**ASSESSMENT OF DEVELOPED COCONUT *(Cocos nucifera)* SHELL-BASED CHARCOAL**

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**ABSTRACT**

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| **Aims:** This study was conducted to explore the potential of utilizing coconut shells as an eco-friendly alternative to commercial charcoal.  **Study design:** The study employed an experimental research design, comparing the two charcoal types via laboratory testing and manual testing.  **Place and Duration of Study:** The study was conducted from January to March 2025, in Brgy. Casisang, Malaybalay City, Bukidnon, Philippines.  **Methodology:** Mature, dry coconut shells were purposely sampled from the local markets of Malaybalay City. Cleaning and air drying proceeded for about 5-7 days to reduce the moisture content. Carbonization took place according to traditional practice using local charcoal makers. That is, the burnt shells were put in a covered pit and ventilated through a bamboo tube. After 2-3 hours of carbonization, the shells were crushed, sifted, and added to a cornstarch-water binder. The mixture was then molded using a metal tube and sun-dried for about 7-14 days before testing.  **Results:** The charcoal product showed higher ash (5.8%) and moisture contents (8.0%) as compared with the commercial charcoal (2.5% and 5.3%, respectively). The volatile matter was 24.5% which may have led to a faster ignition time of 5.63 seconds compared to 11.00 seconds for the commercial sample. On the contrary, it had a relatively lower fixed carbon (61.7%) and bulk density (110 g/L), as compared to the commercial variant, which had 71.9% fixed carbon and 321 g/L bulk density, thus indicating comparatively lower combustion energy efficiency. The pH of the developed charcoal was measured at 8.85, less alkaline than the commercial sample (9.91), possibly influencing its performance in nonfuel applications.  **Conclusion:** Coconut shell charcoal has a fast ignition time due to its high volatile content; however, because of lower fixed carbon and density, it may not be very effective in terms of energy utilization. Potential improvements may allow it to become an eco-friendly fuel alternative. |

*Keywords: Alternative energy, Biomass energy, Carbonization process, Charcoal analysis, Combustion properties, Coconut shell charcoal, Fuel efficiency, Sustainable fuel*

**1. INTRODUCTION**

Charcoal is a fuel source that is used around the world to cook or heat certain foods or objects and is particularly used in developing countries such as the Philippines. To elaborate, charcoal is the impure form of graphitic carbon which can be obtained as a residue when carbonaceous material is partially burned (Augustyn, 2024). The demand for charcoal has had a great contribution to the deforestation of trees in many regions as production relies on the cutting of trees, which leads to a major loss of biodiversity and the destruction of the habitats in which a multitude of species reside (Evans, 2024). Only about 5 to 10% of the coconut husks are currently recycled due to a lack of technical and logistical means, with the production of these coconuts generating nearly 5 million tons of organic waste each year in just the Philippines alone (Kyriazopoulos, 2022). Therefore, utilizing coconut shells as a charcoal alternative can lessen the strain on the environment regarding deforestation for charcoal production or improper disposal of coconut waste.

The demand for charcoal is not only limited to a specific country or nation, and it can be seen that charcoal is in need throughout the world as the global charcoal market was valued at 8.04 billion dollars in 2023, which was expected to rise from 8.38 billion dollars in 2024 to 11.37 billion dollars by 2025 (Skyquest, 2024). Moreover, the widespread use of charcoal has led to a multitude of problems for the environment, such as the release of pollutants, which is stated to result in significant negative impacts on air quality and human health. (Shen et al., 2015), as forest degradation caused by charcoal production is known for it is difficult to monitor and is commonly overlooked (Sedano et al., 2016). Additionally, restraining the use of charcoal could have prevented 79% of the CO2 emitted from steel production between 2000 and 2007, which shows the impact of charcoal use on the environment (Sonter et al., 2015). Moreover, Kouadio et al., (2025), found that activated carbon from coconut shell could remove up to 77% of the contaminant from water systems: 2,4-dichlorophenoxyacetic acid, a typical agricultural pollutant. Thus, this shows that coconut shell waste has a lot of favorable environmental and resource potential.

