which is located in Sei Mao District, Kutai Kartanegara, East Kalimantan Province, Indonesia. Five wood samples from different plant ages were harvested randomly from the forest sites (Figure 1). Each sample was debarked, hammer milled, and sieved to obtain wood powder with a size of 40 and 60 mesh for laboratory testing. All chemicals used in this study, such as sodium chlorite, glacial acetic acid, ethanol, benzene, and sulfuric acid, were analytical grade.

Biomass composition analysis

The dried wood powder with a size of 40 mesh was used as a sample to calculate the biomass composition (extractive, lignin, hemicellulose, and cellulose). Firstly, the sample was placed inside the filter paper. Then, the filter paper was placed inside the reflux containing mixed alcohol and benzene under heating conditions to remove extractives from the sample. The ratio of the alcohol-benzene solution used in this experiment was 1:2 (v/v). After that, the sample was filtered using a Whatman filter paper No. 1 and ~~washed~~ repeatedly washed with hot distilled water until the pH reached 7. The sample was air-dried to remove the moisture ~~prior to~~before the next experiments. The lignin content was determined by the Klason lignin protocol using a 72% sulfuric acid solution according to TAPPI T 222 om-88. The cellulose and hemicellulose contents were determined by a method adapted from Wise et al. (1946).

Ultimate composition analysis

The dried wood sample with a size of 60 mesh was used to analyze the ultimate composition, including carbon (C), hydrogen (H), and oxygen (O). It was determined by using an elemental analyzer according to ASTM D5373-02.

Estimation of higher heating value and electricity potency

The higher heating value (HHV) was calculated based on the amount of C using an equation introduced by Sheng and Azevedo (2005), while the bioelectricity was calculated using an equation modified from Xue et al. (2016):

$$HHV = (0.3295 \times C) + 3.4597 \quad (1)$$

$$Electricity = (HHV \times 0.35 \times 10^3) / 3600 \quad (2)$$

Statistical analysis

The analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at the level of $p < 0.05$ using IBM SPSS Statistic 22 Software (IBM Corp., Armonk, NY) was used to compare any significant differences among the mean values.

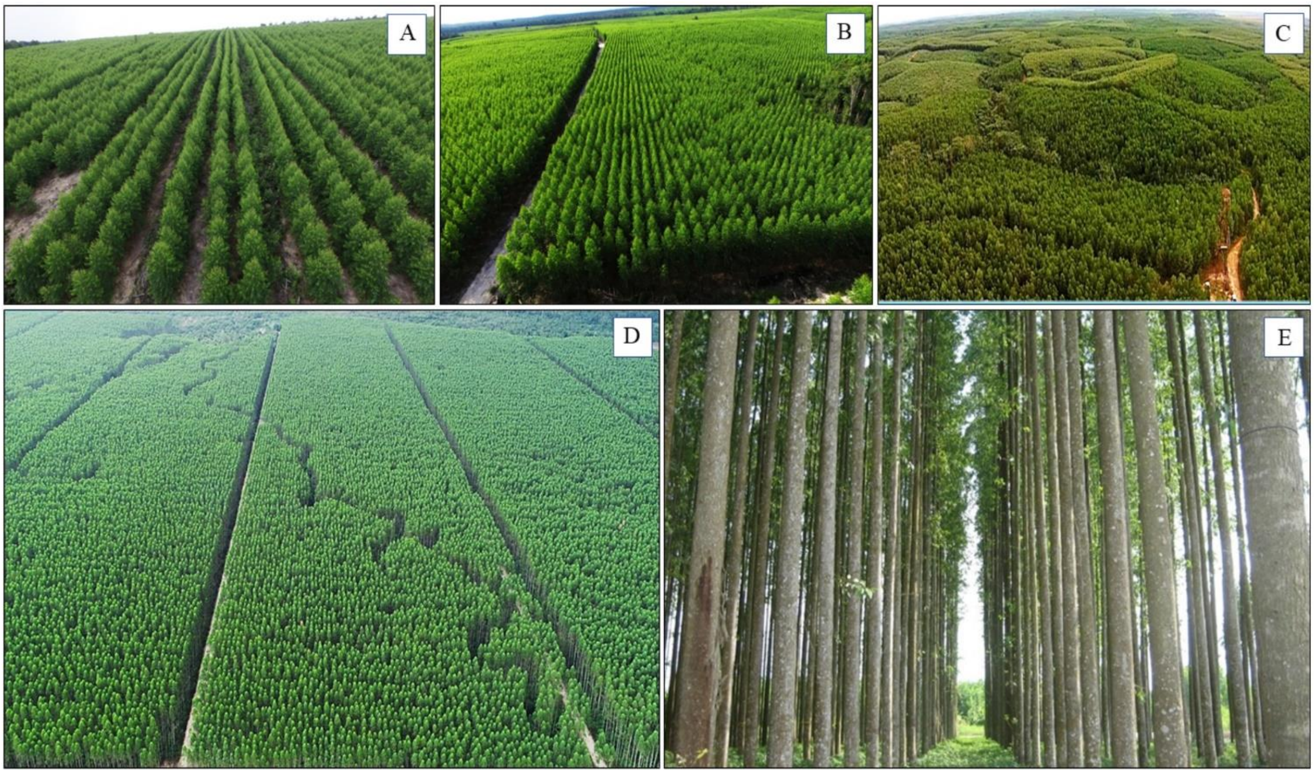

Figure 1. Photograph images of E. pellita crop utilized in this study: 1st year (A), 2nd year (B), 3rd year (C), 4th year (D), and 5th year (E).

RESULTS AND DISCUSSION

Biomass composition

Woody biomass is a complex organic material in nature, produced by lignocellulosic plants through photosynthesis. Therefore, information about its composition, including extractive, lignin, cellulose, and hemicellulose, is considered the basic knowledge for converting the woody biomass into various value-added products. The results of the biomass composition measurement of *E. pellita* at different plant ages are displayed in Table 1. It was found that increased plant age significantly contributed to a decline in the percentage of extractive and cellulose. It could be observed that hemicellulose content was not influenced by plant age. On the other hand, the opposite pattern could be seen from the amount of lignin content. The lignin percentage of *E. pellita* harvested in the first year was 25.35%, and it was significantly enhanced to reach 29.90% after being grown in the fifth year. Although *E. pellita* was reportedly grown worldwide in the plantation forest, its constituents differed, depending on the clone and site. For instance, Menucelli et al. (2019) reported that 31-year-old *E. pellita* collected from Selviria, Brazil had 15.88% extractive, 38.86% lignin, and 45.24% holocellulose (cellulose and hemicellulose). *E. pellita* grown in Sabah, Malaysia, had low extractive (1.4%) with high lignin content (37.3%) (Fiskari and Kilpeläinen, 2021). In this study, the average values of extractive, lignin, cellulose, and hemicellulose among all age classes of *E. pellita* grown in East Kalimantan, Indonesia, were 8.26%, 28.14%, 39.96%, and 26.41%, respectively.

Ultimate composition

The ultimate composition of *E. pellita* wood, including C, H, and O, measured at different plant ages, can be seen from in Figure 2. It was clearly observed that plant age strongly influenced the amount of C and O, whereas H was not affected. The increased C of *E. pellita* might have a relationship with the significant enhancement of lignin content (Table 1). As previously reported by Ma et al. (2019), lignin contained a higher content of C in comparison with hemicellulose and cellulose. Woody biomass with a high content of C could be desirable for solid fuel purposes since it has been reported to generate a significantly higher energy content (Poddar et al., 2014). Hence, to improve biomass energy, Chen et al. (2018)

demonstrated that it could be achieved by improving ~~of~~ C-C and C-H bonds and reducing C-O and O-H bonds in the biomass. Generally, the average values of C, H, and O of the *E. pellita* in this study were 42.82%, 5.30%, and 39.17%.

Table 1. Biomass composition of *E. pellita* wood at different plant ages.

Plant age (year)	Extractive (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
1	10.11 ± 0.17^{a}	25.35 ± 0.42^{c}	41.86 ± 1.24^{a}	26.68 ± 1.13^{ns}
2	8.85 ± 0.09^{b}	28.12 ± 1.15^{b}	40.08 ± 0.04^{b}	26.52 ± 0.88^{ns}
3	8.15 ± 0.15^{c}	28.47 ± 0.94^{b}	40.37 ± 0.21^{b}	26.47 ± 0.79^{ns}
4	7.41 ± 0.11^{d}	28.87 ± 0.31^{b}	39.79 ± 0.25^{c}	26.23 ± 1.23^{ns}
5	7.08 ± 0.05^{e}	29.90 ± 0.78^{a}	37.70 ± 0.46^{d}	26.17 ± 0.15^{ns}
Average	**8.26 ± 1.06**	**28.14 ± 1.52**	**39.96 ± 1.37**	**26.41 ± 0.19**

Different superscript letters (a-e) demonstrated a significant different value at $p < 0.05$; ns = not significant.

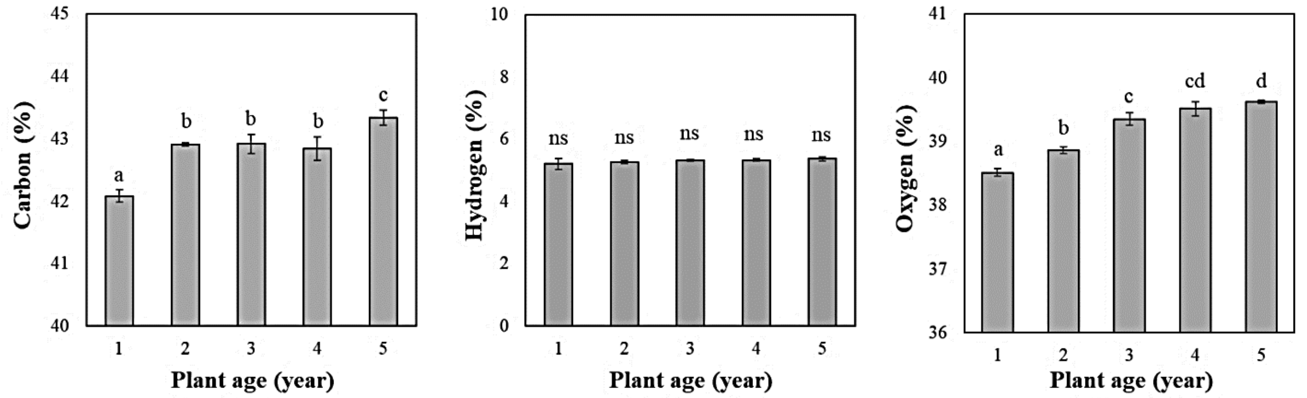

Figure 2. ~~Ultimate~~ The ultimate composition of *E. pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant.

