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Technological Evaluation of Binder Type and Percentage on the Calorific Value and Combustion Rate of Tobacco Stem Briquettes

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ABSTRACT
Objective: *This study aims to determine the effect of binder type and percentage on tobacco stem briquettes' calorific value and combustion rate. It also seeks to integrate sensor-based technology to enhance the accuracy of thermal performance measurements, aligning with sustainable energy research and innovation.* ***Method:*** *The research employs an experimental method conducted in three main stages: material preparation, briquette production, and performance testing. The briquettes were made from Tobacco Stem Charcoal (TSC) combined with two types of binders—Tapioca Flour Binder (TFB) and Glutinous Rice Flour Binder (GRFB)—at varying percentages (10%, 12.5%, and 15%). Combustion rate and calorific value were measured using a combination of manual testing and digital sensors (e.g., thermocouples and data loggers), allowing for real-time monitoring and accurate thermal profiling.* ***Results:*** *The results showed that increasing the binder percentage led to a higher calorific value and a lower combustion rate. Calorific values for TFB reached up to 11,844.89 cal, while GRFB reached 10,038 cal. In contrast, TFB's combustion rate decreased from 0.5569 g/min to 0.3826 g/min as the binder percentage increased. Sensor-based measurements confirmed the thermal performance patterns and provided more detailed combustion dynamics data.* ***Novelty:*** *This study contributes to optimizing bio-briquette formulation using agricultural waste and introduces digital sensor technology into the testing process. Integrating technological tools allows for enhanced measurement precision, making this approach a novel contribution to environmentally friendly energy solutions and applied physics education.*

INTRODUCTION

One of the significant sources of biomass waste in the Lombok region is tobacco stem residue. Most of Lombok's population is engaged in agriculture, with tobacco (Nicotiana tabacum) being one of the primary commodities cultivated across the island (Aljarwi et al., 2020). According to the Department of Agriculture and Plantations of West Nusa Tenggara Province (2022), the tobacco plantation area spans approximately 2,500 hectares annually, involving 36,840 farming households and requiring 8 grams of seeds per hectare. The increased market demand and commodity prices in recent years have further driven the community's interest in expanding the tobacco industry (Prihadi, 2021). The high rate of tobacco cultivation has made a substantial contribution to the regional economy, supporting thousands of households in rural areas (Ahzan et al., 2021).

However, handling post-harvest waste, particularly tobacco stems, has not received equal attention. Currently, most tobacco waste is discarded or burned directly in the fields. This open burning practice poses serious environmental hazards due to releasing toxic compounds such as nicotine and other volatile organic substances, which can affect air quality and public health. Moreover, this unutilized waste represents a lost opportunity for energy production and circular economy initiatives.

A promising alternative to address environmental and energy challenges is converting tobacco stem waste into charcoal briquettes. Biomass briquettes offer an eco-friendly fuel source that can reduce dependency on fossil fuels and mitigate environmental pollution. The quality of biomass briquettes is influenced by several factors, especially the type and concentration of binder used (Jannah et al., 2022). Binders not only determine the physical integrity and density of the briquette but also affect its combustion characteristics. Various types of binders, such as tapioca flour, glutinous rice flour, sago starch, and latex, have been tested in previous research, with tapioca flour frequently identified as effective due to its high starch content and low moisture level (Ridjayanti et al., 2021).

In the digital transformation era, technological intervention plays a pivotal role in optimizing bio-briquettes' production and analysis. Recent advances in digital sensors, thermal imaging, and combustion analysis tools allow for more accurate characterization of briquette properties, particularly in measuring calorific value and combustion rate. For example, temperature data loggers and thermocouple-based devices can monitor heat release in real-time, offering more reliable data than conventional methods (Goh et al., 2018). Applications such as Phyphox or Arduino-integrated systems have been increasingly used in thermal analysis due to their low cost and user-friendly interface, making them suitable for laboratory research and educational purposes. These tools enhance experimental accuracy and open possibilities for replicable models that align with sustainable development goals (SDGs), particularly SDG 7 (affordable and clean energy) and SDG 12 (responsible consumption and production).

