Volume 2 | Issue 2 | Jul - Dec 2024
ISSN: 2984-9896
e-ISSN: 3116-5230
Website: https://csu.org.ph/jpas
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OPEN ACCESS

Production and Evaluation of Carbonized Rice Straw and Corn Husk Briquettes as a Sustainable and Alternative Fuel for Cooking

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DOI: 10.5281/zenodo.20738978 Published: November 04, 2024

ABSTRACT

This study focused on the production and evaluation of briquettes made from agricultural residue as a substitute fuel for cooking. Five different briquette samples were produced: 100 % rice straw, 100% corn husk, 25% rice straw and 75% corn husk, 50% rice straw and 50% corn husk, and 75% rice straw and 25% corn husk. In pursuit of the objectives, an experimental design was employed and ANCOVA was used as the statistical tool to analyze data both from the water-boiling test, heat temperature measurement, and burning rate determination. Five households and five entrepreneurs using the traditional method of cooking were selected using a purposive sampling technique. Responses from participants were gathered using a questionnaire with a 5-point Likert scale. Additionally, ROI (Return on Investment) was calculated to determine the financial feasibility of the briquettes. The study discovered that in the water-boiling test, treatment 2 (100% corn husk) significantly produced heat faster than the rest, taking only 462 seconds to boil 500 ml of water. Treatment 1 (100% rice straw) had the lowest burning rate, with an average rate of 0.021621025 grams/second or 0.12972615 grams/minute. However, it was found out that all treatments reached the same peak temperature, with an average temperature of 594.283 degree Celsius, which is highly acceptable for small business and home cooking use and expected to project 50% ROI. The research concludes that the briquettes produced using the rice straw and corn husk biochar quickly generate significant heat, making them suitable for various cooking methods. The combustion temperature can reach up to 594 degrees Celsius, and these briquettes are more economical and efficient when agro-residues are used separately, highly acceptable for cooking regardless of mixture with 50% ROI.

Keywords: *Agricultural Residue, Rice Straw, Corn Husk, Treatments, Briquettes, ROI*

INTRODUCTION

The world is undeniably endowed with natural resources; however, the need for sustainable and affordable renewable resources such as hydro, geothermal, wind, solar, and biomass, particularly in the Philippines. Instead of harnessing these resources sustainably, people tend to damage and deteriorate the environment due to misuse and abusive activities.

Three primary issues underscore the urgent need to consider alternative fuels for cooking, accessible to poor: deforestation, waste management, and high fuel costs.

Firstly, deforestation which is a major issue in the Philippines, primarily driven by the reliance on wood for lumber and charcoal. Wood charcoal is a primary cooking fuel in the country, and the "kaingin" system of slash-and-burn agriculture exacerbates this problem. As trees are continuously cut to meet the demands for charcoal, the diminishing number of trees leads to reduced oxygen production and increased carbon dioxide in the atmosphere. The Department of Environment and Natural Resources (DENR) has identified traditional charcoal production as the most destructive upland activity, leading to various calamities such as flash floods, droughts, landslides, and global warming, affecting both human and animal lives dependent on forest ecosystems.

Moreover, the Filipinos often engage in a "consume and flee" routine, exploiting the environment without replenishing what they have taken, leaving behind only waste. The Philippines, particularly Cagayan, generates numerous agricultural wastes, including wood chops, hulls, husks, peels, dried leaves, and cobs. Predominantly, these agricultural wastes have no use and should be thrown already, but nowadays, there are lot of environmental campaigns, including the 3Rs (Reduce, Reuse, and Recycle) that help cut down the amount of waste to be thrown away. Also, for some people, these wastes, which they refer to as "abandoned biomass" will be able to create a useful and profitable product which is the briquette that will be surely sustainable and affordable to humankind.

Furthermore, the high price of Liquefied Petroleum Gas (LPG) poses a significant financial burden on Filipino households. As LPG prices continue to rise, people are left with few alternatives, often resorting to forest-depleting activities. While LPG is an important cooking fuel in many developing countries, its high cost limits its use in the Philippines, where households primarily rely on wood charcoal and firewood.

In response to these challenges, alternative fuels have been developed to reduce agricultural waste, lessen reliance on wood charcoal, and alleviate the financial burden of LPG. Cagayan, as one of the largest agricultural sectors in the Philippines, generates a significant amount of biomass waste that can be utilized as a renewable energy source for cooking. Among these biomass wastes are rice straw and corn husk. Utilizing these wastes instead of discarding them can minimize solid waste, reduce deforestation due to charcoal production, and mitigate the financial impact of rising LPG prices. Rice straw and corn husk briquettes are cost-effective, burning longer and more steadily than wood charcoal, while emitting very little smoke. According to Tamolang (2022), briquettes are 50% cheaper than LPG and are more budget-friendly for daily wage earners as they can be purchased in small packs.

Given the potential of rice straw and corn husk as alternative fuel sources, this study aims to assess the effectiveness of briquettes made from these materials as cooking fuel. By exploring their production and evaluating their efficacy, the research seeks to contribute to the sustainable energy discourse and offer practical solutions for Filipino households.

A briquette is a flammable matter block compressed used as fuel to start and maintain a fire. Briquettes come in two types: charcoal briquettes and biomass briquettes. The following are the studies about the preparations done in making briquettes.

Combining different types of biomasses improves the properties of densified biomass briquettes. Briquettes had a unit density up to 1.9 times that of loose biomass. They were stronger than individual materials and absorbed 36% less water than loose corn cobs (Rukayya Muazu, 2015).

