CHARACTERIZATION OF BETUNG (*Dendrocalamus asper*) BAMBOO PELLETS TORREFIED AT VARIOUS TEMPERATURES

(Undergraduate Thesis)

By

BAGUS SAPUTRA
NPM 1814151022

FACULTY OF AGRICULTURE
UNIVERSITY OF LAMPUNG
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BAGUS SAPUTRA

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ABSTRACT

CHARACTERIZATION OF BETUNG (*Dendrocalamus asper*) BAMBOO PELLETS TORREFIED AT VARIOUS TEMPERATURES

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The objective of this study was to evaluate the effects of torrefaction temperatures on the characteristic of betung (*Dendrocalamus asper*) bamboo pellets. Torrefaction was conducted in an electric furnace at 200°C, 240°C, and 280°C for 50 minutes. The properties evaluated consist of color change, density, moisture content, water resistance, water adsorption, compressive strength, proximate analysis, calorific value, and FTIR analysis. The result showed that torrefaction affected the color properties of betung bamboo pellets, showing ΔE value of more than 12 or totally changed. The density and moisture content of torrefied betung bamboo pellets decreased with increasing torrefaction temperature. The torrefied pellets were more hydrophobic than the untorrefied pellets, as exhibited by the improvement of the water resistance and water adsorption values with increasing the torrefaction temperature. Torrefaction temperature of 200°C was the critical temperature that did not cause a decrease in compressive strength. The ash content and fixed carbon increased as temperature increased; in contrast, the volatile matter decreased as the temperature increased. Torrefaction pellets at 280°C had the highest calorific value of 21.13 MJ/kg. Torrefaction caused changes in the functional group that showed in FTIR analysis.

Keywords: betung bamboo, pellets, temperature, torrefaction

ABSTRAK

KARAKTERISASI PELET BAMBU BETUNG (Dendrocalamus asper) HASIL TOREFAKSI PADA BERBAGAI SUHU

Oleh

BAGUS SAPUTRA

Tujuan penelitian ini adalah untuk mengetahui pengaruh suhu torefaksi pada karakteristik pelet bambu betung (Dendrocalamus asper). Torefaksi dilakukan dengan electric furnace pada suhu 200°C, 240°C, dan 280°C selama 50 menit. Karakteristik yang dievaluasi terdiri dari perubahan warna, kerapatan, kadar air, ketahanan terhadap air, penyerapam uap air, kekuatan tekan, analisis proksimat, nilai kalor, dan analisis FTIR. Hasil penelitian menunjukan torefaksi mempengaruhi warna pelet bambu betung, yang menunjukan nilai ∆E lebih dari 12 atau berubah total. Kerapatan dan kadar air pada pelet yang telah ditorefaksi menurun dengan meningkatnya suhu torefaksi. Pelet yang telah ditorefaksi menjadi lebih hidrofobik dibandingkan pelet yang belum ditorefaksi, seperti yang ditunjukan dengan peningkatan ketahanan terhadap air dan penyerapan uap air dengan meningkatnya suhu torefaksi. Torefaksi pada suhu 200°C merupakan suhu kritikal yang tidak menyebabkan penurunan kekuatan tekan. Kadar abu dan karbon terikat meningkat dengan naiknya suhu, sedangkan, zat terbang menurun dengan naiknya suhu. Pelet yang ditorefaksi pada suhu 280℃ memiliki nilai kalor tertinggi sebesar 21.13 MJ/kg. Torefaksi menyebabkan perubahan pada gugus fungsional yang ditunjukan pada analisis FTIR.

Kata kunci: bambu betung, pelet, suhu, torefaksi

Title	: CHARACTERIZATION OF BETUNG (*Dendrocalamus asper*) BAMBOO PELLETS TORREFIED AT VARIOUS TEMPERATURES
Name	: Bagus Saputra
NPM	: 1814151022
Department	: Forestry
Faculty	: Agriculture

APPROVED BY

1. Supervisor

Dr. Wahyu Hidayat, S.Hut., M.Sc.
NIP 197911142009121001

2. Head of Department of Forestry

Dr. Indra Gumay Febryano, S.Hut. M.Si.
NIP 197402222003121001

VALIDATION

1. Examiners

Chairman : Dr. Wahyu Hidayat, S.Hut., M.Sc.

Examiner I : Dr. Indra Gumay Febryano, S.Hut., M.Si.

Examiner II : Dian Iswandaru, S.Hut., M.Sc.

2. Dean of Faculty of Agriculture

Prof. Dr. Ir. Irwan Sukri Banuwa, M.Si.
NIP 196110201986031002

Examination Date: 14 June 2022

PERNYATAAN KEASLIAN SKRIPSI

Yang bertanda tangan di bawah ini:

Nama : Bagus Saputra

NPM : 1814151022

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Adalah benar karya saya sendiri yang saya susun dengan mengikuti norma dan etika akademik yang berlaku. Selanjutnya, saya juga tidak keberatan apabila sebagian atau seluruh data pada skripsi ini digunakan oleh dosen dan/atau program studi untuk kepentingan publikasi. Jika dikemudian hari terbukti pernyataan saya tidak benar, saya bersedia menerima sanksi akademik berupa pencabutan gelar sarjana maupun tuntutan hukum.

