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Impact of Pyrolysis Temperature and Jatropha Seed Adhesive on the Properties of Bio-charcoal from Young Coconut Waste

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ABSTRACT

This study assesses the characteristics of bio-charcoal from young coconut waste with the effect of variations in pyrolysis temperature and the addition of Jatropha seed adhesive. The physical and chemical parameters of bio- charcoal from three temperature variation treatments (380 °C, 430 °C, and 480 °C) and three adhesive concentrations (15%, 20%, and 25%) were analyzed, including moisture content, ash content, volatile matter, calorific value and fixed carbon. In addition, the application of ANOVA and DMRT were used to evaluate the significant differences between the various treatments with significant p-value ⩽ 5%. The optimal result was obtained at temperature of 430 °C and 25% adhesive indicating a calorific value of 6421 cal/g, moisture content of 6.1%, ash content of 7.6% volatile matter of 7.7% and fixed carbon of 78.7%. The findings reveal that adhesive content significantly affects bio-charcoal quality, while temperature variations influence moisture content and heating value. This study concludes that optimizing temperature and adhesive concentrations can yield high-quality bio-charcoal, offering a cleaner, sustainable source.

1. INTRODUCTION

The advent of globalization has resulted in a significant increase in energy consumption across several industries, therefore affecting economic progress. Several factors, including population growth, production costs, rising oil prices, high exploration costs, and the difficulty of locating oil sources, collectively contribute to the escalation of energy demand. Furthermore, this increase in energy consumption has enabled the swift growth of several sectors, but with adverse environmental consequences. Through the successful resolution of these issues, the use of biomass is emerging as a highly promising and environmentally friendly alternative in the biorefinery sector (Olugbenga *et al*., 2024).

Biomass is derived from agricultural waste, forest trash, and other biomass containing organic leftovers. Notwithstanding its plentiful supply, biomass possesses intrinsic attributes such as significant water content and ashes. To achieve maximum efficiency, biomass must undergo comprehensive processing to comply with transportation, storage, and processing regulations (Cheng *et al*., 2022). Among the biomass generated by the plantation is the waste from young coconut beans. The anatomical structure of coconut young waste comprises the mesocarp, endocarp, and exocarp. The potential of young coconut waste rapidly increases along with the booming young coconut water business in various places. Inadequate management and utilization of young coconut trash as an energy source or other material can lead to severe contamination of water, air, and land. Consequently, if not effectively used, it exerts a detrimental influence on the ecosystem.

Researchers have conducted extensive studies on the utilization of young coconut waste. The reference is Naik *et al*. (2023), to assess enzymes and preserve the sensory characteristics of mesocarp, as well as the potential for producing cocopeat young coconuts with good water absorption performance, a dessert based on ready-to-cook milk (kheer) was developed using a blanching technique (microwave, boiling water and measurement) on mesocarp derived from boiled young coconut. It also contains lignocellulose, which is composed of cellulose, hemicellulose, and lignin. This complex can be broken down by pyrolysis, making it suitable for converting young coconut waste into bio-charcoal as an alternative fossil fuel substitute. Pyrolysis refers to a sequence of reactions in which chemical structures are broken down into solid products, liquid fumes, and atmospheric gases. This reaction occurs at a maximum temperature of 550°C (Yahya *et al*., 2021).

In the production of bio-briquette, the application of adhesive is recommended. Research has been conducted on adhesives derived from a wide range of basic materials, including cassava starch (Kongprasert, *et al*., 2019), brown algae (Dewita, *et al*., 2020), tapioca and sago (Anizar, *et al*., 2020), and gum Arabic (Sabo *et al*., 2022). An effective glue possesses robust adhesive characteristics that can influence the combustion rate once it is established. According to this study, the adhesive derived from the *Jatropha curcas* seed can be used up to 30% of the total content. Furthermore, it has the potential to enhance the calorie content of the bio-charcoal, as the seed has a caloric value of 6.343.49 (Suryaningsih, *et al*., 2019). The seed of *Jatropha curcas* yields an only 30% of the oil, with the remaining 70% consisting of seed residue that is managed as trash (Suryaningsih, *et al*., 2019).

Conversely, non-nutritional uses are predominantly observed in technological applications of industrial proteins, including adhesives, coatings, and surfactant (Lestari, *et al*., 2011). Due to its high protein composition, *Jatropha curcas* seeds can serve as a natural adhesive by binding to other polymers through a hot felting mechanism (Setiawan *et al*., 2016). Based on the description above, there has been no research on the conversion of young coconut waste into charcoal for bio-briquette raw materials through the pyrolysis process and the addition of *Jatropha* seed adhesive.