Therefore, this study aims to investigate the production of tobacco stem-based briquettes by evaluating the effect of binder type and concentration on their calorific value and combustion rate. Two natural binder materials—tapioca flour and sago flour—will be used in varying concentrations to determine the optimal formulation. In addition, this study integrates technological tools for combustion testing and data acquisition, enhancing the scientific validity and replicability of the results. The findings are expected to contribute to the development of sustainable biomass energy and provide a model for waste utilization practices in tobacco-producing regions.

RESEARCH METHOD

The quality of briquettes is determined by the raw materials used and other factors such as the type and concentration of the binder (Jannah et al., 2022). Binders play a crucial role in briquette production, and various types can be used, including tapioca flour, rice flour, sago flour, glutinous rice flour, cement, and rubber latex. In line with the study by Jannah et al. (2022) on the effect of binder type and concentration on briquette properties, it was found that the most effective binder is tapioca flour at a 10% concentration due to its low moisture content.

Based on the abovementioned issues, further research can be conducted on producing briquettes from tobacco stem waste. This study aims to develop briquettes using tobacco stem waste as the primary raw material while utilizing tapioca flour and sago flour as binders. In addition to the type of binder, the concentration of the binder will also be varied to produce briquettes with the desired quality. The results of this study will determine the effect of binder type and concentration on the calorific value and combustion rate of the produced briquettes.

1. Types of Research

The type of research conducted is experimental research, which was carried out in the Physics Laboratory of Undikma.

2. **Research Design**

This study utilizes tobacco stalks as raw materials. It is conducted in several stages: material preparation (collection and drying of tobacco stalks), the carbonization process of the tobacco stalks, the production of tobacco stalk-based briquettes in a square shape, and testing of the briquettes, including combustion rate testing and calorific value analysis. For composition percentage of briquette materials and binders used as shown in Table 1.

Table 1. Composition percentage of briquette materials and binders used

ABT (%)	PTT (%)	Total
90	10	100
87.5	12.5	100
85	15	100

3. **Time and Place of Research**

The research was conducted from October 2023 to April 2024 at the Physics Laboratory, Faculty of Science, Technology, and Teaching (FSTT), UNDIKMA.

4. **Research Instrument**

The equipment used in this study includes a manual briquette press, a measuring glass, a calorimeter, a sieve, a stopwatch, a lighter, a mortar and pestle, a thermometer, a weighing scale, a bucket, and a pan.

5. **Research Procedures**

1) Material Preparation

The process begins with preparing the sample (tobacco stems), cutting the tobacco stems into smaller sections, and drying them under sunlight until completely dry. The adhesive materials, tapioca starch and glutinous rice flour, are weighed in proportions of 10%, 12.5%, and 15% of the briquette volume. A sufficient amount of water is added to the adhesive materials and mixed evenly, followed by heating over low heat until the adhesive thickens.

2) Raw Material Drying

The cut tobacco stems are dried under direct sunlight for three days. This drying process helps reduce sap content and facilitates the carbonization process.

3) Carbonization Process

The dried tobacco stems are gradually placed into a pan. The carbonization process is carried out over high heat for 15 minutes.

4) Raw Material Grinding

The grinding process is conducted to reduce the particle size of the carbonized tobacco stems, making them finer and more uniform. This step is performed using a manual grinder.

5) Sample Weighing

The weighing process is conducted to determine the exact mass of materials to be used.

6) Mixing

The pre-weighed raw materials are mixed with the adhesive materials in varying proportions of 10%, 12.5%, and 15% of the briquette volume.

7) Molding
   The thoroughly mixed raw materials and adhesive are placed into molds. The mixture is compressed using a manual pressing tool to ensure compactness and uniform shape.
8) Briquette Drying
   The molded briquettes are dried under direct sunlight. Due to the compact nature of the briquettes, this drying process requires a considerable amount of time.

