Vol. 11, No. 4 (2022) : 713 - 723
DOI : http://dx.doi.org/10.23960/jtep-l.v11i4.713-723

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Production and Characterization of Andong Bamboo (*Gigantochloa pseudoarundinacea* (Steudel) Widjaja) Pellets from Various Stem Parts

Wahyu Hidayat[1], Jacky Michael Pah[2], Lisman Suryanegara[3], Udin Hasanudin[4], Agus Haryanto[5], Christine Wulandari[1,2]✉

[1]Forestry Department, Faculty of Agriculture, University of Lampung, Bandar Lampung, INDONESIA
[2]Magister Program on Forestry Sciences, Faculty of Agriculture, University of Lampung, Bandar Lampung, INDONESIA
[3]Pusat Riset Biomassa dan Bioproduk, Badan Riset dan Inovasi Nasional, Bogor, INDONESIA
[4]Department of Agro-Industrial Technology, Faculty of Agriculture, University of Lampung, Bandar Lampung, INDONESIA
[5]Department of Agricultural Engineering, Faculty of Agriculture, University of Lampung, Bandar Lampung, INDONESIA

Article History :

Received : 17 August 2022
Received in revised form : 14 September 2022
Accepted : 27 December 2022

Keywords :

Andong (Gigantochloa pseudoarundinacea),
Biopellet,
Mechanical Properties,
Physical Properties

✉Corresponding Author:
chs.wulandari@gmail.com

ABSTRACT

Bamboo is an abundant biomaterial having important potential as a resource for bioenergy development. In this study, the potential of andong (Gigantochloa pseudoarundinacea (Steudel) Widjaja) bamboo for pellet production was evaluated. Some properties of bamboo pellets as density, moisture content, moisture adsorption, compressive strength, and heating value were analysed. The results indicated that bamboo is highly prospective to be explored for fuel pellets commercially. All characteristics of pellet made of bamboo fulfilled the requisites of the commercial pellets. The heating value of the pellets achieved the minimum standard for commercial pellets along with SNI 8675:2018 (>17,5 MJ/kg). The effects of culm parts on the moisture content, density, moisture adsorption were not significant. There were significant differences in compressive strength and heating value between bamboo pellets produced from different culm parts. This research showed potential of andong bamboo pellet for bioenergy resource.

1. INTRODUCTION

In 2025, Indonesia is targeting an energy mix from renewable energy sources (biofuel, biomass, biogas and coalbed methane) of 23% and this figure will increase in 2050 to 31% (Priyanto & Abdulah, 2014). Energy sources from biomass are expected to contribute 8.4 million tonnes in 2025 and 22.7 million tonnes in 2050 (Hilmawan *et al.*, 2021). Biomass energy is an alternative energy source with great potential to be explored as a renewable energy source in Indonesia because of its abundant availability and can be obtained in a relatively short time compared to fossil fuels. As an energy source, biomass has disadvantages because it is hygroscopic so it has a high water content, is heterogeneous, has a low energy density, and has a high oxygen content (Haryanto *et al.*, 2021a; Nhuchhen *et al.*, 2014). Biomass with varying sizes and shapes results in problems in storage and handling, and become highly expensive for long distance transportation (Rubiyanti *et al.*, 2019; Sulistio *et al.*, 2020). Bamboo is a biomass that has great potential as an alternative energy source (Aisman, 2016).

Indonesia, with an area of approximately 2,000,000 ha of bamboo forests, is the third largest country in Asia (Lobovikov *et al*., 2007). Andong bamboo (*Gigantochloa pseudoarundinacea* (Steudel) Widjaja) is one of Indonesia's specialty bamboos with many different utilization from crafts, household utensils, to housing materials (Febrianto *et al*., 2017). Bamboo is a lignocellulosic material, the chemical composition of bamboo comprising of lignocellusoses (lignin, cellulose, and hemicellulose), which can be utilized as a substitute of wood for numerous purposes (Hariz *et al*., 2021; Hidayat *et al*., 2019). Bamboo grows quicker than wood in general, and therefore it has a short harvesting cycle and can be definitely cultivated in practically every type of soil (Maulana *et al*., 2021). Bamboo has the prospective to be developed as a source of feedstock for pellet production in Indonesia.

