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COMPARATIVE STUDY ON BIO-BRIQUETTE PRODUCTION USING COCONUT SHELL AND SEASHELL: EFFECTS OF SIZE, RATIO, PYROLYSIS, AND BINDER

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ABSTRACT

Briquettes are seen as a substitute for alternative fuels generated through pyrolysis. A common type of briquette is charcoal made from coconut shells. However, they have poor combustion duration and excessive combustion smoke. It is assumed that adding seashells to coconut shell briquettes can increase their quality while enhancing waste utilization as shells possess adsorption properties. Hence, this study intended to produce shells briquettes on many main factors, namely pyrolysis time, particle size, raw materials ratio, and binder concentration. The method utilized pertained to preliminary study by blending pyrolyzed coconut shell charcoal, shells, and tapioca flour. Proximate analysis was conducted using the Thermogravimetric Analysis 201 based on the American Standard Testing and Material (ASTM) 2014; and briquette calorific value was determined using the GDY-1A bomb calorimeter based on ISO 1928:2020. The best shell briquettes was found at 2.5 hours pyrolysis durations with a particle size of 50 mesh, a raw material ratio of 3:1 (charcoal : shell) and 50% binder concentration. It comprised 13.53 ± 0.23% moisture content; 39.91 ± 0.31% volatile matter content, 15.70 ± 0.07% ash content, 67.66 ± 0.68% fixed carbon content, and a calorific value of 1,942.126 cal/g. Nonetheless, the results were not ideal as the calorific value was lower than full charcoal briquettes. Therefore, to improve proximate quality and combustion efficiency, it is required to combine seashells with other materials that are higher in carbon or to modify the method.

Keywords: briquette; coconut shell; energy; pyrolysis; seashell

INTRODUCTION

Fossil fuels have been used by several countries since ancient times and it has negative impact on the environment. Onifade et al., (2021) stated that the current energy transition policy is not sufficient at driving the state’s environmental sustainability. One of the environmentally sustainability energy sources is biomass. Amrullah et al., (2022); Tchapda & Pisupati, (2014) stated that biomass is an alternative energy source that is cleaner than coal and is the only renewable carbon resource that can be directly converted into fuel. Fitriyano et al., (2023) mentioned that the utilization of biomass when processed through waste-to-energy technologies offers an alternative strategy for mitigating the impacts of an energy crisis. They also can help lower global CO_2 emissions. Unlike fossil fuels, which release carbon that has been locked underground for millions of years, biomass is part of the short-term carbon cycle (Ibitoye et al., 2022; Yu et al., 2022).

Biomass can be used as raw materials for making briquettes. Qanitah et al., (2023); Widjaya et al., (2022) stated that briquettes are the most compact and cheapest fuel that can replace fossil fuels. Converting biomass into briquettes greatly minimizes environmental impact while also extending the combustion duration (Prajapati et al., 2023; Wu et al., 2025). Several studies have been conducted to

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make briquettes from various biomasses including dried leaves (Mulyati, 2016); pine wood (Morales-Máximo et al., 2020); a mixture of organic waste and blotong (waste from sugar production) (Triasmoro et al., 2020); sago pulp (Botahala et al., 2022), a mixture of wastewater treatment plant (WWTP) sludge, fly ash and wood sawdust (Setyono & Purnomo, 2011); candlenut shells (Haurissa et al., 2021); rubber latex (Bazenet et al., 2021); coffe grounds (Qanitah et al., 2023); plastic waste (Amyranti et al., 2023); virgin coconut oil processing waste (Sudiadnyani et al., 2023); mixture of rice husks and bagasse (Putri et al., 2024); egg shells (Pater et al., 2024); areca nut shells (Febrianto et al., 2024); and coconut shells (Rianto et al., 2024).

A common type of briquette is charcoal made from coconut shells. Iskandar et al., (2019) stated that coconut shell briquette has advantages compared to other conventional solid fuels because they are non-toxic, so they have the potential to be a more environmentally friendly substitute for coal. On the other hand, coconut shell briquette also has weaknesses. Paradise et al., (2018) coconut shell briquettes exhibit limited combustion duration and generate smoke emissions that contribute to environmental pollution, so other technologies are needed in making coconut shell briquettes.

Therefore, the aim of this study was to make bio briquettes using seashell, coconut shell charcoal and tapioca flour and then characterize these briquettes. This research utilized the potential of seashells as an alternative adsorbent that is environmentally friendly in the briquettes. Mahidin et al., (2016) reported that seashell contain calcium oxide-based material which can be used as an adsorbent in fuel combustion to reduce gas emissions.

METHODS

Materials

The main components of producing bio-briquettes consisted of coconut shells, seashells, and binder. The seashells utilized were abundant waste materials naturally accumulating along the shoreline of Muncar Beach in Banyuwangi, specifically the yellowish brown Asiatic hard clam (*Meretrix meretrix* (Linnaeus, 1758)). Conversely, the coconut shells were collected at Banjar Tengah, Jembrana disposal area. Whilst the binder was made of tapioca flour.