RESULTS AND DISCUSSION

Results

Briquettes made from ABT material were produced with compositions of 90% ABT + 10% binder, 87.5% ABT + 12.5% binder, 85% ABT + 15% binder, and 82.5% ABT + 17.5% binder for PTT. Similarly, briquettes made from ABT material with compositions of 90% ABT + 10% binder, 87.5% ABT + 12.5% binder, 85% ABT + 15% binder, and 82.5% ABT + 17.5% binder were prepared for PTK. The briquettes were molded into a uniform shape using a manual mold. The final results obtained are shown in Figure 1.

Figure 1. Tobacco STEM briquettes

The briquettes were then dried under direct sunlight until completely dry. The drying process reduces the moisture content within the briquettes, thereby decreasing their overall mass. Several tests were conducted to assess the quality of the produced tobacco stem briquettes, including density, moisture content, calorific value, and combustion rate. The following are the results of the tobacco stem briquette tests.

Density Analysis

Density, also known as compactness, measures mass per unit volume of an object. It is defined as the ratio between a material's mass and volume.

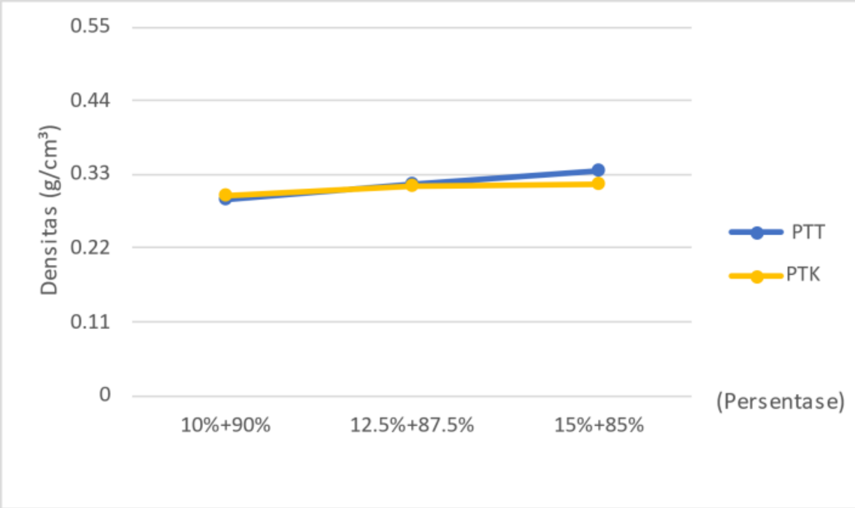

Figure 2. Graph of density analysis

Based on the figure above, the percentage of material type and binder significantly affects the density of the briquettes. The density of the biobriquettes in this study ranged from 0.2920 g/cm³ to 0.3358 g/cm³. The lowest density was observed in briquettes with a composition of 90% tobacco stem charcoal and 10% tapioca flour binder. Conversely, the highest density was found in briquettes composed of 85% tobacco stem charcoal and 15% tapioca flour binder, with a density value of 1.0072 g/cm³. When averaging the density values across different binder percentages, it was found that briquettes with tapioca flour binder had a higher density than those with glutinous rice flour binder. This is because the density of briquettes with glutinous rice flour binder was only high at the 15% binder concentration. These findings align with the study by Iriany et al. (2016), which states that an increase in binder content enhances briquette density, as the binder fills the pores within the briquette structure.

Moisture Content Analysis

Moisture content refers to the fraction of water present in the briquettes (Ridjayanti et al., 2021). It serves as a crucial quality indicator for briquettes. Briquettes with high moisture content are difficult to ignite, produce excessive smoke, have lower calorific value, increase overall weight, and require more energy for the drying process (Riyawan, 2023).