Biomass is bulky that requires to be densified into pellet form with more practical uses. Densification is a method to convert biomass into pellet with the objective of improving density and easing storage, handling, and transportation due to its uniform size and properties. One of the products of biomass densification is pellets. Biomass pellets is generally cylindrical in shape and is used as solid fuel (Syamsiro, 2016). According to Lehtikangas (2001), densification will reduce costs for transportation and ease storage and handling.

Mass density is one of important quality aspects of solid fuel, because high density can improve heating value of the solid fuel (Hidayat *et al*., 2021). Pellet fuel is an alternative energy sources that can be developed to support renewable energy share. These pellets is used as fuel for different scales from domestic fuel to generating electrical power in industries. Pellets as a source of biomass energy offer some advantages as compared to other form of biomass energy sources, such as biomass briquettes and wood chips, especially in terms of density and shape homogeneity (Arranz *et al*., 2015). This greater density causes lower transportation costs and produce greater efficiency in terms of energy transformation (Syamsiro *et al*., 2016), while reducing the water content increases the length of storage capacity.

Studies on biomass pellets have been carried out by many previous studies (Haryanto *et al*., 2021b; Haryanto *et al*., 2021c; Hidayat *et al*., 2020; Hidayat *et al*., 2021; Iryani *et al*., 2019). However, scientific studies on pellets from bamboo biomass are still limited (Pah *et al*., 2021; Saputra *et al*., 2022). In addition, research on the production and characterization of andong bamboo pellets from the parts of the stem, namely the base, middle and tip of the bamboo has not been carried out before. So this research is important to do to add new scientific information.

2. MATERIALS AND METHOD

2.1. Material Preparation

Andong bamboo (*Gigantochloa pseudoarundinacea*) aged 3 to 4 years was gathered from Ciawi (106°49'49.6" East Long.; 6°40'49.3" South Lat.), Regency of Bogor, West Java. A total of 50 poles of Andong bamboo were cut at the fourth node (from the soil surface) with length of 9 m in average. The bamboo sticks were dried naturally under sun rays for one week. The bamboo was then cut into 3 parts (base, middle, and top) by using a circular saw. Each part had a length of 3 m and then splited more into small blades. The inner and outer skin was removed using a planer machine. Bamboo slats were then put into a flaker machine to produce particles or powder like sawdust. The powder was then dried naturally until a moisture content of ±12% (Figure 1).

Figure 1. Stages of making bamboo pellets andong: 1) Site survey in the community forest, 2) Drying of bamboo sticks, 3) Distribution of bamboo sticks, 4) Removal of outer skin and inner skin of bamboo, 5) Cutting of bamboo into flakes, 6) Production of powder bamboo, 7) Drying bamboo powder, 8) Making bamboo pellets using a pelletizer machine, and 9) Cooling bamboo pellets

2.2. Production of Bamboo Pellets

The manufacture of bamboo pellets is carried out at the Integrated Laboratory of the Indonesian Institute of Knowledge (LIPI) Biomaterials Research Center, Cibinong, Bogor using a Pellet Mill Model HM560A (Shandong HM Better Pellet Mill Machinery, China) with a processing capacity of 1 ton/hour (Figure 1). Andong bamboo powder that has been dried is put into the feeder. The material then feeds into the ring die. At this stage, the raw material is pressed through holes with a diameter of 8 mm.

The high pressure during the process causes the raw material temperature to increase which is followed by the plasticization reaction (softening) of the lignin. This lignin softening process allows the lignin to form a natural adhesive that is able to bind raw materials into pellet formations that are intact and sturdy when cold at the end of the printing process (Amirta, 2018).

The Andong bamboo pellets that come out of the pellet machine still have a high temperature, are soft, and emit moisture, so the pellets need to be cooled. Cooling was carried out at room temperature (± 25°C) by laying the pellets on a tarpaulin for about 2 hours while turning it over every 30 minutes (Figure 1). The bamboo andong pellets that have been cooled are then put into plastic and tied so that they do not absorb moisture or moisture from the environment.