The research aims to determine the optimal values of independent variable by examining the effects of pyrolysis temperature and the proportion of natural adhesive from *Jatropha* seeds on the quality of bio-charcoal produced from young coconut waste. The main goal is subjected to develop a more efficient and eco-friendly production process. The use of young coconut waste as a bio-charcoal base material combined with natural adhesive derived from castor seeds, has not been thoroughly investigated previously. This approach has the potential to enhance biochar quality and substantially reduce exhaust emissions, rendering it an eco-friendlier energy alternative compared to current biomass production techniques.

2. MATERIALS AND METHODS

2.1. Sample Preparation and Bio-Charcoal Production Procedures

The main material used in this research is young coconut waste which can no longer be used, then pyrolysis is carried with reactor pyrolysis for 3 h in 1.5 kg to produce bio-charcoal such as Figure 1. Each type of bio-charcoal was derived at different pyrolysis temperatures and treated with adhesives derived from the seeds of the *Jatropha curcas* plant in Banda Aceh and Aceh Besar, Province of Aceh, Indonesia. The experimental protocol entails the manufacture of young coconut waste size 5×5 cm, which was then dried using solar drying for around 3 days until it reaches a water content of 20% (Rahmat, *et al*., 2023). Finally, it is dried in the oven for a duration of 2 h. Following a sequence of bio-charcoal operations, the response variables for assessing the quality of calorie values, moisture content, ash content, volatile matter, and fixed carbon are determined.

2.2. Design of Experiment

Experiment was constructed in completely randomized design with two factors. The firs was pyrolysis temperature, consisted of three levels, namely 380 °C (T1), 430 °C (T2), and 480 °C (T3). The resulted bio-charcoal was subsequently refined using a GM-400S1 grinder and then sifted through a 60 mesh filter media. The second factor was adhesive content. In this case bio-charcoal was added with adhesive solutions containing 15% (K1), 20% (K2), and 25% (K3). The combination of two factors results in 9 treatments labeled as T1K1, T1K2, T1K3, T2K1, T2K2, T2K3, T3K1, T3K2, and T3K3. All measurements were replicated 3 times resulting in 27 responses in the bio-charcoal test.

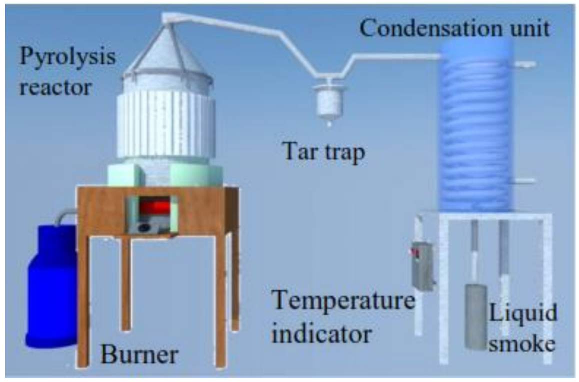

Figure 1. Schematic diagram of pyrolysis reactor (Faisal *et al*., 2020).

2.3. Characteristics of Bio-charcoal

Proximate analysis on bio-charcoal samples of young coconut waste included calorie values, moisture content, volatile matter, ash content, and fix carbon (Dewita *et al*., 2020; Daowwiangkan *et al*., 2023). All analyses followed American Society of Testing and Materials (ASTM) standards. Caloric value refers to the highest quantity of thermal energy produced by a fuel during a flawless combustion process per unit of mass or fuel volume (Aljarwi *et al*., 2020). Utilizing the DDS Bomb calorimeter model CAL3K-S in compliance with the ASTM D5865 standard, the energy generated by a bio-charcoal with a net caloric value (kcal/g).

Quantification of water content conducted with a hot air oven of (Gemmy888 YCO-010). Water content refers to the quantity of water present in the material, which impacts the combustion efficiency and calorie content of the bio-charcoal. To initiate the procedure phase, the samples are weighed at an initial weight of 20 g apiece. Subsequently, the samples are submitted to a preheated oven set at 105 °C and allowed to remain there for a duration of 2 h. Their removal from the oven precedes their weighing. The sample is cooled in a desiccator for 10 minutes to prevent the absorption of water vapor in the air. The sequence of this procedure is repeated until it reaches the constant weight as the final weight. Moisture content (*M*) is calculated based on ASTM D3173 using the Equation 1.

$$M\ (\%) = \left(\frac{w_1 - w_2}{w_2}\right) \times\ 100 \tag{1}$$

where w_1 represents the weight before drying (g) and w_2 represents the weight after drying (g).

