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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 Sub-district, Kutai Kartanegara District, 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.

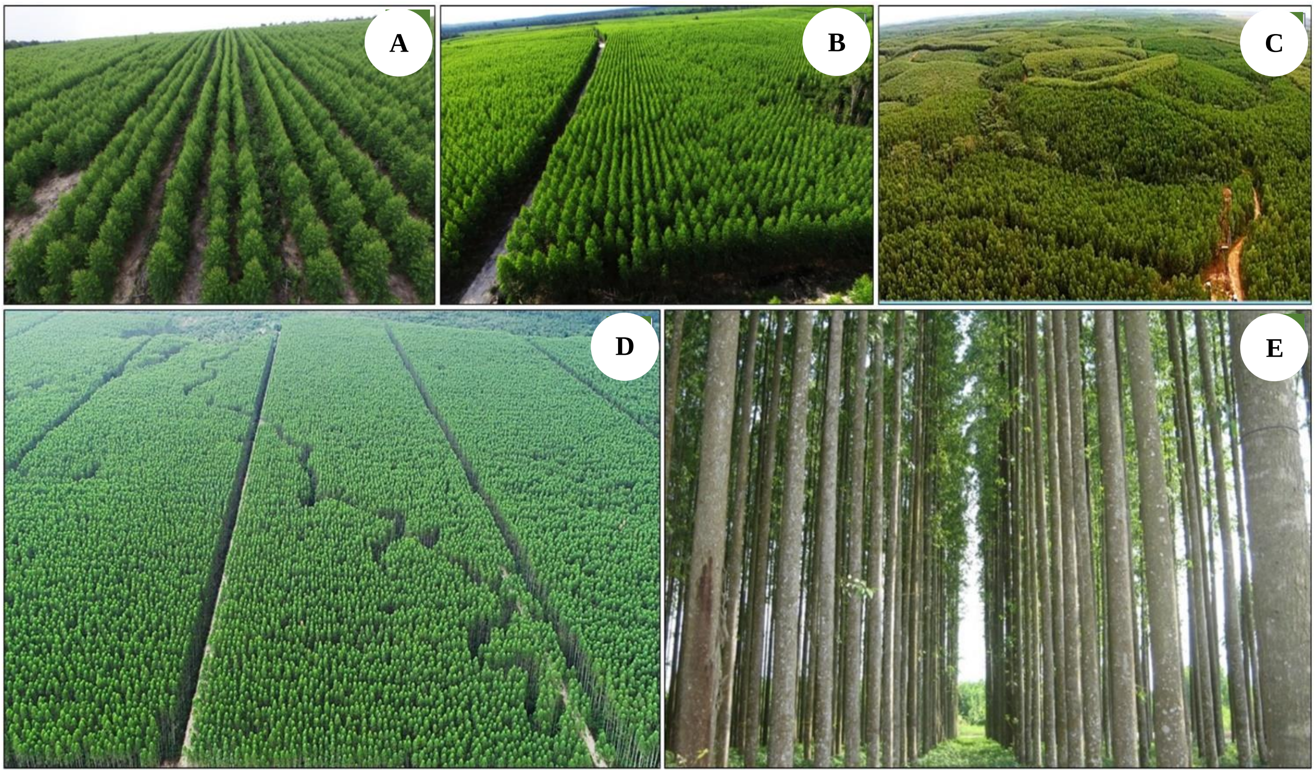

Figure 1. Photograph images of *Eucalyptus pellita*crop utilized in this study: 1st year (A), 2nd year (B), 3rd year (C), 4th year (D), and 5th year (E)

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 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).

