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OPTIMISATION OF SORGHUM PELLETISATION USING A VERTICAL ROLLER-TYPE PELLETISER: A SUSTAINABLE APPROACH TO AGRICULTURAL WASTE-TO-ENERGY CONVERSION

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Bio pellets serve as an eco-friendly alternative for energy production, utilising renewable crops to produce clean energy while supporting agricultural sustainability. This study aims to design and test the performance of a roller-type pellet press for sorghum biopellets. The machine was designed to mix sorghum with other ingredients to increase its calorific value. The testing of performance used sorghum plants of the bioguma variety from sorghum farmers at a seed moisture content of 20–30% after harvest at 105–110 days after planting (DAP) directly from the sorghum field. The results of testing the performance of the pelletiser moulding machine show that the working capacity of the machine is 100–130 kg·h⁻¹. This capacity is influenced by the roller rotation, the rotation of the drive motor, and the moisture content of the sorghum biopellet raw material. The average pelletising efficiency was 98.80%, while the loss rate ranged from 0 to 1%. In addition, the thermogravimetric and derivative thermogravimetric analysis showed that sorghum, rice husk, and their blends have different thermal behaviours, with the sorghum-rice husk blend showing potential as an efficient biomass feedstock for bioenergy production.

Keywords: sorghum; agricultural sustainability; pelletiser machine; bioenergy

Promising solutions to energy issues offer the use of renewable resources such as biomass and reduce dependence on fossil fuels (Shavolkin et al., 2025). Agricultural waste management has become a critical focus in the quest for sustainable energy solutions, as it presents an opportunity to convert otherwise discarded materials into valuable resources (Asim et al., 2012; Maji et al., 2020). The process of pelletisation not only enhances the energy density of agricultural residues but also facilitates their handling, storage, and transportation, making them more viable for industrial application (Ferreira et al., 2019). This approach not only contributes to waste reduction but also supports the transition towards renewable energy sources, aligning with global efforts to mitigate climate change and promote environmental sustainability. The utilisation of raw sorghum in this context offers a promising avenue for maximising the potential of agricultural waste, as it

was both abundant and rich in carbohydrates that can be converted into bioenergy (Theerarattananon et al., 2010; Theuretzbacher et al., 2012; Nurhasanah et al., 2024). By transforming raw sorghum into pellets, industries can tap into a sustainable energy source while simultaneously reducing reliance on fossil fuels and decreasing greenhouse gas emissions.

In recent years, innovative technologies have emerged to enhance the efficiency of converting raw sorghum into biofuels, ensuring that this biomass resource can be effectively harnessed in competitive energy markets (Prakasham et al., 2014; Vermerris and Saballos, 2013). One of the key technologies being developed is the horizontal roller pelletiser machine, which is widely available in the market for biopellet/biomass production. The horizontal roller pelletiser works by feeding shredded sorghum into the hopper at the top of a cylindrical chamber,

where a roller system facilitates the automatic and efficient formation of homogeneous mixtures. This system enables fast and efficient pellet production, significantly improving processing time (Furuhashi et al., 2024; Mostafa et al., 2021; Tingzhou et al., 2025). As a result, this technology not only reduces operational costs but also increases the overall yield of biofuels derived from sorghum, making it a viable alternative to traditional fossil fuels.

Despite the established presence of pelletizer technology, there persist notable deficiencies regarding the processing of diverse sorghum feedstock and the energy efficiency associated with machine operation (Ferrandez-Garcia et al., 2022; Guragain et al., 2013). Addressing these challenges requires ongoing research and innovation to optimise the pelletising process, enhance energy consumption efficiency, and expand the range of sorghum varieties that can be effectively processed into pellets (Theerarattananoon et al., 2011). Innovative approaches, such as the integration of advanced sensors and automation in pelletiser systems, could play a crucial role in overcoming these limitations while ensuring consistent product quality and sustainability. Implementing these technological advancements not only promises to improve the overall efficiency of sorghum pellet production but also has the potential to lower operational costs and reduce environmental impacts, making it a more attractive option for producers (Khodkam et al., 2024).