The samples were then transferred into a heat-resistant container and put into a furnace that had been heated at 600 °C. The duration of the combustion process was 4 hours. After the combustion process was complete, the crucibles were isolated from the furnace and placed in a desiccator to cool before being weighed. The weight of the ash content was determined by subtracting the weight of the empty crucible from the weight of the ash already in the crucible. The ashes level follows the ASTM D3174 standard, calculated with the Equation 2:

$$KA(\%) = \left(\frac{w_1 - w_0}{w_2 - w_0}\right) \times\ 100 \tag{2}$$

where w_0 is the weight of the empty crucible (g), w_1 is the weight of crucible and sample before burning (g), and w_2 is the weight of crucible and sample after burning (g).

Volatile matter testing involves a series of processes to measure the content of vaporizable substances in young coconut waste. One gram of each sample is inserted into the crucible, then heated in a carbolite furnace at 800 °C for an hour. After the process of removing the volatile matter, the sample has been left to cool in the oven until it reaches room temperature. The content of volatile matter based on ASTM D3175, can be calculated with the Equation 3:

$$VM(\%) = \left(\frac{w_b - w_a}{w_c - w_a}\right) \times\ 100 \tag{3}$$

where w_a is the weight of the empty crucible (g), w_b is the weight of sample and crucible before burning (g), and w_c is the weight of the sample and crucible after burning (g).

Fixed carbon is a fraction of carbon (C) that is bound in a bio-charcoal in addition to the fractions of ash, water and vapour. The level of fix carbon can affect the quality of bio-charcoal, where the higher the level of fix carbon, the better the bio-charcoal is produced. Fixed carbon is investigated according to the ASTM D3174 standard, and the Equation (4) used is shown as follows:

$$FC\ (\%) = 100\% - (M + KA + VM) \tag{4}$$

2.4. Statistical analysis

The experimental data were processed using SPSS 29.0.2.0 with ANOVA analysis of the Completely Randomized Design, when the data was homogeneous and uniform, not only factorial effects were obtained, but enabled combined influences and interactions of the factors being tested. Once a significant effect between treatments was established, then Duncan Multiple Range Test (*DMRT*) was proceeded at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1. Bio-charcoal Product

Bio-charcoal from young coconut waste is obtained from the process of pyrolysis at 380 °C, 430 °C and 480 °C. Pyrolysis initiates across a temperature range of 100-120 °C, there is water evaporation of the material, followed by cellulose decomposition up to 260 °C (Loppies, 2016). The charcoal component consists of fixed carbon, ash, water, nitrogen, and sulfur. The majority of coal pores remain coated with hydrocarbon, tar, and other organic chemicals, which also include inorganic elements such as magnesium (Mg), aluminum (Al), potassium (K), calcium (Ca), and iron (Fe) (Rampe *et al*., 2021). The pyrolyzed materials have been subjected to treatment with combinations of adhesives including 15%, 20%, and 25%, which directly impacts the quality of the bio-charcoal when used in bio-briquette production. The findings of the examination of the characteristics of bio-charcoal made from young coconut waste are presented in Table 1.

Tabel 1. Recapitulation of mean ± SD on treatment parameters

Sample	Caloric value	Moisture content	Ash content	Volatile matter	Fix carbon
T1K1	6292±57	3.9±0.2	7.5±0.1	8.4±0.1	80.2±0.0
T1K2	5924±54	5.4±0.1	6.6±0.3	8.0±0.0	80.1±0.0
T1K3	5625±49	8.0±0.5	5.5±0.4	8.0±0.3	78.5±0.5
T2K1	6400±54	3.0±0.3	10.5±0.4	7.9±0.2	78.6±0.9
T2K2	6229±46	4.5±0.1	8.6±0.4	7.4±0.2	79,6±0,1
T2K3	6421±53	6.1±0.6	7.6±0.3	7.7±0.7	78.7±0.4
T3K1	6677±110	2.5±0.1	12.1±0.4	7.2±0.9	78.2±1.1
T3K2	6235±54	4.0±0.1	11.0±0.1	5.6±2.7	79.5±2.9
T3K3	5938±48	5.9±1.4	10.4±0.2	8.4±0.4	75.3±1.9
SNI 01-6235-2000	≥ 5000	≤ 8%	≤ 8%	≤ 15%	≥ 77%