Bandar Lampung, 4 Agustus 2022

Yang menyatakan

Bagus Saputra

NPM 1814151022

CURRICULUM VITAE

The author, Bagus Saputra was born on April 8th, 2002 in Pesawaran, Lampung Province, Republic of Indonesia. The author is the 2nd child of 3 siblings of Sugiarto and Erni Juarni. The author was an alumnus of SDN 37 Gedongtataan, SMPN 22 Pesawaran and SMAN 1 Gedongtataan. Author was accepted to Department of Forestry, Faculty of Agriculture, University of Lampung at 2018 through Seleksi Nasional Masuk Perguruan Tinggi Negeri (SNMPTN).

During collage, the author was active at Himpunan Mahasiswa Jurusan Kehutanan (Himasylva), University of Lampung as member of Division 4 (Communication, Information and Community Service) in 2020 and 2021. The author was also active as a teaching assistant at Basic Chemistry in odd semester (2019/2020), Forest Hydrology in odd semester (2020/2021), Forest Mapping and Geographic Information Systems (GIS) in even semester (2020/2021), Forestry Project Analysis in even semester (2021/2022), and Introduction of Forestry Economy in even semester (2021/2022). The author implemented the general practice (*Praktik Umum*) at Resort Balik Bukit, Bukit Barisan Selatan National Park for 20 days and practice the community service program (*Kuliah Kerja Nyata*) at Taman Sari Village, Pesawaran District for 40 days.

In 2022, the author published a paper in Journal of Agricultural Engineering Vol. 11, No. 2, be entitled "Effects of Torrefaction Temperature on the Characteristics of Betung (*Dendrocalamus asper*) Bamboo Pellets".

“*I Dedicate This Undergraduate Thesis to My Beloved Family*”

PREFACE

Praise and gratitude to Allah SWT for allowing the writer to complete this paper with the title “Characterization of Betung (*Dendrocalamus asper*) Bamboo Pellets Torrefied at Various Temperature” as one of the requirements for achieving a Bachelor’s Degree in Forestry. Shalawat and greetings are always poured out to our beloved Prophet Muhammad SAW., who has brought us from the dark ages to the light of truth.

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The author realizes that the preparation of this thesis is still far from perfect, but the author hopes that this thesis can be useful for the readers.

Bandar Lampung, June 2022

Bagus Saputra

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I. INTRODUCTION

1.1. Background

Indonesia is one of the biggest island countries in the world, with 17,504 islands spread across 34 provinces with an area of 1.9 million km^2 keeping a huge natural resource (Rahma, 2020). The tropical forest that spreads over the island in Indonesia is an ecosystem that has high biodiversity. Tropical forests, especially in the lowlands, are a source of timber, germplasm as a provider of environmental services (Suwardi *et al*., 2013). The high biodiversity of Indonesia's forests can be used as a renewable alternative energy source to replace fossil energy, which continues to decrease over the year. According to Kholiq (2015), Indonesia's oil production has decreased over the year due to a natural decline and the depletion of reserves.

Natural wealth such as a tropical forest ecosystem in Indonesia has potential biomass to use as renewable alternative energy. Biomass is an organic material formed from photosynthesis that can be a product or waste. Biomass energy utilization is called bioenergy (Purnomo *et al*., 2015). Biomass is developed for fuel resources in the future (Yudha *et al*., 2017). One biomass conversion form is pellets. Fuel from the processing of solid material mashed and compressed to have better combustion efficiency and consistency is called pellets. Biomass pellets are generally made from timber or agricultural waste with a high calorific value (Sukarta and Ayuni, 2016).

Indonesia's biomass potential is very diverse, one of them is bamboo, the commodity with the most significant production compared to other non-timber forest products (Hariz *et al*., 2021). As an essential part of non-timber forest products, bamboo can be used as an alternative material for wood products (Mangurai *et al*., 2022; Park *et al*., 2021). At least 600-700 bamboo species in worldwide, 125 species can be found in Indonesia (Arsad, 2015a). The high growth rate of bamboo has potential to developed and used for various purposes (Suriani, 2017). Bamboo cultivation can conducted in natural stands or building bamboo plantations by applying a silvicultural system (Husnul and Sutiono, 2014). Bamboo can be utilized as a raw material for crafts, furniture, and building material (Pujirahayu, 2012). The bamboo species that has been widely used is betung (*Dendrocalamus asper*) bamboo. Betung bamboo has the characteristics of a more tenuous grove, with each grove consisting of about 15 bamboo clumps. Betung bamboo can grow until 20 m with long and thick internodes. Because of its hard characteristic and long internodes, betung bamboo is widely used as a skewer, chopstick, or various kinds of craft and house walls, commonly called *gedhek/bilik* (Putro and Murningsih, 2014).