Investing in such technological advancements not only promises to improve the overall efficiency of sorghum pellet production but also contributes to a more sustainable energy future by reducing reliance on non-renewable resources (de Almeida Moreira et al., 2025; Pimentel et al., 2017). The objective of this research is to engineer the design and test the performance of a horizontal roller-type sorghum pelletiser machine. By focusing on these parameters, the study seeks to establish the best practices for maximising productivity and ensuring that the final product meets industry standards for both energy output and environmental impact. The thermal properties of the produced pellets and raw materials, including the parameters such as thermal stability, are evaluated to ensure their suitability for energy applications. The findings from this research could pave the way for more efficient production methods, ultimately leading to increased

adoption of sorghum pellets as a viable alternative energy source in various applications.

Material and Methods

Material

Materials consisted of special variety sorghum plants from Demak, Central Java, Indonesia, grown on latosol soil under dryland conditions on local farmers' land. The sorghum was harvested at 105–110 days after planting (DAP). Additional materials blended during moulding included sawdust, rice husk, starch, and cassava flour, all sourced from the local markets around Demak (Fig. 1). Research activities, including machine design, fabrication, and technical performance analysis, were carried out at the Appropriate Technology Research Centre of Agriculture and Food Research Organisation, National Research and Innovation Agency (BRIN), Subang, Indonesia.

Sample characterisation and experimental methods

Comprehensive characterisation of the samples included proximate analysis, ultimate analysis, and particle size distribution.

Proximate and ultimate analysis was conducted using a Leco TGA 701 thermogravimetric analyser following ASTM E870-82 (2019) for biomass analysis and LECO TruSpec CHNS/O ASTM D5373-21 (2021) (LECO Corporation, USA). Particle size distribution (PSD) was determined using a Malvern Mastersizer 3000E (Malvern Panalytical Ltd., UK) based on the dynamic light scattering (DLS) method. The powder samples were dispersed in absolute ethanol ($\geq 99.5\%$) at 0.05–0.1% w/v, sonicated for 10 minutes, and measured at $25 \pm 1^\circ\text{C}$. Ethanol was used as the dispersant ($RI = 1.361$).

Phases of investigation

This study follows several phases of investigation, specifically based on a functional design approach and a structural design approach. The process starts by identifying the problem of handling sorghum stalk-leaf waste at the current level of farmers and the sorghum industry (Ferrandez-Garcia et al., 2022; Goel et al., 2024). Then, it analyses the existing problems, collects ideas for



Fig. 1 (a) Sawdust; (b) Rice husks; (c) Starch; (d) Cassava as pelleting material with sorghum cuttings)

solving the problems by considering various related aspects, and then selects design concepts from several existing references.

Following the conceptualisation, the next stage is the functional and structural analysis of the concept to be created as well as the selection of materials (Moreira Ribeiro et al., 2019). However, the analysis requires data on the physical characteristics of sorghum plants. The subsequent stage is the creation of machine designs and machine working drawings using SolidWorks software and then the creation of prototypes based on working drawings. Furthermore, functional tests are carried out on the prototype to determine and ensure that each part functions properly. Performance tests are carried out to determine the efficiency of the sorghum biopellet pelleting, the power requirements, and the working capacity. In case of deficiencies, modifications are made until better results are obtained.

Design criteria

The vertical sorghum biopellet pelletiser is designed to produce the main raw material of sorghum stems and leaves, though other materials such as sawdust, rice husk, starch, and cassava have the potential to be added. The pelletising machine plays a role in the whole sorghum biopellet processing chain and, overall, the pelletising machine capacity is 150–200 kg·h⁻¹ and power 54-HP/46 kW.

Performance test

Throughout the process of producing raw material for sorghum biopellets, measurements and observations of test parameters are carried out, including motor speed with and without load, pelletising capacity, percentage of pellet size uniformity, pelletising efficiency, and fuel consumption. Tests are carried out at drive power revolutions of around 1300, 1400, and 1500 rpm. The result of pelletising is a sorghum biopellet from 100% chopped sorghum stems and leaves or a mixture of chopped sorghum stems and leaves mixed with other materials such as sawdust, rice husk, starch powder, or cassava flour. The primary material in this mixture was sorghum, while sawdust, rice husk, starch, and cassava act as blending agents. The purpose of blending these materials is to study their potential interactions and effects when combined with sorghum for a specific application or process. Each of the blending agents is measured in equal quantities (10.5 kg) to maintain consistency across the experiment and evaluate their individual contributions to the mixture. The materials are blended in a 50 : 50 wt% ratio based on dry weight to ensure proper balance and assess the impact of the mixture's composition on the overall performance.