Table 1 presents 9 samples of biochar that have undergone testing to determine their physical and chemical properties when subjected to thermal treatment and adhesive mixtures. The bio-charcoal examination of young coconut waste reveals that each treatment yields distinct quality outcomes depending on the temperature and adhesive mixture. The calorie values obtained from each test ranged from 6677 cal/g to 5625 cal/g. Moisture content ranging from 8 % to 2.5% contributed to high combustion efficiency and low smoke emissions. Ash content ranging from 7.2% to 5.5%, volatile matter levels ranging from 8.4% to 5.6%, and fixed carbon levels ranging from 80.2% to 75.3% indicated high energy potential and promote clean burning. As a bio-briquette raw material, the bio-charcoal derived from young coconut waste adheres to SNI standard 01-6235-2000.

3.2. Analysis of bio-charcoal quality

3.2.1. Caloric Value

The caloric value, expressed as the thermal energy released by complete combustion under conditions, is crucial for evaluating energy sources like agricultural products, gas fuels, and coal. The heating values of charcoal and biomass are controlled by the composition of chemical constituents, including carbon and oxygen concentration (Miroshnichenko *et al*., 2023). The experimental analysis data included in Table 1 were subjected to ANOVA testing at a significance level of $\alpha = 5\%$ or $\alpha = 0.05$. The treatment of pyrolysis temperature, the *Jatropha* seed adhesive, and its interaction with the calorie values were quantitatively examined using F and Sig (p-value) metrics at 112.038 (0.001), 135.239 (0.001), and 36.803 (0,001). Sayili *et al*. (2024) study suggests a significant influence of the pyrolysis temperature treatment, *Jatropha* seed adhesive, and their interaction on the caloric values in the bio-charcoal. This confirms that a significance level of Sig value (p-value) ≤ 0.05 indicates a significant difference between the analytical data groups. Figure 2 presents a more detailed examination of DMRT tests to verify any variations or consistency in the data specifically related to the calorie values.

The pyrolysis temperature significantly affects the bio-caloric value of coal due to its influence on the chemical and physical properties of the bio-charcoal produced. Research has shown that bio-charcoal derived from different raw materials at varying pyrolysis temperatures exhibit different characteristics, affecting the energy concentration and the heat of its combustion (Kazimierski *et al*., 2022). Higher pyrolysis temperatures result in an increase in the calorie, value of bio-charcoal, with values ranging from 5625 to 6677 cal/g, this result is consistent with Kazimierski *et al*. (2022) in showing the efficiency of burn in increasing energy density. Therefore, the higher the pyrolysis temperature the higher the calorific value, where temperatures above 315°C cause the loss of hydroxyl groups, a decrease in oxygen and hydrogen content, and an increase in carbon content. Arous *et al*. (2021), thereby increasing the energy efficiency of biochar in producing high calorific value products. Therefore, optimizing the pyrolysis temperature is crucial in maximizing the bio-caloric value of charcoal for the various intended purposes.

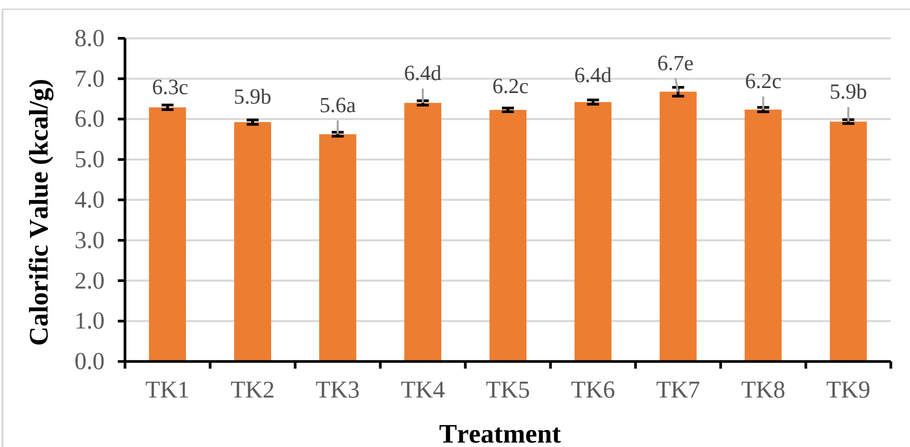

Figure 2. Effect of treatment on calorific value of the resulted charcoal (different letters correspond to a significant difference in the DMRT ($p \leq 0.05$).