Bio-Briquettes Production

The briquette-making procedure is based on the research conducted by Kalsum, (2016) with certain alterations, particularly in the pyrolysis duration, which was adjusted to 1.5 - 2.5 hours. The raw material ratio was also modified to 1:2:3 (coconut shell charcoal to seashells, g) to produce briquettes with enhanced density, compactness, and a higher fixed carbon content. Firstly, bio-briquettes were produced by optimizing the pyrolysis time and raw material sizes in accordance with Figure 1. To start with, the shells were cleaned thoroughly with clean tap water until no dirt remained on them. After being cleaned, the shells were sun-dried for ten hours to eliminate the moisture content. In addition, the pyrolysis equipment was employed to burn the coconut shells into charcoal for 1.5, 2, and 2.5 hours at a temperature of 300°C. The charcoal and seashells were grounded separately and then pulverized in a grinder until the charcoal and shells were smooth. To get uniform particle size, each raw material was filtered through a sieve with 50, 60, or 70 mesh. Subsequently, a mixture of tapioca flour was added to the two basic ingredients with the weight ratio of 1:2:3 (coconut shell charcoal : shells, g) with 60% tapioca flour. A cube-shaped mold (3 x 3 x 3 cm) was used to shape the briquette mixture. After two hours of oven drying at 100°C, the molded briquettes were exposed to ten hours of sun drying. Thereafter, the resultant briquettes (variations in pyrolysis duration and raw material particle size) underwent proximate analysis (moisture, ash, volatile matter, and fixed carbon contents). The sample exhibiting the highest fixed carbon content was selected for use in the second stage of briquette production, which involved variations in raw material ratio and binder concentration.

Secondly, the pyrolysis time and particle size of the first stage were used to optimize the raw material ratio and tapioca concentration parameters. The tapioca concentration ranged from 50, 60, to 70%, and the raw material ratio was varied from 1:1, 2:1, to 3:1 (coconut shell : shell, g). Following that, the proximate content and calorific value of the briquettes produced in the second stage were examined. This experiment was carried out in duplicate.

Proximate Determination

Proximate analysis for raw materials and briquettes included water, ash, volatile matter, and fixed carbon contents. The content was determined using a thermogravimetric analysis (TGA) instrument. The application of the TGA was in accordance with American Standard Testing and Material (ASTM) E1131-08 (ASTM, 2014). At first, an empty cup was first dried for fifteen minutes in a TGA machine. Next, a 1 g sample was placed inside the dried cup to be further analyzed for about 8 hours. The results of

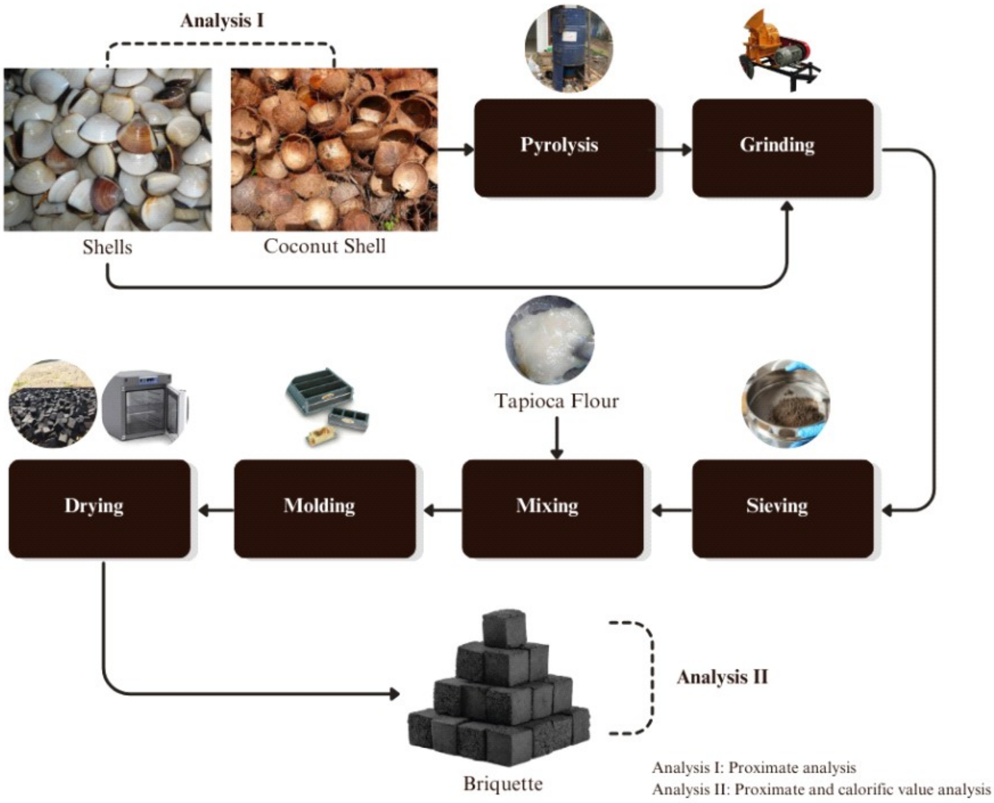

Figure 1. Flow Chart of Briquette Production

proximate analysis were then showed up on the computer screen.

Caloric Value Determination

The gross calorific value of the briquette sample with the highest fixed carbon content was determined using a GDY-1A Bomb Calorimeter. The analysis refers to ISO 1928:2020 (ISO, 2020) concerning solid mineral fuels - determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value. At first, water was added to the bomb until it reached the maximum capacity. Next, a single gram of fuel was introduced into the bomb calorimeter for automated testing. Eventually, the result was shown in the instrument.

Statistical Analysis

The results of the experiments were reported as mean ± SD. The Statistical Package for Social Sciences (SPSS), Version 22 (SPSS Inc., Chicago, Il, USA), was used to conduct statistical analyses. One-way analysis of variance (ANOVA) was used to assess the results. Further analysis was performed using Tukey's multiple range test. The substantial variance is shown by a value of $P < 0.05$.