Ojaomo (2015) reported that the Briquette production is one useful method of managing waste generated by humans and their activities on the earth's surface. Briquetting is a process that compacts waste into a single solid rod or brick. Briquettes are used as an alternative source of energy for cooking as well as a general thermal energy supplement.

L.G. Hassan et al. (2017) conducted water boiling test by combusting 350g of briquettes and wood charcoal samples, respectively using charcoal stove to compare the fuel combustibility and the fuel that cooked food faster, and 1 liter of water was used for test where the temperature reading was taken every minute until the water started to boil. The time taken by each sample burn to ashes was also monitored using stopwatch. The briquette burning rate were also determined by recording the briquettes weight before combustion and after the briquettes are completely burnt. His study shows that the burning rate of the Sample A with a mixture of 80 percent charcoal powder and 20 percent fermented paper is 3.16 grams/seconds.

Jain (2018) also recommended the briquettes made from biomass materials and starch combinations were found to have the best physical properties, with the highest scores. Briquettes were smooth in texture, compact, dry, uniform, even without cracks, and shiny due to the use of starch as a binder with charcoal dust and other biomass materials.

Deric et al. (2018) compared the heating efficiency of the briquettes produced using two kinds of stove (the wood gas stove with fan and the local "tripod" fuel wood stove) and found out that the heat efficiency of each category of briquette, which is practically determined through series of water boiling test, has no significant differences.

D Nurba et al. (2019) also investigated the distribution of hot air drying in the In-Store Dryer (ISD) by means of corncobs and wood charcoal briquettes as heat resources. Though the overall resistance from combustion rate was not significantly different; 9.8 and 9.7 gram/minute for wood charcoal briquettes and corn cobs briquettes respectively. The corncobs briquettes are potentially be used as fuels for ISD heat supply.

K.O. Oladosu (2023) reported in their study "Optimization of fuel briquette made from bicomposite biomass for domestic heating applications" the result of the experiment in which their optimized briquettes were able to boil 500 ml of water in 960 seconds which is longer than the boiling time of charcoal briquettes thy use to compare their product with just 660 seconds to boil the same stud also recorded the burning rate of optimized briquettes and wood charcoal with 0.032 g/s and 0.22 respectively.

It is reported in the study conducted by M.A. Yusuf et al. (2023) titled "Characteristics of charcoal briquettes from rice husk waste with compaction pressure variations as an alternative fuel," briquettes made of rice husk were able to produce combustion temperature that ranges from 300-500 degree Celsius which can be used as an alternative fuel for cooking.

Geranta et al. (2024) also reported in their study "Waste to energy: Charcoal briquettes as an alternative source of solid fuel made from vegetable and fruit wastes as a raw material" that the briquettes were able to boil 500 ml of water in 10 minutes and 25 seconds using 7 pieces of briquettes.

Wood Charcoal

Donsavanh (2023) discovered in their study on characteristics of wood charcoal combustion in different wood species that the temperature during burning of wood charcoal ranges from 647.2 to 677.67-degree Celcius.

L.G. Hassan et al. (2017) reported in their study "Compartive Studies of Burnig Rate and Water Boilng Time of Wood Charcoal and Briquettes Produced from Carbonized Martynia annua Woody Shell" that the wood charcoal they tested had a burning rate of 3.53 grams per minute and a water boiling time of 11minute and 50 seconds.

Briquetting Machine

Briquetting machine, also known as briquette maker or briquette press, is a machine that uses pressure to compress biomass material into square blocks or round sticks. The following are the studies about the development of briquetting machines.

A pressure switch and a band heater are applied by the automated machine for its pressure and temperature variation mechanisms, respectively, while a Programmable Logic Controller (PLC) was used to automate the machine's operation. Furthermore, the machine includes mixing chamber for thorough mixing of the feedstock, a cylindrical mold where the feedstock would be briquetted, and a hydraulic system that is in charge of the mold's movements as well as the machine's compression mechanism (Rey Andrew, 2015).

Satria et al. (2021) developed and tested a hand-operated briquetting machine to meet the domestic energy demand in rural households. Briquettes were made from rice husk, wheat straw, groundnut shells, and sawdust as raw materials. The compaction pressure and force were determined to be 3.955 and 294.3, respectively.

In research done by Inegbedion et al. (2022), the machine was designed to easily compress biomass materials in the briquetting die (sawdust, rice husk, and palm fruit shell). The developed machine was made entirely of local materials. The compressive strength of the briquettes samples ranged from 0.9kN/m 2 to 1.3kN/m 2 according to the results.

Biomass as raw materials

Biomass can be produced from forestry wastes like tree and shrub residues, energy crops like sorghum, miscanthus, kenaf, switchgrass, corn, sugarcane, and any agricultural residues like corn stover, wheat straw, rice straw, and so on.

Briquettes made from biomass with a higher calorific value are important in the production of environmentally friendly solid fuels. Rice husk and sawdust biomass were dried and carbonized in a muffle furnace at 270 0c for 20 minutes on average (Ibrahim Ozigis, 2019).

It has been reported that a recent push has been made to replace the use of fossil fuels with biofuel. Biomass briquettes are a biofuel substitute for coal and charcoal. Waste biomass such as dry leaves, sawdust, rice husk, coffee husk, and so on can also be transported and used as fuel. Biomass briquettes are widely used in thermal applications such as steam generation in boilers, furnaces, and foundries. Sawmill Agri waste is a major issue, particularly in urban areas. These wastes are openly burned, causing environmental pollution and necessitating human health care (Shaikh, 2021).

Islam et al. (2021) studied the possibility of using rice straw as a biomass material to make briquettes mixed with rice husk in a screw press type briquetting machine. The densities of all charcoal briquettes ranged from 630 kg/m3 to 910 kg/m3. The heating value was discovered to be in the range of 14,223 to 15,129 kJ/kg, indicating that it can produce heat required for household cooking as well as industrial applications.