However, with the detrimental effects of charcoal production becoming more and more widespread, an eco-friendly variant of charcoal produced from waste materials could provide a more effective solution for the conservation of the environment. Coconut shell waste is another problem that is proving more prevalent over the years with coconut production increasing each year. Coconut shells in some regions tend to just end up as waste which generates negative economic and environmental issues (Biggs et al., 2015). As observed, coconut farming in tropical regions, such as Asia and the Pacific, plays an important role in producing coconuts worldwide, with considerable contributions from the Philippines, Indonesia, and India (Pham 2016). To elaborate, out of the top 5 rankings for countries that are coconut producers, the Philippines comes in as the top 2, producing around 15 million tons worth of coconuts, yet less than 25% of these coconuts are recycled or repurposed (Gordon & Jackson, 2016).

With the aforementioned issues regarding waste management and harmful environmental effects, there are several benefits of utilizing coconut shells as an alternative to conventional charcoal production; it is necessary to begin conducting studies on coconut-shell charcoal and its potential in the area of further environmental concerns and as a sustainable alternative to commercial charcoal made from deforestation. This study will then focus on feasibly using coconut shell charcoal from the following carbonization process, energy efficiencies, and associated environmental benefits. The study also covers some of the economic and ecological benefits of giving new life to coconut shells, such as clearing agricultural waste, averting deforestation, and supplying a viable and eco-friendly charcoal alternative. Potentially, with the possibility to compete against commercial charcoal products, such coconut shell charcoal can assist regions like the Philippines in the transition toward sustainable energy production while minimizing waste and greenhouse gas emissions.   
  
**2. METHODOLOGY**

**2.1 Research Design**

This quantitative research employed a Research and Development design as the objective of this study is to experiment and analyze, develop, test, and refine the coconut shell-based charcoal and compare its properties with commercial charcoal. This design is used when a clear comprehension of the relationship between variables is desired that goes deep into the details surrounding why and how some treatments affect outcomes which includes a gathering of literature and analysis, formulation of objectives, development and testing of the product, and collecting data for revisions (Gustiani, 2019). The researchers conducted experiments to test the effects of developed biodegradable coconut-based charcoal compared to commercial charcoal. The research and development design is suitable for this study as it fits within the scope of this study, which is intended for experiments and applied product development, for it, as defined, would involve testing and developing the coconut-based charcoal to test the feasibility and benefits of this product to the environment. The initial development phase would include carbonization and physical testing of the coconut shell charcoal. Data gathering and analysis will follow for performance comparison with conventional charcoal.

**2.2. Entry Protocol**

Prior to conducting the research, letters were prepared to ensure proper permissions and consent of all parties involved to officially permit the testing of the developed biodegradable coconut-based charcoal compared to commercial charcoal within Casisang, Malaybalay City, Bukidnon. A formal letter of request was given to seek permission to test coconut-based charcoal in the specified location. The formal letter was an outline of the objectives, scope, and duration of the research. A formal letter of request was also given to the property owner of the land where the research was conducted to ensure that their consent was given to begin performing the study at the location.