RESULTS AND DISCUSSION

Results

Table 1 presented summarizes the comparison of various parameters across three different materials:

Table 1. Characteristics of raw materials

Parameter (%)	Coconut Shell	Charcoals	Shells
Moisture content	18.86 ± 0.36	7.64 ± 0.61	0.21 ± 0.24
Volatile matter content	61.36 ± 1.07	18.76 ± 0.42	43.87 ± 0.68
Ash content	1.06 ± 0.55	1.87 ± 0.79	55.56 ± 0.46
Fixed carbon content	18.72 ± 3.11	71.73 ± 1.27	0.27 ± 2.02

coconut shell, charcoals, and shells. These parameters include water, volatile matter, ash, and fixed carbon contents, each providing insight into the composition of the materials for producing bio-briquettes.

Firstly, the moisture content of the three materials shows a notable different. The coconut shell had a relatively high-moisture content of 18.86 ± 0.36%, which was much higher than that of charcoals, at 7.64 ± 0.61%. Shells exhibited a remarkably low moisture content of only 0.21 ± 0.24%. This indicates that coconut shells retained more moisture compared to the other two materials. On the other hand, the volatile matter content, which often influences the combustion properties of the material, was highest in the coconut shell at 61.36 ± 1.07%. This was substantially higher than the charcoals, which had a volatile matter content of 18.76 ± 0.42%. Shells, while higher than charcoals, still fell below coconut shells, with a volatile matter content of 43.87 ± 0.68%.

In addition, the ash content, which is an indicator of the non-combustible residue left after burning, was lowest in coconut shell at 1.06 ± 0.55%. Charcoals had slightly higher ash content at 1.87 ± 0.79%, whereas shells had a higher ash content at 55.56 ± 0.46%. This suggests that shells would leave much more residue upon combustion compared to coconut shell and charcoals. Whereas, the fixed carbon content, which represents the carbon available for combustion after volatile materials are released, varied greatly among the materials. Charcoals had the highest fixed carbon content at 71.73 ± 1.27%, indicating their higher efficiency as a fuel source. In contrast, coconut shell had a lower fixed carbon content of 18.72 ± 3.11%, and shells showed the lowest at 0.27 ± 2.02%. This reveals that charcoals contributed to the most carbon in the briquettes.

Effect of Pyrolysis Time and Raw Material Size

The charts in Figure 2 represent the proximate analysis results of bio-briquettes made from charcoals and seashells with tapioca flour as the binder. These charts assess the effect of different raw material sizes (50, 60, 70 mesh) and varying pyrolysis times (1.5 hours, 2 hours, and 2.5 hours) on key characteristics of the bio-briquettes: water, volatile matter, ash, and fixed carbon contents.

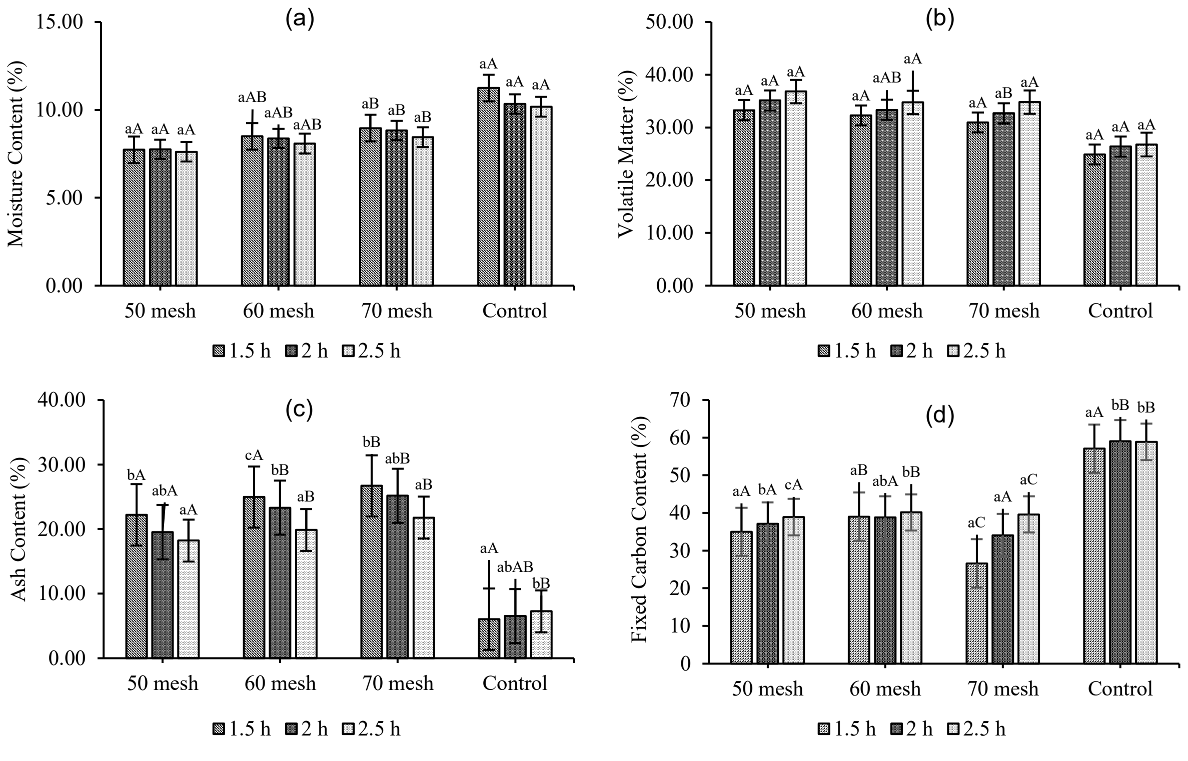

Figure 2. Proximate results of bio-briquettes at different pyrolysis time and raw material size. Average values are shown (n = 2). Different lowercase letters (a, b, c) are significantly different (P < 0.05) in various pyrolysis time, at the same particle size. Different uppercase letters (A, B, C) are significantly different (P < 0.05) in the same pyrolysis time, at different particle size. (a) Moisture content; (b) Volatile matter content; (c) Ash content; (d) Fixed carbon content