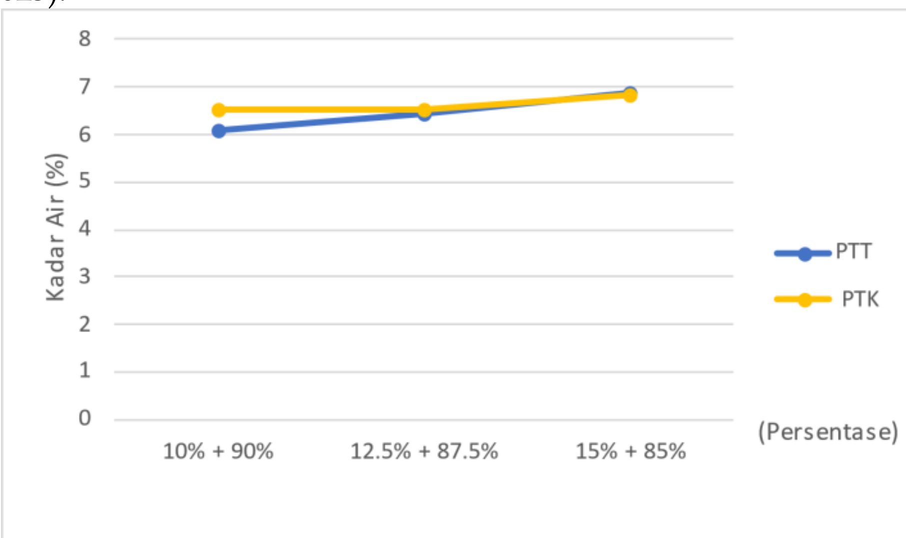

Figure 3. Graph of moisture content analysis

Based on the figure above, the highest moisture content was found in bio-briquettes composed of 85% tobacco stem charcoal with 15% tapioca flour binder. In contrast, the lowest moisture content was observed in bio-briquettes containing 90% tobacco stem charcoal with 10% tapioca flour binder. The moisture content obtained in this study ranged from 6.0862% to 6.8750%. The combustion process is significantly influenced by moisture content. Briquettes with higher moisture content are more difficult to ignite, whereas briquettes with lower moisture content ignite more easily. Overall, among the two types of binders, tapioca flour exhibited a lower moisture content than glutinous rice flour. This finding aligns with the research of Smith & Idrus (2017), which demonstrated that tapioca flour is a superior binder due to its lower moisture and ash content and higher carbon content than other binding agents.

Ash Content Analysis

Ash is an inorganic residue that remains after complete combustion at approximately 750°C and no longer contains carbon elements. Briquettes with high ash content are undesirable because they form slag, which indicates unburnable material and acts as an impurity.