Biomass, like bamboo, has a low density and various sizes, is easy to absorb water (hygroscopic), and is difficult to store and transport because it is still large (Rani *et al*., 2020). Treatment that can increase the quality of bamboo is densification, which is a technique to convert biomass into pellets to increase the density to solve the problem of biomass that has a low density, various sizes, and is difficult to store and transport (Wibowo *et al*., 2017). Pellets are biomass that is reduced in size and then compacted in the form of cylindrical and cans be used as a fuel. Bioenergy development, such as biomass pellets from bamboo materials, can produce renewable energy (Syamsiro, 2016). However, biomass pellets still have weaknesses such as low heat values, high moisture content, and easy to absorb water (Akbar *et al*., 2013).

Based on Fakhruzy (2018) research, betung bamboo can be utilized as renewable alternative energy by converting it into pellets. Betung bamboo pellets based on SNI 8675-2018 as a standard of biomass pellets for energy relatively has low quality. However, the moisture content of betung bamboo pellets is 5.37% that meets the standards of SNI 8675-2018 which <12% for industrial scale and <10% for household scale. Betung bamboo pellets had a calorific value of 17.65 MJ/kg and meet the requirement of SNI 8675-2018, which is more than 16.5 MJ/kg. Therefore, it is necessary to conduct a treatment that can improve the quality of betung bamboo pellets.

Technology that can improve quality and increase the storability of biomass pellets is torrefaction (Basu, 2018). Torrefaction is a thermochemical treatment with a temperature between 200-300℃ with conditions limited or without oxygen and low heating rates that cause a change in the characteristic of biomass to become harder charcoal (Nur, 2014; Syamsiro, 2016; Tumuluru *et al.*, 2011). In addition to increasing the quality, the torrefaction process of biomass pellets can increase the hydrophobicity and prevent fungi and microbes during the storage and transportation process (Alamsyah *et al*., 2018; Tumuluru *et al*., 2011). Pah *et al.* (2021) conducted torrefaction of *Dendrocalamus asper* and *Gigantochloa pseudoarundinacea* bamboo pellets at 260℃ for 40 minutes and showed increasing the quality of pellets. So, it is important to know the results of torrefied betung (*Dendrocalamus asper*) bamboo pellets with different temperatures to determine their characteristics. This study was conducted to determine the characteristics of betung bamboo pellets that have been torrefied at various tempeatures.

1.2. Research Objectives

Considering the result of previous studies that torrefaction can improve the quality of bamboo pellets, the objective of this study is:

1. To determine the effects of torrefaction temperature on the physical and mechanical properties of betung (*Dendrocalamus asper*) bamboo pellets.
2. To determine the effects of torrefaction temperature on the bioenergetic and chemical properties of betung (*Dendrocalamus asper*) bamboo pellets.
3. To determine the optimum torrefaction temperature of betung (*Dendrocalamus asper*) bamboo pellets.

1.3. Research Framework

The decrease of fossil fuels over the year needs renewable alternative energy innovation that can be utilized sustainably and continuously. Indonesia has a huge natural potential that contains biomass that can be used as a source of bioenergy. Betung bamboo is one of the biomass sources that can be converted into pellets. But betung bamboo pellets still have a relatively low quality, therefore it needs an additional treatment to increase the quality of betung bamboo pellets. In addition to increasing the heat value, the torrefaction of betung bamboo pellets can increase the hydrophobicity and prevent fungi and microbes during the storage and transportation process. Based on the description above, the research framework shown in Figure 1.

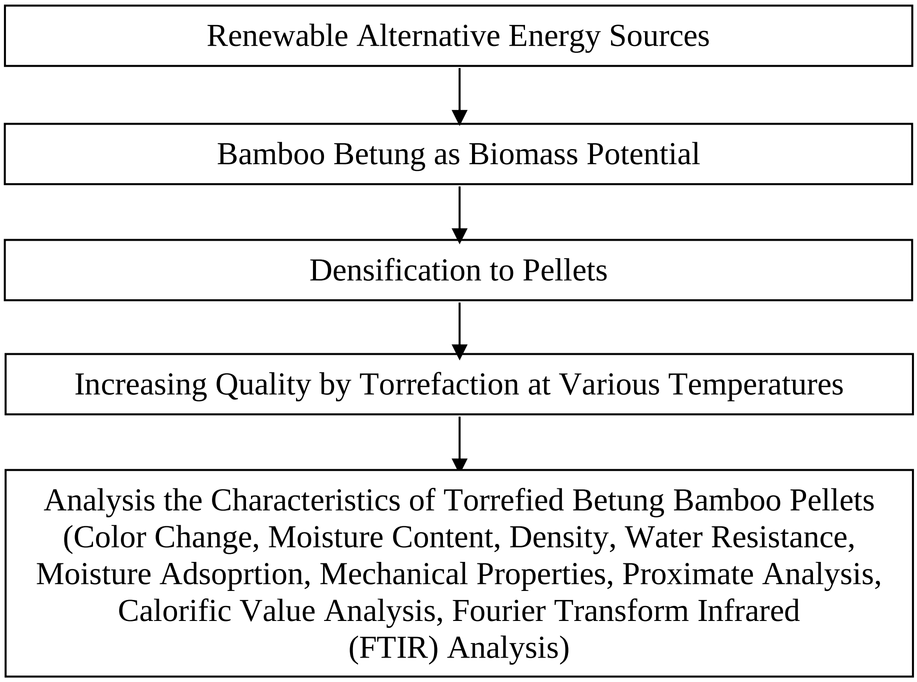

Figure 1. Research framework.