The moisture content tended to insignificantly decrease as the pyrolysis time increasing across all mesh sizes (P > 0.05). The bio-briquettes with a larger particle size (50 mesh) generally had lower moisture content, particularly at longer pyrolysis times (2.5 hours). Prolonged combustion reduces moisture content, possibly due to the extended heat exposure driving off moisture. The larger particle size may release more moisture initially due to less surface area exposure compared to finer particles (60 and 70 mesh). The large particle size also produced larger cavities, allowing water to easily escape from the briquettes. Conversely, because only coconut shell—which has the greatest moisture content of any raw material—was utilized, control had an extremely high-moisture content compared the others (P > 0.05). Moisture content negatively affects the calorific value of briquettes, as higher moisture levels require additional energy for water evaporation during combustion, thereby reducing the net energy output. Thus, briquettes with lower moisture content and higher calorific value are considered superior for fuel applications. Whilst the volatile matter content showed a slight increase as the pyrolysis time greater for all particle sizes, but the differences were not as pronounced (P > 0.05). There was a slight variation between mesh sizes, with 70 mesh tending to have slightly lower volatile matter content, especially at shorter pyrolysis times. Extended pyrolysis time might cause more volatile compounds to escape, hence the increase in volatile matter. The finer particles (70 mesh) may have a lower volatile content due to more efficient combustion. Additionally, because of the briquettes' increased solidity and compactness due to the small particle size, there was typically less volatile stuff throughout the burning process.

Ash content generally declined with pyrolysis time, particularly noticeable at the 2 - 2.5-hours mark across 60 mesh sizes (P < 0.05), whereas the 70-mesh size tended to have a slightly higher ash content overall (P > 0.05). Longer pyrolysis times likely resulted in more complete combustion, leaving behind less ash as a residue. Rougher mesh sizes may lead to more ash content as more of the material was fully burned. As a result of the absence of shellfish in the briquettes production, the control had a lower ash content. Whilst nearly all raw materials can be transformed into fixed carbon in the control to ensure optimal combustion without producing a large amount of ash (P > 0.05). Concurrently, fixed carbon content escalated with pyrolysis time at all raw material sizes, with the highest content observed at 2.5 hours. The 60-mesh size were prone to show higher fixed carbon content, particularly at the 2-hour and 2.5-hour marks (P < 0.05). The increase in fixed carbon with time suggested that prolonged combustion removed more volatile components and moisture, leaving behind a higher percentage of carbon. Fine particles (60 mesh) resulted in better combustion efficiency, hence higher fixed carbon content.

Overall, the parameter employed for the optimization procedure in the following stage is the variable that yields the highest fixed carbon content. This is so because the primary determinant of a fuel's ability to burn through to the end is its fixed carbon content. The highest fixed carbon content was achieved at this point with a burning period of 2.5 hours and a particle size of 60 mesh. Comparing this briquette to SNI 01-6235-2000, which has briquettes with a calorific value of at least 5000 cal/g, the calorific value of 1,942.126 cal/g was still low (NSAI, 2000).

Effect of Raw Material Ratio and Binder Concentration

The moisture content of the bio-briquettes was generally low, ranging from 10% to 15%. There was no significant difference in moisture content among the different raw material ratios or binder concentrations (P > 0.05). At a 3:1 raw material ratio—where the coconut shell material made up the greatest portion—the maximum moisture content was achieved when the binder concentration was supplied at 70% (Figure 3). This is because the coconut shell and binder both had extremely moisture contents, which gave the briquettes moisture. In contrast, the control has a comparatively low moisture content due to the addition of a 60% binder concentration without the addition of shells (P > 0.05). Volatile matter content varied from 32% to 48%, with a general trend of decreasing volatile matter with declining charcoal content and binder concentration (P < 0.05). A lower proportion of charcoal and binder likely resulted in more complete devolatilization during combustion, leading to a lower volatile matter content in the bio-briquettes.

Ash content ranged from 15% to 27% where the content declined when the charcoals reached maximum concentration (P < 0.05). The variation in ash content was likely due to the inherent variability in the ash content of the charcoal and seashell raw materials. Meanwhile, fixed carbon content rose up from 20% to 67% with increasing charcoal content (P < 0.05) and decreasing binder concentration (P < 0.05). This is consistent with the trend in volatile matter, as the decrease in volatile matter is accompanied by a corresponding increase in fixed carbon. A higher proportion of charcoal allowed for more complete carbonization, resulting in a higher fixed carbon content in the bio-briquettes.

