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Characterization and performance analysis of Kesambi branch biomass briquettes: A study on particle size effects

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ABSTRACT

This study investigates the characterization and performance of biomass briquettes produced from the branches of the Kesambi tree (*Schleichera oleosa*), a previously underutilized biomass resource in East Nusa Tenggara, Indonesia. The increasing demand for Kesambi wood in traditional sei meat smoking has raised concerns about the sustainability of tree resources, highlighting the need for alternative fuel solutions. Utilizing Kesambi branches as briquette material could alleviate pressure on tree trunks while preserving the unique qualities of sei meat. The research focuses on the effects of particle size on the briquette's physical and thermal properties. Kesambi branches were ground to different particle sizes (20, 40, and 60 mesh) and mixed with a tapioca flour binder. Briquette properties were analyzed through density, compressive strength, moisture content, ash content, volatile matter, and fixed carbon, using ASTM standards. Results indicated that smaller particle sizes resulted in higher density and compressive strength, enhancing combustion efficiency. The study also applied various empirical models to predict the higher heating value (HHV) based on proximate analysis data, evaluated through AIC and BIC for model accuracy. This research demonstrates that Kesambi branch briquettes not only provide a sustainable fuel alternative but also contribute to local economic development by creating job opportunities in biomass processing. Ultimately, these innovations support the conservation of Kesambi tree resources while promoting environmental sustainability in energy production.

Keywords: Kesambi branch biomass, briquette characteristics, combustion performance, renewable energy source, sustainable fuel production.

INTRODUCTION

The branches of the Kesambi tree (*Schleichera oleosa*) represent a plentiful biomass resource; however, they are often regarded as underutilized waste. In the region of east nusa tenggara (NTT), Indonesia, the Kesambi tree plays a significant role, particularly in cultural and economic contexts. One traditional use of the Kesambi tree's trunk is as the primary fuel source in the smoking process of sei meat, a smoked dish that is a culinary specialty of NTT. The smoking process using Kesambi wood is integral to the unique flavor and aroma of sei, a traditional meat preparation gaining popularity across Indonesia. This distinctive smoking method not only enhances sensory qualities but also influences the antioxidant properties of the meat, contributing to its appeal.

Kesambi wood imparts specific phenolic compounds that enhance the aroma and flavor of smoked meats, similar to findings with other woods like beech and oak (Cheng et al., 2024). The presence of compounds such as guaiacol and syringol, noted in liquid smoke preparations, contributes to the organoleptic properties of smoked products (Guillén and Ibargoitia, 1998). Smoking with Kesambi wood may improve the antioxidant capacity of the meat, reducing lipid and protein oxidation, which is crucial for maintaining quality during storage (Zhou et al., 2022). The phenolic content in smoke from various woods correlates positively with antioxidant activity, suggesting that Kesambi wood could offer similar benefits (Zhou et al., 2022). The rising popularity of sei has led to increased demand for Kesambi wood, reflecting a broader trend in Indonesia where traditional smoking methods are being embraced for their unique flavors and health benefits.

However, alongside the rising demand for sei, there has been an increase in the exploitation of Kesambi tree trunks for fuel. This has raised concerns about the sustainability of Kesambi tree resources, which, if not managed properly, may lead to a decline in tree populations and disrupt the forest ecosystem in the area. Therefore, there is a need for solutions that can alleviate the pressure on the use of Kesambi tree trunks without compromising the quality of the smoking process produced.

One promising approach is to utilize Kesambi branches as an alternative fuel source through the process of briquette manufacturing. These branches, often overlooked and deemed waste in the management of the tree, actually possess significant potential to be processed into efficient and environmentally friendly biomass briquettes. Kesambi branch briquettes can replace the direct use of Kesambi tree trunks, thereby reducing pressure on natural resources while maintaining the unique aroma produced by Kesambi wood in the smoking of sei meat. The development of biomass briquettes from candlenut shell charcoal and Kesambi twigs, as demonstrated by Dethan, (2024), shows that increasing the proportion of candlenut shell charcoal enhances the properties of the briquettes. Additionally, predictive models such as the Nhuchhen model with an R^2 of 0.93 have estimated calorific values exceeding 19 MJ/kg, underscoring the potential of such briquettes as a sustainable alternative to conventional fuels.