An essential factor in assessing the value of a charcoal briquette is the adhesive. The adhesive from *Jatropha* seeds is very helpful in producing the calorific value of bio-charcoal, as it contains oil ranging from 48.3% to 51.7% (Satar *et al*., 2022). In this study, the highest calorific value was obtained from T3K1 with a 15% adhesive and a temperature of 480°C. This is because, under pressure, the loss of some water and binder material can reduce the moisture and ash content of the charcoal bio-briquettes from the binder, thereby increasing the calorific value produced (Rusman *et al*., 2023). This shows that the choice of adhesive has a big effect on how much energy the briquette produces (Hamzah *et al*., 2023). The results of this study are based on the calorific which is in accordance with the SNI 01-6235-2000 standard that requires a minimum of 5000 cal/g.

3.2.2. Moisture Content

Analysis of experimental data on moisture content was carried out using the ANOVA test at a significance level of α = 5% or α = 0.05. The F and Sig (*p*-value) values for pyrolysis temperature treatment and *Jatropha* seeds on moisture content were 20.285 (0.000) and 89.882 (0.000). Considering that these values fall below the acceptable threshold of significance, it can be inferred that the adjustment of pyrolysis temperature and *Jatropha* seed adhesive had a significant effect on the moisture content in the bio-charcoal, hence dramatically affecting the moisture content. In contrast, the correlation between pyrolysis temperature and *Jatropha* seed adhesive distance were found to be 0.761 (0.564). This indicates that the interaction between the temperature at which pyrolysis occurs and the *Jatropha* seed adhesive has an insignificant impact on moisture content. Duncan's Multiple Range Test (DMRT) post-hoc analysis was not conducted due to the absence of a significant impact on the interaction between treatment groups. To provide further clarity, the results of the analysis of variance (ANOVA) can be seen in Figure 3.

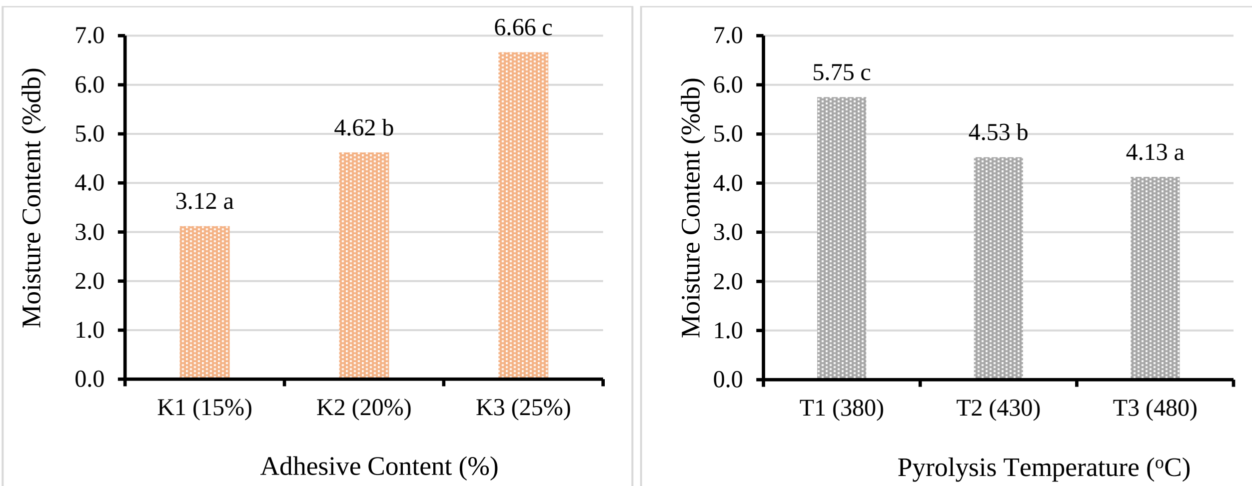

Figure 3. (a) Effect adhesive content on moisture content; (b) Effect pyrolysis temperature on moisture content (different letters correspond to a significant difference in the DMRT ($p \leq 0.05$).