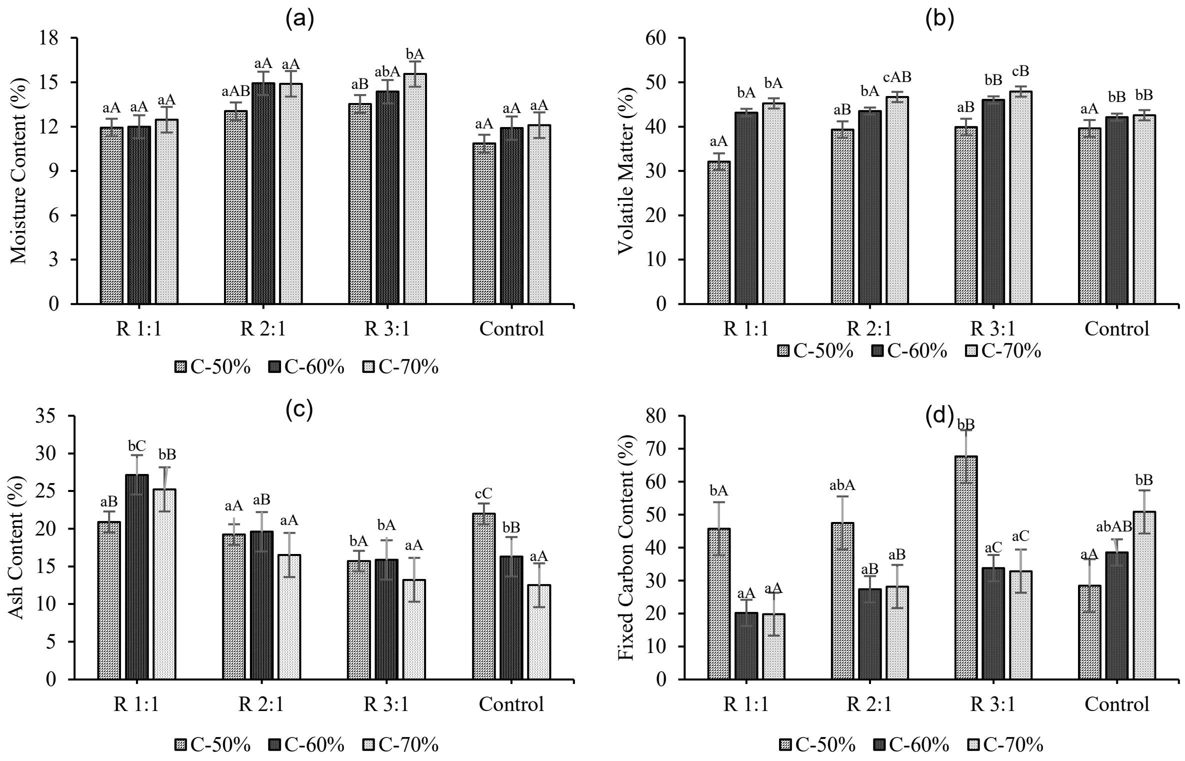

Figure 2. Proximate results of bio-briquettes at different raw material ratio and binder concentration. Average values are shown (n = 2). Different lowercase letters (a, b, c) are significantly different ($P < 0.05$) in the same raw material size, at different binder concentration. Different uppercase letters (A, B, C) are significantly different ($P < 0.05$) in various raw material size, at the same binder concentration. (a) Moisture content; (b) Volatile matter content; (c) Ash content; (d) Fixed carbon content

With 50% binder added and a ratio of 3:1, briquettes with the highest overall fixed carbon content were produced. Compared to SNI 01-6235-2000 (NSAI, 2000), which specifies that the minimum calorific value of fuel is 5000 cal/g, the calorific value produced in this briquette was only 1,942.126 cal/g.

Discussion

Effect of Pyrolysis Time and Raw Material Size

Moisture content is the ratio of a material's initial weight to the amount of water lost throughout the drying stage of the sample (Asfar et al., 2023; Sanchez et al., 2022a). Since it influences both the high and low calorific value, moisture content is one of the elements used to determine the quality of briquettes (Pratama et al., 2016). Figure 2a provides information about the moisture content of multiple samples at different pyrolysis time and particle sizes. The control briquette (made without employing shells) with a burning time of 2.5 hours and a particle size of 60 mesh had the highest moisture content, with a value of 11.25 ± 0.29% ($P > 0.05$). In contrast, the briquette with the lowest moisture content value, which was pyrolyzed for 2.5 hours and had a particle size of 50 mesh, had a value of 7.62 ± 0.16%. Improper drying of the raw materials resulted in briquettes with varied moisture contents, depending on how much water is present in the feedstock. According to Ramadha et al., (2023), the moisture content decreases with increasing temperature and pyrolysis time. The moisture content obtained from samples burned for 1.5 hours was much larger than that of samples burned for 2-2.5 hours. Other than that, the denser and more compact briquettes at small particle sizes made it harder for the moisture content to escape. In contrast to briquettes with smaller spaces between particles, water will therefore evaporate more readily from the pore gaps, resulting in a smaller amount of water remaining (Jaswella et al., 2022; Priyanto et al., 2018). These findings are consistent with a study by Pane et al., (2015) that used tapioca flour binder to create briquettes out of palm fronds and lime. The moisture content in this investigation ranged from 6.6% to 8.3%. Conversely, the moisture content in these results was significantly higher than in previous research. By using binders made of tapioca flour and sago as well as a combination of bamboo charcoal and coconut shells (60 mesh) as raw materials, Syaiful & Tang, (2020) were able to get a moisture content ranging from 3.3–3.7%. In the meantime, the moisture content of briquettes manufactured from pure coconut shell charcoal and wheat flour as a binder ranged from 3.1-3.6% (Kusmartono et al., 2021). This can demonstrate that the moisture content is significantly affected by the presence of biomass raw materials, as in this study, the addition of shells resulted in briquettes with a high- moisture content. Additionally, while storing briquettes in damp and open areas, environmental variables such as moisture content may also have an impact.