The particle size of raw materials significantly influences the characteristics and quality of biomass briquettes, particularly in terms of density, durability, and combustion efficiency. Smaller particle sizes generally enhance briquette density and combustion performance, while larger particles can lead to increased porosity and reduced efficiency. This relationship underscores the importance of optimizing particle size in the production of briquettes from Kesambi branches. Smaller particles (e.g., < 1.2 mm) yield briquettes with higher density and compressive strength, enhancing durability (Setter et al., 2021). Briquettes made from finer particles (e.g., sieve number 60) exhibited the highest hardness and density (Heya et al., 2022). Finer particles improve combustion efficiency due to better packing and reduced void spaces, leading to more complete combustion (Pang et al., 2019). Studies indicate that briquettes with smaller particle sizes have higher calorific values, enhancing energy output (Heya et al., 2022). The briquetting process is more energy-efficient with smaller particles, as they require less force for compaction (Heya et al., 2022). Mixed particle sizes can optimize energy consumption and improve product quality compared to uniform sizes (Wang et al., 2018).

The benefits of Kesambi branch briquettes extend beyond merely serving as a substitute for traditional fuels. Environmentally, the use of these biomass briquettes contributes to lower carbon emissions compared to direct wood burning. This positions Kesambi branch briquettes as a more environmentally friendly and sustainable fuel source. Furthermore, Kesambi branch briquettes can be utilized not only for the smoking process of sei meat but also for various household and industrial applications, particularly in areas lacking access to fossil fuels or conventional firewood.

Innovations in the use of Kesambi branches for briquettes have significant socio-economic impacts. The production of Kesambi branch briquettes can empower local communities, especially in rural areas, by creating new job opportunities in the biomass processing sector. The development of a sustainable briquette industry can significantly enhance local incomes and improve production efficiency in the sei meat smoking industry. Briquettes, made from agricultural and municipal waste, offer a cleaner and more efficient alternative to traditional firewood, providing stable heat and longer combustion times. Income Generation: The briquette industry can create jobs in production and distribution, particularly in rural areas where agricultural waste is abundant (Kapen et al., 2022; Khan et al., 2023). Waste Reduction: Utilizing agricultural and municipal waste for briquette production helps mitigate waste disposal issues and reduces deforestation (Khan et al., 2023; Nikiema et al., 2022). Lower Emissions: Briquettes produce fewer harmful emissions compared to traditional fuels, contributing to better air quality (Mendoza et al., 2024).

As the popularity of sei meat spreads beyond NTT, including various regions in Indonesia, it is essential to ensure that the production methods used support the conservation of natural resources and mitigate negative environmental impacts. Kesambi branch briquettes, with their efficiency and sustainability advantages, can serve as a relevant solution in this context. Furthermore, this innovation contributes new scientific knowledge to the field of renewable energy research, particularly regarding local biomass as a sustainable alternative energy source.

The use of Kesambi branches as raw material for briquettes offers an innovative and sustainable solution to the challenges posed by the scarcity of traditional firewood. Through the development of Kesambi branch briquettes, not only is the conservation of Kesambi trees maintained, but the distinctive quality of sei meat is also preserved. Additionally, these briquettes can help strengthen local energy resilience, support carbon emission reduction efforts, and create economic opportunities for local communities in East Nusa Tenggara and other regions in Indonesia.

MATERIAL AND METHODS

The branches of Kesambi (*Schleichera oleosa*) will be used as the primary raw material for the production of briquettes. These branches are collected from forested areas or fields containing Kesambi trees, which are known as one of the sources of firewood in the East Nusa Tenggara region. Kesambi branches are selected due to their abundance and significant potential as a base material for briquette production, exhibiting favorable combustion characteristics. To enhance the cohesion and strength of the briquettes, tapioca flour is utilized as a binding agent. The observation variable analysis was conducted at the Agricultural Product Technology Laboratory, Kupang State Agricultural Polytechnic and the Exact Sciences Laboratory at Artha Wacana Christian University.

A grinder reduces Kesambi branches into particles of various sizes, which are classified using a sieve with mesh standards of 20, 40, and 60. A digital scale measures the weight of the materials to maintain a consistent composition for briquette production. The materials are molded into briquettes of uniform size and density using a pressing machine. After molding, the briquettes are dried in an oven to lower moisture content, improving combustion quality.