2.3. Pellet Testing

Tests carried out on andong bamboo pellets included geometry, density, equilibrium moisture content, color, adsorption, functional group characteristics, calorific value, and pellet hardness.

a.Pellet Geometry

The pellet geometry test was carried out by randomly taking 100 bamboo carriage pellets from each section (base, middle, and tip) and measuring their length and diameter.

b.Density

Pellet density testing was performed by measuring the weight, length, and diameter of the pellets in air-dry and oven-dry conditions. The test was carried out using ten repetitions.

c.Water Content

Pellet moisture content testing was carried out by weighing the pellets in air-dry and oven-dry conditions. The test was carried out using five repetitions.

d.Color

Pellet color testing was carried out with five replicates using the AMT507 Colorimeter (Amtast, China) based on the CIE-Lab color system (Hidayat *et al*., 2017). The color parameters measured include brightness (L^*), red-green chrome (a^*), and yellow-blue chrome (b^*). The difference in color (DE^*) between raw materials and pellets is calculated based on the differences in L^*, a^*, and b^* with the following formula:

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \qquad (1)$$

e.Pellet Adsorption

The pellet adsorption capacity was tested by placing the pellet sample in the oven at 100±2 °C for 24 hours, then weighing it. The sample weight was then weighed every day for 30 days.

f.Functional Group Characterization Analysis

Characterization of functional groups was carried out using a Fourier-Transform Infrared (FTIR) spectrometer (Scimitar 2000 FT-IR, Varian Inc., USA). A sample of 2 g of bamboo pellets andong (oven dry) together with KBr solids is crushed in a small mortar, then pressed in a ring-shaped mold evenly. The sample is then put into the FTIR spectrometer for later analysis.

g.Calorific Value

The calorific value test was carried out using 5 g of oven-dried pellet samples which had been powdered. Tests were carried out using a bomb calorimeter (PARR 1341 Calorimeter, Parr Instrument, USA) based on SNI 8675:2018 (BSN, 2018). Pellet strength testing was performed using a Universal Testing Machine (UTM) Brand Testometric Model DBMTCL-5000 kg (Testometric Co. Ltd., UK). The test was carried out parallel to the long direction of the pellet with a loading speed of 1 N/mm.

h.Data analysis

Data were analyzed using descriptive statistics to provide a general description of the characteristics of each research variable as seen from the average, maximum, and minimum values.

3. RESULTS AND DISCUSSION

3.1. Pellet Geometry

The length of the andong bamboo pellets from the three parts of the bamboo culms ranged from 13.21 – 69.56 mm, while the diameter of the pellets ranged from 8.11 – 8.75 mm (Table 1). The geometrical dimensions of the pellets, both diameter and length, are important factors with respect to firing. Experiments show that thinner pellets allow a more uniform firing rate than thicker ones, especially in small furnaces (Lehtikangas, 2001).

Table 1. Geometry of the bamboo pellets andong from various parts of the stem

Stem part	Description	Parameter (mm)	
		Diameter	Length
Base	Average	8.24	34.62
	Standard Deviation (SD)	0.05	8.35
	Minimum	8.15	17.96
	Maximum	8.42	59.01
Middle	Average	8.26	33.18
	Standard Deviation (SD)	0.06	8.98
	Minimum	8.11	14.87
	Maximum	8.45	51.12
Top	Average	8.30	33.45
	Standard Deviation (SD)	0.08	10.41
	Minimum	8.17	13.21
	Maximum	8.75	69.56

Note: the data presented is the average of measurements made of 100 pellets for each part of the bamboo stem SD = standard deviation, Min. = smallest measurement value, and Max. = largest measurement value.

3.2. Pellet Color

The visual appearance of the pellets produced is presented in Figure 2. The horse cart pellets produced have a brownish yellow color. The results of color measurements show the difference in color (ΔE^*) between the raw materials and the pellets produced (Table 2). The color differences that occur are included in the very large change category ($6 < \Delta E^* \leq 12$) (Hidayat & Febrianto, 2018; Valverde & Moya, 2014). The change in the color of the bamboo andong after being made into pellets occurs due to an increase in the temperature of the raw material at the pellet pressing stage.

Table 2 shows that the wood color parameters (L^*, a^*, and b^*) of andong bamboo pellets from the base, middle, and ends show uniform values. The value of ΔE^* between raw materials and pellets from the three sections of the stem also shows a uniform value.