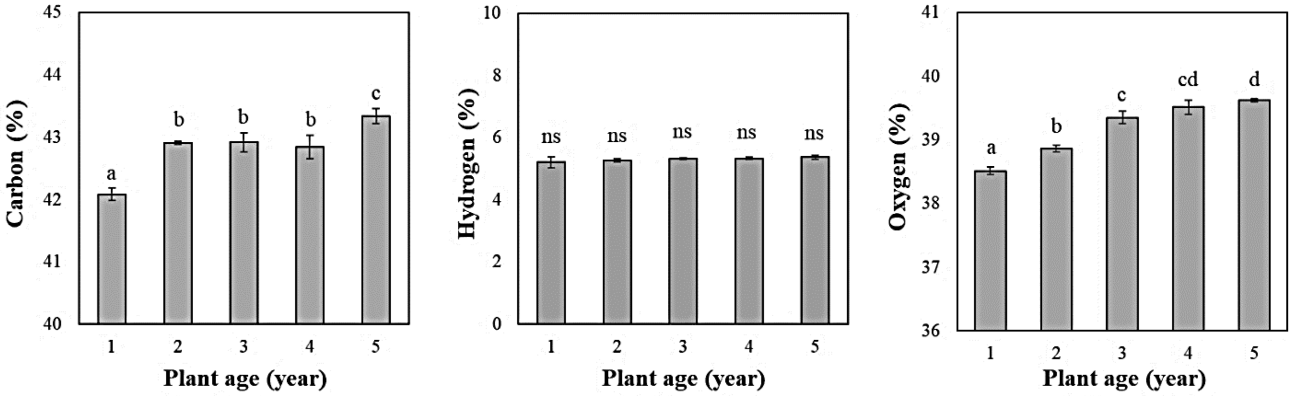

Figure 2. The ultimate composition of *Eucalyptus pellita* wood at different plant ages. Different letters showed a significant different value at $p < 0.05$; ns = not significant

Table 1. Biomass composition of *Eucalyptus 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

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

Table 2. HHV and electricity potency of *Eucalyptus 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

Note: 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.

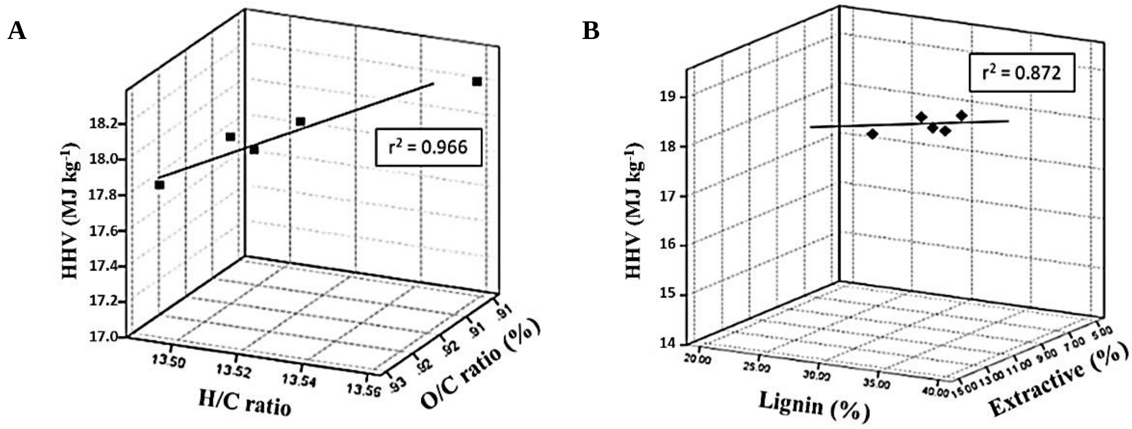

Figure 3. The strong influence of ultimate composition ratio (A) and lignin-extractive content (B) on the HHV of *Eucalyptus pellita* wood

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

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REFERENCES

Amirta R, Herawati E, Suwinarti W, Watanabe T. 2016a. Two-steps utilization of shorea wood waste biomass for the production of oyster mushroom and biogas–a zero waste approach. Agric Agric Sci Proc 9: 202-208. DOI: 10.1016/j.aaspro.2016.02.127.

Amirta R, Yuliansyah, Angi EM, Ananto BR, Setiyono B, Haqiqi MT, Septiana HA, Lodong M, Oktavianto RN, 2016b. Plant diversity and energy potency of community forestin East Kalimantan, Indonesia: Searching for fast growing wood species for energy production. Nusantara Biosci 8 (1): 22-31. DOI: 10.13057/nusbiosci/n080106.

Amirta R, Haqiqi MT, Saparwadi S, Septia E, Mujiasih D, Setiawan KA, Sekedang MA, Yuliansyah Y, Wijaya A, Setiyono B, Suwinarti W. 2019. Searching for potential wood biomass for green energy feedstock: A study in tropical swamp-peat forest of Kutai Kertanegara, Indonesia. Biodiversitas 20 (6): 1516-1523. DOI: 10.13057/biodiv/d200605.

Arisandi R, Ashitani T, Takahashi K, Marsoem SN, Lukmandaru G. 2020. Lipophilic extractives of the wood and bark from *Eucalyptus pellita* F. Muell grown in Merauke, Indonesia. J Wood Chem Technol 40 (2): 146-154. DOI: 10.1080/02773813.2019.1697295.