The pelletising capacity of a vertical pelletiser could be comprehensively defined as the machine's proficiency in generating a specified quantity of pellets within a defined unit of time, thereby reflecting its operational efficiency in terms of pellet production output (Macko and Mrozinski, 2019). The calculation of the pelletising capacity, denoted as (K_p), can be meticulously derived through the use of Eq. (1), which is articulated as follows:

$$K_p = \frac{(W_p \times 60)}{t} \quad (1)$$

where: K_p – the pellet capacity that is being discharged from the pellet dispensing chamber, measured in kilograms per hour (kg·h⁻¹), W_p – signifies the total weight of the biopellet feedstock that has been accommodated in the mixing chamber over a specified period of t minutes, expressed in kilograms (kg); t – denotes the duration of the pelleting process.

The production efficiency, which can be defined as the ratio expressed in percentage terms that quantitatively represents the weight of produced sorghum biopellets in relation to the total weight of the original raw material utilised in the production of sorghum biopellets, is calculated by employing a formula delineated in percent (Guragain et al., 2013). The pelletising efficiency is quantitatively determined through the utilisation of Eq. (2), which is presented as follows.

$$\eta = \frac{W_p}{W_o} \quad (2)$$

where: η – stands for the pelletising efficiency expressed as a percentage (%); W_p – the weight of the initial sorghum biopellet raw material entering the hopper (kg); W_o – the total weight of sorghum biopellets deposited in the output chamber (kg)

Data analysis was carried out using the T-student statistical test using the analysis of variance (ANOVA), the factors used included engine speed (rpm) and continued with a real difference test with T-student at the 0.05 significance level.

TG-DTG analysis

The simultaneous thermal analyser (STA) by Setaram Themys is used to perform the thermogravimetric (TG) and derivative thermogravimetric (DTG) analysis of individual and mixed biomass. Samples, weighing approximately 2 mg, were heated to 800 °C ambient temperature. A constant heating rate of 10 °C·min⁻¹ was used from room temperature to 800 °C. The flowrate and initial temperature were chosen according to Wibawa et al. (2022). For all experiments, nitrogen gas (N₂) was used as a purge gas, and its flow was set at 20 mL·min⁻¹ to ensure an inert environment.

Results and Discussion

Vertical biopellet machine prototype

The prototype of the vertical pelletiser machine for biopellets made of sorghum was developed from the roller pelletiser machine for rice husks that had been developed by Center for the Assembly and Modernisation of Agricultural Mechanisation, Indonesia (Fig. 2). The main parts that were modified include the pressing roller components, the pressing chamber walls, and the pressing roller spindle. The fabrication and modification of the vertical pellet press is shown in Fig. 2. The dimensions of the prototype of this machine are defined by the length of 2485 mm, width of 510 mm, and height of 1520 mm, respectively.



Fig. 2 Prototype of a roller-type biopellet raw material pelleting machine

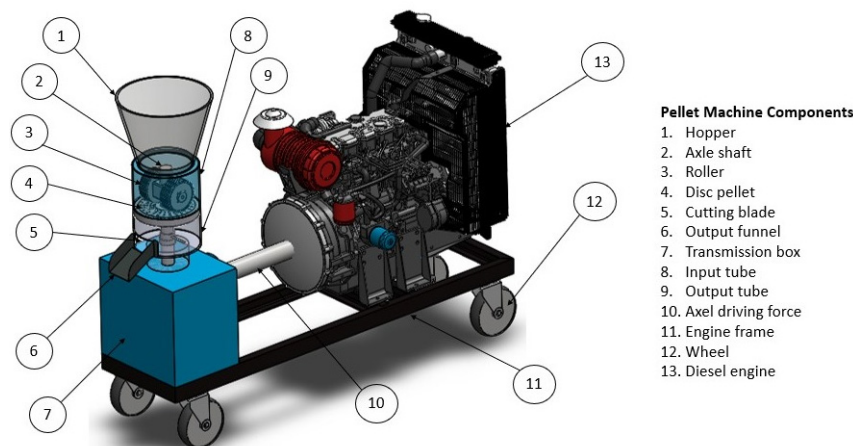


Fig. 3 Draft of a machine for pelletising raw materials for roller-type sorghum biopellets