Higher heating value and electricity potency

The higher heating value (HHV) is an important indicator to assess the suitability of woody biomass to produce heat and electricity. Hence, its excessive value is preferable. The information about the HHV of *E. pellita* calculated from all age classes is illustrated ~~on~~ in Table 2. It was found that increasing plant age significantly influenced the obtained HHV. The average value of all of them reached 17.41 MJ kg^{-1}. According to Ghugare et al. (2014), this value was characterized in~~as being in~~ the mid-range (16-25 MJ kg^{-1}). It was in line with the study from Telmo and Lousada, who reported that hardwood had HHV ~~ranged~~ ranging from 17.38 to 23.05 MJ kg^{-1}. Nevertheless, the HHV value of *E. pellita* in this study was still higher than that of another forest plantation crop, *Anthocephalus macrophyllus*, reported by Mukhdlor et al. (2021). We stated that it might have a relationship with the high presence of lignin since this macromolecule could be a primary ~~source of C~~C source in the lignocellulosic biomass. Besides lignin, Telmo and Lousada (2011) reported that extractives also had a significant role in achieving better HHV. Therefore, we further evaluated the correlation of ultimate composition, lignin, and extractive to the obtained HHV of *E. pellita* (Figure 3). We found that the combination of H/C ratio and O/C ratio contributed to a significant correlation ($r^2 = 0.966$) compared to lignin and extractive ($r^2 = 0.872$). This condition ~~was in~~was aligned ~~agreement~~ with the previous work reported by Nhucchen and Afzal (2017).

Biomass can be applied to produce electricity through several thermochemical processes. This study evaluated E. pellita wood harvested at different plant ages ~~In this study, *E. pellita* wood harvested at different plant ages was evaluated~~ to generate electricity through a direct combustion stage. Its calculation is summarized in Table 2. It is noticeable that the trend of the electricity potency was in line with the HHV results, in which a high lignin content due to the increase in plant age had a significant enhancement to the values. In general, *E. pellita* wood obtained ~~from~~ in the 1st year produced 1.67 MWh ton^{-1}, and this value increased to ~~reach~~ 1.71 MWh ton^{-1} in the 5th year. The mean values of all age classes were 1.69 MWh ton^{-1}. ~~As it was reported by our previous study,~~Our previous study reported that some fast-growing tree species, such as *Acacia mangium*, *Anthocephalus cadamba*, *Gmelina arborea*, and *Paraserianthes falcataria*, commonly produce lower energy potency than those of the low growing tree species, such as *Shorea balangeran* (Amirta et al. 2016b; 2019). This phenomenon might be due to the high lignin content of woody biomass of the Dipterocarpaceae family. It has been reported by Amirta et al. (2016a) that *Shorea* sp. contained 31.5% of lignin, while *E. pellita* possessed a lower percentage of lignin (28.14%), ~~as~~ as ~~appeared~~ appears in Table 1. However, we believe that the characteristics of *E. pellita* will be suited to the criteria of an ideal energy crop since its woody biomass can be produced sustainably using a short rotation harvesting cycle with appropriate energy content.

Table 2. HHV and electricity potency of *E. pellita* wood at different plant ages.

Plant age (year)	HHV (MJ kg^{-1})	Electricity Potency (MWh ton^{-1})
1	17.17 ± 0.03^{a}	1.67 ± 0.00^{a}
2	17.44 ± 0.01^{b}	1.69 ± 0.00^{b}
3	17.45 ± 0.05^{b}	1.69 ± 0.00^{b}
4	17.42 ± 0.06^{b}	1.69 ± 0.01^{b}
5	17.58 ± 0.04^{c}	1.71 ± 0.00^{c}
Average	**17.41 ± 0.15**	**1.69 ± 0.01**

Different superscript letters (a-c) demonstrated a significant different value at $p < 0.05$; ns = not significant.

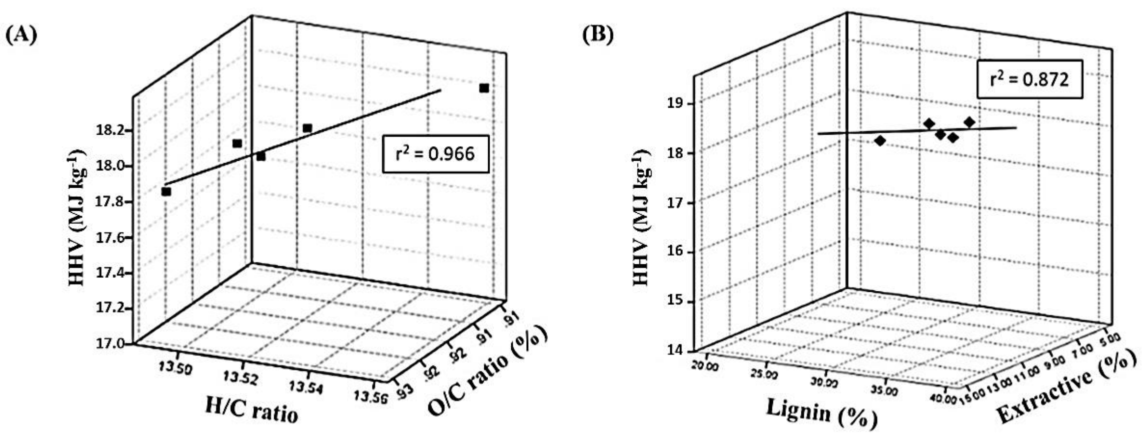

Figure 3. ~~High~~ The strong influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *E. pellita* wood.

A recent study points out the suitability of *E. pellita* wood to be used as an energy feedstock for biomass-based electricity production. Our previous research also found that East Kalimantan Province has ~~an abundance of~~abundant natural resources from forest plant diversity~~,~~ which is promising for future energy feedstock (Amirta et al., 2016b; 2019; Haqiqi et al., 2018; Yuliansyah et al., 2019). In this study, *E. pellita* log wood harvested from forest plantations is suggested to be debarked and converted into the wood chip for further utilization as electricity via a direct combustion process (see Figure 4). Implementation of this process will promote green electricity production since E. pellita plants could capture excessive CO2 emissions~~excessive CO_2 emissions could be captured by *E. pellita* plants~~ to create a ~~carbon neutral~~neutral carbon cycle. Therefore, the results of this study are expected to be one of the viable options for the development of bioelectricity to increase the bioeconomy of local society in this province due to its high availability and suitability. Since this study revealed that the *E. pellita* crop possesses great potential to generate bioelectricity, future work about its sustainable biomass production under different planting distances will be interesting to be carried out to determine the best condition to obtain the highest woody biomass yield.

Figure 4. Forest plantation (A), harvested wood (B), and wood chip (C) of *E. pellita*.

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Revised manuscript of Haqiqi et al_Short Communication: Analysis of wood ultimate composition of a forest plantation species

From: Rudianto AMIRTA (r_amirta@yahoo.com)

To: smujo.id@gmail.com

Date: Tuesday, April 19, 2022 at 07:42 AM GMT+8

Dear Editor,
The enclosed is our manuscript entitled Short Communication: Analysis of wood ultimate composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bio-electricity potency that has been revised to full fill requirement condition as suggested by reviewer. I do hope that our revised manuscript was fit and match to the suggested comment and can be published soon. Thank you.

Sincerely yours,
Rudianto Amirta

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Short Communication: Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency

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ABSTRACT

Eucalyptus pellita F. Muell is one of the short rotation wood crop species widely planted in tropical countries, including Indonesia. Woody biomass obtained from this species is commonly utilized to produce fiber in the pulp and paper industry. Due to the growing interest in expanding *E. pellita* plantations, the potential application of *E. pellita* woody biomass to provide sustainable energy feedstock has been studied. Therefore, this study aimed to investigate the ultimate composition of *E. pellita* wood (carbon (C), hydrogen (H), and oxygen (O)) to estimate its higher heating value (HHV) and bioelectricity potency. The wood samples were harvested at different plant ages, from the first to the fifth year. The percentage of biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also calculated. The results demonstrated that lignin in the *E. pellita* wood increased to align with the increased plant age. Thus, this pattern was followed by significantly increased C content in the wood since lignin contained a primary source of C. Hence, this condition might enhance the HHV and electricity potency. The ratio of H/C and O/C was found to be one of the most promising factors to improve HHV compared to the extractive/lignin ratio. In the fifth year, the electricity potency of *E. pellita* showed the highest value (1.71 MWh ton^{-1}). Therefore, this study suggests that *E. pellita* possesses the potential to be one of the promising crops for green electricity production.

Keywords: bioelectricity, carbon, *Eucalyptus pellita*, lignin, woody crop.

Running title: Analysis of the ultimate composition of *Eucalyptus pellita* wood

INTRODUCTION

Nowadays, several countries have tried to initiate the transition from using non-renewable fossil fuels to the use of renewable resources. The application of biomass for energy production has received significant interest since it is abundantly available worldwide. Its recent utilization is estimated to reach 13% of the entire energy structure (Xing et al., 2019). It has offered direct and indirect advantages to human societies, including environmental and economic aspects (Nimmanterdwong et al., 2021). Also, biomass energy (BE) is becoming more important to mitigate the high level of carbon dioxide (CO_2) emission, which is one of the most crucial causes of climate change and environmental degradation (Zafar et al., 2021). Biomass is a renewable and sustainable organic source that stores energy through a photosynthesis process mainly produced by plants in the presence of sunlight (Demirbaş, 2001; McKendry, 2002; Sansaniwal et al., 2017; Islas et al., 2019). BE releases less CO_2 emissions and does not compete with global food supplies (Ashokkumar et al., 2022). Biomass can be converted through thermochemical, chemical, and biological processes into various forms, such as solid, liquid, and gas, which can be further utilized in heating, transportation, and electricity (Demirbaş, 2008; Konuk et al., 2021).

Combustion is the most widely applied process to produce heat and electricity from biomass (Briones-Hidrovo et al., 2021). When the biomass is burned, its chemical and physical structure changes step by step due to drying, devolatilization, steam gasification, volatile matter burning, and char combustion process (Cui et al., 2006). Biomass is composed of carbon (C), hydrogen (H), and oxygen (O), which are desired properties for solid fuel (Nussbaumer, 2003). Nevertheless, the distribution of these organic constituents differs according to the type of biomasses. Herbaceous plants such as miscanthus, kenaf, straw, and switchgrass reportedly contained more nitrogen (N), sulfur (S), potassium (K), and chlorine (Cl), which potentially released dangerous emissions during the combustion process (Cui et al., 2006; Lee et al., 2021). Due to this limitation, using other biomass types, such as woody biomass, could be a great option for future sustainable energy feedstocks. Woody biomasses store C, H, and O in their macromolecular ingredients, such as cellulose, hemicellulose, and lignin. Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_n$ generally consist of polysaccharides, while lignin consists of aromatic polyphenols (Ozyuguran et al., 2018). The amount of C, H, and O significantly influences the biomass's higher heating value (HHV) (Bounmanchar et al., 2019). Thus, this could be one of the important parameters to point out the energy-electricity potency of the woody biomass.