Figure 2. Pellets of bamboo carriage from various parts of the stem: 1) Base, 2) Middle, and 3) End

Table 2. Parameters of the color of raw materials and bamboo pellets Andong

Stem Part	Treatment	*L**	*a**	*b**	*ΔE**
Base	Raw material	72.7 ± 1.8	7.0 ± 0.8	24.4 ± 1.4	-
	Pellet	66.5 ± 1.8	6.2 ± 1.1	22.7 ± 1.2	6.5 ± 0.7
Middle	Raw material	73.4 ± 1.1	6.4 ± 0.3	23.9 ± 1.0	-
	Pellet	66.6 ± 2.2	6.2 ± 1.1	21.4 ± 1.1	7.6 ± 0.7
Top	Raw material	73.4 ± 1.1	6.1 ± 0.6	22.6 ± 2.3	-
	Pellet	65.4 ± 0.4	5.6 ± 0.5	21.1 (1.1)	8.3 ± 1.1

Note: Value is the average of 5 measurements.

3.3. Pellet Density

The density of horse-drawn wood pellets in air-dry and oven-dry conditions is presented in Table 3. The higher the pellet density the better the quality of the pellets produced and also makes it easier to handle, store and transport, thereby reducing costs (Tumuluru, 2014).

Based on the research results, the air dry density of Andong bamboo pellets between the base, middle and ends ranged from 1.27 – 1.28 g/cm^3 while the oven dry density ranged from 1.25 – 1.26 g/cm^3. When compared with the SNI 8675: 2018 standard concerning biomass pellets for bioenergy, the density of the Andong bamboo pellets in this study was far greater than the standard, namely at least 0.8 g/cm^3.

Table 3. Density and pellets of Andong bamboo from various parts of the stem

Stem Part	Density (g/cm^3)	
	Air Dry	Oven Dry
Base	1.27 ± 0.03	1.25 ± 0.03
Middle	1.28 ± 0.02	1.26 ± 0.03
Top	1.28 ± 0.04	1.25 ± 0.05

3.4. Water Vapor Adsorption

The adsorption of andong bamboo pellets was observed for 30 days and the data is presented in Figure 3. The results showed that for each part of the stem, the weight gain of the pellets on the first day was the highest.

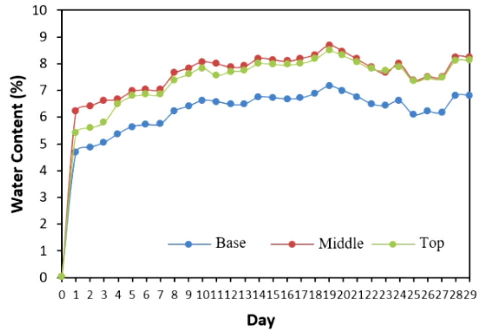

Figure 3. Adsorption of water vapor by carriage pellets from various parts of the stem

The water content of the wood pellets on the 30th day ranged from 6.25 to 7.04%. This water content value does not exceed the quality standard required by SNI 8675:2018 concerning biomass pellets for bioenergy, namely a maximum of 12%. Moisture content of biomass pellets is one of the parameters that affect the heating value, combustion efficiency, combustion temperature, and moisture balance related to the storage conditions of biomass pellets. Tumuluru *et al.* (2010) stated that pellets with low moisture content will tend to crack, but are less susceptible to drying and condensation of moisture that evaporates during storage and shipping.

3.5. Functional Group Characteristics

The results of the analysis of functional group characteristics using FTIR are presented in Figure 5. This test was carried out to determine the quality of a biomass that has undergone structural changes due to heat treatment (Rani *et al*., 2020).

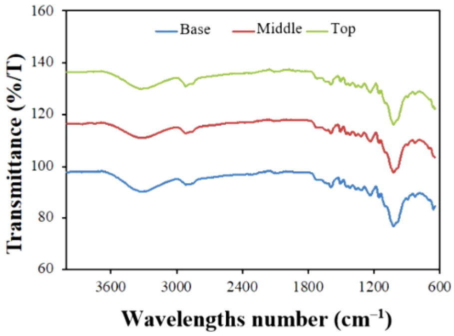

Figure 5. FTIR spectra of Andong bamboo pellets from various parts of the stem

The depressions and waves show that the elemental bonds in the sample tested have changed functional groups. The results showed that there was a change in the functional groups of the andong bamboo pellets in several ranges of wave numbers.