II. LITERATURE REVIEW

2.1. Alternative Energy Potential in Indonesia

The primary need for modern humans is not only food but also energy. Nowadays, energy is a primary need that cannot be separated from everyday life. Energy is needed to move almost all aspects of life (Agung, 2013). The need for energy is also increasing, in line with the level of human life. Currently, fuel oil is the primary national energy source with a proportion of use of 52.50%, followed by coal at 21.52%, gas at 19.04%, water at 3.73%, geothermal at 3.01%, and new energy at only 0.20% (Kholiq, 2015). The top two energy sources used in Indonesia are non-renewable fossil energy, so both energy sources will run out one day. Therefore, it is necessary to develop renewable alternative energy to meet human energy needs in the future (Alkusma *et al*., 2016).

There are many alternative renewable energy sources in Indonesia, such as wind energy (Habibie *et al*., 2011), solar energy (Widayana, 2012), geothermal, water, bioenergy, biomass, biogas, ocean or marine energy, and others (Kholiq, 2015). The utilization of each alternative energy source depends on the needs. Such as wind energy which has the potential to be developed as a wind power plant. Solar panel as an alternative energy sources is more efficient when compared to using generators as a power sources (Purwoto *et al*., 2018). Biogas from livestock manure can be used as a source of electrical energy and can reduce the cost of caring for livestock (Purnomo *et al*., 2020).

The reduce of fosil energy sources will increase the price, while its use continues to increase. Therefore, it is necessary to use renewable energy that easily to obtained and relatively low price compared to fosil energy (Padang *et al*., 2020). Indonesia, with its abundant natural resource potential, holds a large amount of renewable energy potential. The high biodiversity of Indonesia's forests can be used as a renewable alternative energy source to replace fossil energy, which continues to decrease over the year. Kholiq (2015) predict the potential utilization of fossil energy such as coal in Indonesia is about 75 years will run out, while the potential utilization of petroleum is only about 12 years away. Natural wealth such as a tropical forest ecosystem in Indonesia has potential biomass to use as renewable alternative energy.

2.2. Biomass

The increase in population growth causes the human need for energy to increase, and biomass can be used as an alternative energy source (Shobar *et al*., 2020). Biomass is organic material from photosynthesis, which can be either a product or a waste. Some examples of biomass in everyday life include plants, trees, grass, tubers, agricultural or forestry waste, feces, and livestock manure. As the primary purpose, biomass can be used as fiber, food, animal feed, vegetable oil, and building material. In addition, biomass can also be used as an energy source. The advantage of using biomass as an energy source was it is a renewable energy source. However, to provide a sustainable energy source (renewable), biomass used as a fuel source is usually as low economic value and is in the form of waste (Parinduri and Parinduri, 2020). Forest Biomass which can be utilized comes from logging waste which more than 40% in natural forests. Apart from natural forests, the potential for forest biomass that can be used as bioenergy can come from plantation forests with value between 20%-35% (Heriansyah, 2005). Forest also sources of more type of plant-based products than just timber. Non-timber forest products such as bamboo also has high utilization potential for sources of biomass (Chamberlain *et al*., 2019).

The potential for biomass energy in Indonesia is estimated at 49,810 MW. This value is based on the energy content of the annual production of 200 million tons of biomass from agricultural, plantation, and urban waste. The amount of potential is not proportional to the installed capacity of 302.40 MW or only about 0.64% which can only be utilized (Pranoto *et al*., 2013). Agricultural and forestry waste biomass has the potential to be developed into solid fuels such as briquettes or pellets. Such as, Ridjayanti *et al.* (2021) conducted a study by utilizing wood waste from *Falcataria moluccana* into briquettes with tapioca starch adhesive, and Hidayat *et al.* (2020) performed torrefaction on oil palm empty bunches pellets to improve the quality. Fakhruzy (2018) conducted study of converting betung bamboo to utilized as renewable alternative energy by converting it into pellets, and had a respectable quality. The potential of Indonesia biomass is very diverse, one of them is bamboo. At least 600-700 bamboo species in worldwide, 125 species can be found in Indonesia (Arsad, 2015a). The cultivation of bamboo can be done generatively and vegetatively (Simangunsong *et al*., 2014). Bamboo can be used as a raw material for crafts, furniture, and building (Pujirahayu, 2012). The ecological function of bamboo as a soil and water conservation plant is because it has strong roots and is used to store water and prevent erosion (Irvantia *et al*., 2014).

2.3. Betung Bamboo

Betung bamboo with the scientific name *Dendrocalamus asper* (Schult. f.) Backer ex Heyne is a type of bamboo that is quite well known and is widely used for various purposes. Betung bamboo is known for its large size with a diameter of the stem base that can reach 26 cm with a height of 25 m. The rugged and strong classification owned by betung bamboo causes it to be often used as a construction material for simple houses in rural areas, bridges, and craft material (Prasetyawati and Wibowo, 2018; Sari *et al*., 2016). Betung bamboo stem can be used as raw materials for high-yield paper, furniture, handicrafts, household appliances, particleboard, fiberboard, charcoal, and pulp (Arsad, 2014; Wardani, 2015; Zulkarnaen and Andila, 2015). Meanwhile, young bamboo stems, commonly known as bamboo shoots, can be consumed and used for food because of their sweet taste and high nutritional content (Zulkarnaen and Andila, 2015). The taxonomy of betung bamboo is shown below.