Eucalyptus pellita F. Muell is the most widely planted hardwood tree in Southeast Asia. This species is native to Indonesia, New South Wales, Queensland, Australia, and Papua New Guinea (Arisandi et al., 2020). The main utilization of this species is to provide the raw material for pulp and paper production. However, *Eucalyptus* plants have been recently used for raw materials in various industries, such as perfumery, pharmaceuticals, nutraceuticals, and furniture (Salehi et al., 2019). *E. pellita* has been considered one of Indonesia's most important fast-growing trees. Therefore, the government and cooperation are pursuing the tree breeding program to improve its sustainability in the forest plantation areas (Leksono et al., 2008). *E. pellita* is reportedly more resistant to pests and diseases than other crop species (Jang et al., 2020). This could be one of the reasons why the plantation of *Acacia mangium* in both Sumatera (465,000 ha) and Kalimantan (225,500 ha) has been partially changed to *E. pellita* (Hardiyanto et al., 2021). Since there has been an increased demand for *E. pellita* plantations, it will allow the use of *E. pellita* woody biomass in various applications, such as heat and electricity production.

The aim of this study was to evaluate the ultimate composition of the *E. pellita* woody biomass in order to estimate its HHV and electricity potency. The wood samples harvested at the plant ages of first to fifth years were collected and were used for analysis. This study also measured its biomass composition, including cellulose, hemicellulose, lignin, and extractives.

MATERIALS AND METHODS

Materials

The *E. pellita* wood used in this study was obtained from a forest plantation company, PT. Sumalindo Hutani Jaya II, which is located in Sei Mao District, Kutai Kartanegara, East Kalimantan Province, Indonesia. Five wood samples from different plant ages were harvested randomly from the forest sites (Figure 1). Each sample was debarked, hammer milled, and sieved to obtain wood powder with a size of 40 and 60 mesh for laboratory testing. All chemicals used in this study, such as sodium chlorite, glacial acetic acid, ethanol, benzene, and sulfuric acid, were analytical grade.

Biomass composition analysis

The dried wood powder with a size of 40 mesh was used as a sample to calculate the biomass composition (extractive, lignin, hemicellulose, and cellulose). Firstly, the sample was placed inside the filter paper. Then, the filter paper was placed inside the reflux containing mixed alcohol and benzene under heating conditions to remove extractives from the sample. The ratio of the alcohol-benzene solution used in this experiment was 1:2 (v/v). After that, the sample was filtered using a Whatman filter paper No. 1 and repeatedly washed with hot distilled water until the pH reached 7. The sample was air-dried to remove the moisture before the next experiments. The lignin content was determined by the Klason lignin protocol using a 72% sulfuric acid solution according to TAPPI T 222 om-88. The cellulose and hemicellulose contents were determined by a method adapted from Wise et al. (1946).

Ultimate composition analysis

The dried wood sample with a size of 60 mesh was used to analyze the ultimate composition, including carbon (C), hydrogen (H), and oxygen (O). It was determined by using an elemental analyzer according to ASTM D5373-02.

Estimation of higher heating value and electricity potency

The higher heating value (HHV) was calculated based on the amount of C using an equation introduced by Sheng and Azevedo (2005), while the bioelectricity was calculated using an equation modified from Xue et al. (2016):

$$\text{HHV} = (0.3295 \times C) + 3.4597 \quad (1)$$

$$\text{Electricity} = (\text{HHV} \times 0.35 \times 10^3) / 3600 \quad (2)$$

Statistical analysis

The analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at the level of $p < 0.05$ using IBM SPSS Statistic 22 Software (IBM Corp., Armonk, NY) was used to compare any significant differences among the mean values.

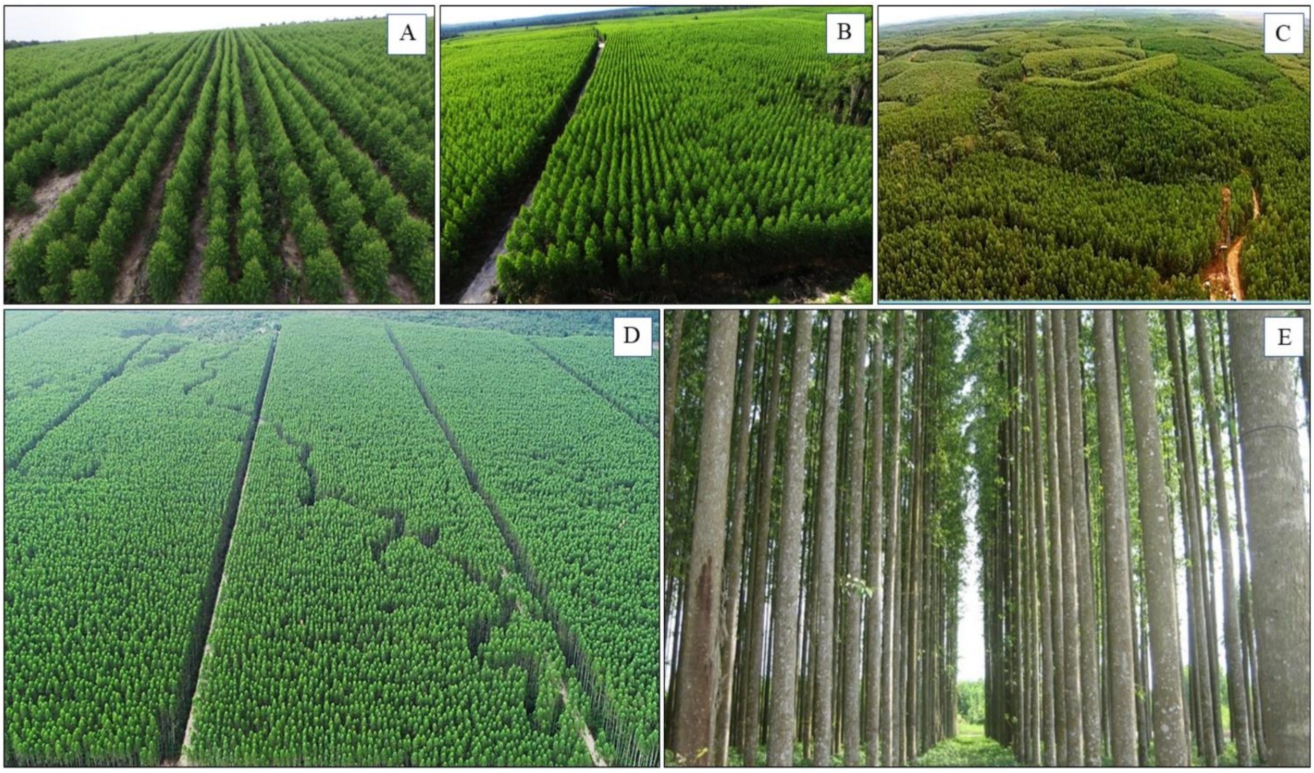

Figure 1. Photograph images of *E. pellita* crop utilized in this study: 1st year (A), 2nd year (B), 3rd year (C), 4th year (D), and 5th year (E).

RESULTS AND DISCUSSION

Biomass composition

Woody biomass is a complex organic material in nature, produced by lignocellulosic plants through photosynthesis. Therefore, information about its composition, including extractive, lignin, cellulose, and hemicellulose, is considered the basic knowledge for converting the woody biomass into various value-added products. The results of the biomass composition measurement of *E. pellita* at different plant ages are displayed in Table 1. It was found that increased plant age significantly contributed to a decline in the percentage of extractive and cellulose. It could be observed that hemicellulose content was not influenced by plant age. On the other hand, the opposite pattern could be seen from the amount of lignin content. The lignin percentage of *E. pellita* harvested in the first year was 25.35%, and it was significantly enhanced to reach 29.90% after being grown in the fifth year. Although *E. pellita* was reportedly grown worldwide in the plantation forest, its constituents differed depending on the clone and site. For instance, Menucelli et al. (2019) reported that 31-year-old *E. pellita* collected from Selviria, Brazil had 15.88% extractive, 38.86% lignin, and 45.24% holocellulose (cellulose and hemicellulose). *E. pellita* grown in Sabah, Malaysia, had low extractive (1.4%) with high lignin content (37.3%) (Fiskari and Kilpeläinen, 2021). In this study, the average values of extractive, lignin, cellulose, and hemicellulose among all age classes of *E. pellita* grown in East Kalimantan, Indonesia, were 8.26%, 28.14%, 39.96%, and 26.41%, respectively.

Ultimate composition

The ultimate composition of *E. pellita* wood, including C, H, and O, measured at different plant ages, can be seen in Figure 2. It was clearly observed that plant age strongly influenced the amount of C and O, whereas H was not affected. The increased C of *E. pellita* might have a relationship with the significant enhancement of lignin content (Table 1). As previously reported by Ma et al. (2019), lignin contained a higher content of C in comparison with hemicellulose and cellulose. Woody biomass with a high content of C could be desirable for solid fuel purposes since it has been reported to generate a significantly higher energy content (Poddar et al., 2014). Hence, to improve biomass energy, Chen et al. (2018) demonstrated that it could be achieved by improving C-C and C-H bonds and reducing C-O and O-H bonds in the biomass. Generally, the average values of C, H, and O of the *E. pellita* in this study were 42.82%, 5.30%, and 39.17%.

Table 1. Biomass composition of *E. pellita* wood at different plant ages.

Plant age (year)	Extractive (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
1	10.11 ± 0.17^{a}	25.35 ± 0.42^{c}	41.86 ± 1.24^{a}	26.68 ± 1.13^{ns}
2	8.85 ± 0.09^{b}	28.12 ± 1.15^{b}	40.08 ± 0.04^{b}	26.52 ± 0.88^{ns}
3	8.15 ± 0.15^{c}	28.47 ± 0.94^{b}	40.37 ± 0.21^{b}	26.47 ± 0.79^{ns}
4	7.41 ± 0.11^{d}	28.87 ± 0.31^{b}	39.79 ± 0.25^{c}	26.23 ± 1.23^{ns}
5	7.08 ± 0.05^{e}	29.90 ± 0.78^{a}	37.70 ± 0.46^{d}	26.17 ± 0.15^{ns}
Average	**8.26 ± 1.06**	**28.14 ± 1.52**	**39.96 ± 1.37**	**26.41 ± 0.19**

Different superscript letters (a-e) demonstrated a significant different value at $p < 0.05$; ns = not significant.