The moisture content affects the quality of the bio-charcoal, the less water content the material does not waste much energy to dry it (Ajimotokan *et al*., 2019). The moisture content is a crucial factor in assessing the quality of charcoal bio-briquette. The study conducted by Abdel Aal *et al*. (2023), revealed that the optimal water content for producing high-quality is around 8%. For instance, briquette made from the of the *Ficus nitida* tree residues. At this ideal humidity level, briquette are produced with exceptional durability, density high, pressure strength, and caloric efficiency. The management of moisture content is of crucial importance as it directly impacts the physical characteristics, combustion rate, caloric value, and overall quality of bio-charcoal. This underscores the criticality of this aspect in the process of production (Puspitawati *et al*., 2023).

The temperature at which pyrolysis occurs significantly affects the water content of bio-charcoal. In this study, the lowest recorded water content is 2.5%, while the highest reaches 8%. In line with the pyrolysis temperature study of 400°C, biochar shows a water content of 5.8% (Ginting *et al*., 2023). This result demonstrates that moisture content is influenced by pyrolysis temperature, the greater the pyrolysis temperature, the lower the moisture content. Prior to the organic material breaking down, free and bound moisture evaporates at a pyrolysis temperature of 250°C. However, because there is still a lot of moisture in the *Jatropha* seed adhesive, the moisture content achieved likewise increases as the adhesive % rises. Together with the research that was done, this finding shows that *Jatropha* seeds have a lower moisture content of 2.5% at 480 °C with a 15% adhesive than the study found. Radyantho *et al*. (2023) using pine resin around 3.7%. However, the results match with the specifications of SNI standard 01-6235-2000.

3.2.3. Ash Content

Analysis of experimental data on ash content was carried out using the ANOVA test at a significance level of α = 5% or α = 0.05. The treatment of pyrolysis temperature, the *Jatropha* seed adhesive, and its interaction with the ash content were quantitatively examined using F and Sig (*p*-Value) metrics at 487.559 (0.001), 117.092 (0.001), and 4.320 (0.013). A significant influence of the pyrolysis temperature treatment, *Jatropha* seed adhesive, and their interaction on the ash content in the bio-charcoal. The significance level, determined when the Sig value (*p*-value) ≤ 0.05, indicates a significant difference between the data groups analyzed. The pyrolysis temperature has the greatest influence, followed by the adhesive, while the interaction has the least influence on the ash content. Figure 4 presents a detailed examination of DMRT testing to verify any variations or uniformity in the data about the ash content produced by each treatment.

The ash content in bio-charcoal significantly impacts the quality achieved. The research results show the lowest ash content in T1K3 at 5.5% and the highest in T3K1 at 12.08%. This trend indicates that an increase in pyrolysis temperature tends to increase ash content, as high temperatures accelerate the decomposition of organic materials and leave more mineral residues. In accondance with the research Gómez *et al*. (2018) a temperature of 500°C significantly affects the ash content of biomass with high ash content. At this temperature, the thermal decomposition process increases the release of volatile compounds while concentrating on inorganic materials, leading to a relatively higher ash content in the produced biochar. In addition, high levels of ash are suspected to be impurities or toxic substances caused by the process of pyrolysis and the adhesion of *Jatropha* seed. In addition, the bio-briquette ash content is a key parameter that is evaluated against standards such as SNI 01-6235-2000, where a maximum ash content of 8% is often determined (Sitogasa *et al*., 2022).

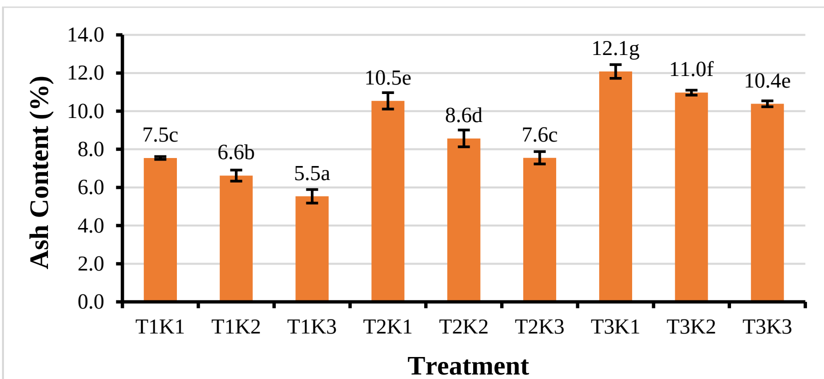

Figure 4. Effect of treatment on calorific value of the resulted charcoal (different letters correspond to a significant difference in the DMRT ($p \leq 0.05$).