Other than water, volatile materials are chemicals that can evaporate during the decomposition of compounds still present in the briquettes (Ristianingsih et al., 2015). A fuel emits more smoke the more volatile matter it contains (Iskandar et al., 2019). The amount of smoke generated by fuel can be calculated using the level of volatile chemicals. Figure 2b shows the value of the volatile matter levels at different particle size and pyrolysis time. The briquettes with a burning time variable of 1.5 hours and a particle size of 70 mesh had the lowest volatile matter, with a value of 30.95 ± 0.14%. When the shell briquettes burned for 2.5 hours and had a particle size of 50 mesh, they had the maximum level of volatile matter, with a value of 36.82 ± 0.56%. Inadequate pyrolysis or combustion results in a higher volatile matter level. According to Syaiful & Tang, (2020), there is a direct correlation between temperature and charring time where greater temperatures and time lead to the waste of more volatile matter content. In contrast to the control, the inclusion of shells in this study also resulted in a higher volatile matter concentration due to shells had a comparatively high volatile matter concentration. The findings also indicate that the concentrations of volatile chemicals can be impacted by the particle size used in the briquette-making process. According to Sudiro, (2014), lower concentrations of volatile compounds are obtained in briquettes with smaller particle sizes. This is since briquettes with smaller pores and higher compressive strengths have smaller particle sizes (Iriany et al., 2016). Compared to briquettes derived from rice husks and tapioca flour binders, which had volatile matter contents ranging from 46-48%, this finding had a lower volatile matter content (Asfar et al., 2023). In contrast to Sugiharto & Firdauz, (2021) that utilized bagasse and rice husks as source materials, there is a striking similarity in the volatile matter level (31-36%). High volatile matter content briquettes typically burn easily and ignite quickly. But since most of the briquettes' bulk is consumed as gas, this also implies that they will burn through more quickly. On the other hand, low volatile matter briquettes tend to be denser and hold heat longer. It might take longer for this kind of briquette to ignite.

Ash content is a mineral that cannot be burned after the combustion process. The substance that remains after combustion and no longer contains carbon components is known as ash content (Fatriani et al., 2018). Figure 2c shows that the control briquette (without the use of shells), with a burning time of 1.5 hours and a particle size of 50 mesh, had the lowest ash content, with a value of 6.04 ± 0.09%. On the other hand, the shell briquette, which burned for 1.5 hours and had a particle size of 70 mesh, had the greatest ash percentage, at 26.71 ± 0.64%. Inadequate burning time is the cause of ash content. Uncooked charcoal, which retains biomass constituents, is the result of poor pyrolysis, according to Sudiro, (2014), hence resulting in briquettes with a high ash content. When pyrolysis proceeds adequately, maximum charcoal will be produced, lowering the ash content (Junary et al., 2015). Additionally, because of its high mineral concentration, adding shells also tends to result in a high ash content which can be observed in control. The ash contents of briquettes can also be influenced by particle size. The burning process will result in briquettes with larger particle sizes producing more ash than briquettes with smaller particle sizes since the latter will be more easily carried away by the wind (Iriany et al., 2016). This is consistent with research by Kusmartono et al., (2021), which found that the amount of ash created increased with the size of the particles. However, with levels ranging from 1 to 8%, the ash concentration in this study was higher than that of pure coconut shell briquettes (Kusmartono et al., 2021). This is because of the addition of shells, which have a very high mineral content of 43.87 ± 0.68% (Table 1).

According to Kurniawan et al., (2019), fixed carbon is the proportion of carbon that remains after burning. Fixed carbon is a component of the carbon fraction (C) that is present in materials other than water, ash, and volatile matter, according to Iskandar et al., (2019). As a result, the ash and volatile matter contents of briquettes affect the existence of fixed carbon in briquettes. Particle size of the input material affects fixed carbon. The fixed carbon content rises with decreasing particle size since higher fixed carbon and less evaporated material are present in briquettes with narrower pores (Sudiro, 2014). Reducing particle size led to improvements in briquette density, mechanical strength, hardness, durability, impact resistance, and burning duration (Sanchez et al., 2022; Srisang et al., 2017). Additionally, finer biomass particles produced briquettes with smoother surfaces, slows the combustion rate and extends the burning time — a desirable quality, especially for commercial applications (Sanchez et al., 2022). Furthermore, the temperature and duration of pyrolysis can have an impact on the fixed carbon content. The fixed carbon concentration tends to decrease with increasing temperature (Ramadha et al., 2023). In this investigation, the control briquette had a higher fixed carbon content. The control briquette, which burned for two hours and had a particle size of 60 mesh, had the maximum carbon content, as shown by Figure 2d, with a value of 59.02 ± 0.01%. While the briquette, which burned for 1.5 hours and had a particle size of 70 mesh, had the lowest fixed carbon concentration, which was 26.61 ± 0.87%. This is because the control did not contain any additional shells because most of the shellfish content is made of calcium carbonate ($CaCO_3$), which results in low fixed carbon and less efficient burning. Comparing the fixed carbon content in this study to briquettes composed entirely of coconut shells, which had a composition of 51-63%, it was substantially lower (Syaiful & Tang, 2020). This is because the carbon content of the briquettes was decreased by the mixing of shells; in the shells, there was only 0.27 ± 2.02% carbon, compared to 71.73 ± 1.27% in coconut shell charcoal (Table 1).