**2.3. Locale Of The Study**

The study was conducted within Malaybalay City, Bukidnon, Philippines. The collection of *C. nucifera* samples was done at Malaybalay City's Public Marketplace in Brgy. 9, Malaybalay City, Bukidnon, among the local vendors that had coconut shell wastes. Once the samples were prepared for the production of coconut shell-based charcoal, the samples were taken to Bgry. Casisang, Malaybalay City, Bukidnon for the production process. The study was conducted from January to March 2025 at Brgy. Casisang, Malaybalay City, Bukidnon, Philippines. The study was conducted from January to March, 2025 at Brgy. Casisang, Malaybalay City, Bukidnon, Philippines. The timeline would be 2 days collection of coconut shells from local market of Malaybalay City, 2 days cleaning of coconut shells, 7 days drying of coconut shells, 3 days carbonization of coconut shells, then later on proceeded to molding. Situated in the capital of Bukidnon province in the Philippines, Brgy. Casisang offers an environment well-suited for the development and testing of coconut shell-based charcoal. The favorable climate and local conditions make it an ideal setting for the design and development and even testing of the burning duration and other metrics. The study aims to benefit the farmers and communities within the Philippines by providing more eco-friendly, sustainable, and reusable charcoal and hopefully provide valuable insights into the effects of charcoal and its environmental impact.

Figure 1. Map of the Sampling Site Malaybalay City, Bukidnon



Figure 2. Map of Study Site Malaybalay City, Bukidnon



**2.4. Establishment Of The Study Site**

The study site was situated in Casisang, Malaybalay City, Bukidnon, at an elevation of approximately 828 meters above sea level. The researchers used a method for evaluating the effects of developing biodegradable coconut-based charcoal. The researchers made plots within the site, where the testing of burning rate and ignition time had occurred, to ensure the same factors prior to the study. The location was selected due to its accessibility and control of other environmental factors that may lead to inaccurate results.

**2.5. Sample Collection And Preparation of *Cocos nucifera***

The researchers utilized purposive sampling to gather coconut shells for charcoal production wherein only mature, dry, and clean coconut shells were used. The coconut shells were collected from local markets around Malaybalay City, Bukidnon. The coconut shells, which are considered waste materials, were selected based on maturity and dryness so that they are deemed to have the best quality for charcoal preparation. The samples were then correctly cleaned to remove dirt, debris, and other materials that may degrade the quality of the charcoal that would have been produced. After cleaning, air drying was done for 5-7 days to lessen moisture content which is important for efficient carbonization.

**2.6. Production of Coconut Shell based Charcoal**

For the carbonization of coconut shells, the researchers had asked for guidance from local charcoal producers, as they assisted in the carbonization process by following their traditional way of creating charcoal. The process started with digging a knee-deep hole in the ground, then they proceeded to put the coconut shells *(C. nucifera)* inside the hole and burnt them inside. Once the fire ignited, they then put grass and fallen leaves to cover the hole, then added soil on top of it to seal the opening. Once the hole was fully covered, a bamboo tube was then pressed into the soil so that smoke from under would come out through the tube. The duration of the carbonization lasted 2-3 hours of waiting until they opened the hole again and collected the carbonized Coconut shells *(C. nucifera)*. Following this traditional method of carbonization instead of the common method of carbonization is what makes this study distinct after carbonization is the pulverization of the charcoal, which was crushed and ground into fine granules to maintain uniformity for the samples.

The crushed charcoal was then passed through a fine mesh sifter to again maintain uniformity for the granules by removing large pieces that had not been processed thoroughly. This process was then repeated until there were no longer any large pieces within the charcoal. After the sifting process of the developed charcoal, the powder was then blended with a water and cornstarch solution, where the pasty cornstarch solution acted as a binding agent. The mixture was then molded using a metal tube and cut into smaller sizes then was allowed to dry under direct sunlight for 7-14 days so that proper solidification could occur. Afterward, the solidified residue from coconut shell charcoal was ready for combustion testing and further studies.

**2.8. Data Gathering Procedure**

In gathering the essential data for this study, the on-site data gathering was held at Casisang, Malaybalay City, Bukidnon, where the tests were conducted. All samples of the coconut shell charcoal and commercial charcoal were burnt under the same conditions to maintain consistency in the burning duration record of each sample. The measurement of the burning sample duration in minutes and seconds with a stopwatch was done until the sample had completely combusted.