Kingdom	: Plantae
Subkingdom	: Tracheobionta
Superdivisi	: Spermatophyta
Divisi	: Magnoliophyta

Class : Liliopsida
Subclass : Commelinidae
Order : Poales
Family : Poaceae
Genus : Dendrocalamus
Species : *Dendrocalamus asper* (Schult. f.) Backer ex Heyne

Bamboo is a light material but has high strength. The tensile strength of bamboo can compare with the tensile strength of steel (Yoresta, 2013). Betung bamboo is a strong type of bamboo, but it is very susceptible to attack by destructive organisms. Therefore, in long-term use, preservation treatment is necessary. The use of betung bamboo is not only on lands, such as in the construction of buildings and others but can be used at sea as stakes, fishing rods, boat wings, and others (Muslich and Rulliaty, 2014).

Betung bamboo has a stem size that is much larger than other types of bamboo and with shorter internodes (Rini, 2018). Betung bamboo is a type of bamboo with a relatively dense grove. The height of the stem can reach 20 m with a diameter of up to 20 cm. In the nodal, there are often short and clustered roots, the length of the internodes ranges from 40-60 cm, and the stem walls are quite thick, 1-1.5 cm (Rulliaty *et al*., 2013). Betung bamboo is mainly found on the islands of Java and Sumatra with a fiber diameter range of 195~361 mm, a tensile strength range of 114~314 MPa, and a modulus of elasticity between 3.2~7 GPa (Refiadi *et al*., 2018).

2.4. Biomass Densification

Biomass used for fuel can be used directly or processed first (Yudha *et al*., 2017). In general, biomass used as fuel is usually still not processed, such as firewood. Conversion of biomass into energy can be done by thermochemically and biologically. The form of biomass conversion can be solid, liquid, or gas. Biomass usually still has a low density and calorific value, so it is necessary to perform a process to increase these values. Densification is a process to increase the density value of biomass, while torrefaction is a process to increase its calorific value (Syamsiro, 2016). Solid biomass can be used to partially replace coal in power plants, reducing carbon emissions and the effect of greenhouse gases (Panwar *et al*., 2011).

Densification or compaction is a process conducted on biomass to be formed into briquettes or pellets. This densification or compaction process aims to increase its density, facilitate storage and transfer, increase the calorific value per unit volume, and make the size and quality uniform (Frida *et al*., 2019). The densification process is carried out at sufficiently high pressure or temperature, with shapes and sizes tailored to user needs. The nature of porosity is essential in the results of the densification process. It is greatly influenced by the particle size and the adhesive used. Therefore, the results of the densification process are said to be of high quality if they have characteristics such as rugged, dry, durable, and low ash content (Mangalla *et al*., 2017).

2.5. Biomass Pelletization

The abundant potential of biomass can be used as fuel. However, due to the various forms of biomass and the low energy value, it is necessary to convert the biomass into a more consistent shape and higher energy value. Pellets are solid fuels derived from biomass or biomass waste with a smaller size than briquettes. Pellets can be made from wood, bamboo, or sawdust that contain lignin and cellulose materials, which are the highest biopolymer in nature (Solihat *et al*., 2021). Pelletization is done by mixing the mashed biomass with adhesive, then molding and drying (Alipan *et al*., 2019).

Utilizing biomass into solid fuels such as biomass pellets can produce renewable energy. Conversion from biomass to pellets will increase the calorific value per unit volume, facilitate storage and transportation, and have a uniform shape and quality (Rubiyanti *et al*., 2019). One of the essential factors in making pellets is the moisture content of the biomass raw material. It is because the moisture content will affect the characteristics of the pellets produced. Determination of the moisture content must follow the equilibrium value because shots with too high a moisture content will be susceptible to microorganisms and fungi. The pellets will quickly expand in storage and delivery (Lestari *et al*., 2019).

2.6. Biomass Pellet Standardization

There is an increase in fuel use from alternative energy sources such as biomass pellets for household and small-scale needs. Meanwhile, in Indonesia, biomass pellets as fuel are still on an industrial scale and for export needs (Lestari *et al*., 2019). Since 2008 there has been a significant increase in the production and trade of biomass pellets as an alternative energy source. The demand for biomass pellets is also driven by policies to reduce greenhouse gas emissions and increase the use of renewable energy (Sidabutar, 2018)

The development of the pellet industry accompanies the increasing demand for world pellets, so there is a need for internationally recognized pellet quality standards such as ISO 17225 in 2014. This standard covers two quality classes of wood pellets: wood pellets for commercial and household needs and industrial needs. Pellets for non-industries are divided into three levels, namely A1, A2, and B. Industrial grades are divided into 3, namely I1, I2, and I3. Pellets with grade A1 have the best quality from pure wood, namely wood that is not chemically treated and has low ash and nitrogen content. Pellets with grade A2 have ash and nitrogen content values of pellets A1. Meanwhile, pellets with grade B are from forest product waste such as branches, by-products, and production waste not contaminated with chemicals and used wood that is not chemically needed (ISO 17225-2: 2014). Meanwhile, pellet standardization in Indonesia uses the SNI 8675-2018 standard, namely biomass pellets for energy, divided into household and industrial standards.