Design experiment

This research employs a laboratory experimental method, with independent variables consisting of the particle size of Kesambi branches categorized into three sizes: small (20 mesh), medium (40 mesh), and large (60 mesh). The dependent variables in this study are the physical and thermal characteristics of the briquettes, which include density measured by ASTM D1895, compressive strength following ASTM E9 standards, moisture content measured using the oven drying method in accordance with ASTM D3173, ash content following ASTM D3174, volatile matter using ASTM D3175, and fixed carbon calculated with the formula: fixed carbon (%) = 100 – (moisture content (%) + volatile matter (%) + ash content (%)). To obtain accurate results, this study applies a completely randomized design (CRD) with four replications for each particle size category.

Research procedure

The research procedure begins with the collection of Kesambi branches at predetermined locations. The branches are cut into smaller pieces to facilitate subsequent processing. After cutting, the branches are cleaned of dirt and rough outer bark, leaving only the clean and ready-to-use material. This step is essential to ensure that the raw materials do not contain contaminants that could affect the quality of the resulting briquettes.

Once the raw materials are prepared, the next stage is grinding. The cleaned Kesambi branches are ground using the grinder. The grinding process aims to transform the branches into powder with varying particle sizes. To classify these particle sizes, sieves with mesh sizes of 20, 40, and 60 are used. Utilizing the sieve allows for the separation of the produced powder based on the desired sizes, which is a crucial step in ensuring that each particle size will yield different briquette characteristics.

After the Kesambi branch powder is ready, the next step involves preparing the tapioca solution. Tapioca flour is mixed with water in a proportion of 5% of the weight of the Kesambi powder. This solution is stirred until homogeneous to ensure that the tapioca flour is well-integrated and ready for use as a binding agent in the briquette production process.

The briquette production begins with the mixing of materials. The ground and sieved Kesambi powder is combined with the tapioca flour solution. This mixing process is performed carefully to ensure a uniform mixture and good distribution of the binder throughout the powder. A well-mixed composition will yield briquettes with optimal strength and density.

Upon completion of the mixing, the mixture is placed into the briquette mold. In this step, the powder and binder mixture is compacted using the pressing machine at a specified pressure. This molding aims to form briquettes with uniform size and shape. After the molding process, the formed briquettes are dried in an oven at 105 °C for 24 hours. This drying is vital to reduce the moisture content of the briquettes to a standard level, specifically below 10%. Low moisture content is crucial for enhancing the combustion efficiency of the briquettes.

Data analysis

The data were analyzed using ANOVA and Duncan's post-hoc test. The obtained proximate data were compared using three empirical models to predict the higher heating value (HHV). The first model, based on the work of Parikh et al. (2005), is represented by the equation:

$$HHV = -0.0078Ash + 0.1559VM + 0.353FC \quad (1)$$

The second model, from Yin (2011), is expressed as:

$$HHV = 0.2521FC + 0.1905VM \quad (2)$$

The third model, derived from Nhuchhen and Salam (2012), is given by:

$$HHV = -0.0022\frac{FC}{VM} + 0.1625VM + + 0.0075Ash + 0.3451FC \quad (3)$$

The comparison of the model results was conducted using the Akaike information criterion (AIC) and Bayesian information criterion (BIC) to assess model accuracy, along with the coefficient of determination (R^2).

RESULT AND DISCUSSION

Table 1 presents a comparative analysis of various physical and chemical properties of briquettes produced from different mesh sizes, specifically examining density, compression strength, moisture content, ash content, volatile matter, and fixed carbon. Each parameter is reported along with its corresponding mean value and standard deviation, emphasizing the impact of particle size on the quality of the briquettes.

Density

The density measurements for particles sized 60 mesh range from 0.66 to 0.71 MPa. Smaller particles enhance the adhesion among briquette components, allowing for the efficient filling of finer gaps. Conversely, larger particles result in an increase in void spaces, consequently decreasing the briquette's overall density. A higher density indicates a more compact structure, which typically enhances both the combustion quality and mechanical strength of the briquettes.