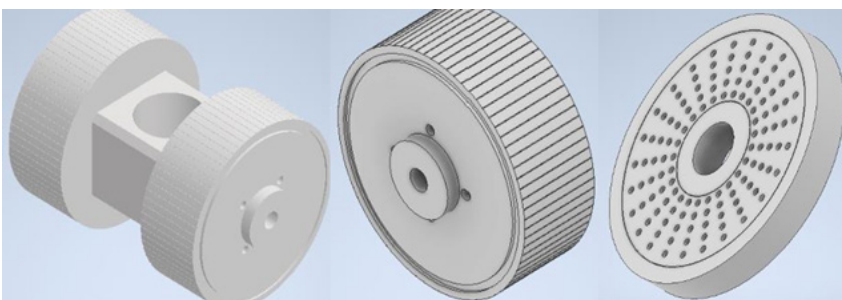


Fig. 4 Design of perforated plate and roller for pressing biopellets

Functional design

The pelletiser machine produces sorghum pellets driven by a diesel motor that presses the material onto a pellet plate (vertically). It consists of a hopper/material feed funnel, material pressing roller, pellet plate, cutting section, and discharge funnel (shown in Fig. 3). These units are manufactured and assembled into a biopellet pelletiser machine according to the pelletiser quality standards of (Indonesian National Standard) SNI 9198 (2023).

The hopper is designed using a 1.5 mm thick stainless steel for a holding capacity of around 10 kg of material. The stainless-steel plate is chosen because it is strong and rust resistant. The pressure roller is designed in the form of a roller that aims to maximise its function, which is to press the raw material of chopped sorghum stalks and leaves or those mixed with other materials to enter the moulding plate to become sorghum biopellets. This chamber is designed with 3 pieces of medium carbon steel roller pipes with a diameter of 160 mm. In the pellet moulding machine, there is a perforated moulding plate made of a 40-mm thick medium carbon steel with an 8-mm diameter vertical hole. The plate is placed on a rotating axle shaft, and then material pressing rollers are placed on the top of the plate so that pellets are formed and come out of the hole in the bottom plate. The image of the perforated plate and the pressure roller in the pellet moulding machine design can be seen in Fig. 4.

This pelletiser machine was designed for pelleting sorghum stalk-leaf chips or those mixed with sawdust or chaff, starch, or cassava flour. It was powered by a 56-horsepower (HP) diesel engine. The pelletiser developed was a vertical type with direct material input (the material to be moulded was fed through a hopper feeder) (Fig. 2).

The performance testing of the biopellet pelletiser machine was carried out using test materials in the form of sorghum plants of the local special Demak variety that had been harvested with a seed moisture content of 30.26% wet basis. Then, stems and leaves were chopped and dried to about 6–9% and mixed with other ingredients, namely