The Ignition Time test was conducted indoors at room temperature using a stove as the fire source. Each group of samples underwent three trials, with three samples from the coconut shell charcoal and three from the commercial charcoal. For the duration of each trial, the sample was placed directly above the fire source while the researchers measured the time taken for ignition using a stopwatch to record the data. For the Burning Rate test, we used the same charcoal samples from the three trials to record the time it took until the charcoal no longer produced heat. All of the burning time measures were noted, and the mean values were calculated for a comparative analysis via a t-test. Additionally, the researchers conducted a boiling rate test following the method in a study by Bonsu et al., (2020) to further show the effectiveness and functionality of the coconut shell charcoal samples compared to commercial charcoal.

To evaluate the physical and chemical properties of both the developed charcoal and commercial charcoal samples, the researchers adopted the procedures and methodologies derived from studies undertaken by Leones et al., (2023) that mainly focused on the utilization of vegetable waste in the form of raw materials for preparation of the charcoal briquettes. Their work also contains explicit guidance on the sample preparation and laboratory testing, and evaluation of important characteristics such as moisture content, ash content, volatile matter, and fixed carbon. Moreover, the charcoal samples were forwarded to the Davao Analytical Laboratories Inc. for testing regarding the physical and chemical properties, ash content, volatile matter, and other metrics of the charcoal. Additionally, the total production cost of coconut shell charcoal was determined, considering all material and processing costs, alongside labor, if applicable. The procedure included preparations for the coconut shells, as mentioned earlier followed by repeated experimental trials. Such preparation was repeated for three trials in coconut shell charcoal and commercial charcoal to justify the reliability of the results. Each trial measuring the burning duration was taken using a clock and stopwatch for accuracy. Such procedures provided a yield of sufficient data in the evaluated performance and environmental benefits of the developed product.

**2.9. Statistical Treatment of Data**

For the statistical treatment of data, the ignition time data was subjected to a T-Test to determine whether there was a significant difference in ignition duration between the developed coconut shell-based charcoal and commercial charcoal. The rest of the study's results, including physical and chemical properties, were presented descriptively for comparison. This format had only been applied to the results of the coconut shell-based charcoal to be compared with the performance of the commercial charcoal. The data from these two mentioned forms of charcoal shall only serve as a basis for comparing the aforementioned metrics.

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**3. RESULTS AND DISCUSSION**

**3.1 Physical Properties of Charcoal Samples**

The physical properties of the developed coconut shell-based charcoal and commercial charcoal are presented in Table 1.

**Table 1. Physical Properties of Charcoal Samples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Developed Charcoal** | **Commercial Charcoal** | **Method** |
| **Bulk Density (g/L)** | 110 | 321 | Gravimetric |
| **Moisture Content (%)** | 8.0 | 5.3 | ASTM D1762 |
| **Ash Content (%)** | 5.8 | 2.5 | ASTM D1762 |

*\*Physical properties of the charcoal samples after laboratory testing*

The table found above shows the different physical properties of the developed charcoal compared to commercial charcoal. The coconut shell-based charcoal displayed a bulk density value of (110 g/L) which is significantly lower compared to the bulk density of commercial charcoal, (321 g/L). This suggests that coconut shell charcoal is more porous and much lighter, as found out by Arellano and Kato (2014), stating that density is a vital factor that affects combustion properties, material handling, and the strength of the briquettes overall for biomass-derived products. In addition, biochar density is stated to be determined by the raw material and processing methods and could justify why charcoal from coconut shells is much lower in density than its commercial counterpart. Moreover, the lower density could cause poor fuel efficiency because densified charcoal generally imparts more impact resistance and has greater burn time (Kongprasert et al., 2019). Moreover, in terms of moisture content, the developed coconut shell-based charcoal was revealed to have contained 8.0% moisture, which is slightly higher as compared to 5.3% in commercial charcoal. The moisture content is an important determinant of charcoal quality-supply stability and combustion characteristics (Kumar & Saha, 2022). High moisture implies longer ignition time and more production of smoke during burning, the end effects to be considered in its practical use as fuel.