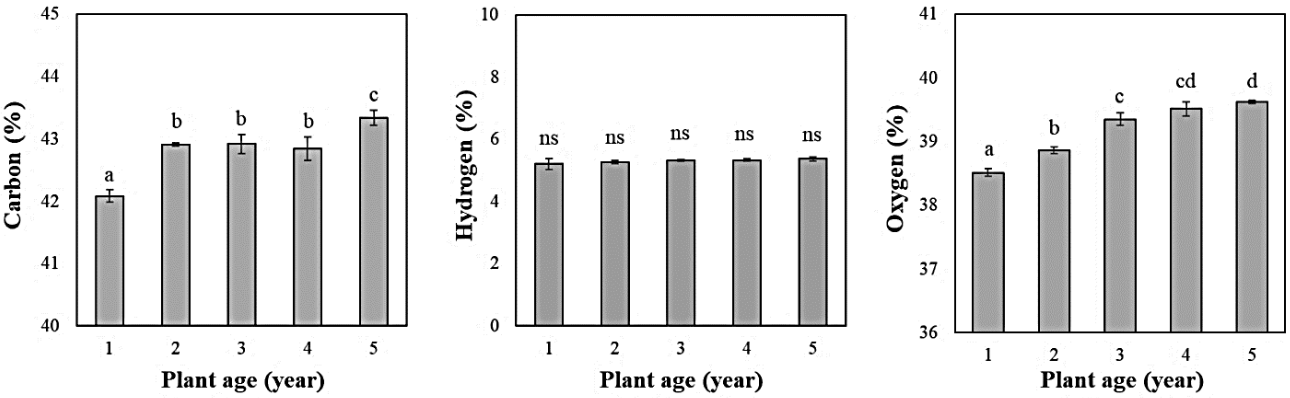

Figure 2. The ultimate composition of *E. pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant.

Higher heating value and electricity potency

The higher heating value (HHV) is an important indicator to assess the suitability of woody biomass to produce heat and electricity. Hence, its excessive value is preferable. The information about the HHV of *E. pellita* calculated from all age classes is illustrated in Table 2. It was found that increasing plant age significantly influenced the obtained HHV. The average value of all of them reached 17.41 MJ kg^{-1}. According to Ghugare et al. (2014), this value was characterized in the mid-range (16-25 MJ kg^{-1}). It was in line with the study from Telmo and Lousada, who reported that hardwood had HHV ranging from 17.38 to 23.05 MJ kg^{-1}. Nevertheless, the HHV value of *E. pellita* in this study was still higher than that of another forest plantation crop, *Anthocephalus macrophyllus*, reported by Mukhdlor et al. (2021). We stated that it might have a relationship with the high presence of lignin since this macromolecule could be a primary C source in the lignocellulosic biomass. Besides lignin, Telmo and Lousada (2011) reported that extractives also had a significant role in achieving better HHV. Therefore, we further evaluated the correlation of ultimate composition, lignin, and extractive to the obtained HHV of *E. pellita* (Figure 3). We found that the combination of H/C ratio and O/C ratio contributed to a significant correlation ($r^2 = 0.966$) compared to lignin and extractive ($r^2 = 0.872$). This condition was aligned with the previous work reported by Nhucchen and Afzal (2017).

Biomass can be applied to produce electricity through several thermochemical processes. This study evaluated *E. pellita* wood harvested at different plant ages to generate electricity through a direct combustion stage. Its calculation is summarized in Table 2. It is noticeable that the trend of the electricity potency was in line with the HHV results, in which a high lignin content due to the increase in plant age had a significant enhancement to the values. In general, *E. pellita* wood obtained in the 1st year produced 1.67 MWh ton^{-1}, and this value increased to 1.71 MWh ton^{-1} in the 5th year. The mean values of all age classes were 1.69 MWh ton^{-1}. Our previous study reported that some fast-growing tree species, such as *Acacia mangium*, *Anthocephalus cadamba*, *Gmelina arborea,* and *Paraserianthes falcataria,* commonly produce lower energy potency than those of the low growing tree species, such as *Shorea balangeran* (Amirta et al. 2016b; 2019). This phenomenon might be due to the high lignin content of woody biomass of the Dipterocarpaceae family. It has been reported by Amirta et al. (2016a) that *Shorea* sp. contained 31.5% of lignin, while *E. pellita* possessed a lower percentage of lignin (28.14%), as appears in Table 1. However, we believe that the characteristics of *E. pellita* will be suited to the criteria of an ideal energy crop since its woody biomass can be produced sustainably using a short rotation harvesting cycle with appropriate energy content.

Table 2. HHV and electricity potency of *E. pellita* wood at different plant ages.

Plant age (year)	HHV (MJ kg^{-1})	Electricity Potency (MWh ton^{-1})
1	17.17 ± 0.03^{a}	1.67 ± 0.00^{a}
2	17.44 ± 0.01^{b}	1.69 ± 0.00^{b}
3	17.45 ± 0.05^{b}	1.69 ± 0.00^{b}
4	17.42 ± 0.06^{b}	1.69 ± 0.01^{b}
5	17.58 ± 0.04^{c}	1.71 ± 0.00^{c}
Average	**17.41 ± 0.15**	**1.69 ± 0.01**

Different superscript letters (a-c) demonstrated a significant different value at $p < 0.05$; ns = not significant.

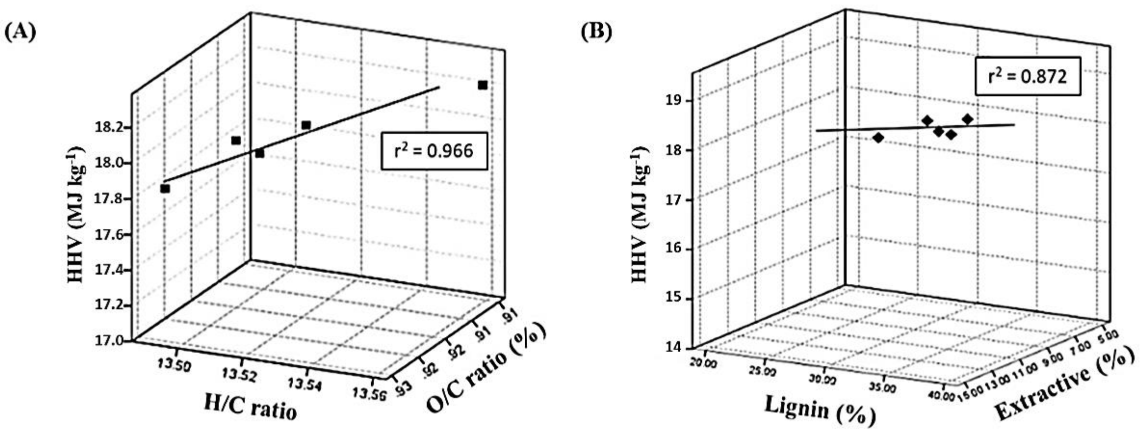

Figure 3. The strong influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *E. pellita* wood.

A recent study points out the suitability of *E. pellita* wood to be used as an energy feedstock for biomass-based electricity production. Our previous research also found that East Kalimantan Province has abundant natural resources from forest plant diversity which is promising for future energy feedstock (Amirta et al., 2016b; 2019; Haqiqi et al., 2018; Yuliansyah et al., 2019). In this study, *E. pellita* log wood harvested from forest plantations is suggested to be debarked and converted into the wood chip for further utilization as electricity via a direct combustion process (see Figure 4). Implementation of this process will promote green electricity production since *E. pellita* plants could capture excessive CO_2 emissions to create a neutral carbon cycle. Therefore, the results of this study are expected to be one of the viable options for the development of bioelectricity to increase the bioeconomy of local society in this province due to its high availability and suitability. Since this study revealed that the *E. pellita* crop possesses great potential to generate bioelectricity, future work about its sustainable biomass production under different planting distances will be interesting to be carried out to determine the best condition to obtain the highest woody biomass yield.

Figure 4. Harvested wood (A) and wood chip (B) of *E. pellita*.

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Notifications

[biodiv] Editor Decision

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MUHAMMAD TAUFIQ HAQIQI, DUDU HUDAYA, HELMI ALFATH SEPTIANA, RICO RAMADHAN, YULIANSYAH YULIANSYAH, WIWIN SUWINARTI, RUDIANTO AMIRTA:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Short Communication: Analysis of the ultimate wood composition of a forest plantation species, Eucalyptus pellita, to estimate its bioelectricity potency".

Our decision is to: Accept Submission

Best Regards,
Team Support Smujo.id

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Short Communication:
Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency

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Abstract. *Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R, Yuliansyah, Suwinarti W, Amirta R. 2022. Short Communicarion: Analysis of the ultimate wood composition of a forest plantation species,* Eucalyptus pellita, *to estimate its bioelectricity potency. Biodiversitas 23: xxxx. Eucalyptus pellita* F. Muell is one of the short rotation wood crop species widely planted in tropical countries, including Indonesia. Woody biomass obtained from this species is commonly utilized to produce fiber in the pulp and paper industry. Due to the growing interest in expanding *E. pellita* plantations, the potential application of *E. pellita* woody biomass to provide sustainable energy feedstock has been studied. Therefore, this study aimed to investigate the ultimate composition of *E. pellita* wood (carbon (C), hydrogen (H), and oxygen (O)) to estimate its higher heating value (HHV) and bioelectricity potency. The wood samples were harvested at different plant ages, from the first to the fifth year. The percentage of biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also calculated. The results demonstrated that lignin in the *E. pellita* wood increased to align with the increased plant age. Thus, this pattern was followed by significantly increased C content in the wood since lignin contained a primary source of C. Hence, this condition might enhance the HHV and electricity potency. The ratio of H/C and O/C was found to be one of the most promising factors to improve HHV compared to the extractive/lignin ratio. In the fifth year, the electricity potency of *E. pellita* showed the highest value (1.71 MWh ton^{-1}). Therefore, this study suggests that *E. pellita* possesses the potential to be one of the promising crops for green electricity production.