3.6. Calorific Value

Calorific value is one of the main factors in choosing solid fuels such as biomass pellets and is the main parameter in determining the quality of biopellets because it can determine the amount of energy from biopellets. The calorific value also determines the quantitative energy content of a type of fuel and is the result of the interaction of the chemical components making up the biomass which is influenced by several factors, namely moisture content, volatile matter content, ash content and bound carbon content (Basu, 2013). The calorific value of Andong bamboo pellets ranges from

17.56-18.59 MJ/kg. The results of this study did not show a tendency to increase or decrease in calorific value based on the bamboo section. Overall, this calorific value complies with the quality standards required by SNI 8675:2018 concerning biomass pellets for bioenergy, namely a minimum of 16.5 MJ/kg. The calorific value of andong bamboo pellets is presented in Figure 6.

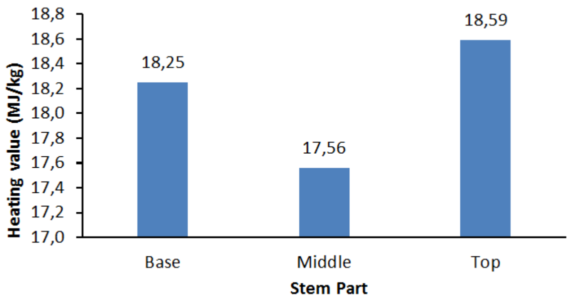

Figure 6. Calorific value of Andong bamboo pellets from various parts of the stem

3.7. Mechanical Properties

The compressive strength of the biopellets is the ability of the biopellets to provide durability or cohesiveness of the biopellets against breaking or crushing of the biopellets when a load is placed on the biopellets. Compressive strength test to simulate pressure on the pellets due to the weight of the pellets during the storage period. The greater the compressive strength value, the better the durability or compactness of the biopellets.

The value of compressive strength is strongly influenced by the type of material, particle size, particle density, compression pressure, and product density. The higher the density value of a product, the higher the resulting compressive strength value. The results showed that the compressive strength of bamboo pellets based on the stem section was relatively uniform with values ranging from 19.18 to 20.58 N/mm^2 (Figure 7). The relatively uniform compressive strength values correspond to the uniform pellet density values (Table 3).

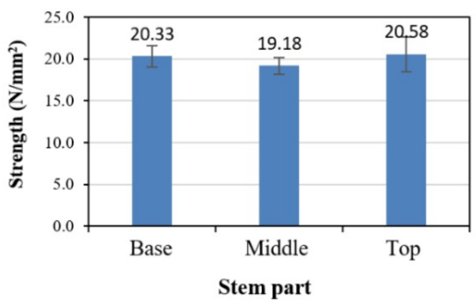

Figure 7. Strength of Andong bamboo pellets from various parts of the stem.

4. CONCLUSION

Andong bamboo pellets from various parts of the stems showed relatively uniform results, especially on the parameters of density, calorific value, and compressive strength. So that the production of andong bamboo pellets from the middle and tip of the stem has the potential to produce pellets with characteristics comparable to pellets from the base of the stem.

ACKNOWLEDGEMENT

The author would like to thank the University of Lampung for research funding through the Masters Research Grant Contract Number: 044/SP2H/LT/DRPM/2020.

REFERENCES

Aisman, A. (2016). Study of the Potential Development of Biomass Based Electricity Bamboo. *Jurnal Agroindustri*, ***6***(2), 65–72. https://doi.org/10.31186/j.agroind.6.2.65-72

Amirta, R. (2018). *Pellet Kayu Energi Hijau Masa Depan*. Mulawarman University Press. Samarinda.

Arranz, J.I., Miranda, M.T., Montero, I., Sepúlveda, F. J., & Rojas, C.V. (2015). Characterization and combustion behaviour of commercial and experimental wood pellets in South West Europe. *Fuel*, ***142***, 199–207. https://doi.org/10.1016/j.fuel.2014.10.059

Basu, P. (2013). *Biomass gasification, pyrolysis, and torrefaction: Practical design and theory* (Second edition). Academic Press.

Febrianto, F., Sumardi, I., Hidayat, W., & Maulana, S. (2017). *Papan Untai Bambu Berarah: Material Unggul untuk Komponen Bahan Bangunan Struktur*. IPB Press, Bogor, Indonesia.