Ashokkumar V, Venkatkarthick R, Jayashree S, Chuetor S, Dharmaraj S, Kumar G, Chen WH, Ngamcharussrivichai C. 2022. Recent advances in lignocellulosic biomass for biofuels and value-added bioproducts-A critical review. Bioresour Technol 344: 126195. DOI: 10.1016/j.biortech.2021.126195.

Boumanchar I, Charafeddine K, Chhiti Y, Alaoui FEMH, Sahibed-Dine A, Bentiss F, Jama C, Bensitel M. 2019. Biomass higher heating value prediction from ultimate analysis using multiple regression and genetic programming. Biomass Convers Biorefin 9 (3): 499-509. DOI: 10.1007/s13399-019-00386-5.

Briones-Hidrovo A, Copa J, Tarelho LA, Gonçalves C, da Costa TP, Dias AC. 2021. Environmental and energy performance of residual forest biomass for electricity generation: Gasification vs. combustion. J Clean Prod 289: 125680. DOI: 10.1016/j.jclepro.2020.125680.

Chen D, Gao A, Cen K, Zhang J, Cao X, Ma Z. 2018. Investigation of biomass torrefaction based on three major components: Hemicellulose, cellulose, and lignin. Energy Convers Manag 169: 228-237. DOI: 10.1016/j.enconman.2018.05.063.

Cui H, Ninomiya Y, Masui M, Mizukoshi H, Sakano T, Kanaoka C. 2006. Fundamental behaviors in combustion of raw sewage sludge. Energy Fuels 20 (1): 77-83. DOI: 10.1021/ef050188d.

Demirbaş A. 2001. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers Manag 42 (11): 1357-1378. DOI: 10.1016/S0196-8904(00)00137-0.

Demirbaş A. 2008. Importance of biomass energy sources for Turkey. Energy Policy 36 (2): 834-842. DOI: 10.1016/j.enpol.2007.11.005.

Fiskari J, Kilpeläinen P. 2021. Acid sulfite pulping of *Acacia mangium* and *Eucalyptus pellita* as a pretreatment method for multiproduct biorefineries. Asia-Pac J Chem Eng 16 (6): 2707. DOI: 10.1002/apj.2707.

Ghugare SB, Tiwary S, Elangovan V, Tambe SS. 2014. Prediction of higher heating value of solid biomass fuels using artificial intelligence formalisms. Bioenergy Res 7 (2): 681-692. DOI: 10.1007/s12155-013-9393-5.

Hardiyanto EB, Inail MA, Nambiar EK. 2021. Productivity of *Eucalyptus pellita* in Sumatra: *Acacia mangium* legacy, response to phosphorus, and site variables for guiding management. Forests 12 (9): 1186. DOI: 10.3390/f12091186.

Haqiqi MT, Suwinarti W, Amirta R. 2018. Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species. IOP Conf Ser: Earth Environ Sci 144 (1): 012041. DOI: 10.1088/1755-1315/144/1/012041.

Islas J, Manzini F, Masera O, Vargas V. 2019. Solid Biomass to Heat and Power. The Role of Bioenergy in The Bioeconomy. Academic Press. DOI: 10.1016/B978-0-12-813056-8.00004-2.

Jang SK, Choi JH, Kim JH, Kim H, Jeong H, Choi IG. 2020. Statistical analysis of glucose production from *Eucalyptus pellita* with individual control of chemical constituents. Renew Energ 148: 298-308. DOI: 10.1016/j.renene.2019.11.058.

Konuk F, Zeren F, Akpınar S, Yıldız Ş. 2021. Biomass energy consumption and economic growth: Further evidence from NEXT-11 countries. Energy Rep 7: 4825-4832. DOI: 10.1016/j.egyr.2021.07.070.

Lee BH, Sh L, Lee DG, Jeon CH. 2021. Effect of torrefaction and ashless process on combustion and NOx emission behaviors of woody and herbaceous biomass. Biomass Bioenerg 151: 106133. DOI: 10.1016/j.biombioe.2021.106133.

Leksono B, Kurinobu S, Ide Y. 2008. Realized genetic gains observed in second-generation seedling seed orchards of *Eucalyptus pellita* in Indonesia. J For Res 13 (2): 110-116. DOI: 10.1007/s10310-008-0061-0.

Ma Z, Yang Y, Wu Y, Xu J, Peng H, Liu X, Zhang W, Wang S. 2019. In-depth comparison of the physicochemical characteristics of bio-char derived from biomass pseudo components: Hemicellulose, cellulose, and lignin. J Anal Appl Pyrolysis 140: 195-204. DOI: 10.1016/j.jaap.2019.03.015.