Briquettes made from rice husk and corn cob can be used as a cooking fuel as well as in small businesses. As reported by Obu (2022), Maize cob briquettes had the highest compressed density (2.1 g/cm3), relaxed density (0.82 g/cm3), shattering index (99.53%), and water resistance capacity (11.9 minutes).

Segun Emmanuel et al. (2022) concluded that in order to reduce the environmental impact of their disposal, solid fuel briquettes were created from a mixture of torrefied corncob and rice husk. Briquettes were made with various blending ratios and compaction pressures. The trend of the mechanical properties of the manufactured briquettes could be predicted using empirical models.

Carbonizer

Carbonizer is the equipment for making charcoal from solid or organic matter and for producing heat from the combustion of biomass waste materials and high purity biocarbon.

In research done by Belonio (2015), a manually operated briquette molder and a drumtype rice hull carbonizer were designed and tested. The carbonizer has a loading capacity of 22.5 to 33.75 kg of rice hull per batch, according to the results. When CRH was used as a soil conditioner for growing radish, no significant effect was observed.

Carbonization, also known as slow pyrolysis, is a thermochemical conversion of solid organic materials at high temperatures in the absence of oxygen or air. Thermal decomposition processes produce a solid product known as biochar, as well as gaseous and liquid byproducts. In a semi-continuous carbonization reactor system, a large amount of corn cobs was successfully converted to high-quality biochar. Biochar yields ranged from 23 to 33%, with heating values as high as 24 MJ/kg (Tippayawong N., 2018).

Takafumi et al. (2019) developed a 200-liter carbonizer out of simplified used oil drum (572 mm diameter, 851 mm high). The drum lid was removed and replaced with a custom-made still lid that was 15 cm high, 7 cm internal diameter in the center, and several ventilation holes in the bottom at approximately 10-15 cm intervals, and drum was placed on four bricks to ensure air flow from the bottom at the start of ignition. Also, to promote carbonization, the drum was maintained for the next 56.5 hours while the carbonizer's temperature was continuously measured. The carbonization was the stopped 48 hours after ignition by opening the lid and immediately applying 10 liters of water to the top of the pile. The drum was then left for 6 hours, after which time the biochar was spread out on a steel sheet in the open air and left to dry.

Binder

Binder is a substance used to make other substances or materials to stick and mix together. The briquettes were made mechanically using hydraulic briquetting machine and sawdust and cornstarch as binder. This was accomplished by combining 30ml, 40ml, and 50ml of cornstarch with 100g, 150g, and 200g of sawdust with 75ml, 100ml, and 125ml of water in various combinations to produce briquettes. The results showed that as the volume of the binder increased, the boiling time and fuel consumption rate decreased while the calorific value, fuel efficiency, and cooking efficiency increased (D. C. Chinyere, 2015).

Borowski (2017) also reported that at 8% of the total, two types of binders used repeatedly to make briquettes were wheat starch and modified wheat starch. The moisture content of the mixed materials ranged between 28% and 32%. Toughness, calorific heating value, volatiles, fixed carbon content, and ash content were unaffected by the starch binder type. The concluded that briquettes with native wheat starch as a binder are more appropriate for burning in the grill due to their longer burning time and lower smokiness, as well as their maximum temperature and long burning time.

Zhang (2018) concluded that starch is the most common binder though it is usually expensive. It doesn't have to be a food grade. In general, about 4-8% of starch is needed to make the briquettes. Starch sources can be corn starch, wheat starch, maize flour, wheat flour, rice flour, cassava flour, potato starch, etc.

The literature and studies reviewed indicate that carbonized rice straw and corn husk briquettes are promising alternatives to traditional cooking fuels. They offer environmental, economic, and practical benefits that can help address issues related to deforestation, waste management, and high fuel costs. These insights provide a solid foundation for the current study, guiding the researchers in their investigation into the production and evaluation of these briquettesas a sustainable cooking fuel.

Objectives of the Study

Generally, the study aimed to produce briquettes out of agricultural residue as a substitute fuel for cooking.

Specifically, the study aimed to answer the following questions:

1. What is the combustion performance of the rice straw and corn husk biochar briquettes in terms of:
    1.1. Water boiling test
    1.2. Heat temperature measurement
    1.3. Burning rate
2. What is the acceptability of carbonized rice straw and corn husk biochar briquettes among Barangay folks?
3. What is the return on investment of the rice straw and corn husk briquettes?
4. Is there a significant difference in all parameters tested across treatments and of the performance of traditional wood charcoal?

MATERIALS AND METHODS

Research Design

An Experimental Research Design was used using the different treatments. There are five (5) treatments used in briquette productions. These treatments were replicated three (3) times. The following are the formulations used based on the weight of the biochar:

Treatment 1 – 100% rice straw biochar

Treatment 2 – 100% corn husk biochar

Treatment 3 – 25% rice straw biochar and 75% corn husk biochar

Treatment 4 – 50% rice straw biochar and 50% corn husk biochar

Treatment 5 – 75% rice straw biochar and 25% corn husk biochar

The binder added to each treatment was 8% of the total weight of the biochar mixture (Zhang, 2018).

Materials

Sto. Niño, Cagayan is a municipality primarily known for its production of palay grains and corn. Given that the study was conducted in Niug Sur, Sto. Niño, Cagayan, the biomass *(agroresidues)* used in the study was sourced locally from this barangay, where both palay and corn are cultivated extensively. The materials utilized in the production of the briquettes include:

1. Rice Straw: Collected from the local palay fields in Niug Sur, Sto. Niño, Cagayan.
2. Corn Husk: Sourced from the local cornfields in the same area.
3. Cassava Flour: Used as a binding agent, the cassava flour was purchased from the Sto. Niño Municipal Market.