Hariz, T.M.R., Santosa, I.A., Maulana, M.I., Prasetia, D., Hidayat, W., Lubis, M.A.R., Kim, N.H., & Febrianto, F. (2021). Effects of resin content on the characteristics of bamboo oriented strand board prepared from strands of betung, ampel, and their mixtures. *Jurnal Sylva Lestari*, ***9***(3), 454–465. DOI: 10.23960/jsl.v9i3.520

Haryanto, A., Hidayat, W., Hasanudin, U., Iryani, D.A., Kim, S., Lee, S., & Yoo, J. (2021a). Valorization of Indonesian wood wastes through pyrolysis: A review. *Energies,* 14 (5), 1407. DOI: 10.3390/en14051407

Haryanto, A., Iryani, D.A., Hasanudin, U., Telaumbanua, M., Triyono, S., & Hidayat, W. (2021a). Biomass fuel from oil palm empty fruit bunch pellet: Potential and challenges. *Procedia Environmental Science, Engineering and Management*, ***8***(1), 33–42.

Haryanto, A., Nita, R., Telaumbanua, M., Suharyatun, S., Hasanudin, U., Hidayat, W., Iryani, D.A., Triyono, S., Amrul, & Wisnu, F. K. (2021c). Torréfaction to improve biomass pellet made of oil palm empty fruit bunch. *IOP Conference Series: Earth and Environmental Science*, ***749***, 012047. DOI: 10.1088/1755-1315/749/1/012047

Hidayat, W., & Febrianto, F. 2018. *Teknologi Modifikasi Kayu Ramah Lingkungan: Modifikasi Panas dan Pengaruhnya Terhadap Sifat-Sifat Kayu.* Pusaka Media, Bandar Lampung, Indonesia.

Hidayat, W., Qi, Y., Jang, J.H., Park, B.H., Banuwa, I.S., Febrianto, F., & Kim, N.H. (2017). Color change and consumer preferences towards color of heat-treated Korean white pine and royal paulownia woods. *Journal of the Korean Wood Science and Technology*, ***45***(2), 213–222. DOI: 10.5658/wood.2017.45.2.213

Hidayat, W., Febrianto, F., Purusatama, B.D., & Kim, N.H. (2018). Effects of heat treatment on the color change and dimensional stability of *Gmelina arborea* and *Melia azedarach* woods. *E3S Web of Conferences,* 03010. DOI: 10.1051/e3sconf/20186803010

Hidayat, W., Suri, I.F., Safe'i, R., Wulandari, C., Satyajaya, W., Febryano, I.G., & Febrianto, F. 2019. Keawetan dan stabilitas dimensi papan partikel hibrida bambu-kayu dengan perlakuan steam dan perendaman panas. *Jurnal Ilmu dan Teknologi Kayu Tropis*, ***17***(1), 68–82. DOI: 10.51850/jitkt.v17i1.462

Hidayat, W., Rani, I.T., Yulianto, T., Febryano, I.G., Iryani, D.A., Hasanudin, U., Lee, S., Kim, S., Yoo, J., & Haryanto, A. (2020). Peningkatan kualitas pelet tandan kosong kelapa sawit melalui torefaksi menggunakan reaktor counter-flow multi baffle (COMB). *Jurnal Rekayasa Proses*, ***14***(2), 169–181. DOI: 10.22146/jrekpros.56817

Hidayat, W., Rubiyanti, T., Sulistio, Y., Iryani, D. A., Haryanto, A., Amrul, Yoo, J., Kim, S., Lee, S., & Hasanudin, U. (2021). Effects of torrefaction using comb dryer/pyrolizer on the properties of rubberwood (*Hevea brasiliensis*) and jabon (*Anthocephalus cadamba*) pellets. *Proceedings of the International Conference on Sustainable Biomass (ICSB 2019), Bandar Lampung, Indonesia,* 209–213. DOI: 10.2991/ aer.k.210603.037

Hilmawan, E., Fitriana, I., Sugiyono, A., & Adiarso, A. (2021). *BPPT - Outlook Energi Indonesia 2021.* Tangerang: Pusat Pengkajian Industri Proses dan Energi.

Iryani, D.A., Haryanto, A., Hidayat, W., Amrul, Talambanua, M., Hasanudin, U., and Lee, S. (2019). Torrefaction upgrading of palm oil empty fruit bunches biomass pellets for gasification feedstock by using COMB (Counter Flow Multi-Baffle) reactor. *7th Trend in Agricultural Engineering (TAE) 2019,* 212–217.