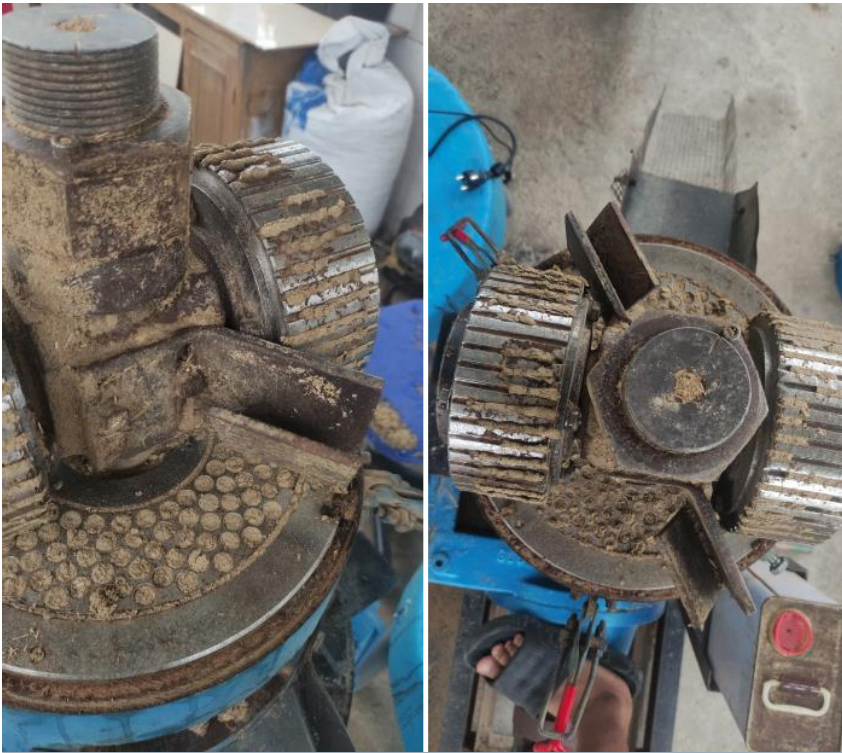


Fig. 5 Modification and testing process of biopellet pelleting using a vertical pelletiser

sawdust, ricehusk, starch, or cassava flour. The result of the proximate and ultimate analysis of the biomass feed stock as fuel in this study is shown in Table 1 (all values are reported on a dry basis). Prior to pelletisation, all samples were reduced to particle sizes of less than 500 μm . The mean particle diameters for sorghum, rice husk, sawdust, starch, and cassava were measured to be 135.94 μm , 151.44 μm , 160.51 μm , 73.69 μm , and 14.16 μm , respectively, as shown in Table 2. Testing was carried out at drive motor speeds of around 1300, 1400, and 1500 rpm. The testing process for the sorghum biopellet pelleting machine is shown in Fig. 5.

The raw material for producing biopellets is chopped sorghum stems and leaves with a moisture content of around 6–9%. Other materials such as rice husk, sawdust, starch, and cassava flour, which are also moulded using a pelletiser, were tested for pellet moulding machine performance, as shown in Table 3. These results are

Table 1 Proximate and ultimate analysis of the biomass feedstocks

| Properties | Feedstock | | | | |
|---|-----------|-----------|---------|--------|---------|
| | Sorghum | Rice husk | Sawdust | Starch | Cassava |
| Proximate | | | | | |
| Moisture (wt%)* | 6.29 | 6.05 | 8.72 | 7.12 | 7.29 |
| Volatile (wt%)* | 70.23 | 68.56 | 69.86 | 75.6 | 71.2 |
| Ash (wt%)* | 1.29 | 4.95 | 1.02 | 1.82 | 5.2 |
| Fix Carbon (wt%)* | 22.19 | 18.39 | 21.88 | 14.4 | 16.3 |
| Ultimate | | | | | |
| Carbon (wt%)* | 43.11 | 55.03 | 71 | 81 | 79.5 |
| Hydrogen (wt%)* | 6.67 | 5.46 | 4.3 | 6.4 | 6.1 |
| Nitrogen (wt%)* | 0.33 | 1.04 | 1.1 | 6.43 | 6.12 |
| HHV ($\text{kJ}\cdot\text{kg}^{-1}$) | 4117 | 3854 | 6377 | 3100 | 3000 |
| Density ($\text{kg}\cdot\text{m}^{-3}$) | 540 | 210 | 641 | 720 | 690 |

*) dried basis

Table 2 Particle size distribution (PSD) of biomass feedstock

| Diameter | Sorghum | Rice husk | Sawdust | Starch | Cassava |
|-----------------------------------|---------|-----------|---------|--------|---------|
| Diameter at 10% (μm) | 15.45 | 7.28 | 13.62 | 6.71 | 4.17 |
| Diameter at 50% (μm) | 103.92 | 129.31 | 151.06 | 17.37 | 14.27 |
| Diameter at 90% (μm) | 295.94 | 337.19 | 326.11 | 231.43 | 22.07 |
| Mean diameter (μm) | 135.94 | 151.44 | 160.51 | 73.69 | 14.16 |



Fig. 6 Sorghum biopellet products by vertical pelletiser

the mean values from pelletising performed in triplicate. Pellets coming out of the machine can be seen in Fig. 6.

Table 3 shows the results of the pelletising machine performance test at three speeds. The results of the statistical analysis of the effect of the drive motor rotational speed are presented in Table 3. These results show that the rotational speed of the drive motor and the stirring time have a significant effect ($P > 0.05$) on the uniformity of pelletising of raw materials for sorghum biopellets.