These locally sourced materials were chosen to ensure the sustainability and feasibility of the briquette production process, leveraging the readily available agricultural residues within the community

Respondents and Sampling Technique

The respondents of this study were composed of residents of Niug Sur, Sto. Niῆo, Cagayan. Primary respondents were chosen based on method of their cooking, preferably the household that uses traditional way of cooking using firewood, LPG or charcoal. Those who are using charcoal for cooking for their business (e.g., ihawan) are the secondary respondents. The researcher used purposive sampling to select five households and five entrepreneurs that are using traditional method of cooking.

Procedures

Carbonizing Biomass (Carbonization)

The carbonizer used for the study was an oil drum with a capacity of 200 liters with several holes at its bottom and a custom-built lid with a funnel. The drum was raised several inches for the air to enter the holes at the bottom of the drum. Below are the steps in carbonizing Biomass:

1. Pack the biomass inside the drum.
2. Ignite the top of the biomass for 5 minutes or until the combustion starts.
3. Cover the drum with lid and cover the bottom of it with soil to prevent air flow inside the drum and suppress combustion.
4. Monitor the carbonizer for at least 2 days or until the biomass is completely turned into biochar. Data Gathering Procedure

Briquetting

Mixture Preparation

The carbonizer used for the study was an oil drum with a capacity of 200 liters with several holes at its bottom and a custom-built lid with a funnel. The drum was raised several inches for the air to enter the holes at the bottom of the drum. Below are the steps in carbonizing Biomass:

1. Weigh the biochar (carbonized biomass) and pour it inside a large bucket. The weight of the biochar will depend on the formulations specified in each treatment.
2. Gradually add about 8 percent of binding agent (cooked cassava flour mixture) into the bucket with biochar (Zhang, 2018).

Briquetting process

1. Using a measuring cup, scoop out the biochar-binder mixture and pour it inside the feeder the briquetting machine.
2. Squeeze the machine's lever downwards until the desired density of the compacted briquettes are attained.
3. Eject the briquettes from the briquetting machine's mould and lay the briquettes on pavement under direct sunlight for drying.
4. Turn the briquettes upside down every 2 hours for at least 2 days or until the briquettes are completely dried.

Water-boiling Test

In this procedure, an improvised fan-powered stove was used.

1. Prepare 5 pieces of dried briquettes and place them into the stove.
2. Ignite the briquettes using a little amount of kerosene for a minute or two.
3. Open the fan to supply oxygen for better combustion.
4. In a casserole, put 500 ml of water inside it.
5. Put the casserole over the stove and start the stopwatch.
6. Monitor the water temperature until it reaches 100 degrees Celsius.
7. Stop the stopwatch when the water reaches boiling point and record the time in a piece of paper.

Heat Temperature Measurement

In this procedure, a stove, a metal grill, and a thermometer were used.

1. Prepare the briquettes inside the stove and light them up to start combustion.
2. When the briquettes are already burning, place the metal grill on the stove and place the thermometer over grill.
3. Monitor the thermometer and record the highest temperature that will be read by the thermometer.

Determining Burning Rates

Testing the briquettes for their burnings rate is done to determine how much fuel is consumed in every second. The fuel consumed is determined by getting the difference of weighing the briquettes before combustion and after the briquettes completely turned into ash. The burning rate was computed using the following formula:

$$Burning\ Rate = \frac{\text{Mass of the total fuel consumed (gram)}}{\text{total time taken } (second)}$$

1. Prepare 1 briquette and weigh it.
2. Ignite the briquette using a paper for 2 minutes.
3. When combustion starts, open the fan and turn it to low speed to continuously supply oxygen.
4. Start the stopwatch as the combustion starts.
5. When the briquette is completely burnt, stop the stopwatch, take the ashes and weigh it using weighing scale.

Questionnaire Preparation and Administration for Acceptability Evaluation

The questionnaire that was floated was a 5-point Likert scale to determine the level of acceptability of the briquettes in every consumer.

1. Make a questionnaire based on the expected outcomes of using the briquettes to be approved by the research adviser.
2. Prepare a permission letter to conduct the study at the specified barangay addressed to the Barangay Captain.
3. Float the questionnaire on the specific date and time indicated at the approved letter.
4. Gather the questionnaire on the next day.

Data Gathering Tools

The following were the data that were expected to be gathered during the conduct of this research. The data was divided into three categories since there were 3 tests conducted.

Determining Burning Rates

Boiling time (bt) – this was recorded from the time the casserole was placed on top of the stove until it reached 100 degrees Celsius.

Average Boiling Time – this was computed for each treatment using the following formula:

$$\boldsymbol{Average\ boiling\ time} = \frac{btR1 + btR2 + btR3}{3}$$

Heat Temperature Measurement

Heat Temperature (ht) – a metal grill was placed over the burning briquettes, then the thermometer over the grill. The peak temperature received by the thermometer is recorded.

Average Heat Temperature – this was computed for each treatment using the following formula:

$$\boldsymbol{Average\ Heat\ Temperature} = \frac{htR1 + htR2 + htR3}{3}$$

Burning Rate Determination

Weight before Combustion (wbc) – briquettes were weighed before ignition using weighing scale.

Weight after Complete Combustion (wcc) – ashes or the remains of briquettes after complete combustion were weighed using a weighing scale

Total Time Taken (ttt) – this was recorded starting from the time of ignition until the briquette was completely burned.