Smaller particle sizes indeed enhance the density of briquettes by effectively filling interstitial voids between larger grains, leading to a more compact arrangement. This phenomenon is supported by various studies that highlight the relationship between particle size and packing density, which is crucial for optimizing the physical and mechanical properties of briquettes. Smaller particles occupy voids more efficiently, increasing overall density (Setter et al., 2021). Multimodal particle size distributions can achieve higher packing densities than uniform distributions (Du et al., 2021).

Experimental results indicate that briquettes made from particles smaller than 1.2 mm exhibit superior physical and mechanical properties, including higher compressive strength and energy density (Setter et al., 2021). The mechanical meshing force between particles increases as

Table 1. Effects of particle size on the physical and chemical properties of briquettes

Treatment	Density	Compression strength	Moisture content	Ash content	Volatile matter	Fixed carbon
Mesh 60	0.71±0.01[a]	2.81±0.01[a]	5.57±0.21[a]	4.00±0.70[a]	70.32±1.95[a]	20.11±1.92[a]
Mesh 40	0.70±0.03[b]	2.58±0.02[b]	7.05±0.17[b]	5.05±0.12[b]	69.39±2.08[a]	18.51±1.85[b]
Mesh 20	0.66±0.01[b]	2.16±0.08[c]	8.20±0.20[c]	7.04±0.30[c]	73.47±0.73[b]	11.28±0.65[b]

Note: numbers followed by different letters within the same column indicate significant differences among treatments at $\alpha < 0.05$.

particle size decreases, enhancing cohesion and strength (Pang et al., 2019).

Smaller particles reduce void spaces, leading to improved compaction and density (Hettiarachchi and Mampearachchi, 2020).

Larger particle sizes create significant gaps, which can hinder compaction and reduce density. This highlights the importance of optimizing particle size in briquette production to achieve desired physical properties and energy efficiency.

Compression strength

Observational data reveal that the compression strength varies between 2.16 and 2.81 MPa. The compression strength is influenced by the particles' ability to bond under pressure. Finer particles provide a greater number of contact points, which improves adhesion, while coarser particles offer fewer contact points, leading to lower compression strength. The higher compression strength noted for the 60 mesh indicates that these briquettes are more capable of withstanding external forces, which is essential for their handling, transportation, and storage.

The relationship between particle size and the mechanical properties of briquettes is significant, particularly regarding compressive strength. Smaller particles enhance inter-particle interactions due to their increased surface area, leading to stronger bonds and improved compressive strength. Conversely, larger particles exhibit weaker bonds due to their reduced surface area, resulting in diminished strength. Smaller particles (less than 1.2 mm) in coffee husk briquettes showed superior compressive strength compared to larger particles (Setter et al., 2021).

In coal briquettes, a decrease in particle size resulted in increased uniaxial compression strength and cohesion, indicating stronger interparticle bonding (Pang et al., 2019). The mechanical properties of bonded granules also depend on particle size, with smaller particles providing better compressive resistance due to enhanced contact area (Liu et al., 2015). Smaller particles exhibit more uniform normal contact forces, which contribute to stronger inter-particle interactions (Yang et al., 2008).

The cohesive forces between fine particles increase as particle size decreases, further enhancing the mechanical integrity of the briquettes (Yang et al., 2008). Although smaller particles generally improve compressive strength, they also require increased energy for processing and may pose potential handling issues associated with fine materials. Biomass as an energy source often faces challenges, such as low energy density, high moisture content, and high tar content, which can be mitigated through pre-treatment methods like torrefaction. (Dethan et al., 2024a) explored torrefaction at optimal conditions of 300 °C for 20 minutes, which significantly enhances the calorific value of biomass. Such pre-treatment processes align with findings from this study, which demonstrate the potential improvements in Kesambi briquettes' heating efficiency through careful management of particle size and moisture content.

Moisture content

Observational data indicate moisture content values ranging from 5.57% to 8.20%. Briquettes manufactured from finer particles are more likely to exhibit lower moisture content due to their smaller pore sizes and superior compacting capabilities. In contrast, larger particles allow for more air and moisture to occupy space, thereby increasing the overall moisture content. Elevated moisture levels can negatively impact combustion quality, decrease energy efficiency, and produce more smoke during the burning process.