However, according to Atoyebi et al. (2021), a moisture content of around 9% is considered satisfactory for most biochar applications, which makes the developed charcoal viable, nevertheless having little excess moisture. In addition, Ahmad et al. (2021) noted that the pyrolysis process determines the moisture content directly, thus implying that if the conditions for pyrolysis improved, moisture stability developed charcoal would be enhanced. Moreover, the ash content of developed coconut shell-based charcoal is quite high (5.8%) when compared to commercial charcoal (2.5%). Abdullah et al. (2017) also revealed that coconut shell-based charcoal generally contains about 1% to 3% total ash content within the charcoal; thus the figures reported in this study exceed the standard range.

A higher ash content reflects incomplete carbonization or possible contamination during the production process (Hwangdee, 2025). Alongside that, according to Ahmad et al. (2021), charcoal is preferred to have lesser ash content (less than 3%) because ash reduces the efficiency of combustion and increases the retained residue after burning. Therefore increased ash content in developed charcoal may reduce its performance as a high-efficiency fuel but may still find application in agriculture as soil amendments due to mineral compositions. This is reinforced by Pimenta et al. (2015), that different types of biochar have varying compositions in their ash content. In contrast, coconut husk biochar would have the highest ash content of all the tested materials.

**3.2 Chemical Properties of Charcoal Samples**

The chemical properties of the developed coconut shell-based charcoal and commercial charcoal are shown in Table 2.

**Table 2. Chemical Properties of Charcoal Samples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Developed Charcoal** | **Commercial Charcoal** | **Method** |
| **Volatile Matter (%)** | 24.5 | 20.3 | Gravimetric |
| **Fixed Carbon Content (%)** | 61.7 | 71.9 | ASTM D1762 |
| **pH (25°C)** | 8.85 | 9.91 | ASTM D1762 |

*\*Chemical properties of the charcoal samples after laboratory testing*

The results reveal a significant difference in the volatile matter levels between the developed coconut shell-based charcoal at 68.2% compared to the commercial charcoal at 55.7%. Volatile matter is very critical in ignition time as it aids in the quick initiation of burning in a material. Nagarajan et al. (2014) considered coconut shell charcoal high in volatile matter (usually in the range between 65 and 75%); hence the higher volatility in the charcoal produced compared with commercial charcoal. The higher volatile matter implies that developed charcoal will ignite faster, favoring combustion applications that require rapid ignition. Coconut shells contain a relatively higher amount of volatile matter as compared to most biomass materials, hence the rapid ignition and combustion of materials. Studies confirmed that coconut shells themselves contain about 83.5% volatile matter, which may be expressed in easier burning due to the presence of compounds that vaporize on heating (Magtoto et. al., 2020). In addition, coconut shells were stated to be made up of cellulose, hemicellulose, and lignin, which are the major components of lignocellulosic biomass. This finding is found to be consistent with the study of Syarif et al. (2023), which also revealed that bio-briquettes with a high volatile matter similar to the volatile matter in the developed coconut shell charcoal, had combusted with ignition times of 24-76 seconds, mainly depending on particle size and moisture content. Moreover, In terms of fixed carbon contents, the commercial charcoal exhibited a much higher value, which is indicated at a level of 41.8%, as compared to the developed coconut-shell-based charcoal at 29.6%. Fixed carbon largely influences the charcoal's energy density, extending the duration of time it burns, as well as heat output. The generally accepted view is that higher fixed carbon signifies a longer-lasting fuel with high energy efficiency (Sunardi et al. 2019). Lower fixed carbon in developed charcoal would therefore mean rapid burning of coal relative to any sustained heat output expected from commercial charcoal. This thought is reinforced by Sabo et al. (2022) that high compact structure of coconut shell charcoal increases burning time due to longer heat retention. Lastly, SSH contents for both charcoal samples are relatively low, with developed coconut charcoal recorded at 2.2% and commercial charcoal at 2.5%. According to Nagarajan et al. (2014), the ash content for a coconut shell is typically low at 0.61%, but this may change due to the different processing conditions and impurities. It is better to have a lower ash content since this reduces the residue remaining after combustion, thus enhancing the general quality of the fuel (Sunardi et al., 2019). Nevertheless, the small difference in ash content may cause similar behavior of the two samples regarding the amount of residue produced after combustion.