Burning Rate (br) – this was computed using the following formula:

$$\boldsymbol{Burning\ Rate} = \frac{\text{Mass of the total fuel consumed (gram)}}{\text{total time taken } (second)}$$

Average Burning Rate – this was computed for each treatment using the following formula:

$$\boldsymbol{Average\ Burning\ Rate} = \frac{brR1 + brR2 + brR3}{3}$$

Briquette Acceptability Evaluation

Average score in each item – In a 5 point-likert scale, each response has corresponding score. 1 point for poorly acceptable, 2 points for fairly acceptable, 3 points for acceptable and 4 points for moderately acceptable and 5 points for highly acceptable. The average score was computed by computing the summation score for every item divided by the total number of participants.

Data Analysis

To analyze the data obtained from water-boiling test, heat temperature measurement, and burning rate determination, the statistical analysis that was used is the Analysis of Covariance (ANCOVA). For gathering the responses of the participants, a questionnaire with a 5 point-Likert scale was used.

Table 1. 5-point Likert Scale with Descriptive Value.

Average Weighted Mean Range	Mean
5	Highly Acceptable
4	Moderately Acceptable
3	Acceptable
2	Fairly Acceptable
1	Poorly Acceptable

For evaluating the acceptability of the briquettes, the table below was used to interpret the gathered data.

Table 2. Average Weighted Mean Range with Descriptive Value.

Average Weighted Mean Range	Descriptive Equivalent (Level of Acceptability)
4.21 – 5.00	Highly Acceptable
3.41 – 4.20	Moderately Acceptable
2.61 – 3.40	Acceptable
1.80 – 2.60	Fairly Acceptable
1 - 1.79	Poorly Acceptable

Return on Investment (ROI) Computation

To compute the expected Return on Investment of the rice straw and cornhusk biochar briquettes, the researchers identified total investment, total briquettes weight(kg) produced per day, cost per kilo of briquettes with and without mark-up, profit per kilo of briquettes and total profit per day. The ROI was computed using the following formulas:

Total investment = material cost + labor

Total Bw per day = Pr per day / Baw

Cost per kilo (w/o mark-up) = Total Investment per day / Total Bw per day

Cost per kilo (w/ 50% mark-up) = Cost per kilo (w/o mark-up) x 1.5

Profit = Cost per kilo (w/ mark-up) – Cost per kilo (w/o mark-up)

Total profit = Profit per kilogram x total kilograms produced per day

ROI = (Total Profit / Investment) x 100 wherein: Bw = briquettes' weight Pr = production rate Baw = briquettes average weight

RESULTS AND DISCUSSION

Burning Tests

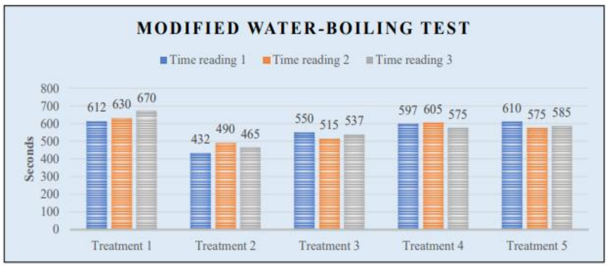

Figure 1. Clustered Column Chart of Modified Water Boiling Test Time Readings.

Table 3 shows the Heat Temperature Measure of briquettes with a composition of 100 percent carbonized Corn Husk. Based on the table, Treatment 1 has an average peak temperature of 582.13 degree Celsius. This suggests efficient heat generation, making these briquettes suitable for cooking purposes.

Table 3. Heat Temperature Measurement Table (T1).

Treatment 1: 100% Rice Straw					
Replication	Heat Temperature Measure every 5 minutes (Celsius)				
	5 Mins	10 Mins	15 Mins	20 Mins	Peak Temp.
R1	471.1	595.7	420	477.9	595.7
R2	450	590.5	600	410.1	600
R3	490.3	550.7	520	486	550.7
Average					**582.13**

Table 4 shows the Heat Temperature Measure of briquettes with a composition 100 percent carbonized Corn Husk.

Based on the data, it is evident that Treatment 2, which consists of briquettes composed entirely of carbonized Corn Husk, produced an average peak temperature of 594.63 degrees Celsius. This indicates that Treatment 2 generated higher temperatures compared to Treatment 1, suggesting potentially improved combustion efficiency and heat output.

Table 4. Heat Temperature Measurement Table (T2).

Treatment 2: 100% Corn Husk					
Replication	**Heat Temperature Measure every 5 minutes (Celsius)**				
	5 Mins	**10 Mins**	**15 Mins**	**20 Mins**	**Peak Temp.**
R1	591.7	587.3	588.6	594.9	594.9
R2	600	545.1	580	564	600
R3	537.3	521	589	572.1	589
Average					**594.63**

Table 5 shows the Heat Temperature Measure of briquettes with a composition of 25 percent carbonized Rice straw and 75 percent carbonized Corn Husk. Treatment 3 was able to produce an average peak heat temperature of 600 degrees Celsius. This indicates that the combination of rice straw and corn husk resulted in a slightly higher average temperature compared to treatments with solely corn husk composition.

Table 5. Heat Temperature Measurement Table (T3).

Treatment 3: 25% Rice Straw 75% Corn Husk					
Replication	**Heat Temperature Measure every 5 minutes (Celsius)**				
	5 Mins	**10 Mins**	**15 Mins**	**20 Mins**	**Peak Temp.**
R1	581.6	512.6	600	592.4	600
R2	584.1	598.2	600	545.9	600
R3	589.3	600	581.8	582.5	600
Average					**600**

Table 6 shows the Heat Temperature Measure of briquettes with a composition of 50 percent carbonized Rice straw and 50 percent carbonized Corn Husk. Based on the table above, the average peak temperature of Treatment 4 is 594.83 degrees Celsius. This indicates that the combination of rice straw and corn husk in equal proportions resulted in a temperature similar to Treatment 2 (which comprised solely corn husk) and slightly lower than Treatment 3 (with a higher proportion of corn husk).