2.7. Bamboo Pellets

Bamboo is alternative biomass to replace sustainable wood because it grows faster than wood. The utilization of bamboo as an alternative energy source by converting it into biomass pellets. The number of types of bamboo in Indonesia, which is the third-largest country after China and Thailand, further expands the potential for using bamboo as an alternative energy source (Arsad, 2015a).

Bamboo clumps that can continue to grow if harvested in a controlled and planned manner will cause their production to be maintained for their use as biomass pellets (Arsad, 2014).

The demand for biomass pellets as fuel from alternative energy sources continues to increase every year, causing the need for other sources of biomass that can be used as pellets. One biomass that is now becoming the world's attention in its utilization is bamboo (Arsad, 2015b). Based on Fakhruzy (2018) research regarding bio pellets of betung (*Dendrocalamus asper*) bamboo as a renewable energy source, he said bamboo was not optimal. Still, its growth was very fast, making the use of bamboo in bio pellets one of the right choices. In addition, processing into bio pellets can also increase the use-value of biomass.

Converting bamboo into pellets will increase the economic value and improve people's income if produced in large quantities for export purposes. Arsad (2015a) reported that bamboo pellets could be made from kuning bamboo or buluh bamboo powder. The calorific value of kuning bamboo pellets is 19.20 MJ/kg while buluh bamboo is 18.93 MJ/kg. Fakhruzy (2018) also reported that bio pellets from betung bamboo have a density of 1.08 g/cm^3, moisture content of 5.37%, volatile matter of 73.97%, ash content of 6.05 %, fixed carbon content of 20.09%, and the calorific value of 17.65 MJ/kg.

2.8. Torrefaction

Biomass as fuel in solid form such as pellets or briquettes as alternative energy sources has been widely carried out. The use of solid fuels from biomass certainly has its drawbacks. This raw biomass tends to have high water and volatile content. Besides that, the energy produced is still low compared to fossil fuels shaped as coal (Azhar and Rustamaji, 2012; Mamvura and Danha, 2020). Therefore, other treatments must be carried out to increase the calorific value and reduce the moisture content after the densification process, such as pellets. A potential remedy to improve the quality of solid biomass is torrefaction (Barskov *et al.*, 2019).

Torrefaction is converting biomass into a cleaner solid fuel by heating the biomass with a controlled temperature between 200°C-300°C at a particular time

(Basu, 2018; Nur, 2014). Torrefaction can also be called roasting, slow-mild pyrolysis, wood cooking, or high-temperature drying (Tumuluru *et al*., 2011). The torrefaction process will improve the physical characteristics of the biomass so that its utilization into fuel will have higher economic value (Alamsyah *et al*., 2018). The combination of pelletization with the torrefaction process will produce pellets with a high calorific value hydrophobic properties and improved grinding characteristics compared to biomass pellets that are not torrefied (Nunes *et al*., 2014).

Electric Furnace (EF) or electric arc furnace is an oven that can be used to perform torrefaction. Based on Yulianto *et al.* (2020) research, they conducted torrefaction of empty palm fruit bunches pellets with an electric furnace. Before torrefaction, the sample used was wrapped in aluminum foil with holes perforated on each side to prevent burning during the torrefaction process. Torrefaction with an electric furnace was carried out at a temperature of 280°C for 20 minutes.

Many benefits are obtained after carrying out the torrefaction process, especially in solid biomass. The torrefaction process can eliminate unwanted volatiles, such as nitrogen and sulfur oxides (Chen *et al.*, 2012). With lower oxygen content, the ratio of oxygen to carbon will decrease so that the biomass has characteristics close to coal (Van der Stelt *et al*., 2011). In addition, the reduced moisture content during torrefaction will also reduce the moisture level for other conversion processes, reduce transportation costs associated with biomass weight loss, and prevent biomass decomposition and water absorption during storage and transportation (Tumuluru *et al*., 2011). However, each process has advantages and disadvantages. The torrefaction process, which requires additional treatment, causes additional costs in the production process, mainly if carried out on a large scale.

III. METHODS

3.1. Time and Location

This study was conducted from December 2021—January 2022 at Workshop Forest Products in Integrated Field Laboratory, Faculty of Agriculture, University of Lampung. Physical and mechanical properties testing was conducted at Forest Products Laboratory, Department of Forestry, University of Lampung. Fourier Transform Infrared (FTIR) analysis was conducted at Integrated Laboratory and Technological Innovation Center, Faculty of Mathematics and Natural Sciences, University of Lampung. Proximate and calorific value analysis was conducted at Agricultural Power and Machine Equipment Laboratory, Department of Agricultural Engineering, University of Lampung.