The relationship between particle size and the physical properties of briquettes is significant, particularly regarding water absorption and retention. Smaller particles facilitate tighter packing, leading to reduced pore spaces and lower moisture content, while larger particles create more interstitial spaces, enhancing water retention. This dynamic is evident in various studies. Compaction and smaller coal particles increase the mechanical meshing force, resulting in higher uniaxial compression strength and reduced plastic deformation (Pang et al., 2019). Water absorption smaller particles yield a finer pore structure, which enhances water absorption efficiency, while larger particles lead to increased voids that retain more water (Wang et al., 2023). The blending of briquettes with fine coal can create localized low-bulk-density regions, further influencing the overall density and moisture retention of the briquette (Watanabe et al., 2023). While smaller particles enhance compaction and reduce moisture retention, larger particles can improve structural integrity and resilience in certain applications, suggesting a balance is necessary for optimal briquette performance (Dobrzanski et al., 2024).

Ash content

Observational data for 60 mesh particles indicate a minimum ash content of 4.00%, whereas the 20 mesh particles exhibit a maximum ash content of 7.04%. The more complete combustion of finer particles can be attributed to their larger surface area, which improves their interaction with oxygen, accelerates combustion, and minimizes ash residue. In contrast, larger particles are more challenging to combust completely, resulting in greater amounts of ash remaining after combustion. Ash is considered non-combustible residue, and an increase in ash content adversely affects fuel quality.

The combustion efficiency of biomass fuels is significantly influenced by particle size, with smaller particles generally leading to more complete combustion and reduced ash content. This phenomenon is critical in optimizing biomass energy production and minimizing environmental impacts. The following sections elaborate on the effects of particle size on combustion efficiency and ash formation. Smaller particles (less than 1 mm) enhance combustion efficiency by increasing surface area, allowing for better air-fuel mixing and more complete combustion (Plankenbühler et al., 2019). Larger particles tend to combust less completely, resulting in higher residual ash due to insufficient heat and oxygen penetration (Hedayati et al., 2022). Studies indicate that co-combustion of smaller particles with other biomass types can reduce particulate matter and slag formation, further decreasing ash content (Falk et al., 2023). Demineralization techniques can significantly lower ash content in biomass, with reductions of up to 99% observed in certain cases (Kukuruzović et al., 2023). While smaller particles generally improve combustion efficiency, it is essential to consider that the composition of the biomass and the presence of certain minerals can also affect ash behavior. For instance, the interaction of potassium and phosphorus with other elements during combustion can lead to complex ash formations, regardless of particle size (Hedayati et al., 2022).

Volatile matter

Observational data indicate that volatile matter for 60 mesh particles ranges from 70.32% (lower) to 73.47% (higher) for 20 mesh particles. Volatile matter consists of organic compounds that readily vaporize and are released during combustion. For smaller particles, the release of volatile matter occurs more rapidly because of a more uniform heat distribution throughout the particles. Conversely, larger particles require more time to heat their interiors, resulting in prolonged retention of volatile matter within their structure, which in turn leads to a higher volatile matter content.

Finer particles in coal combustion enhance the release of volatile matter due to their increased surface area and uniform heat distribution. This results in more efficient combustion processes compared to larger particles, which tend to retain volatile matter longer due to uneven heating. Finer coal particles (25–75 μm) exhibit higher burnout rates compared to larger sizes (250–500 μm), indicating more effective combustion under high heating rates (Fragoso et al., 2019). The intermediate particle size (105–250 μm) showed similar conversion rates to finer particles, suggesting a balance between size and combustion efficiency (Fragoso et al., 2019). Larger particles retain volatile matter longer, as evidenced by delayed pressure variations during combustion, which correlates with slower reaction times (Fragoso et al., 2019). The presence of fine mineral particles in coal also influences particulate emissions, with larger particles contributing to higher PM emissions due to their retention of volatile components (Gao et al., 2016).

Fixed carbon

Observational data for 60 mesh particles reveal a maximum fixed carbon content of 20.11%, while 20 mesh particles show a minimum of 11.28%. Fixed carbon refers to the carbon remaining after volatile matter has been expelled during combustion. With smaller particle sizes, more complete combustion occurs, resulting in higher fixed carbon production. Conversely, larger particles experience less efficient combustion, leading to a lower fixed carbon content. Fixed carbon is a vital component contributing to the calorific value of the fuel, thus a higher fixed carbon content indicates superior fuel quality for the briquettes.