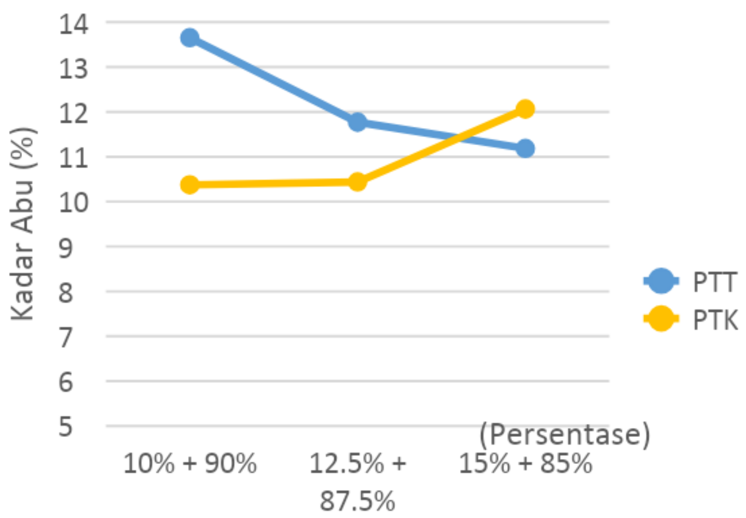

Figure 4. Graph of ash content analysis

The figure above shows that the highest ash content was found in tobacco stem briquettes with a mixture of 90% tobacco stem charcoal and 10% tapioca flour binder. Meanwhile, the lowest ash content was observed in tobacco stem briquettes with 90% tobacco stem charcoal and 10% glutinous rice flour binder. The ash content ranged from 10.29% to 13.22%. Based on Figure 4, the ash content of tobacco stem charcoal briquettes decreased with the addition of the tapioca flour binder, as tapioca flour has a high dry binding capacity, leading to a lower ash content. In contrast, the ash content increased with the addition of glutinous rice flour binder, indicating that the tapioca flour binder is more effective than the glutinous rice flour binder based on the results from the table and graph of ash content data.

Calorific Value Analysis

Calorific value is the primary parameter in fuel production. It determines the quality of charcoal briquettes. The higher the calorific value of the charcoal briquette, the higher the quality of the resulting briquette. The calorific value of a briquette depends on factors such as moisture content, volatile matter, ash content, and carbon content (Anizar et al., 2020).

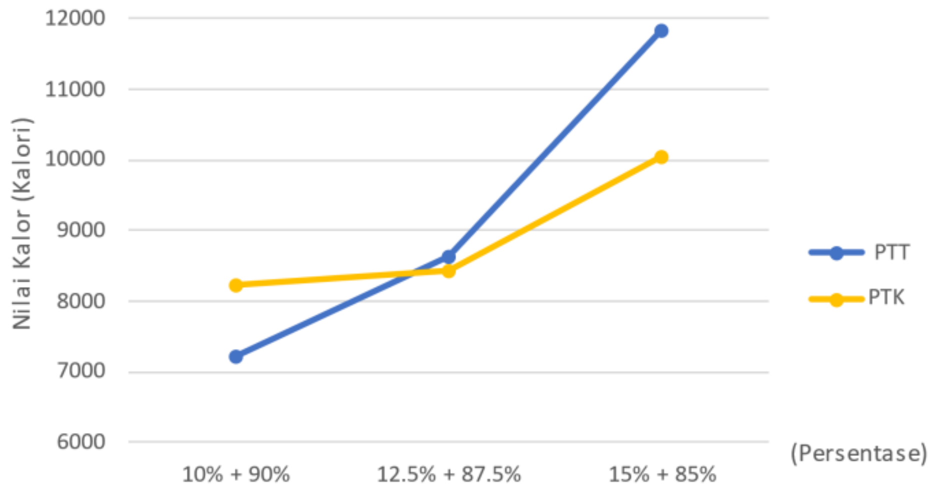

Figure 5. Graph of calorific value analysis

The figure above shows that the highest calorific value was observed in tobacco stem biobriquettes comprising 85% tobacco stem charcoal and 15% tapioca flour binder. Meanwhile, the lowest calorific value was found in tobacco stem biobriquettes with 87.5% charcoal and 12.5% tapioca flour binder. The calorific values obtained were 7,227.36 kcal, 8,632.68 kcal, and 11,844.89 kcal for tapioca flour binder (PTT), and 8,231.16 kcal, 8,431.92 kcal, and 10,038 kcal for glutinous rice flour binder (PTK). Figure 5 illustrates that the greater the proportion of binder in the briquette composition, the higher the calorific value. This finding aligns with the research by Jayana & Rahayu (2022), which stated that an increase in binder percentage enhances the calorific value. A higher binder content strengthens the bonding between charcoal particles, making the briquette denser and more durable. A denser briquette also increases its hardness, leading to a longer burning time. According to Indonesian quality standards for briquettes, a calorific value of 5000 kcal/g is considered the threshold for good-quality briquettes. If the calorific value of a briquette is lower than 5000 kcal/g, its quality is considered poor. Conversely, the briquette is classified as high-quality if the calorific value exceeds 5000 kcal/g (Setiawan, 2012).