Lehtikangas, P. (2001). Quality properties of pelletised sawdust, logging residues and bark. *Biomass and Bioenergy*, ***20***(5), 351–360. https://doi.org/10.1016/S0961-9534(00)00092-1

Lobovikov, M., Ball, L., Guardia, M., & Russo, L. (Eds.). (2007). *World bamboo resources: A thematic study prepared in the framework of the Global Forest Resouces Assessment 2005*. Food and Agriculture Organization of the United Nations.

Maulana, M.I., Jeon, W.S., Purusatama, B.D., Nawawi, D.S., Nikmatin, S., Sari, R.K., Hidayat, W., Febrianto, F., Kim, J.H., Lee, S.H., & Kim, N.H. (2021). Variation of anatomical characteristics within the culm of the three gigantochloa species from Indonesia. *BioResources*, ***16***(2), 3596–3606. DOI: 10.15376/biores.16.2.3596-3606

Nhuchhen, D., Basu, P., & Acharya, B. (2014). A comprehensive review on biomass torrefaction. *International Journal of Renewable Energy & Biofuels*, ***2014***, 506376 (56 pp). https://doi.org/10.5171/2014.506376

Pah, J.M., Suryanegara, L., Haryanto, A., Hasanudin, U., Iryani, D. A., Wulandari, C., Yoo, J., Kim, S., Lee, S., & Hidayat, W. 2021. Product characteristics from the torrefaction of bamboo pellets in oxidative atmosphere. *Proceedings of the International Conference on Sustainable Biomass* (*ICSB 2019*), 185–189. DOI: 10.2991/aer.k.210603.032

Priyanto, P., & Abdulah, L. (2014). *PD-600-11-R1-I-Technical Report-Act-2.1.* Downloaded from: http://www.itto.int/files/itto_project_db_input/2981/ Technical/PD-600-11-R1-I-Technical%20Report-Act-2.1.pdf

Rani, I.T., Hidayat, W., Febryano, I.G., Iryani, D. A., Haryanto, A., & Hasanudin, U. (2020). Pengaruh torefaksi terhadap sifat kimia pelet tandan kosong kelapa sawit. *Jurnal Teknik Pertanian Lampung*, ***9***(1), 63–70. DOI: 10.23960/jtep-l.v9i1.63-70

Rubiyanti, T., Hidayat, W., Febryano, I.G., & Bakri, S. (2019). Karakterisasi pelet kayu karet (*Hevea brasiliensis*) hasil torefaksi dengan menggunakan reaktor counter-flow multi baffle (COMB). *Jurnal Sylva Lestari*, ***7***(3), 321–331. DOI: 10.23960/ jsl37321-331

Saputra, B., Tambunan, K.G.A., Suri, I.F., Febryano, I.G., Iswandaru, D., & Hidayat, W. (2022). Effects of torrefaction temperature on the characteristics of betung (*Dendrocalamus asper*) bamboo pellets. *Jurnal Teknik Pertanian Lampung*, ***11***(2), 339–353. DOI: 10.23960/jtep-l.v11i2.339-353

Sulistio, Y., Febryano, I.G., Yoo, J., Kim, S., Lee, S., Hasanudin, U., & Hidayat, W. (2020). Pengaruh torefaksi dengan reaktor Counter-Flow Multi Baffle (COMB) dan electric furnace terhadap pelet kayu jabon (*Anthocephalus cadamba*). *Jurnal Sylva Lestari*, ***8***(1), 65–76. DOI: 10.23960/jsl1865-76

Syamsiro, M. (2016). Peningkatan kualitas bahan bakar padat biomassa dengan proses densifikasi dan torrefaksi. *Jurnal Mekanika dan Sistem Termal,* ***1***(1), 7-13.

Tumuluru, J.S. (2014). Effect of process variables on the density and durability of the pellets made from high moisture corn stover. *Biosystems Engineering,* ***119***, 44-57. DOI: 10.1016/j.biosystemseng.2013.11.012

Tumuluru, J.S., Sokhansanj, S., Lim, C.J., Bi, T., Lau, A., Melin, S., & Oveisi, E. (2010). Quality of wood pellets produced in British Columbia for export. *Applied Engineering in Agriculture*, ***26***(6), 1013–1020.

Valverde, J.C., & Moya, R. (2014). Correlation and modeling between color variation and quality of the surface between accelerated and natural tropical weathering in Acacia mangium, Cedrela odorata and Tectona grandis wood with two coating. *Color Research and Application*, ***39***(5), 519-529.