In the pelletising of sorghum biopellets, the rotation speed of the motor and stirring time play a crucial role in the pelletising process. Higher motor rotation speeds result in greater pelletising capacity. Specifically, at a high motor rotation of around 1500 rpm, the average pelletising capacity was $129.39 \text{ kg}\cdot\text{h}^{-1}$, while at medium (1400 rpm) and low (1300 rpm) motor speeds, the pelletising capacities were $115.62 \text{ kg}\cdot\text{h}^{-1}$ and $113.72 \text{ kg}\cdot\text{h}^{-1}$, respectively. Additionally, the time taken for pelletising at these speeds was 5.54 minutes for 1300 rpm, 5.44 minutes for 1400 rpm, and 4.87 minutes for 1500 rpm. These findings indicate that increasing motor speed enhances pelletising capacity, which aligns with the expectations of pellet press operations.

The density of the pellets produced is also influenced by the rotation speed of the motor. At high speed, the average pellet density reaches $1.192 \text{ g}\cdot\text{cm}^{-3}$, while at medium and low speeds, the densities are $1.161 \text{ g}\cdot\text{cm}^{-3}$ and $1.136 \text{ g}\cdot\text{cm}^{-3}$, respectively. This indicates that the faster the motor rotation, the denser the formed pellets. The reason for this is the greater pressure applied during the pelletising process, which accelerates the compression of biomass and results in denser pellets. Although the shape, diameter, and length of pellets remain similar, the weight of the biomass used can vary, as the faster impact at higher motor speeds makes the biomass more compact and denser.

However, while the results on pelletising capacity are consistent with known principles of pellet press operation, the focus of this study is on optimising the pelletising process, improving the machine efficiency, and ensuring the sustainability of the feedstock used. The machine design and the role of material characteristics in pellet formation are central to the innovation of this research.

Our findings suggest that the optimisation of machine settings, such as adjusting motor speed and stirring time, can contribute significantly to improving pelletising efficiency. Moreover, the use of biomass without binders is another key innovation in this study, as it not only reduces costs but also ensures that resulting pellets meet sustainability standards for energy production. The materials used, such as sorghum, sawdust, rice husk, and cassava, were selected for their renewable nature and availability as agricultural by-products. These materials are abundant, locally sourced, and do not contribute to deforestation or the depletion of natural resources, making them sustainable choices for bioenergy production. The results show that the rotational speed of the pelletising motor has a significant effect ($P > 0.05$) on both pelletising capacity and efficiency.

In addition to the sustainability of input materials, process optimisation was aimed at maximising the efficiency of the pelletising process. By improving the conversion of raw materials into high-quality pellets with minimal waste, we reduced the overall environmental impact. This includes optimising energy consumption during pellet production, which contributes to the sustainability of the entire process. The use of agricultural residues like rice husks and sawdust further promotes circular economy by utilising materials that would otherwise be discarded.

Table 3 Effect of the rotational speed of the motion motor and stirring time on pelletising capacity

| Motor rotation (rpm) | Pelletising capacity ($\text{kg}\cdot\text{h}^{-1}$) | Pelletising efficiency (%) | Pellet density ($\text{g}\cdot\text{cm}^{-3}$) |
|----------------------|--|----------------------------|--|
| High 1500 | 132.30* | 99.77* | 1.195 |
| | 129.12 | 99.72 | 1.192 |
| | 126.76 | 99.10 | 1.189 |
| Medium 1400 | 115.60* | 98.33* | 1.156 |
| | 114.50 | 98.20 | 1.158 |
| | 116.75 | 98.52 | 1.169 |
| Low 1300 | 102.80* | 97.33* | 1.131 |
| | 105.00 | 97.23 | 1.135 |
| | 103.35 | 97.35 | 1.139 |

* numbers followed by the same letter indicate no significant difference at the level α of 5%

In this study, we monitored the machine speed qualitatively under both load and no-load conditions. However, due to limitations inherent in the experimental design, quantitative data on speed differences between these conditions were not collected. The absence of quantitative data on speed variations between load and no-load conditions represents a limitation of this study. Future research should focus on systematically collecting and analysing quantitative speed data under various load conditions. This would facilitate a deeper understanding of how machine speed influences pellet production efficiency and product quality, thus providing valuable insights for optimising the pelletisation process.