Keywords: Bioelectricity, carbon, *Eucalyptus pellita*, lignin, woody crop

INTRODUCTION

Nowadays, several countries have tried to initiate the transition from using non-renewable fossil fuels to the use of renewable resources. The application of biomass for energy production has received significant interest since it is abundantly available worldwide. Its recent utilization is estimated to reach 13% of the entire energy structure (Xing et al. 2019). It has offered direct and indirect advantages to human societies, including environmental and economic aspects (Nimmanterdwong et al. 2021). Also, biomass energy (BE) is becoming more important to mitigate the high level of carbon dioxide (CO_2) emission, which is one of the most crucial causes of climate change and environmental degradation (Zafar et al. 2021). Biomass is a renewable and sustainable organic source that stores energy through a photosynthesis process mainly produced by plants in the presence of sunlight (Demirbaş 2001; Islas et al. 2019; McKendry 2002; Sansaniwal et al. 2017). BE releases less CO_2 emissions and does not compete with global food supplies (Ashokkumar et al. 2022). Biomass can be converted through thermochemical, chemical, and biological processes into various forms, such as solid, liquid, and gas, which can be further utilized in heating, transportation, and electricity (Demirbaş 2008; Konuk et al. 2021).

Combustion is the most widely applied process to produce heat and electricity from biomass (Briones-Hidrovo et al. 2021). When the biomass is burned, its chemical and physical structure changes step by step due to drying, devolatilization, steam gasification, volatile matter burning, and char combustion process (Cui et al. 2006). Biomass is composed of carbon (C), hydrogen (H), and oxygen (O), which are desired properties for solid fuel (Nussbaumer 2003). Nevertheless, the distribution of these organic constituents differs according to the type of biomasses. Herbaceous plants such as miscanthus, kenaf, straw, and switchgrass reportedly contained more nitrogen (N), sulfur (S), potassium (K), and chlorine (Cl), which potentially released dangerous emissions during the combustion process (Cui et al. 2006; Lee et al. 2021). Due to this limitation, using other biomass types, such as woody biomass, could be a great option for future sustainable energy feedstocks. Woody biomasses store C, H, and O in their macromolecular ingredients, such as cellulose, hemicellulose, and lignin. Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_n$ generally consist of polysaccharides, while lignin consists of aromatic polyphenols (Ozyuguran et al. 2018). The amount of C, H, and O significantly influences the biomass's higher heating value (HHV) (Boumanchar et al. 2019). Thus, this could be one of the important parameters to point out the energy-electricity potency of the woody biomass.

Eucalyptus pellita F. Muell is the most widely planted hardwood tree in Southeast Asia. This species is native to Indonesia, New South Wales, Queensland, Australia, and Papua New Guinea (Arisandi et al. 2020). The main utilization of this species is to provide the raw material for pulp and paper production. However, *Eucalyptus* plants have been recently used for raw materials in various industries, such as perfumery, pharmaceuticals, nutraceuticals, and furniture (Salehi et al. 2019). *E. pellita* has been considered one of Indonesia's most important fast-growing trees. Therefore, the government and cooperation are pursuing the tree breeding program to improve its sustainability in the forest plantation areas (Leksono et al. 2008). *E. pellita* is reportedly more resistant to pests and diseases than other crop species (Jang et al. 2020). This could be one of the reasons why the plantation of *Acacia mangium* in both Sumatera (465,000 ha) and Kalimantan (225,500 ha) has been partially changed to *E. pellita* (Hardiyanto et al. 2021). Since there has been an increased demand for *E. pellita* plantations, it will allow the use of *E. pellita* woody biomass in various applications, such as heat and electricity production.

The aim of this study was to evaluate the ultimate composition of the *E. pellita* woody biomass in order to estimate its HHV and electricity potency. The wood samples harvested at the plant ages of first to fifth years were collected and were used for analysis. This study also measured its biomass composition, including cellulose, hemicellulose, lignin, and extractives.

MATERIALS AND METHODS

Materials

The *E. pellita* wood used in this study was obtained from a forest plantation company, PT. Sumalindo Hutani Jaya II, which is located in Sei Mao District, Kutai Kartanegara, East Kalimantan Province, Indonesia. Five wood samples from different plant ages were harvested randomly from the forest sites (Figure 1). Each sample was debarked, hammer milled, and sieved to obtain wood powder with a size of 40 and 60 mesh for laboratory testing. All chemicals used in this study, such as sodium chlorite, glacial acetic acid, ethanol, benzene, and sulfuric acid, were analytical grade.

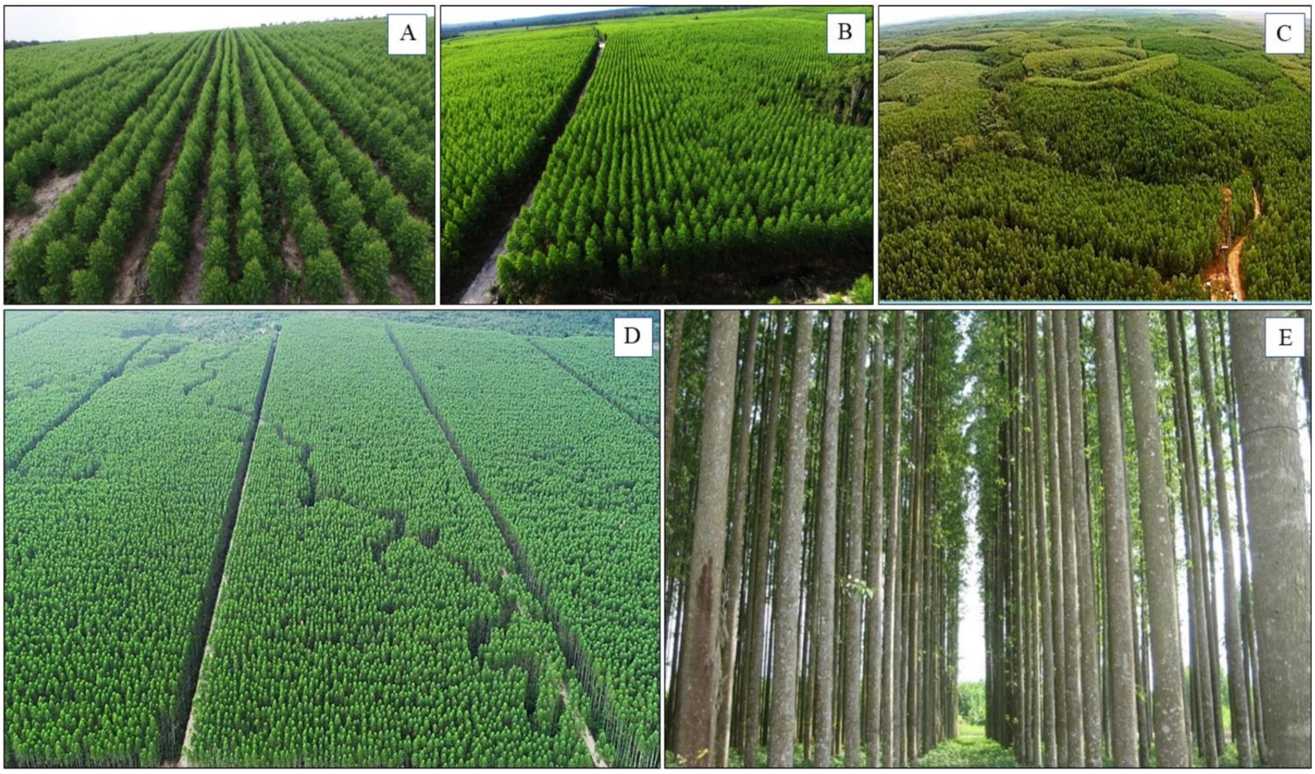

Figure 1. Photograph images of *E. pellita* crop utilized in this study: 1st year (A), 2nd year (B), 3rd year (C), 4th year (D), and 5th year (E)

Biomass composition analysis

The dried wood powder with a size of 40 mesh was used as a sample to calculate the biomass composition (extractive, lignin, hemicellulose, and cellulose). Firstly, the sample was placed inside the filter paper. Then, the filter paper was placed inside the reflux containing mixed alcohol and benzene under heating conditions to remove extractives from the sample. The ratio of the alcohol-benzene solution used in this experiment was 1:2 (v/v). After that, the sample was filtered using a Whatman filter paper No. 1 and repeatedly washed with hot distilled water until the pH reached 7. The sample was air-dried to remove the moisture before the next experiments. The lignin content was determined by the Klason lignin protocol using a 72% sulfuric acid solution according to TAPPI T 222 om-88. The cellulose and hemicellulose contents were determined by a method adapted from Wise et al. (1946).

Ultimate composition analysis

The dried wood sample with a size of 60 mesh was used to analyze the ultimate composition, including carbon (C), hydrogen (H), and oxygen (O). It was determined by using an elemental analyzer according to ASTM D5373-02.

Estimation of higher heating value and electricity potency

The higher heating value (HHV) was calculated based on the amount of C using an equation introduced by Sheng and Azevedo (2005), while the bioelectricity was calculated using an equation modified from Xue et al. (2016):

$$\text{HHV} = (0.3295 \times \text{C}) + 3.4597 \quad (1)$$

$$\text{Electricity} = (\text{HHV} \times 0.35 \times 10^3) / 3600 \quad (2)$$

Statistical analysis

The analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at the level of $p < 0.05$ using IBM SPSS Statistic 22 Software (IBM Corp., Armonk, NY) was used to compare any significant differences among the mean values.

RESULTS AND DISCUSSION

Biomass composition

Woody biomass is a complex organic material in nature, produced by lignocellulosic plants through photosynthesis. Therefore, information about its composition, including extractive, lignin, cellulose, and hemicellulose, is considered the basic knowledge for converting the woody biomass into various value-added products. The results of the biomass composition measurement of *E. pellita* at different plant ages are displayed in Table 1. It was found that increased plant age significantly contributed to a decline in the percentage of extractive and cellulose. It could be observed that hemicellulose content was not influenced by plant age. On the other hand, the opposite pattern could be seen from the amount of lignin content. The lignin percentage of *E. pellita* harvested in the first year was 25.35%, and it was significantly enhanced to reach 29.90% after being grown in the fifth year. Although *E. pellita* was reportedly grown worldwide in the plantation forest, its constituents differed depending on the clone and site. For instance, Menucelli et al. (2019) reported that 31-year-old *E. pellita* collected from Selviria, Brazil had 15.88% extractive, 38.86% lignin, and 45.24% holocellulose (cellulose and hemicellulose). *E. pellita* grown in Sabah, Malaysia, had low extractive (1.4%) with high lignin content (37.3%) (Fiskari and Kilpeläinen 2021). In this study, the average values of extractive, lignin, cellulose, and hemicellulose among all age classes of *E. pellita* grown in East Kalimantan, Indonesia, were 8.26%, 28.14%, 39.96%, and 26.41%, respectively.