According to Ekayuliana & Hidayati, (2020), heat is energy that is transported because of a system's environment having a different temperature. According to Ridhuan & Suranto, (2017), the primary attribute of a fuel is its calorific value, which expresses the quantity of heat it contains. A briquette's quality increases with its calorific value (Pane et al., 2015). High-fixed carbon content briquettes were the ones that underwent calorific value analysis. With a minimum calorific value of 5000 cal/g, the SNI 01-6235-2000 requirement was not met by the calorific value of 1,942.126 cal/g that was produced. This is due to the briquette's poor calorific value caused by the addition of shells. While there is very little carbon in shells, most of the material is made up of calcium carbonate ($CaCO_3$) and calcium oxide (CaO), or lime. Shells lowered the calorific value hence was unable to produce fixed carbon as a result.

Effect of Raw Material Ratio and Binder Concentration

The moisture content of multiple samples in distinct variants is known to have varying values, as shown by Figure 3a. At 10.86 ± 2.49%, the control group had the lowest moisture content, whereas briquettes made of a 3:1 ratio of coconut shells to mussel shells and 70% tapioca flour had the highest moisture content at 15.55 ± 0.08%. The moisture content rises with the addition of tapioca flour, as reported by Ramdani et al., (2017). The investigation found that the briquettes with the highest tapioca flour addition also had the highest moisture content. Because coconut shell raw materials include a significant amount of water, the addition of coconut shell charcoal also led to a high- moisture content in the briquettes. According to Kusmartono et al., (2021), the moisture content of the briquettes increases with the concentration of the binder. A change in the concentration of wheat flour from 1 to 5% resulted in an increase in the moisture content of the coconut shell briquettes. Higher moisture content in the biomass also leads to greater energy loss during combustion, as more energy is consumed to evaporate the water, thereby reducing the calorific value of the bio-briquettes (Ifa et al., 2020).

A metric used to quantify the number of materials that evaporate during heating or the substance that can evaporate due to the remaining components in charcoal breaking down other than water is known as the volatile matter (Song et al., 2020; Susmanto et al., 2020). Figure 3b illustrates how the addition of tapioca flour adhesive and coconut shell charcoal raised the volatile matter content of the briquettes. The highest volatile matter content was found 47.93 ± 0.30% (3:1, 70%), whilst the lowest accounted for 32.14 ± 0.31% (1:1, 50%). This is because the tapioca flour adhesive that was added to the briquette did not go through pyrolysis; as a result, the volatile matter content increased due to the volatile chemicals such CO, CO_2, H_2, and CH_4 that were formed by the adhesive (Sulistyaningkarti & Utami, 2017). Furthermore, binder addition tends to raise briquettes' volatile matter, according to Pane et al. (2015). The study found that adding a different amount of binder (between 0 and 30%) increased the volatile matter content of palm frond briquettes by 31-53%. The rise in the briquettes' volatile matter concentration was likewise impacted by the inclusion of shells. Shells contain calcium carbonate ($CaCO_3$), which can break down into calcium oxide (CaO) (Kurniawan et al., 2019). The briquettes' high volatile matter content may be impacted by the contents of the shells. In addition to being impacted by temperature and duration during the carbonization process, flaws in the process can also result in briquettes' volatile matter content (Syaiful & Tang, 2020).

Since ashless fuel has higher combustion qualities, ash content is one of the key factors in establishing the quality of briquettes. According to Fatriani et al., (2018), ash content is the material left from combustion that has no calorific value and no longer includes carbon components. The ash content results indicate that the briquettes' increased ash content is a result of the material's composition and adhesive concentration interacting with one another which was obtained at 1:1 and 60% (27.16 ± 0.17%). Iskandar et al., (2019) state that when the adhesive content rises, so does the ash content. This is because the adhesive that was utilized included ash. The amount of ash created increases with adhesive content. When more tapioca flour was added, the amount of ash in palm frond briquettes also rose, rising from 10 to 31% (Pane et al., 2015). This is so because the extra tapioca flour adhesive already contains inorganic components with corresponding ash content percentages, which raise the briquettes' own ash content percentage.

One of the factors that determines briquette quality is fixed carbon content; the higher the fixed carbon content, the higher the calorific value that results from producing high fixed carbon briquettes. Briquettes with a high fixed carbon content also burn with less smoke (Sulistyaningkarti & Utami, 2017). This is in line with previous studies indicating that biofuels with elevated fixed carbon levels burn more efficiently and generate less ash and exhaust emissions (Wulandari et al., 2024). The findings indicate that the briquettes' carbon content is influenced by the interplay between the material's composition and the adhesive's concentration as shown in Figure 3d. Pane et al., (2015) state that the briquettes' carbon content decreases when the number of other materials—such as binder, water, and lime—increases. The highest carbon content was achieved at 60 mesh and 2.5 hours pyrolysis accounting for 67.66 ± 0.68%. Meanwhile, the lowest reached 19.78 ± 0.64% at 70 mesh and 1.5 hours pyrolysis. This is since briquettes with large proportions of extra components have higher levels of ash and volatile matter, which lower the amount of bound carbon. Shellfish-infused briquettes exhibit variations in the bound carbon content value. The water, ash, and volatile matter content of the resulting shells briquettes have an impact on the variable bound carbon value.

The quantity of heat energy that a fuel releases or produces during its combustion process is known as its calorific value. A briquette's quality increases with its calorific value (Jannah et al., 2022). The shell briquettes with the highest fixed carbon content were the ones that underwent calorific value analysis. The calorific value is highly influenced by the carbon content. Syaiful & Tang, (2020) assert that the calorific value increases with increasing carbon content. The briquettes yielded a calorific value of just 1,942.126 cal/g. The obtained calorific value is less than the minimum calorific value of 5000 cal/g required by SNI 01-6235-2000. The addition of binder had an impact on this as well. The briquettes' moisture content will rise due to an improper adhesive concentration, lowering the calorific value that results. This is consistent with study findings (Bazenet et al., 2021) that indicate a reduced calorific value is displayed by adhesives that are more heavily combined with charcoal. This is due the briquettes' calorific value is utilized to evaporate the water that has been trapped inside of them before creating heat that is employed for burning (Jannah et al., 2022).