3.2. Equipment

The tools used in this study, including digital caliper (scale 0.01 mm), electric scale (scale 0.0001 g), oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia), colorimeter (AMT507, Amtast, Qingdao, China), universal testing machine (M500-50AT, Testometric, Rochdale, United Kingdom), bomb calorimeter (1341, Parr, Moline, United States), and spectroscopy (Scimitar 2000 FTIR, Varian, Palo Alto, United States). The material used in this study was betung (*Dendrocalamus asper*) bamboo pellets and aluminum foil.

3.3. Material Preparation and Pre-Treatment

The first step is shifting betung (*Dendrocalamus asper*) bamboo pellets using a strainer to separate them from dust and remaining pellets powder. Then pellets were sorted of the same size by 3-4 cm. Later on, pellets were dried using an oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia) at 100°C for 24 hours. Drying was conducted to evaporate water during storage and make pellets become oven dry.

3.4. Torrefaction Process

Torrefaction was conducted using an oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia) at 200°C, 240°C dan 280°C for 50 minutes in Workshop Forest Products at the Integrated Field Laboratory, Faculty of Agriculture, University of Lampung at 14-17 December 2021. Each torrefaction pellet was prepared as much as 12 bar and wrapped using aluminum foil, then given a little hole on the sides to allow air to escape. The oven was set to a predetermined temperature and added 20°C more degrees because the temperature would decrease after the oven was opened. After the oven reached the predetermined temperature, pellets were put into an oven, set to torrefaction temperature, and then set on the timer. After 50 minutes, pellets were taken out from the oven, cooled at room temperature ranging from 20°C-30°C and covered with a cloth to prevent combustion. The torrefaction scheme presented in Figure 2.

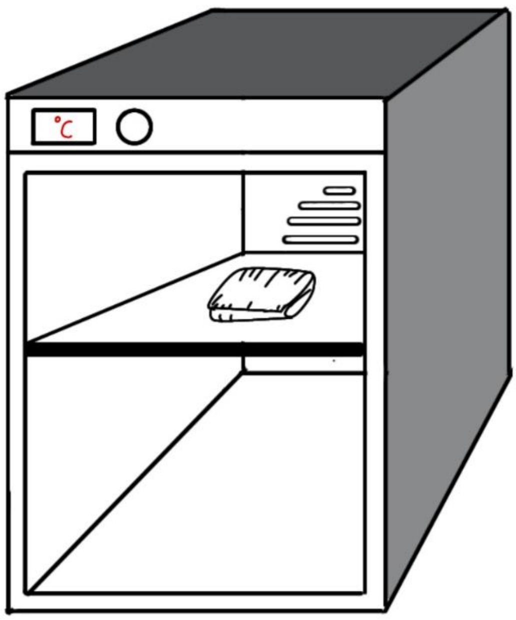

Figure 2. Torrefaction scheme using the oven.

3.5. Testing and Analysis

3.5.1. Color change

Color change test was performed before and after torrefaction using a colorimeter (AMT507, Amtast, Qingdao, China) with a CIE-Lab system. Measurement was conducted randomly 5 times at the sample stack (Figure 3). This testing used $L*$, $a*$, and $b*$ parameters. The $L*$ axis showed a brightness level with a maximum value of 100, which means perfect white, and a minimum value of 0 means perfect black. The $a*$ axis showed red/green chromaticity with a positive value in the red direction and a negative value in the green direction. While the $b*$ axis showed yellow/blue chromaticity with a positive value in the yellow direction and a negative value in the blue direction (Hidayat *et al.*, 2017). The overall color change ($\Delta E*$) was calculated using the following equation.

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

Description:
$\Delta E*$ = Overall color change
$\Delta L*$ = Change in lightness
$\Delta a*$ = Change in red/green chromaticity
$\Delta b*$ = Change in yellow/blue chromaticity

Figure 3. Color change measurement.

Classification of color change is presented in Table 1.

Table 1. Classification of Color Changes

No	Classification Value	Description
1	$0.0<\Delta E^*\leq 0.5$	Negligible
2	$0.5<\Delta E^*\leq 1.5$	Slightly Perceivable
3	$1.5<\Delta E^*\leq 3$	Noticeable
4	$3<\Delta E^*\leq 6$	Appreciable
5	$6<\Delta E^*\leq 12$	Very Appreciable
6	$\Delta E>12$	Totally Changed

Source: Valverde and Moya (2014)

3.5.2. Moisture content

The moisture content determination used principally to compare losing weight after heat treatment with weight samples before. Moisture content measurement was performed by drying the sample using an oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia) at 100°C for 24 hours, and sample weight was measured before and after drying. Based on SNI 01-1506, the moisture content was calculated using the following equation.

$$\mathrm{MC} = \frac{(W_1 - W_0)}{W_0} \times 100\%$$

Description:
MC = Moisture content (%)
W_1 = Initial weight (g)
W_0 = Oven dried weight (g)

3.5.3. Density

Density is the ratio between sample weight and volume. Measurement was conducted by measuring the weight and volume at air-dry and oven-dry conditions. Based SNI 8021-2014, the density was calculated using the following equation.

$$\mathrm{D} = \frac{\mathrm{W}}{\mathrm{V}}$$

Description:
D = Density (g/cm^3)
W = Weight (g)
V = Volume (cm^3)

3.5.4. Water resistance

The observation of water resistance was conducted by soaking torrefied pellets at the different timeframes, that is, 0 minutes or right after soaking, 1 minute, 5 minutes, 30 minutes, 1 hour, 6 hours, 12 hours, 1 day, and 3 days. This observation was conducted to see visual and physical changes due to water immersion. According to Rubiyanti *et al.* (2019), torrefied pellets were more resistant to water or hydrophobic. This observation would show how long pellets were not absorbing water, indicating how long pellets can be stored.