Ultimate composition

The ultimate composition of *E. pellita* wood, including C, H, and O, measured at different plant ages, can be seen in Figure 2. It was clearly observed that plant age strongly influenced the amount of C and O, whereas H was not affected. The increased C of *E. pellita* might have a relationship with the significant enhancement of lignin content (Table 1). As previously reported by Ma et al. (2019), lignin contained a higher content of C in comparison with hemicellulose and cellulose. Woody biomass with a high content of C could be desirable for solid fuel purposes since it has been reported to generate a significantly higher energy content (Poddar et al. 2014). Hence, to improve biomass energy, Chen et al. (2018) demonstrated that it could be achieved by improving C-C and C-H bonds and reducing C-O and O-H bonds in the biomass. Generally, the average values of C, H, and O of the *E. pellita* in this study were 42.82%, 5.30%, and 39.17%.

Higher heating value and electricity potency

The higher heating value (HHV) is an important indicator to assess the suitability of woody biomass to produce heat and electricity. Hence, its excessive value is preferable. The information about the HHV of *E. pellita* calculated from all age classes is illustrated in Table 2. It was found that increasing plant age significantly influenced the obtained HHV. The average value of all of them reached 17.41 MJ kg^{-1}. According to Ghugare et al. (2014), this value was characterized in the mid-range (16-25 MJ kg^{-1}). It was in line with the study from Telmo and Lousada, who reported that hardwood had HHV ranging from 17.38 to 23.05 MJ kg^{-1}. Nevertheless, the HHV value of *E. pellita* in this study was still higher than that of another forest plantation crop, *Anthocephalus macrophyllus*, reported by Mukhdlor et al. (2021). We stated that it might have a relationship with the high presence of lignin since this macromolecule could be a primary C source in the lignocellulosic biomass. Besides lignin, Telmo and Lousada (2011) reported that extractives also had a significant role in achieving better HHV. Therefore, we further evaluated the correlation of ultimate composition, lignin, and extractive to the obtained HHV of *E. pellita* (Figure 3). We found that the combination of H/C ratio and O/C ratio contributed to a significant correlation (r^2 = 0.966) compared to lignin and extractive (r^2 = 0.872). This condition was aligned with the previous work reported by Nhuchhen and Afzal (2017).

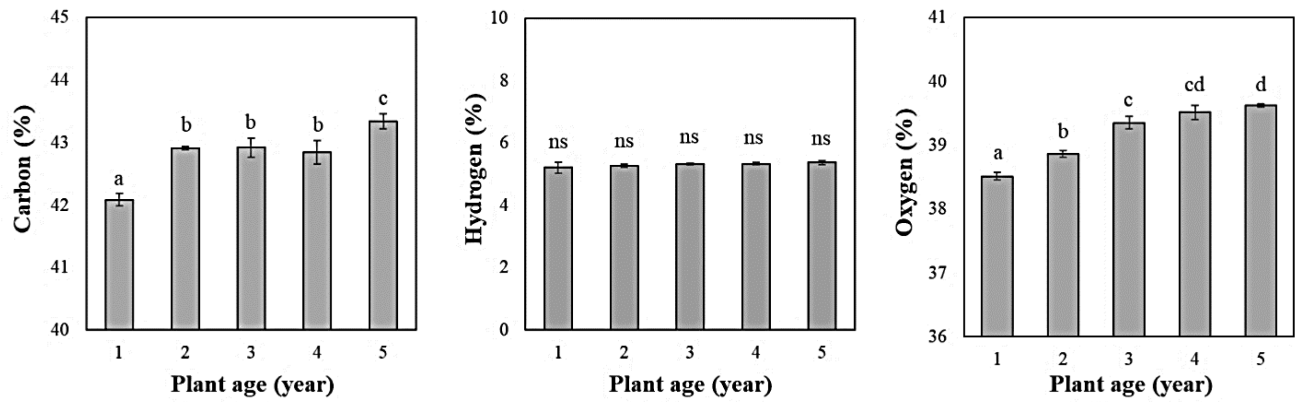

Figure 2. The ultimate composition of *E. pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant

Table 1. Biomass composition of *E. pellita* wood at different plant ages

Plant age (year)	Extractive (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
1	10.11 ± 0.17^{a}	25.35 ± 0.42^{c}	41.86 ± 1.24^{a}	26.68 ± 1.13^{ns}
2	8.85 ± 0.09^{b}	28.12 ± 1.15^{b}	40.08 ± 0.04^{b}	26.52 ± 0.88^{ns}
3	8.15 ± 0.15^{c}	28.47 ± 0.94^{b}	40.37 ± 0.21^{b}	26.47 ± 0.79^{ns}
4	7.41 ± 0.11^{d}	28.87 ± 0.31^{b}	39.79 ± 0.25^{c}	26.23 ± 1.23^{ns}
5	7.08 ± 0.05^{e}	29.90 ± 0.78^{a}	37.70 ± 0.46^{d}	26.17 ± 0.15^{ns}
Average	8.26 ± 1.06	28.14 ± 1.52	39.96 ± 1.37	26.41 ± 0.19

Different superscript letters (a-e) demonstrated a significant different value at $p < 0.05$; ns = not significant

Table 2. HHV and electricity potency of *E. pellita* wood at different plant ages

Plant age (year)	HHV (MJ kg^{-1})	Electricity potency (MWh ton^{-1})
1	17.17 ± 0.03^{a}	1.67 ± 0.00^{a}
2	17.44 ± 0.01^{b}	1.69 ± 0.00^{b}
3	17.45 ± 0.05^{b}	1.69 ± 0.00^{b}
4	17.42 ± 0.06^{b}	1.69 ± 0.01^{b}
5	17.58 ± 0.04^{c}	1.71 ± 0.00^{c}
Average	17.41 ± 0.15	1.69 ± 0.01

Different superscript letters (a-c) demonstrated a significant different value at $p < 0.05$; ns: not significant

Biomass can be applied to produce electricity through several thermochemical processes. This study evaluated *E. pellita* wood harvested at different plant ages to generate electricity through a direct combustion stage. Its calculation is summarized in Table 2. It is noticeable that the trend of the electricity potency was in line with the HHV results, in which a high lignin content due to the increase in plant age had a significant enhancement to the values. In general, *E. pellita* wood obtained in the 1st year produced 1.67 MWh ton^{-1}, and this value increased to 1.71 MWh ton^{-1} in the 5th year. The mean values of all age classes were 1.69 MWh ton^{-1}. Our previous study reported that some fast-growing tree species, such as *A. mangium*, *Anthocephalus cadamba*, *Gmelina arborea*, and *Paraserianthes falcataria*, commonly produce lower energy potency than those of the low growing tree species, such as *Shorea balangeran* (Amirta et al. 2016b; 2019). This phenomenon might be due to the high lignin content of woody biomass of the Dipterocarpaceae family. It has been reported by Amirta et al. (2016a) that *Shorea* sp. contained 31.5% of lignin, while *E. pellita* possessed a lower percentage of lignin (28.14%), as appears in Table 1. However, we believe that the characteristics of *E. pellita* will be suited to the criteria of an ideal energy crop since its woody biomass can be produced sustainably using a short rotation harvesting cycle with appropriate energy content.

A recent study points out the suitability of *E. pellita* wood to be used as an energy feedstock for biomass-based electricity production. Our previous research also found that East Kalimantan Province has abundant natural resources from forest plant diversity which is promising for future energy feedstock (Amirta et al. 2016b; 2019; Haqiqi et al. 2018; Yuliansyah et al. 2019). In this study, *E. pellita* log wood harvested from forest plantations is suggested to be debarked and converted into the wood chip for further utilization as electricity via a direct combustion process (see Figure 4). Implementation of this process will promote green electricity production since *E. pellita* plants could capture excessive CO_2 emissions to create a neutral carbon cycle. Therefore, the results of this study are expected to be one of the viable options for the development of bioelectricity to increase the bioeconomy of local society in this province due to its high availability and suitability. Since this study revealed that the *E. pellita* crop possesses great potential to generate bioelectricity, future work about its sustainable biomass production under different planting distances will be interesting to be carried out to determine the best condition to obtain the highest woody biomass yield.

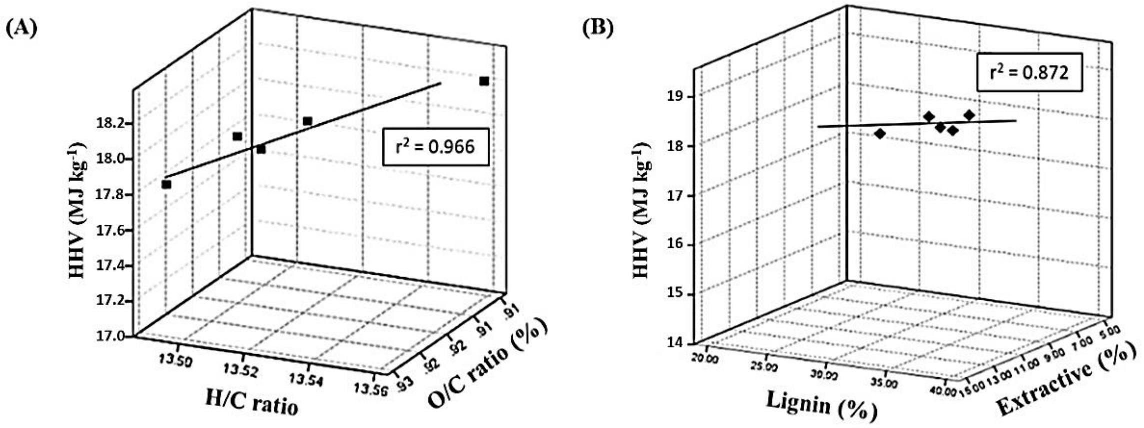

Figure 3. The strong influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *E. pellita* wood

Figure 4. Harvested wood (A) and wood chip (B) of *E. pellita*

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Short Communication: Analysis of the ultimate wood composition of a forest plantation species, *Eucalyptus pellita*, to estimate its bioelectricity potency

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Abstract. *Haqiqi MT, Hudaya D, Septiana HA, Ramadhan R, Yuliansyah, Suwinarti W, Amirta R. 2022. Short Communicarion: Analysis of the ultimate wood composition of a forest plantation species,* Eucalyptus pellita, *to estimate its bioelectricity potency. Biodiversitas 23: 2389-2394. Eucalyptus pellita* F. Muell is one of the short rotation wood crop species widely planted in tropical countries, including Indonesia. Woody biomass obtained from this species is commonly utilized to produce fiber in the pulp and paper industry. Due to the growing interest in expanding *E. pellita* plantations, the potential application of *E. pellita* woody biomass to provide sustainable energy feedstock has been studied. Therefore, this study aimed to investigate the ultimate composition of *E. pellita* wood (carbon (C), hydrogen (H), and oxygen (O)) to estimate its higher heating value (HHV) and bioelectricity potency. The wood samples were harvested at different plant ages, from the first to the fifth year. The percentage of biomass composition, including cellulose, hemicellulose, lignin, and extractives, was also calculated. The results demonstrated that lignin in the *E. pellita* wood increased to align with the increased plant age. Thus, this pattern was followed by significantly increased C content in the wood since lignin contained a primary source of C. Hence, this condition might enhance the HHV and electricity potency. The ratio of H/C and O/C was found to be one of the most promising factors in improving HHV compared to the extractive/lignin ratio. In the fifth year, the electricity potency of *E. pellita* showed the highest value (1.71 MWh ton^{-1}). Therefore, this study suggests that *E. pellita* possesses the potential to be one of the promising crops for green electricity production.