The relationship between particle size and fixed carbon content is significant in combustion processes. Smaller particles tend to retain a higher percentage of fixed carbon due to more efficient combustion and quicker release of volatile matter, while larger particles exhibit lower fixed carbon retention due to slower volatile release and less efficient combustion. The slower release of volatiles in larger particles contributes to this inefficiency. Studies show that smaller biomass particles yield lower fixed carbon during pyrolysis, emphasizing the importance of particle size in optimizing charcoal production (Wang et al., 2013). Smaller biochar particles enhance pellet strength and reactivity, indicating that size reduction can improve performance in applications like metallurgical-grade silicon production (Xu et al., 2024). Smaller particles generally yield higher fixed carbon, it is essential to consider the trade-offs in combustion efficiency and emissions, particularly in the context of air quality and health impacts associated with particulate matter from various fuel sources (Xie et al., 2023). Particle size has a profound impact on both the physical and chemical properties of briquettes, with finer particles consistently yielding superior outcomes in terms of density, strength, and combustion efficiency. The physical and chemical characteristics of the briquettes produced from different mesh sizes reveal that finer particles result in briquettes with superior qualities. According to Dethan and Lalel (2024), the optimal combination of a 60-mesh particle size and a 5% binder ratio in similar biomass briquettes achieved desirable properties, including a moisture content of 3.37%, ash content of 2.28%, volatile matter of 14.83%, fixed carbon of 79.53%, a density of 0.57 g/cm^3, and a calorific value of 15.91 MJ/kg. These properties contribute to enhanced combustion efficiency, aligning well with findings in this study. Increasing residence time during the torrefaction of Kesambi branches can influence the color transformation from brown to black and reduce yield percentages, with water absorption values remaining below 1%. In a related study, Dethan et al. (2024b) observed similar results, noting that residence times significantly impacted the color and calorific potential of Kesambi-based briquettes. They reported a high heating value (HHV) prediction reaching 29.0750 MJ/kg under optimized conditions, further highlighting the importance of controlled residence time for optimal briquette quality.

Table 2. Comparison of AIC, BIC, and R^2 for various proximal models

Model	AIC	BIC	R2
Parikh	30.56	9.04	0.92
Yin	15.77	-5.75	0.92
Nhuchhen	82.92	61.40	0.89

HHV models

To facilitate informed decision-making in model selection, criteria such as the AIC, BIC, and R^2, are commonly utilized. AIC provides a measure of the relative quality of statistical models for a given dataset, balancing goodness of fit with model complexity. Lower AIC values indicate a model that achieves a better fit with fewer parameters, thus reducing the risk of overfitting. BIC, on the other hand, incorporates sample size into its penalty term, often favoring simpler models when the sample size is large. Like AIC, lower BIC values suggest a preferable model. R^2 quantifies the proportion of variance in the dependent variable that can be explained by the model, with values closer to 1 indicating stronger explanatory power.

Table 2 presents a comparative analysis of three proximal models Parikh, Yin, and Nhuchhen using AIC, BIC, and R^2 as evaluative metrics. A lower AIC suggests a model with better fit and complexity balance. Here, the Yin model has the lowest AIC (15.77), indicating it likely provides the best trade-off between accuracy and simplicity among the models compared. Similar to AIC, a lower BIC value is preferred. The Yin model also has the lowest BIC (-5.75), further supporting its suitability among the options given. R^2 indicates the proportion of variance explained by the model, where a higher value suggests better explanatory power. Both the Parikh and Yin models achieve the highest R^2 (0.92), meaning they both explain 92% of the data's variance, which is strong. Based on the combined values, the Yin model appears most optimal, balancing both accuracy (high R^2) and model fit efficiency (low AIC and BIC) in your comparison.

This comparative assessment lays the groundwork for selecting the most suitable model based on the specific objectives of the analysis, whether to maximize explanatory power or to maintain model simplicity and efficiency. The selection of an appropriate statistical model is crucial for effective data analysis, as it directly impacts the model's efficiency and predictive power. An efficient model balances complexity and performance, minimizing the number of parameters while maximizing explanatory capability.