**3.3 Ignition and Burning Properties**

**Table 3. T-test calculation on the Ignition Time of the Charcoal Samples**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sample** | **Mean** | **SD** | **t-value** | **p-value** | **Results** |
| **Coconut Shell-Based Charcoal** | 5.63 | 0.34 | -7.33 | 0.012 | Significant |
| **Commercial Charcoal** | 11.00 | 1.22 |  |  |  |

*\*Significant at 0.05 level*

Table 3 contains the statistical results gathered from conducting a t-test comparing the ignition times of both the produced coconut shell-based charcoal and the commercial charcoal. The ignition time for the coconut shell charcoal had averaged 5.63 seconds (SD = 0.34), whereas the commercial charcoal had an overall increased ignition time average of 11.00 seconds (SD = 1.22). The calculated t-value of -7.33 and a p-value of 0.012 imply that the difference between the two samples is significant at the 0.05 level, suggesting that this faster ignition of coconut shell charcoal is not due to random variation. The result agreed with Syarif et al. (2023) that bio-briquettes with substantial coconut shell constituents would show a favorable ignition nature. The shorter ignition time mentioned may be due to lower volatile matter and better-optimized density, which are properties of coconut shell charcoal that directly influence ignition speed. Added to this, Sunardi et al. (2019) argued that volatile matter holds an emphasis on combustion characteristics; hence, charcoal with controllable volatile contents, such as cocoa shell charcoal, would ignite faster with a controlled burn. Sabo et al. (2022), in addition, pointed out that density contributes to the burning behavior in charcoal in terms of ignition and heat retention for sustained energy output.

**Figure 3. Chart displaying the Ignition Time of the Charcoal Samples**

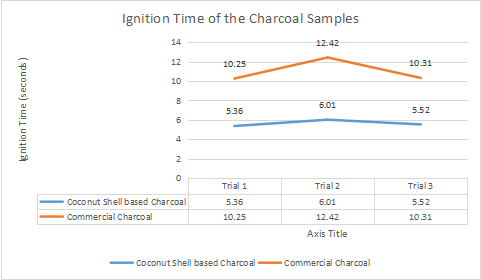


Figure 3 details the ignition times of the developed charcoal and commercial charcoal samples for three trials. It was revealed that the commercial charcoal took 10.25 seconds (Trial 1), peaked at 12.42 seconds (Trial 2), and slightly reduced to 10.31 seconds (Trial 3) in terms of ignition time, whereas coconut shell-based charcoal went off very quickly during all trials-5.36 seconds (Trial 1), 6.01 seconds (Trial 2), and 5.52 seconds (Trial 3) thus contrasting with commercial charcoal in terms of a faster ignition time. The data illustrates the consistent performance of coconut shell charcoals over commercial ones, which were both slower and more variable in their ignition rates. The small range of the values for the charcoal developed only indicates that the burning behavior is much more predictable and is a viable alternative as a fuel source. That high peak at Trial 2 in commercial charcoal furthers the argument regarding the lack of consistent ignitability in the material by pointing to perhaps variability regarding moisture content, homogeneity of the material, or its density. The pattern, as reflected in this chart has supported the argument posed by Syarif et al. (2023) that biochar products derived from coconuts are recognized to be quicker in flames due to their thermal friendliness. The pattern of consistency at ignition processes also strengthens arguments from Sunardi et al. (2019) regarding contribution to initiation during combustion from volatile matter and by Sabo et al. (2022) on the influence of material compactness (density) to time for combustion.