3.2.4. Volatile Matter

Analysis of experimental data on volatile matter was carried out using the ANOVA test at a significance level of α = 5% or α = 0.05. The treatment of pyrolysis temperature, the *Jatropha* seed adhesive, and its interaction with the volatile matter were quantitatively examined using F and Sig (*p*-value) metrics at 2.472 (0.113), 0.088 (0.088), and 1.695 (0.195). This indicates that the relationship between the temperature at which pyrolysis occurs and the *Jatropha* seed adhesive has an insignificant impact on volatile matter. Duncan's Multiple Range Test (DMRT) post-hoc analysis was not conducted due to the absence of a significant impact on the interaction between treatment groups. To provide further clarity, the results of the analysis of variance (ANOVA) can be seen in Figure 5.

Volatile matter is a substance that can evaporate or undergo thermal decomposition. In addition to water, this component includes flammable gases such as methane, hydrocarbons, hydrogen, and carbon monoxide, as well as non-flammable gases like carbon dioxide and nitrogen (Yuliah, *et al*., 2017). The volatile matter content of bio-charcoal is very important because it can affect the combustion process. If the volatile matter content is high, then the combustion process can be easier or more difficult, depending on the composition of the substances contained in the bio-charcoal

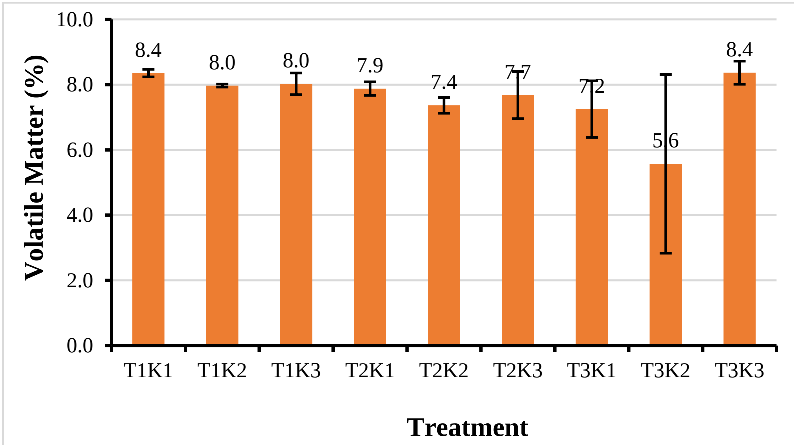

Figure 5. Effect of treatment on volatile matter content of the resulted charcoal

(Ridjayanti *et al*., 2021). Research on briquettes made from palm leaves and shells showed that the volatile material content affects the combustion rate and calorie value of the briquette produced, with optimum results achieved at certain volatility levels (Bani, *et al*., 2018). Figure 5 shows the results of the study on low volatile matter, ranging from 5.572% to 8.366%, with the highest in bio-charcoal, indicating that the decrease in volatile matter content is likely due to higher pyrolysis temperatures, which enhance the decomposition of volatile compounds. Additionally, the role of the adhesive is also important, where natural adhesive processed at lower temperatures can retain more volatile substances. However, the T3K3 treatment has the highest volatiles, likely due to a higher number of volatiles in the initial raw materials, resulting in more volatiles remaining after pyrolysis. And another possibility is due to the higher percentage of *Jatropha* seeds adhesive, which does not decompose sufficiently during the drying process in the oven. This remains in accordance with the SNI 01-6235-2000 standard, which requires a maximum volatile matter of 15%.

3.2.5. Fix Carbon

The results obtained from the experimental analysis are presented in Table 1, obtain recommendations for the treatment of production systems with the opportunity to produce products with adjacent fixed carbon, then test ANOVA at the threshold of significance $\alpha = 5\%$ or $\alpha = 0.05$. The metric F and Sig (*p*-value) related to the treatment of the pyrolysis temperature, the adhesive of the *Jatropha* seed, and its interaction with fixed carbon are recorded at 5.104 (0.018), 6.858 (0.006) and 1.696 (0.195). Under the threshold of statistical significance, it can be inferred that both the temperature of pyrolysis and the adhesives used in the *Jatropha* seed have a substantial impact on the fixed carbon in the bio-charcoal. Therefore, both factors have a genuine influence on fixing carbon. That means the interaction between the pyrolysis temperature and the adhesive of the distant seed gives an unrealistic influence on the fixed carbon. The DMRT post-hoc analysis was not conducted due to the absence of a significant impact on the interaction between treatment groups. For more clarity the results of ANOVA can be seen in Figure 6.