Previous Study

In comparison to earlier studies, Table 2 demonstrates that the briquettes made by adding shells and coconut shell charcoal had a much higher moisture content (more than 8%). Higher moisture content requires more energy to vaporize the water, reducing the overall heating value of the briquettes, leads to mold, decay, and structural integrity issues during storage, and is more difficult to handle. The volatile matter is also higher than 30% which is good to quickly burn and produce a flame, but they can contribute to particulate matter emissions if not properly controlled. Other than that, the as content is pretty high (more than 13%) that can reduce the overall heating value and clog grates or furnaces. Some types of ash can contain harmful substances that contribute to air pollution. Whilst a lower fixed carbon content (less than 70%) was also achieved. As a result, the calorific value was extremely low and did not meet the fuel criteria. Fixed carbon is the non-volatile portion of the fuel that remains after the volatile matter has been released. It burns slowly and produces a steady heat output. Higher fixed carbon content generally results in a longer burn time and lower heat release rate.

In comparison with previous studies, the briquettes produced in this study exhibited distinct characteristics due to the incorporation of seashells as an inorganic component. While the calorific value of this study (1,942.126 cal/g) was lower than those reported by Ifa et al., (2020); Nurhamida et al., (2023); Rindayatno et al., (2022) who achieved values above 5,400 cal/g, the difference can be attributed to the high mineral content of seashells in this study, which contributed to a significantly higher ash content (67.66%). This contrasts with the lower ash levels (7–21%) found in studies that used purely organic materials such as palm shells or charcoal powder.

Despite the higher ash content, the fixed carbon content in this study remained relatively stable, indicating that the addition of coconut shell still

Table 2. Comparative Study of Briquettes Production

Raw Material	Binder Used	Particle Size	Pyrolysis Time and Temperature	Quality		References
				Parameter	Value	
Coconut shell, seashell	Tapioca flour (50%)	50 mesh	300°C, 2.5 h	– Moisture content – Volatile matter content – Ash content – Fixed carbon content – Calorific value	– 13.53 ± 0.23% – 39.91 ± 0.31% – 15.70 ± 0.07% – 67.66 ± 0.68% – 1,942.126 cal/g	This study
Palm shell and coconut shell	Tapioca flour (6 and 8%)	20 mesh	500°C, 2 h	– Moisture content – Ash content – Flying substance content – Calorific value	– 6.5% – 7% – 21% – 5,448.1737	(Nurhamida et al., 2023)
Palm Oil (*Elais guineensis Jacq*), Midrib Charcoal Powder	Tapioca flour	60 mesh	400°C	– Density – Moisture content – Compressive strength – Volatile matter content – Ash content – Fixed carbon – Calorific value	– 0.574 g/cm^3 – 4.504% – 80.451 kg/cm2 – 37.400% – 7.800% – 54.800% – 5,623 cal/g	(Rindayatno et al., 2022)
Corn cobs and rice husks	Tapioca flour (40 g)	24 mesh	105°C, 24 h	– Moisture content – Particle loss – The longest burning time	– 47,64% – 0,77 % – 113 min	(Binar, 2021)
Cashew nut shell waste	Tapioca flour and ethanol (50:50%)	70, 140, 200 mesh	350°C,	– Moisture content – Ash content – Flying substance content – Calorific value	– 5.3% – 4.96% – 17.16% – 72.62% – 29.49 MJ/kg	(Ifa et al., 2020)
Mahogany rind	Tapioca flour (25%)	-	100°C, 9 h	– Moisture content – Ash content – Volatile matter content – Fixed carbon content	– 2.7731% – 7.4227% – 14.2192% – 75.5850%	(Indrawijaya et al., 2020)
Coconut shell	Rubber sap (15 g, 25 g, 35 g)	50 and 80 mesh	105°C, 3 h	– Moisture content – Combustion rate – Caloric value	– 6,4 - 8,4% – 0.052-0.07 g/min, – 26,651 cal/g for 50 mesh – 29,327 cal/g for 80 mesh	(Muhammad et al., 2018)

provided sufficient combustible carbon. This suggests a trade-off between utilizing waste materials like seashells and maintaining high energy output. However, this approach introduces a novel formulation that addresses waste management while still producing a functional solid fuel, which is particularly relevant for sustainable bioenergy solutions.

CONCLUSION

Based on the findings, the optimal shell briquettes were discovered after 2.5 hours of pyrolysis, with a particle size of 50 mesh, a raw material ratio of 3:1 (charcoal:shell), and a 50% binder concentration. The moisture content was 13.53 ± 0.23%, the volatile matter content was 39.91 ± 0.31%, the ash content was 15.70 ± 0.07%, and the fixed carbon content was 67.66 ± 0.68% ($P < 0.05$), respectively, whilst the calorific value was only 1,942.126 cal/g. It can be inferred that adding shells to coconut shell charcoal briquettes cannot enhance the briquettes quality because the water, ash and volatile matter contents were still high; in contrast, the fixed carbon content and calorific value were relatively low. In the future, the use of various biomass, the duration of the briquette drying process, and the pressure during briquette formation are thus examples of process modification and variable optimization. Moreover, as shells may absorb particles, their addition in the future could be more applicable to lower the number of emissions from combustion, negating the necessity for exhaust gas monitoring throughout the combustion process.

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