3.5.5. Moisture adsorption

Moisture adsorption observation was performed for 30 days because during that period; the betung bamboo pellets reached the equilibrium moisture content (EMC). The observation was conducted by placing one bar torrefied pellet in an aluminum container and left in an open space at room temperature and kept away from nuisance and dirt such as dust that can affect its weight. Every day pellets were weighed using an electric scale with an accuracy of 0.001g to see the weight gain. The change in moisture adsorption was determined using moisture content gain of pellets.

3.5.6. Mechanical properties

The compressive strength tests were conducted using a universal testing machine (M500-50AT, Testometric, Rochdale, United Kingdom). Measure the diameter of torrefied pellets and flatten both tips so they can stand on the measurement machine. Then press pellets using the machine and count the time until pellets break or crack. Afterward, the machine automatically stopped and shown the graphic and maximum value on the test. The compressive strength value was calculated using the following equation.

$$\sigma = \frac{P}{A}$$

Description:
σ = Compressive Strength (N/mm^2)
P = Maximum Test Load (N)
A = Surface Area (mm^2)

3.5.7. Proximate analysis

The proximate analysis was performed to determine the combustion efficiency of biomass (fuel pellet). Biomass consists of several components such as moisture content, ash content, volatile matter, and fixed carbon.

3.5.7.1. Ash content

Ash content is the percentage of mineral content that does not evaporate and becomes a residue during combustion. The analysis of the ash content test refers to the SNI 8675-2018 standard. The following equation calculated the ash content.

$$\text{Ash Content (\%)} = \frac{\text{Ash Weight (g)}}{\text{Dry Sample Weight (g)}} \times 100\%$$

3.5.7.2. Volatile matter

Volatile matter is lost weight percentage due to heating without outside air. The volatile matter analysis is based on SNI 8675-2018 standard. The volatile matter was calculated using the following equation.

$$\text{Volatile Matter (\%)} = \frac{\text{Sample Weight Loss (g)}}{\text{Dry Sample Weight (g)}} \times 100\%$$

3.5.7.3. Fixed carbon

Fixed carbon is the fraction rate contained in the sample, excluding moisture content, ash content, and volatile matter fraction. SNI 8675-2018 was used as a base for fixed carbon analysis. The following equation was used to calculate the fixed carbon.

$$\text{Fixed Carbon (\%)} = 100\% - (\text{Ash Content} - \text{Volatile Matter})$$

3.5.8. Calorific value analysis

Calorific value is the amount of heat produced during complete combustion of one unit mass of fuel with water due to combustion in steam form with units of (MJ/kg). The calorific test was performed using a bomb calorimeter (1341, Parr, Moline, United States), and SNI 8675-2018 was used as the analysis standard.

3.5.9. Fourier transform infrared (FTIR) analysis

The Fourier transform infrared (FTIR) analysis was conducted using spectroscopy Fourier transform infrared (Scimitar 2000, Varian, Palo Alto, United States) with the KBr method. FTIR analysis was conducted to determine the quality of biomass and functional group change. The working principle of the FTIR spectrum is infrared that passes through the sample gap, and the slit controls the amount of energy delivered to the sample. Some infrared would absorb by the sample, and the others are transmitted through the sample's surface. Then infrared rays pass to the detector, and the measured signal is then sent to the computer.

3.5.10. Data analysis

Data analysis was performed based on descriptive statistics, namely statistical analysis that provides a general description of the characteristics of each research variable seen from the average value (mean), maximum value, minimum value, and standard deviation.

V. CONCLUSIONS AND RECOMMENDATION

5.1. Conclusion

The color change (Δ*E*) of torrefied betung bamboo pellets was totally changed. The moisture content decreased after the torrefaction. Air-dry and oven-dry density reduced with increasing the torrefaction temperature. Torrefied pellets at 280°C exhibited a best water resistance. The moisture adsorption of torrefied betung bamboo tended to be more stable than the untorrefied pellets. Pellets that torrefied at 200°C were the critical temperature that did not cause a decrease in the strength. With increasing the torrefaction temperature, the ash content and fixed carbon values increased, in contrast, the volatile matter values decreased. Torrefied pellets at 280°C showed the highest calorific value. Torrefaction caused changes in the functional group such as OH, CH, C=C, C-O group by FTIR analysis.

5.2. Recommend

Considering some results from this study, we suggested further studies with different types of bamboo species as raw materials for making pellets.

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