Table 6. Heat Temperature Measurement Table (T4).

Treatment 4: 50% Rice Straw 50% Corn Husk					
Replication	**Heat Temperature Measure every 5 minutes (Celsius)**				
	5 Mins	**10 Mins**	**15 Mins**	**20 Mins**	**Peak Temp.**
R1	547.9	594.8	524.8	539.3	594.8
R2	543.2	520.3	560	589.6	589.7
R3	600	589.6	539.5	544.9	600
Average					**594.83**

Table 7 shows the Heat Temperature Measure of briquettes with a composition of 75 percent carbonized Rice straw and 25 percent carbonized Corn Husk. Based on the table above, the average peak temperature of Treatment 5 is 599.83 degrees Celsius. This indicates that the combination of rice straw and corn husk with a higher proportion of rice straw resulted in a slightly higher average temperature compared to Treatment 3 (with a higher proportion of corn husk) and Treatment 4 (with equal proportions of rice straw and corn husk).

Table 7. Heat Temperature Measurement Table (T5).

Treatment 4: 75% Rice Straw 25% Corn Husk					
Replication	**Heat Temperature Measure every 5 minutes (Celsius)**				
	5 Mins	**10 Mins**	**15 Mins**	**20 Mins**	**Peak Temp.**
R1	485.5	489.9	524.9	600	600
R2	519	500	599.5	529.9	599.5
R3	524.9	553.6	592.5	600	600
Average					**599.83**

Table 8 shows the Average Heat Temperature Measure of briquettes in all treatments. It is reflected in the table that Treatment 3 has the highest average Heat Temperature Measurement followed by Treatment 5, Treatment 4, Treatment 2, and Treatment 1 respectively. This indicates that the composition of 25 percent carbonized Rice Straw and 75 percent carbonized Corn Husk (Treatment 3) resulted in the highest average temperature compared to the other treatments. The average heat temperature of the briquettes across treatments with 599.83 degrees Celsius is lower compared to the maximum recorded heat temperature of wood charcoal by Donsavanh (2023) with 677 degrees Celsius.

Table 8. Average Peak Temperature Measurement.

Replication	Heat Temperature Measure (Celsius)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	595.7	600	550.7	582.13
T2	594.9	600	589	594.63
T3	600	600	600	600
T4	594.8	589.7	600	594.83
T5	600	599.5	600	599.83
Mean Across Treatment				594.283

Figure 2 shows the clustered column chart of the briquettes' heat temperature measure of each replication in five different formulations. The chart visually shows the differences of the measured peak temperature among treatments.

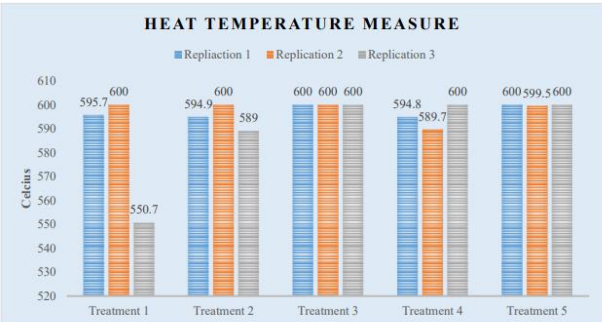

Figure 2. Clustered Column Chart of Heat Temperature Measure.

Table 9 shows the weight of the briquettes before combustion. Both Treatment 1 and treatment has the heaviest average weight across treatments followed by Treatment 4, treatment, Treatment 3, and Treatment 2, respectively. This suggests that Treatments 1 and 2 may have used a higher quantity of biomass or denser materials compared to the other treatments.

Table 9. Briquettes' Weight Before Combustion Table.

Replication	Weight Before Combustion (Grams)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	44	45	45	44.67
T2	39	37	39	38.33
T3	41	44	44	43
T4	46	43	43	44
T5	45	46	43	44.67

As reflected in the table 10, Treatment 5 has the heaviest ash remains followed by Treatment 3, Treatment 4, Treatment 1, and Treatment 2, respectively. This suggests that Treatment 5 may have produced a greater amount of residual ash after combustion compared to the other treatments.

Table 10. Briquettes' Weight After Complete Combustion Table.

Replication	Weight Before Combustion (Grams)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	6	6	6	6
T2	6	5	6	5.67
T3	6	8	7	7
T4	7	6	6	6.33
T5	8	8	7	7.67

Table 11 shows the total fuel consumed in all Treatments. Treatment 1 has the highest average fuel consumed of 38.67 grams with treatment 2 consuming the least fuel. This indicates that Treatment 1 required the highest amount of fuel for combustion compared to the other treatments, whereas Treatment 2 utilized the least amount of fuel.

Table 11. Average Total Fuel Consumed Table.

Replication	Mass of the Total Fuel Consumed (wbc-wcc)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	38	39	39	38.67
T2	33	32	33	32.67
T3	35	36	37	36
T4	39	37	37	37.67
T5	37	38	36	37

Table 12 shows the time taken to burn the briquettes in seconds. As reflected in the table, Treatment 1 is the longest to be burned completely and Treatment 3 being the fastest to be burned. This suggests that Treatment 1 had a slower burning time compared to Treatment 3.

Table 12. Total Time Taken to Completely Burn the Briquettes.