Keywords: Bioelectricity, carbon, *Eucalyptus pellita*, lignin, woody crop

INTRODUCTION

Nowadays, several countries have tried to initiate the transition from using non-renewable fossil fuels to the use of renewable resources, such as biomass (Amirta et al. 2019). The application of biomass for energy production has received significant interest since it is abundantly available worldwide. Its recent utilization is estimated to reach 13% of the entire energy structure (Xing et al. 2019). It has offered direct and indirect advantages to human societies, including environmental and economic aspects (Nimmanterdwong et al. 2021). Also, biomass energy (BE) is becoming more important to mitigate the high level of carbon dioxide (CO_2) emission, which is one of the most crucial causes of climate change and environmental degradation (Zafar et al. 2021). Biomass is a renewable and sustainable organic source that stores energy through a photosynthesis process mainly produced by plants in the presence of sunlight (Demirbaş 2001; Islas et al. 2019; McKendry 2002; Sansaniwal et al. 2017). BE releases less CO_2 emissions and does not compete with global food supplies (Ashokkumar et al. 2022). Biomass can be converted through thermochemical, chemical, and biological processes into various forms, such as solid, liquid, and gas, which can be further utilized in heating, transportation, and electricity (Demirbaş 2008; Konuk et al. 2021).

Combustion is the most widely applied process to produce heat and electricity from biomass (Briones-Hidrovo et al. 2021). When the biomass is burned, its chemical and physical structure changes step by step due to drying, devolatilization, steam gasification, volatile matter burning, and char combustion process (Cui et al. 2006). Biomass is composed of carbon (C), hydrogen (H), and oxygen (O), which are desired properties for solid fuel (Nussbaumer 2003). Nevertheless, the distribution of these organic constituents differs according to the type of biomasses. Herbaceous plants such as miscanthus, kenaf, straw, and switchgrass reportedly contained more nitrogen (N), sulfur (S), potassium (K), and chlorine (Cl), which potentially released dangerous emissions during the combustion process (Cui et al. 2006; Lee et al. 2021). Due to this limitation, using other biomass types, such as woody biomass, could be a great option for future sustainable energy feedstocks. Woody biomasses store C, H, and O in their macromolecular ingredients, such as cellulose, hemicellulose, and lignin. Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_n$ generally consist of polysaccharides, while lignin consists of aromatic polyphenols (Ozyuguran et al. 2018). The amount of C, H, and O significantly influences the biomass's higher heating value (HHV) (Boumanchar et al. 2019). Thus, this could be one of the important parameters to point out the energy-electricity potency of the woody biomass.

Eucalyptus pellita F. Muell is the most widely planted hardwood tree in Southeast Asia. This species is native to Indonesia, New South Wales, Queensland, Australia, and Papua New Guinea (Arisandi et al. 2020). The main utilization of this species is to provide the raw material for pulp and paper production. However, *Eucalyptus* plants have been recently used for raw materials in various industries, such as perfumery, pharmaceuticals, nutraceuticals, and furniture (Salehi et al. 2019). *E. pellita* has been considered one of Indonesia's most important fast-growing trees. Therefore, the government and cooperation are pursuing the tree breeding program to improve its sustainability in the forest plantation areas (Leksono et al. 2008). *E. pellita* is reportedly more resistant to pests and diseases than other crop species (Jang et al. 2020). This could be one of the reasons why the plantation of *Acacia mangium* in both Sumatera (465,000 ha) and Kalimantan (225,500 ha) has been partially changed to *E. pellita* (Hardiyanto et al. 2021). Since there has been an increased demand for *E. pellita* plantations, it will allow the use of *E. pellita* woody biomass in various applications, such as heat and electricity production.

The aim of this study was to evaluate the ultimate composition of the *E. pellita* woody biomass in order to estimate its HHV and electricity potency. The wood samples harvested at the plant ages of first to fifth years were collected and were used for analysis. This study also measured its biomass composition, including cellulose, hemicellulose, lignin, and extractives.

MATERIALS AND METHODS

Materials

The *E. pellita* wood used in this study was obtained from a forest plantation company, PT. Sumalindo Hutani Jaya II, which is located in Sei Mao District, Kutai Kartanegara, East Kalimantan Province, Indonesia. Five wood samples from different plant ages were harvested randomly from the forest sites (Figure 1). Each sample was debarked, hammer milled, and sieved to obtain a wood powder with a size of 40 and 60 mesh for laboratory testing. All chemicals used in this study, such as sodium chlorite, glacial acetic acid, ethanol, benzene, and sulfuric acid, were analytical grade.

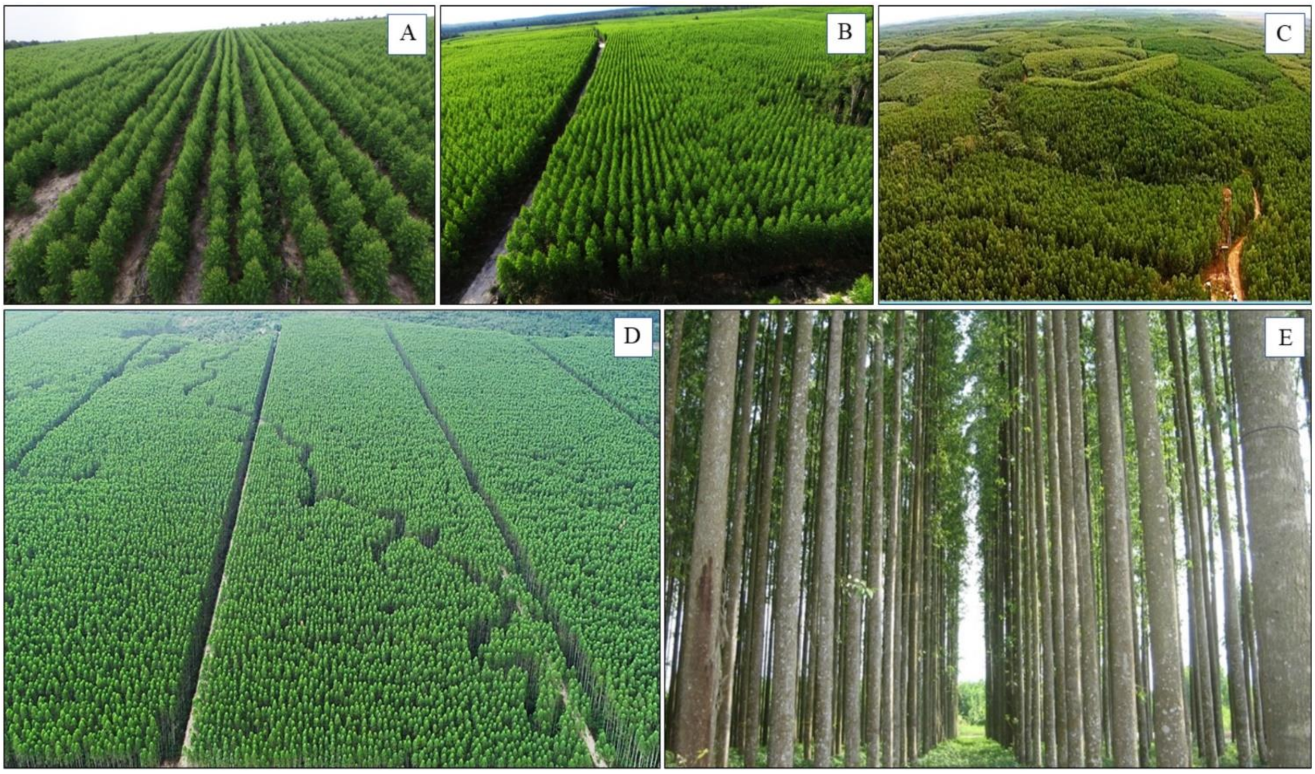

Figure 1. Photograph images of *E. pellita* crop utilized in this study: 1st year (A), 2nd year (B), 3rd year (C), 4th year (D), and 5th year (E)

Biomass composition analysis

The dried wood powder with a size of 40 mesh was used as a sample to calculate the biomass composition (extractive, lignin, hemicellulose, and cellulose). Firstly, the sample was placed inside the filter paper. Then, the filter paper was placed inside the reflux containing mixed alcohol and benzene under heating conditions to remove extractives from the sample. The ratio of the alcohol-benzene solution used in this experiment was 1:2 (v/v). After that, the sample was filtered using a Whatman filter paper No. 1 and repeatedly washed with hot distilled water until the pH reached 7. The sample was air-dried to remove the moisture before the next experiments. The lignin content was determined by the Klason lignin protocol using a 72% sulfuric acid solution according to TAPPI T 222 om-88. The cellulose and hemicellulose contents were determined by a method adapted from Wise et al. (1946).

Ultimate composition analysis

The dried wood sample with a size of 60 mesh was used to analyze the ultimate composition, including carbon (C), hydrogen (H), and oxygen (O). It was determined by using an elemental analyzer according to ASTM D5373-02.

Estimation of higher heating value and electricity potency

The higher heating value (HHV) was calculated based on the amount of C using an equation introduced by Sheng and Azevedo (2005), while the bioelectricity was calculated using an equation modified from Xue et al. (2016):

$$\text{HHV} = (0.3295 \times C) + 3.4597 \quad (1)$$

$$\text{Electricity} = (\text{HHV} \times 0.35 \times 10^3) / 3600 \quad (2)$$

Statistical analysis

The analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at the level of $p < 0.05$ using IBM SPSS Statistic 22 Software (IBM Corp., Armonk, NY) was used to compare any significant differences among the mean values.