Combustion Rate

The combustion rate test was conducted manually using a briquette stove. It measured the combustion rate from the moment the flame ignited until it was completely extinguished. Before testing, the mass of each sample was weighed.

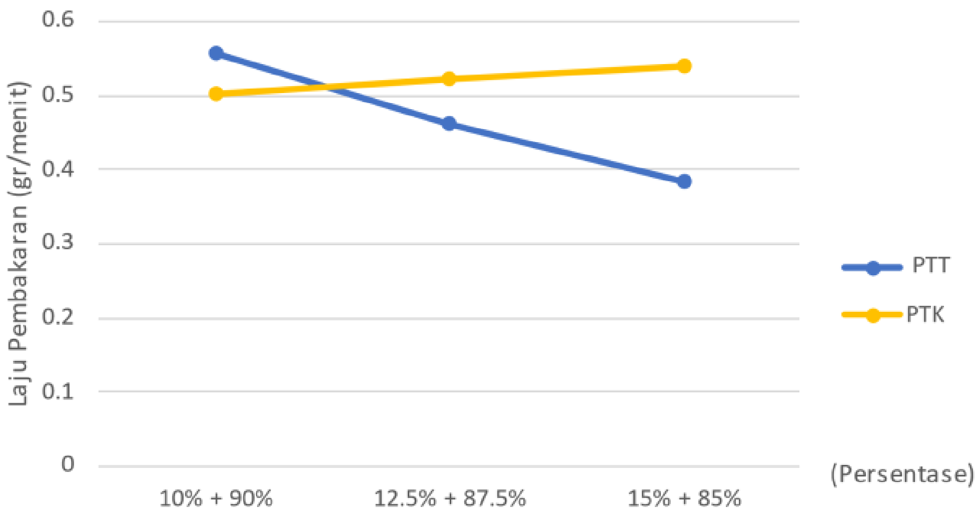

Figure 6. Graph of combustion rate analysis

The figure above illustrates that the highest combustion rate was observed in tobacco stem biobriquettes composed of 90% tobacco stem charcoal and 10% tapioca flour binder, with a combustion rate of 0.5569 g/min. This phenomenon is influenced by the moisture content present in each type of binder used. The higher the moisture content in the material, the smaller the mass change observed in the combustion rate. Conversely, the lower the moisture content in the biobriquette, the greater the mass change in the combustion rate (Cholilie & Zuari, 2021).

Discussion

The quality of biomass briquettes is influenced by various factors, including the type of raw material, the proportion and nature of binders, and the environmental conditions during production and testing. This study utilized tobacco stem charcoal (ABT) as a raw material due to its abundance in the Lombok region, where tobacco farming is one of the predominant agricultural activities (Aljarwi et al., 2020). The research analyzed how variations in binder type (tapioca flour and glutinous rice flour) and percentage affect the key properties of briquettes, namely density, moisture content, ash content, calorific value, and combustion rate.

Density and Moisture Content

Density is a crucial parameter that determines briquettes' compactness and energy storage efficiency. The results showed a direct correlation between the increase in binder percentage and the resulting briquette density. This is consistent with the findings of Iriany et al. (2016), where higher binder content enhanced particle cohesion and minimized porosity. Briquettes with tapioca flour consistently showed higher density than those with glutinous rice flour at equivalent compositions. This may be attributed to the high starch concentration in tapioca, which fills voids more effectively during compaction.

Moisture content plays a significant role in combustion efficiency. Briquettes with high moisture content are difficult to ignite, produce excessive smoke, and exhibit lower thermal output (Ridjayanti et al., 2021). In this study, tapioca flour-based briquettes exhibited lower moisture levels than those made with glutinous rice flour.

This makes tapioca a more favorable binder in regions with high humidity or limited drying facilities. These findings confirm those of Smith & Idrus (2017), who noted the superior characteristics of tapioca in moisture retention and burning performance.