Replication	Total Time Taken to Completely Burn (Seconds)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	1765	1800	1800	1788.33
T2	1529	1438	1421	1462.67
T3	1224	1295	1288	1269
T4	1423	1362	1390	1391.67
T5	1341	1400	1330	1357

Table 13 reflects how much fuel is consumed every second of combustion. The table shows that Treatment 1 being the least to consume fuel per second with 0.021621025 g./sec compared to treatment 3 with 0.028373568 g./sec which has the most fuel consumed per second. This indicates that Treatment 1 burned fuel at a slower rate compared to Treatment 3. The result shows that Treatment 1 consumes less fuel compared to the burning rate of wood charcoal recorded by L.G. Hassan (2017) with 3.53 g/min or 0.058833333 g/sec.

Table 13. Burning Rate Table.

Replication	Burning Rate – Total Fuel Consume / Total Time Taken (grams/sec)			
	Rep 1	**Rep 2**	**Rep 3**	**Mean**
T1	0.021529745	0.021666666	0.021666666	0.021621025
T2	0.021582733	0.022253129	0.023223082	0.022352981
T3	0.028594771	0.027799227	0.028726708	0.028373568
T4	0.027406886	0.027165932	0.026618705	0.027063841
T5	0.027591349	0.027142857	0.027067669	0.027267291

Figure 3 is the clustered column chart of the burning rates of 5 different treatment in 3 replications. As reflected in the chart, there is an obvious gap between treatments 1 and 2 compared to treatments 3, 4 and 5.

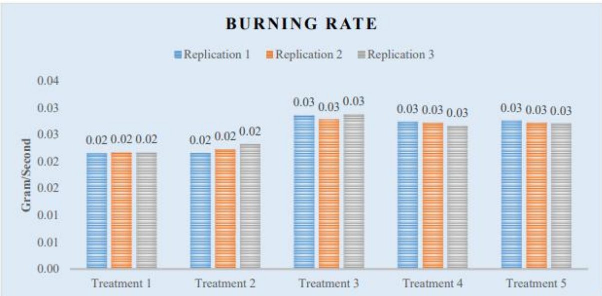

Figure 3. Clustered Column Chart of Burning Rate.

Level of Acceptability Evaluation

Table 14 shows the mean of the participants' responses with corresponding descriptive value of the briquettes in Treatment 1. Treatment 1 received a categorical mean of 4.23, indicating a highly acceptable level based on the participants' responses. Specifically, 50 percent of the parameters were rated as highly acceptable, while the other half were rated as moderately acceptable. Overall, the majority of participants found Treatment 1 to be highly acceptable as an alternative fuel source.

Table 14. Respondents' Acceptability in Utilizing 100 percent Carbonized Rice Straw Briquettes Table.

Parameters	Mean	Descriptive Value
1. The carbonized rice straw and corn husk briquettes are easy to ignite. *(Alisto laeng nga maarunan adiay uging manipud garami ken ukis iti mais)*	3.7	Moderately Acceptable
2. The carbonized rice straw and corn husk briquettes emit little smoke during combustion. *(Haan nga naa sok adiay uging manipud garami ken ukis iti mais nu mausar)*	3.9	Moderately Acceptable
3. The carbonized rice straw and corn husk briquettes have a long burning time. *(Nabayag iti panaguram na adiay uging manipud garami ken ukis iti mais)*	4.3	Highly Acceptable
4. The carbonized rice straw and corn husk briquettes are suitable for a various cooking method (e.g., stove, grill, oven). *(Mabalin iti nadumaduma nga pakaiyusaran iti panagluto adiay uging manipud garami ken ukis iti mais)*	4.6	Highly Acceptable
5. The carbonized rice straw and corn husk briquettes are durable and not easily to break or crumble. *(Natibser adiay uging manipud garami ken ukis iti mais haan ketdi nga alisto maburak wenno madadael)*	3.6	Moderately Acceptable
6. The carbonized rice straw and corn husk briquettes do not leave a residue or ashes. *(Haan unay nadapo adiay uging manipud garami ken ukis iti mais)*	3.9	Moderately Acceptable
7. The carbonized rice straw and corn husk briquettes provide a similar cooking experience to traditional fuels (e.g., charcoal, firewood). *(Agpada laeng iti maipaay a panagluto adiay uging manipud garami ken ukis iti mais a kas panagusar iti kayo ken rubo iti mais)*	4.6	Highly Acceptable
8. The carbonized rice straw and corn husk briquettes doesn't have any strange odor. *(Awan sabsabali nga angot na adiay uging manipud garami ken ukis iti mais)*	4.5	Highly Acceptable
9. The carbonized rice straw and corn husk briquettes have a consistent combustion and heat temperature. *(Agpapada iti pannakapuor ken pudut nga maited adiay uging maipud iti garami ken ukis iti mais)*	4.2	Moderately Acceptable
10. The carbonized rice straw and corn husk briquettes rapidly reaches high temperatures. *(Alisto laeng nga magaw-at adiay uging manipud garami ken ukis iti mais adiay nangato a temperatura)*	4	Moderately Acceptable
11. The carbonized rice straw and corn husk briquettes are easy to store and transport. *(Nalaka lang nga ipakni wenno idulin ken ibiahe adiay uging manipud garami ken ukis iti mais)*	4.6	Highly Acceptable
12. The carbonized rice straw and corn husk briquettes are environmentally friendly. *(Haan nga makadadael iti aglawlaw adiay uging manipud garami ken ukis iti mais)*	4.8	Highly Acceptable
Categorical Mean	**4.23**	**Highly Acceptable**

Cost and Return Analysis

The following were the different computations necessary to get the Return of Investment.