Thermal behaviour of sorghum, rice husk, and their blends

The TG and DTG curves for the pyrolysis process presented in Fig. 7 were selected from biomass samples including SO (100% sorghum), RH (rice husk 100%), and their mixtures BB-1 (25% sorghum + 75% rice husk w/w), BB-2 (50% sorghum + 50% rice husk w/w), and BB-3 (75% sorghum + 25% rice husk w/w), produced at a heating rate of $10^{\circ}\text{C}\cdot\text{min}^{-1}$.

During the pyrolysis process, the organic components of biomass decompose in various phases of steam and different gaseous compounds, leaving a residue rich in carbon (biochar). The loss of biomass mass during the pyrolysis process is mainly due to the evolution of the release of steam and gas from the biomass. There is at least a division of three zones that occur during the pyrolysis of SO, RH, and mixed samples (BB-1, 2, 3). In the first zone, pyrolysis occurs at a low temperature ($< 150^{\circ}\text{C}$), which indicates a physical change in the biomass due to the evaporation of moisture content (Kudo et al., 2021; Wang et al., 2023; Wibawa et al., 2022). The main pyrolysis occurs between 180 and 550°C . This zone is considered the main zone due to the maximum weight loss in each individual sample and its mixture.

For the SO sample (Fig. 7a), the second zone occurs in the temperature range of 180 – 350°C with a characteristic peak at 301°C , followed by a decrease in temperature from 350 to 500°C . This main peak corresponds to the decomposition of complex polysaccharides, especially lignocellulosic components, which consist of hemicellulose, cellulose, and some lignin (Kudo et al., 2021; Wibawa et