This balance is essential to avoid issues such as overfitting and underfitting, which can compromise the model's reliability. Large models can inflate variance, leading to overfitting, while smaller models may introduce bias, resulting in

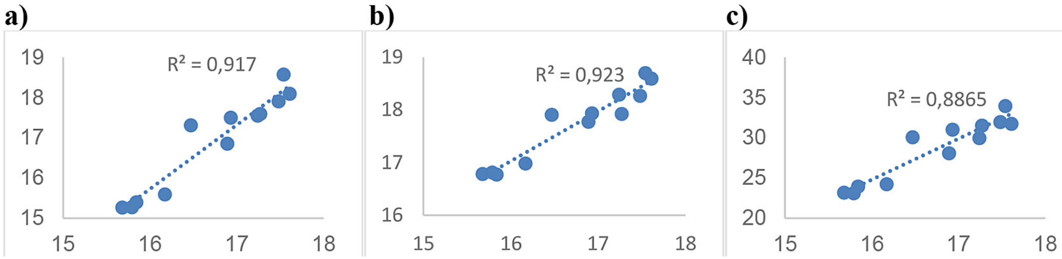

Figure 1. Comparison of predictive models based on R^2 Values: (a) Parikh, (b) Yin, and (c) Nhuchhen

underfitting (Ding et al., 2021). A generalized approach to model selection can achieve optimal predictive performance by balancing fitting and complexity (Ding et al., 2021). Various methods, including AIC and BIC, are commonly used for model selection, each with its strengths and weaknesses (Dziak et al., 2020). Triangulation of multiple variable selection methods can enhance model stability and accuracy in high-dimensional data (Lima et al., 2021). While efficient models are essential for accurate data analysis, the choice of model selection technique can significantly influence outcomes. Different criteria may yield varying results, highlighting the importance of understanding their implications in specific contexts (Dziak et al., 2020).

The Yin model, with the lowest AIC and BIC values, indicates a higher likelihood of avoiding overfitting. Simpler models tend to have fewer independent variables and, therefore, are easier to analyze. Additionally, they can provide faster computation and analysis, thereby saving time and resources. Moreover, simpler models are generally better at generalization, meaning they possess a greater ability to make accurate predictions on unseen data.

Predictive models are commonly used to estimate the quality or characteristics of materials based on measurable parameters. In this study, the Parikh, Yin, and Nhuchhen models were employed to assess prediction accuracy against specific experimental data (Figure 1).

Figure 1a (Parikh model), with an R^2 of 0.92, the Parikh model demonstrates a strong correlation, suggesting that it effectively predicts the data with 92% of the variance explained by the linear relationship. Figure 1b (Yin model), similarly, the Yin model also shows an R^2 of 0.92, indicating a strong fit comparable to the Parikh model, where the linear model explains 92% of the data variability. Figure 1c (Nhuchhen model), the Nhuchhen model has a slightly lower R^2 of 0.89, meaning that it still captures a strong linear relationship but with slightly less accuracy than the Parikh and Yin models, explaining 89% of the variance. All three models (Parikh, Yin, and Nhuchhen) provide strong predictive capabilities, the Parikh and Yin models are slightly more accurate than the Nhuchhen model for this dataset.

CONCLUSSIONS

The comparative analysis of the physical and chemical properties of briquettes produced from different mesh sizes highlights the profound impact of particle size on briquette quality. Briquettes created from finer particles (60 mesh) consistently exhibit superior characteristics compared to those made from coarser particles (20 mesh). Specifically, smaller particles result in increased density and compression strength while reducing moisture content and ash content. These enhancements contribute to improved combustion efficiency, as finer particles facilitate more complete combustion, leading to lower residual ash and higher fixed carbon content. The findings confirm that smaller particle sizes effectively enhance the overall quality of briquettes, creating denser, stronger, and more efficient fuel sources.

The evaluation of the Parikh, Yin, and Nhuchhen models using criteria such as AIC, BIC, and R^2 provides a robust framework for understanding model efficiency and predictive power. The Yin model's favorable metrics suggest it as the most efficient option for analyzing HHV, balancing complexity and performance while minimizing the risk of overfitting.

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