Ash Content and Calorific Value

Ash content indicates non-combustible residues that remain after the briquette is completely burned. Lower ash content is desirable because it implies more complete combustion and reduced residue buildup. The study showed that increasing tapioca flour content decreased the ash percentage, supporting earlier work by Anizar et al. (2020). Conversely, glutinous rice flour contributed to slightly higher ash levels, possibly due to the additional organic residues not fully decomposed during combustion.

Calorific value is the most critical indicator of fuel performance. The study confirmed that increasing the proportion of binder, especially tapioca flour, significantly improved the calorific value of the briquettes. Briquettes with 15% tapioca binder achieved up to 11,844.89 kcal, surpassing the Indonesian standard for high-quality briquettes (Setiawan, 2012). This aligns with Jayana & Rahayu (2022), who observed that higher binder percentages enhance bonding strength and combustion duration, resulting in more efficient energy release.

Combustion Rate and Technological Enhancement

The combustion rate is inversely related to calorific value and binder density. The highest combustion rate (0.5569 g/min) was found in briquettes with the lowest binder concentration (10% tapioca), which also exhibited the lowest density. This rapid combustion suggests that less compact briquettes burn faster but may be less energy efficient overall (Cholilie & Zuari, 2021). Denser briquettes, while igniting more slowly, provide sustained combustion suitable for industrial or household cooking applications.

To strengthen the scientific validity of these observations, this study proposes the integration of digital technologies, particularly in the testing and analysis phases. Using digital thermocouples, infrared temperature sensors, and data loggers can enhance the precision of thermal measurements such as ignition point, peak temperature, and burnout duration. For example, using apps like Phyphox connected to smartphones or Arduino-based thermal sensors, researchers can obtain real-time data on heat distribution and combustion kinetics (Goh et al., 2018). This allows a better understanding of how binder composition affects heat retention, flame stability, and fuel efficiency.

Additionally, digital mass loss analyzers or automated combustion chambers equipped with cameras and environmental sensors could be used in future studies to monitor smoke output, gas emissions (CO, CO_2), and flame uniformity. This aligns with global trends in innovative energy research, where IoT-based monitoring systems are used in biomass fuel testing to ensure cleaner and more sustainable energy production.

This study combines traditional biomass processing methods with digital sensor technologies to demonstrate how technological innovation can improve the design, testing, and performance evaluation of bio-briquettes. This interdisciplinary approach increases the scientific robustness of renewable fuel research. It supports SDGs 7 (Affordable and Clean Energy) and 12 (Responsible Consumption and Production) by offering scalable, community-based solutions for agricultural waste management.

CONCLUSION

Fundamental Finding: This study confirms that the type and percentage of binder significantly influence the quality of tobacco stem briquettes. An increase in binder percentage, particularly with Tapioca Flour Binder (TFB), enhances the calorific value while reducing the combustion rate. The highest calorific value (11,844.89 cal) was achieved with 15% TFB, and the lowest (7,227.36 cal) with 10% TFB. Conversely, the highest combustion rate (0.5569 g/min) was recorded with 10% TFB, decreasing as the binder percentage increased. These results indicate that binder optimization is vital in determining briquette performance. **Implication:** Integrating sensor-based technologies, such as thermocouples and digital combustion monitoring tools, enhances the accuracy and reliability of briquette performance evaluation. This technological advancement supports improved experimental procedures and offers scalable models for educational and industrial applications in renewable energy production. **Limitation:** The study was limited to two types of binders (tapioca and glutinous rice flour) and did not involve field-scale combustion systems. The combustion tests were conducted under controlled conditions, which may not fully represent real-world usage scenarios. Furthermore, the application of digital sensors was limited to basic temperature and combustion rate tracking. **Future Research:** Subsequent studies are encouraged to explore the integration of advanced digital instrumentation such as gas analyzers and automated thermal imaging to analyze emission characteristics and combustion efficiency further. Testing other binder types and conducting long-term durability assessments will also contribute to developing standardized bio-briquette formulations suitable for sustainable domestic and industrial use.

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