**4. CONCLUSION**

The study developed a coconut shell-based charcoal, analyzed the physical and chemical properties of the developed charcoal, and compared it to its commercial counterpart. Based on the findings, both types differ remarkably in many aspects. In terms of physical characteristics, the developed charcoal had less weight and exhibited a more porous structure. These properties and data suggest that whilst the developed charcoal may be more manageable and transportable; it possibly may affect the burning stability and uniformity of the charcoal. In regards to the chemical properties, the developed charcoal contained more volatile matter, which meant a relatively faster ignition speed compared to commercial charcoal. However, the amount of fixed carbon was lower, which might limit the burning duration as heat deterioration occurs faster. This also indicates that between the two samples, ash content was found to be higher in the developed charcoal and this may decrease burning efficiency, yet enhance for agricultural applications due to mineral contents in ash matter. The pH values between both samples were alike, indicating their overall chemical stability was almost equivalent. The combustion and energy performance findings suggest that the developed coconut shell-based charcoal ignited faster than the commercial charcoal, which is likely due to a higher volatile matter promoting rapid combustion. However, it is somewhat negligible due to the interaction of increased burning rate and heat retention, which would, in fact, affect the overall efficiency of the material as a long-term fuel source. Moreover, the statistical comparison shows a significant difference between the two types of charcoal, particularly in ignition time, confirming that performance for the developed product is meaningfully deviated from that of the commercial variant. In conclusion, coconut shell-based charcoal shows suitable properties that allow for it to be an environment-friendly and sustainable alternative due to its rapid ignition and availability. However, the charcoals themselves require further refinement, and future work should target its fixed carbon improvement and ash reduction for enhanced commercial and energy intensity application suitability. In the future, one possible improvement is to experiment with alternative binders for combustion performance enhancement or mechanical carbonization for greater uniformity in briquette quality. Also, any study on the application of coconut shell briquettes in industries or households as an eco-friendly fuel will further help promote eco-friendly options to commercial charcoal.

**Ethical Approval and consent**

All ethical guidelines and rules that are relevant to this study were ensured to be followed when the research was conducted. All necessary permissions and approvals were secured from the appropriate authorities. All participants in the project were asked for their informed consent in data collecting and granting access to their land for research. The research made sure to be honest by not fabricating false information and by thoroughly checking all the resources that were used in this research to be credible. In addition, by following the common research etiquette when conducting the study. Moreover, by observing what is ethically right or wrong in moral assessments when conducting the research, and when the research was conducted, this was done responsibly, and all resources were given where credit was due

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**COMPETING INTERESTS**

The authors have declared that no competing interests exist.

**AUTHORS CONTRIBUTION**

William Nathan T. Rodriguez, Noelle Alexandra Caingcoy, Grace Danielle A. Coñales, Kyla Nicole B. Pañares, Aivan A. Omamalin, and Ian Jay P. Saldo collaboratively designed the study. William Nathan T. Rodriguez wrote the first draft of the manuscript and handled all revisions. In contrast, Noelle Alexandra Caingcoy, Grace Danielle A. Coñales, Kyla Nicole B. Pañares, and Aivan A. Omamalin collaboratively reviewed the Related studies. Noelle Alexandra Caingcoy, Grace Danielle A. Coñales, and Kyla Nicole B. Pañares, along with William Nathan T. Rodriguez, managed the analyses of the study. Aivan A. Omamalin was responsible for most of the charcoal development and carbonization. All authors contributed to the literature searches, as well as the production process of the charcoal samples, specifically the crushing, molding, and drying processes. Additionally, Grace Danielle A. Coñales, Kyla Nicole B. Pañares, and Aivan A. Omamalin conducted the burning tests together. Moreover, Grace Danielle A. Coñales and William Nathan T. Rodriguez finalized and handled the revisions of the finished manuscript. All authors read and approved the final manuscript.

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