Higher fixed carbon content is associated with better bio-charcoal quality due to its positive impact on calorie values and combustion efficiency. As can be seen from Figure 6, the fixed carbon content obtained from this research ranges from 71.3 to 80.1%. It can be proven that the highest fixed carbon yield is T3K2. This highlights that the fixed carbon content in bio-charcoal is influenced by the pyrolysis temperature, with optimal carbon retention occurring at 480℃, leading to a reduction in volatiles, thereby proportionally increasing the fixed carbon. The low carbon ash and volatile content result in high fixed carbon. Conversely, high ash and volatile content lower the fixed carbon. Although the base material already has a large surface area, its adsorption capacity remains relatively low due to the presence of other compounds and tar residues that block the pores (Norhikmah *et al.*, 2021).

The increase in carbon content retained in bio-charcoal is correlated positively with its use as a solid fuel, due to increased calorie values and decreased volatile components, making it suitable for a variety of applications. Pyrolysis temperature plays an important role in determining the carbon content of biochar in accordance with the quality of SNI

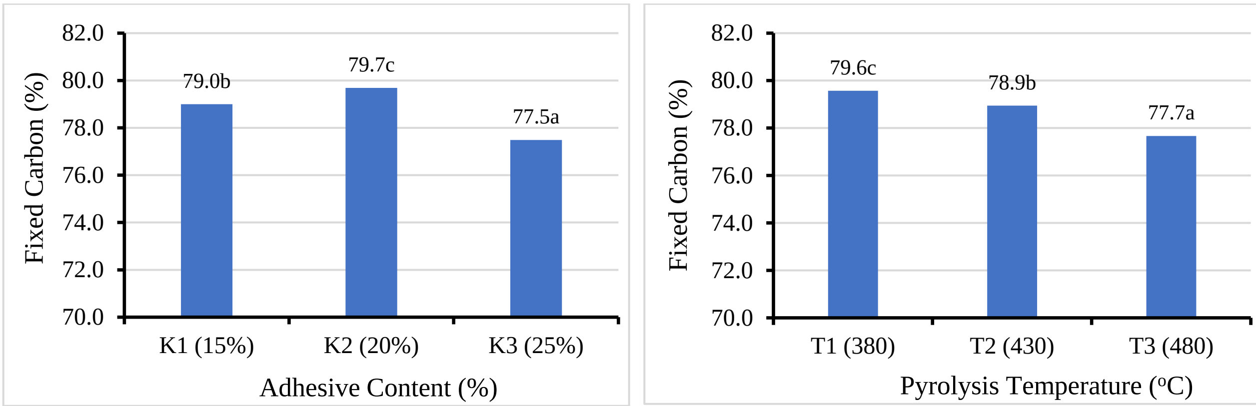

Figure 6. (a) Effect adhesive content on fixed carbon; (b) Effect pyrolysis temperature on fixed carbon (different letters correspond to a significant difference in the DMRT ($p \leq 0.05$).

01-6235-2000 in Table 1. Similarly, a study on charcoal briquettes of agricultural waste found that the highest constant carbon content of 75.9% was obtained from rubber seed shells at a pyrolysis temperature of 600 °C (Murni & Setyoningrum, 2020). Furthermore, research on the pyrolysis of date shells showed that starch-bound briquettes have superior physicochemical and fuel qualities, with the highest carbon content observed at 800 °C (Ige *et al*., 2022).

4. CONCLUSION

From the description given, it can be concluded that the interaction of pyrolysis temperature and adhesive affects the quality of bio-charcoal where high temperature and *Jatropha* seeds adhesive can improve the quality of bio-charcoal such as calorific value, moisture content, ash content, volatile matter, and fixed carbon. Higher temperatures can increase the fixed carbon content and improve the pore structure, but too high temperatures can damage the solid structure of the bio-charcoal. The presence of natural adhesives in bio-charcoal plays an important role, high protein and oil content can bind other polymers and provide complete combustion. The optimal treatment of T2K3 at 430°C and 25% adhesive concentration resulted in a caloric content of 6421 cal/g, 6.1% moisture content, 7.6% ash content, 7.7% volatile matter, and 78.7% fixed carbon. The use of ANOVA analysis method has shown that the interaction of pyrolysis temperature fluctuation and adhesive has a great impact on calorific value, and ash content. However, there are no notable impacts on the moisture content, volatile matter and fixed carbon.

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