Total investment / day = material cost + labor

= 180 (cassava flour) + 800 (2 persons @ 400 per day)

= 180 + 800

= 980 Pesos per day

Total Bw per day = Pr per day / Baw

= 960/day x 42.53 grams

= 40,828 grams/day or **40.83 Kg. /Day**

Cost per kilo (w/o mark-up) = Total Investment per day / Total Bw per day

= 960 Pesos / 40.83 Kg

= 23.51 or **24 Pesos/Kg.**

Cost per kilo (w/ 50% mark-up) = Cost per kilo (w/o mark-up) x 1.5

= 24 Pesos per Kg. x 1.5

= 36 Pesos/Kg

Profit = Cost per kilo (w/ mark-up) – Cost per kilo (w/o mark-up)

= 36 Pesos/Kg. – 24 Pesos/Kg.

= 12 Pesos/Kg.

Total profit = Profit per kilogram x total kilograms produced per day

= 112 Pesos/Kg. x 40.83 Kg/day

= 489.96 or 490 Pesos/day

ROI = (Total Profit / Investment) x 100

= (490 / 980) x 100

= 0.5 x 100

= 50%

Table 15 shows the total return on investment of rice straw and cornhusk biochar briquette computed per day. As reflected on the table, the total investment made by the researchers was 980 pesos, and the total return gained was 490 pesos. This results in a return on investment (ROI) of 50 percent.

An ROI of 50 percent indicates that for every peso invested in producing rice straw and cornhusk biochar briquettes, the researchers were able to generate approximately 50 cents in profit. This suggests that the production of these briquettes has the potential to be financially viable, with a relatively high return compared to the initial investment.

Table 15. Total Return on Investment.

Total Investment	Total Profit	ROI (Profit/Investment) x 100
980 Pesos per day	490 Pesos/day	50%

Analysis of Covariance (ANCOVA) of the Different Parameters

Table 16 shows the result of the Analysis of Covariance in each parameter tested. The decision for the water boiling test is significant, resulting in the rejection of the null hypothesis. This indicates a significant difference among the water boiling time readings across treatments.

Furthermore, Post hoc analysis identified Treatment 1, Treatment 2, and Treatment 3 as the sources of variance. Treatment 1 was found to make water boil faster compared to the rest of the treatments.

It is also reflected in the table that there is no significant difference among treatments when it comes to the peak temperature it can generate. This means that regardless of the mixture, rice straw and cornhusk biochar briquettes can produce the same amount of heat across treatments.

Lastly, the decision for burning rate is significant. This only means that the burning rates are significantly different across treatments. The table also revealed that the source of variance is between Treatments 3,4 and 5 respectively. It is safe to infer, based on the results of ANCOVA, that Treatment 3 has the highest burning rate among the treatments. Since Treatment 1 and 2 were not included in the post hoc and considering that the burning rates of the treatments are lower than treatments 3, 4 and 5, it can be inferred that Treatment 1 and 2 have the lowest burning rates among them.

In summary, the rice straw and cornhusk biochar briquettes offer a sustainable and efficient alternative fuel source for cooking, with comparable performance to other briquette products. Through rigorous testing and analysis, this study has developed a viable cooking fuel that meets practical requirements and holds promise for addressing energy challenges in households and small businesses

Table 16. Results of Analysis of Covariance of Different Parameters.

Parameters	F-VALUE	P-VALUE	CRITICAL VALUE AT 0.05	DECISION
Water Boiling Test POST HOC: TREATMENT 1: 637.33 TREATMENT 2: 462.33 TREATMENT 3: 534	26.02	0	3.48	**SIGNIFICANT**
Heat Temperature Measure	0.99	0.46	3.48	**NOT SIGNIFICANT**
Burning Rate POST HOC: TREATMENT 3: 0.02837 TREATMENT 4: 0.02706 TREATMENT 5: 0.02727	122.65	0	3.48	**SIGNIFICANT**

CONCLUSIONS

The rice straw and cornhusk biochar briquettes were able to perform great in water boiling test, which is par to other briquettes with different compositions. Treatment 2, consisting of 100% cornhusk, demonstrated exceptional performance in producing fast combustion, making it ideal for situations requiring quick heat generation. Moreover, all treatments achieved a high combustion temperature averaging 594 degrees Celsius, suitable for various cooking methods, with no significant difference among them.

The efficiency of the briquettes was further highlighted by their low burning rates, particularly in Treatment 1 and Treatment 2, resulting in longer burning times and reduced fuel consumption. It was concluded that mixing rice straw and cornhusk biochar may not be beneficial, as evidenced by the lower burning rates compared to individual biochar compositions.

The high acceptability of the briquettes for home cooking purposes underscores their potential to alleviate fuel expenses for households and small businesses. Additionally, the study projected a promising return on investment of around 50 percent, indicating economic viability and potential marketability of the briquettes.

RECOMMENDATION

The researchers recommend the widespread adoption of rice straw and corn husk biochar briquettes as a substitute fuel for cooking in domestic settings. This initiative can aid households in minimizing their fuel expenses while contributing to anti-deforestation efforts by utilizing readily available agro-residues.

Among the different treatments tested, Treatment 2, consisting of 100 percent cornhusk biochar briquettes, is particularly recommended for situations requiring quick heat generation. However, both 100 percent rice straw and 100 percent cornhusk biochar briquettes are suitable for longer production of continuous heat and demonstrate fuel efficiency.

Future entrepreneurs are encouraged to explore the use of locally abundant agro-residues to minimize production expenditures and streamline production processes. Furthermore, this research serves as a valuable foundation for future studies aimed at producing low-cost cooking fuel using agricultural waste. By building upon the findings of this study, future researchers can develop alternative cost-efficient fuel options to benefit communities and promote sustainable practices.

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