McKendry P. 2002. Energy production from biomass: overview of biomass. Bioresour Technol 83: 55-63. DOI: 10.1016/S0960-8524(01)00118-3.

Menucelli JR, Amorim EP, Freitas MLM, Zanata M, Cambuim J, de Moraes MLT, Yamaji FM, da Silva Júnior FG, Longui EL. 2019. Potential of *Hevea brasiliensis* clones, *Eucalyptus pellita*, and *Eucalyptus tereticornis* wood as raw materials for bioenergy based on higher heating value. Bioenergy Res 12 (4): 992-999. DOI: 10.1007/s12155-019-10041-6.

Mukhdlor A, Haqiqi MT, Tirkamiana MT, Suwinarti W, Amirta R. 2021. Assessment of wood biomass productivity from *Anthocephalus macrophyllus* forest plantation for energy production. Adv Biol Sci Res 11: 21-25. DOI: 10.2991/absr.k.210408.005.

Nhuchhen DR, Afzal MT. 2017. HHV predicting correlations for torrefied biomass using proximate and ultimate analyses. Bioengineering 4 (1): 7. DOI: 10.3390/bioengineering4010007.

Nimmanterdwong P, Chalermsinsuwan B, Piumsomboon P. 2021. Prediction of lignocellulosic biomass structural components from ultimate/proximate analysis. Energy 222: 119945. DOI: 10.1016/j.energy.2021.119945.

Nussbaumer T. 2003. Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. Energy Fuels 17 (6): 1510-1521. DOI: 10.1021/ef030031q.

Ozyuguran A, Akturk A, Yaman S. 2018. Optimal use of condensed parameters of ultimate analysis to predict the calorific value of biomass. Fuel 214: 640-646. DOI: 10.1016/j.fuel.2017.10.082.

Poddar S, Kamruzzaman M, Sujan SMA, Hossain M, Jamal MS, Gafur MA, Khanam M. 2014. Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. Fuel 131: 43-48. DOI: 10.1016/j.fuel.2014.04.061.

Salehi B, Sharifi-Rad J, Quispe C, Llaique H, Villalobos M, Smeriglio A, Trombetta D, Ezzat EM, Martins N. 2019. Insights into *Eucalyptus* genus chemical constituents, biological activities, and health-promoting effects. Trends Food Sci Technol 91: 609-624. DOI: 10.1016/j.tifs.2019.08.003.

Sansaniwal SK, Pal K, Rosen MA, Tyagi SK. 2017. Recent advances in the development of biomass gasification technology: A comprehensive review. Renew Sust Energ Rev 72: 363-384. DOI: 10.1016/j.rser.2017.01.038.

Sheng C, Azevedo, JLT. 2005. Estimating the higher heating value of biomass fuels from basic analysis data. Biomass Bioenerg 28 (5): 499-507. DOI: 10.1016/j.biombioe.2004.11.008.

Telmo C, Lousada J, Moreira N. 2010. Proximate analysis, backwards stepwise regression between gross calorific value, ultimate and chemical analysis of wood. Bioresour Technol 101 (11): 3808-3815. DOI: 10.1016/j.biortech.2010.01.021.

Wise LE, Murphy M, D'Addieco AA. 1946. Chlorite holocellulose, its fractionation, and bearing on summative wood analysis and on studies on the hemicelluloses. Paper Trade J 122 (2): 35-43.

Xing J, Luo K, Wang H, Fan J. 2019. Estimating biomass major chemical constituents from ultimate analysis using a random forest model. Bioresour Technol 288: 121541. DOI: 10.1016/j.biortech.2019.121541.

Xue S, Lewandowski I, Wang X, Yi Z. 2016. Assessment of the production potentials of Miscanthus on marginal land in China. Renew Sustain Energy Rev 54: 932-943. DOI: 10.1016/j.rser.2015.10.040.

Yuliansyah, Haqiqi MT, Septia E, Mujiasih D, Septiana HA, Setiawan KA, Setiyono B, Angi EM, Sari NM, Kusuma IW, Suwinarti W, Amirta R. 2019. Diversity of plant species growing during fallow period of shifting cultivation and potential of its biomass for sustainable energy production in Mahakam Ulu, East Kalimantan, Indonesia. Biodiversitas 20 (8): 2236-2242. DOI: 10.13057/biodiv/d200818.

Zafar MW, Sinha A, Ahmed Z, Qin Q, Zaidi SAH. 2021. Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation countries. Renew Sust Energ Rev 142: 110868. DOI: 10.1016/j.rser.2021.110868.