RESULTS AND DISCUSSION

Biomass composition

Woody biomass is a complex organic material in nature, produced by lignocellulosic plants through photosynthesis. Therefore, information about its composition, including extractive, lignin, cellulose, and hemicellulose, is considered the basic knowledge for converting the woody biomass into various value-added products. The results of the biomass composition measurement of *E. pellita* at different plant ages are displayed in Table 1. It was found that increased plant age significantly contributed to a decline in the percentage of extractive and cellulose. It could be observed that hemicellulose content was not influenced by plant age. On the other hand, the opposite pattern could be seen from the amount of lignin content. The lignin percentage of *E. pellita* harvested in the first year was 25.35%, and it was significantly enhanced to reach 29.90% after being grown in the fifth year. Although *E. pellita* was reportedly grown worldwide in the plantation forest, its constituents differed depending on the clone and site. For instance, Menucelli et al. (2019) reported that 31-year-old *E. pellita* collected from Selviria, Brazil had 15.88% extractive, 38.86% lignin, and 45.24% holocellulose (cellulose and hemicellulose). *E. pellita* grown in Sabah, Malaysia, had low extractive (1.4%) with high lignin content (37.3%) (Fiskari and Kilpeläinen 2021). In this study, the average values of extractive, lignin, cellulose, and hemicellulose among all age classes of *E. pellita* grown in East Kalimantan, Indonesia, were 8.26%, 28.14%, 39.96%, and 26.41%, respectively.

Ultimate composition

The ultimate composition of *E. pellita* wood, including C, H, and O, measured at different plant ages, can be seen in Figure 2. It was clearly observed that plant age strongly influenced the amount of C and O, whereas H was not affected. The increased C of *E. pellita* might have a relationship with the significant enhancement of lignin content (Table 1). As previously reported by Ma et al. (2019), lignin contained a higher content of C in comparison with hemicellulose and cellulose. Woody biomass with a high content of C could be desirable for solid fuel purposes since it has been reported to generate a significantly higher energy content (Poddar et al. 2014). Hence, to improve biomass energy, Chen et al. (2018) demonstrated that it could be achieved by improving C-C and C-H bonds and reducing C-O and O-H bonds in the biomass. Generally, the average values of C, H, and O of the *E. pellita* in this study were 42.82%, 5.30%, and 39.17%.

Higher heating value and electricity potency

The higher heating value (HHV) is an important indicator for assessing the suitability of woody biomass to produce heat and electricity. Hence, its excessive value is preferable. The information about the HHV of *E. pellita* calculated from all age classes is illustrated in Table 2. It was found that increasing plant age significantly influenced the obtained HHV. The average value of all of them reached 17.41 MJ kg^{-1}. According to Ghugare et al. (2014), this value was characterized in the mid-range (16-25 MJ kg^{-1}). It was in line with the study from Telmo and Lousada, who reported that hardwood had HHV ranging from 17.38 to 23.05 MJ kg^{-1}. Nevertheless, the HHV value of *E. pellita* in this study was still higher than that of another forest plantation crop, *Anthocephalus macrophyllus*, reported by Mukhdlor et al. (2021). We stated that it might have a relationship with the high presence of lignin since this macromolecule could be a primary C source in the lignocellulosic biomass. Besides lignin, Telmo and Lousada (2011) reported that extractives also had a significant role in achieving better HHV. Therefore, we further evaluated the correlation of ultimate composition, lignin, and extractive to the obtained HHV of *E. pellita* (Figure 3). We found that the combination of H/C ratio and O/C ratio contributed to a significant correlation (r^2 = 0.966) compared to lignin and extractive (r^2 = 0.872). This condition was aligned with the previous work reported by Nhuchhen and Afzal (2017).

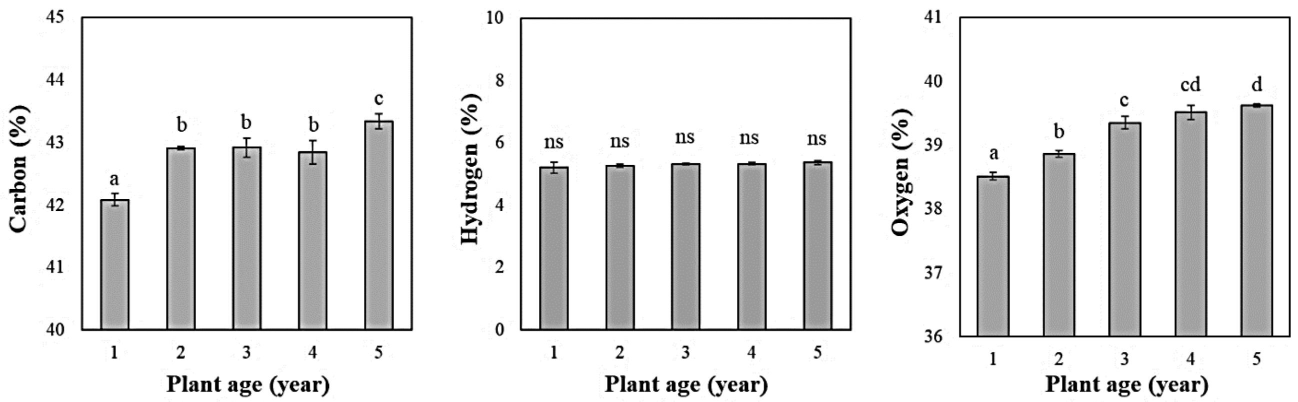

Figure 2. The ultimate composition of *E. pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant

Table 1. Biomass composition of *E. pellita* wood at different plant ages

Plant age (year)	Extractive (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
1	10.11 ± 0.17^{a}	25.35 ± 0.42^{c}	41.86 ± 1.24^{a}	26.68 ± 1.13^{ns}
2	8.85 ± 0.09^{b}	28.12 ± 1.15^{b}	40.08 ± 0.04^{b}	26.52 ± 0.88^{ns}
3	8.15 ± 0.15^{c}	28.47 ± 0.94^{b}	40.37 ± 0.21^{b}	26.47 ± 0.79^{ns}
4	7.41 ± 0.11^{d}	28.87 ± 0.31^{b}	39.79 ± 0.25^{c}	26.23 ± 1.23^{ns}
5	7.08 ± 0.05^{e}	29.90 ± 0.78^{a}	37.70 ± 0.46^{d}	26.17 ± 0.15^{ns}
Average	8.26 ± 1.06	28.14 ± 1.52	39.96 ± 1.37	26.41 ± 0.19

Different superscript letters (a-e) demonstrated a significant different value at $p < 0.05$; ns = not significant

Table 2. HHV and electricity potency of *E. pellita* wood at different plant ages

Plant age (year)	HHV (MJ kg^{-1})	Electricity potency (MWh ton^{-1})
1	17.17 ± 0.03^{a}	1.67 ± 0.00^{a}
2	17.44 ± 0.01^{b}	1.69 ± 0.00^{b}
3	17.45 ± 0.05^{b}	1.69 ± 0.00^{b}
4	17.42 ± 0.06^{b}	1.69 ± 0.01^{b}
5	17.58 ± 0.04^{c}	1.71 ± 0.00^{c}
Average	17.41 ± 0.15	1.69 ± 0.01

Different superscript letters (a-c) demonstrated a significant different value at $p < 0.05$; ns: not significant

Biomass can be applied to produce electricity through several thermochemical processes. This study evaluated *E. pellita* wood harvested at different plant ages to generate electricity through a direct combustion stage. Its calculation is summarized in Table 2. It is noticeable that the trend of the electricity potency was in line with the HHV results, in which a high lignin content due to the increase in plant age had a significant enhancement to the values. In general, *E. pellita* wood obtained in the 1st year produced 1.67 MWh ton^{-1}, and this value increased to 1.71 MWh ton^{-1} in the 5th year. The mean values of all age classes were 1.69 MWh ton^{-1}. Our previous study reported that some fast-growing tree species, such as *A. mangium*, *Anthocephalus cadamba*, *Gmelina arborea*, and *Paraserianthes falcataria*, commonly produce lower energy potency than those of the low growing tree species, such as *Shorea balangeran* (Amirta et al. 2016b; 2019). This phenomenon might be due to the high lignin content of woody biomass of the Dipterocarpaceae family. It has been reported by Amirta et al. (2016a) that *Shorea* sp. contained 31.5% of lignin, while *E. pellita* possessed a lower percentage of lignin (28.14%), as appears in Table 1. However, we believe that the characteristics of *E. pellita* will be suited to the criteria of an ideal energy crop since its woody biomass can be produced sustainably using a short rotation harvesting cycle with appropriate energy content.

A recent study points out the suitability of *E. pellita* wood to be used as an energy feedstock for biomass-based electricity production. Our previous research also found that East Kalimantan Province has abundant natural resources from forest plant diversity which is promising for future energy feedstock (Amirta et al. 2016b; 2019; Haqiqi et al. 2018; Yuliansyah et al. 2019). In this study, *E. pellita* log wood harvested from forest plantations is suggested to be debarked and converted into the wood chip for further utilization as electricity via a direct combustion process (see Figure 4). Implementation of this process will promote green electricity production since *E. pellita* plants could capture excessive CO_2 emissions to create a neutral carbon cycle. Therefore, the results of this study are expected to be one of the viable options for the development of bioelectricity to increase the bioeconomy of local society in this province due to its high availability and suitability. Since this study revealed that the *E. pellita* crop possesses great potential to generate bioelectricity, future work about its sustainable biomass production under different planting distances will be interesting to be carried out to determine the best condition to obtain the highest woody biomass yield.

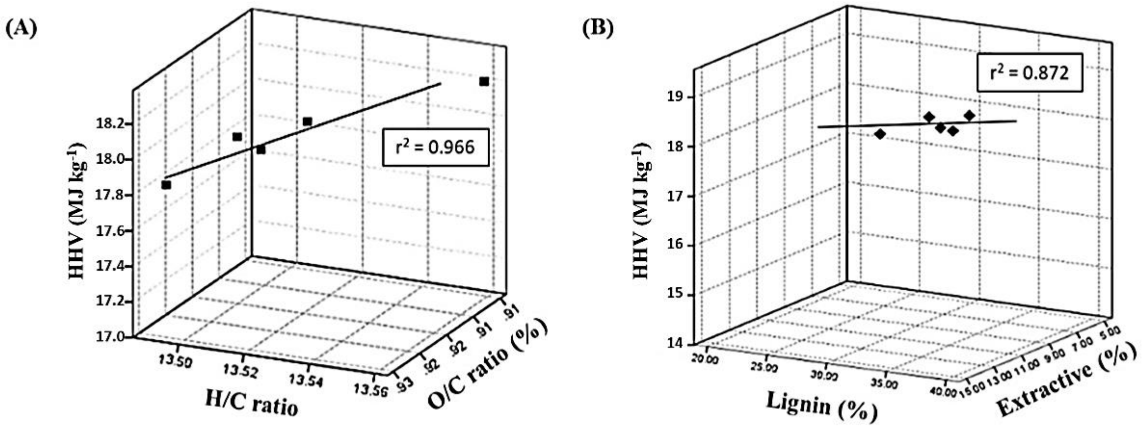

Figure 3. The strong influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *E. pellita* wood

Figure 4. Harvested wood (A) and wood chip (B) of *E. pellita*

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