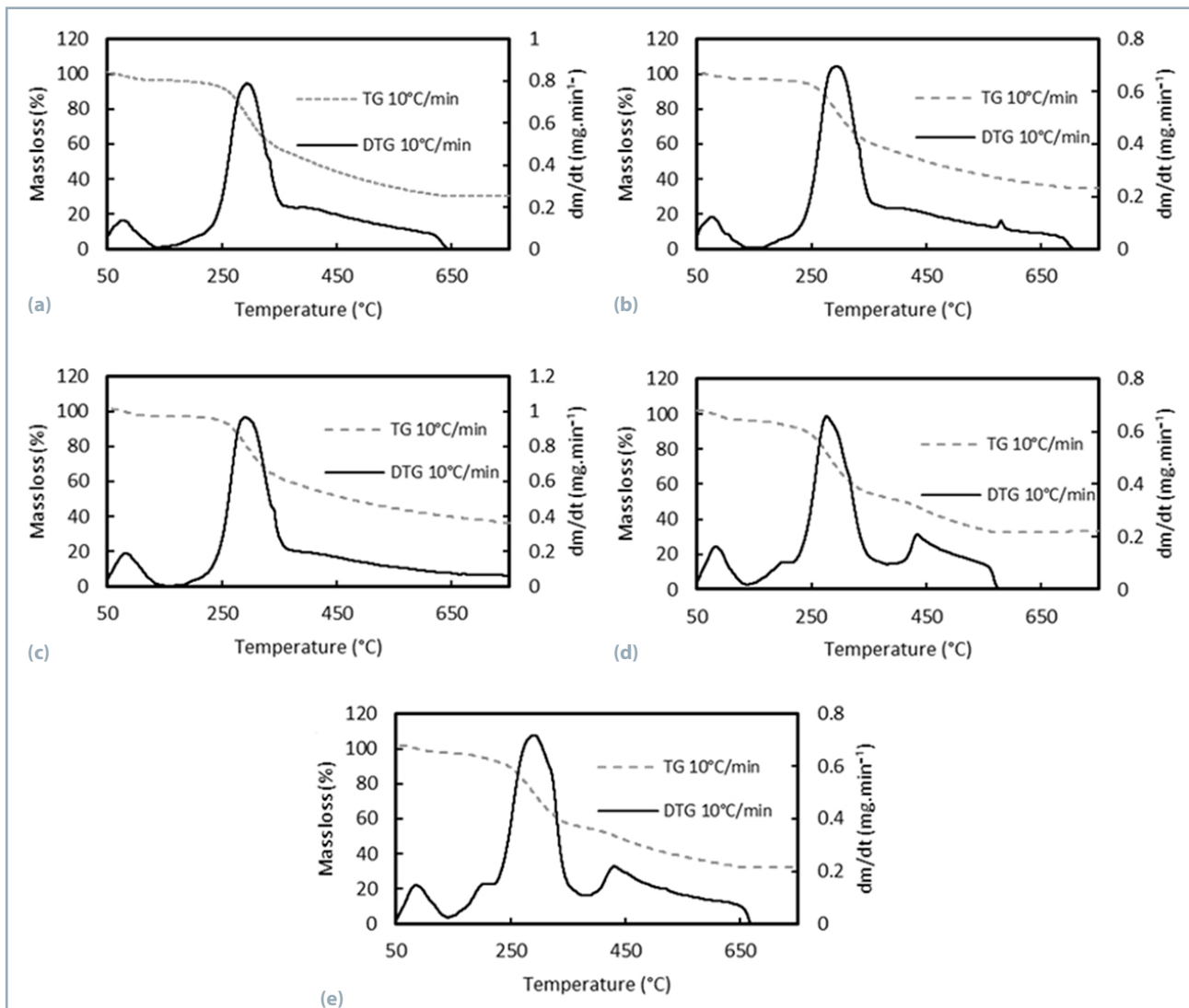


Fig. 7 TG and DTG curves of biomass samples and their blends: (a) SO; (b) BB-1; (c) BB-2; (d) BB-3; (e) RH, at heating rate $10^{\circ}\text{C}\cdot\text{min}^{-1}$

al., 2023). On the other hand, RH shows three different peaks (Fig. 7e). The main decomposition stage is identified in the temperature range of 200–350 °C with the main peak at around 295 °C and can be associated with the degradation of hemicellulose and cellulose. The third zone at a temperature of around 425 °C can be associated with the decomposition of lignin and the removal of volatile residues from the previous zone (below 400 °C). Finally, after reaching a temperature of 650 °C, this period is quite stable and residues in the form of ash corresponding to around 32% of the total are measured.

The DTG profiles for BB-1 (Fig. 7b), BB-2 (Fig. 7c), and BB-3 (Fig. 7d) are similar to the DTG profiles that contribute the most to mixing. For example, the BB-1 DTG profile is similar to SO, while the BB-3 DTG profile is similar to RH. However, the peak in the 3rd mixing zone decreases as the proportion of SO increases. The peak temperatures for BB-1, BB-2, and BB-3 are 303, 298, and 275 °C, respectively. The main weight loss occurs in the range of 225–370 °C, which is mostly hemicellulose.

The TGA data of biomass compared to the SO and RH mixtures show no apparent synergistic effect during the pyrolysis process. The amount of solid residue remaining at the end of pyrolysis (800 °C) is the value of individual residues remaining during the pyrolysis process. Nevertheless, the amount of residue obtained during SO mixing is much lower than the RH pyrolysis residue. There are two possible causes for this: the evolution of hot gas from thermal decomposition, and also the thermal decomposition of biomass from the catalytic activity of metal content in SO and RH ash.

Further comparison with similar technologies

In the field of agricultural waste-to-energy conversion, energy efficiency and operational cost are essential benchmarks in determining the feasibility of the technology employed. This study introduces and evaluates a vertical roller-type pelletiser specifically developed for processing chopped stalks and leaves of sorghum, achieving an average production capacity of 100–130 kg·h⁻¹, with pelletising efficiency reaching up to 99.77%, and a power requirement of approximately 46 kW. When compared to the more widely available horizontal roller-type pelletiser, the specific energy consumption of the vertical system ranges between 0.35 and 0.46 kWh·kg⁻¹, slightly higher than the horizontal counterpart, which operates around 0.24–0.30 kWh·kg⁻¹, particularly at industrial-scale output volumes (Theerarattananoon et al., 2011; Mostafa et al., 2021). However, the vertical system demonstrates superior adaptability to variable moisture content and heterogeneous raw materials, making it more energy-efficient in decentralised or medium-scale production contexts, particularly in rural or farm-based environments.

From a cost perspective, the vertical pelletiser technology offers significant advantages in terms of local implementation and applicability for small and medium-scale enterprises. The construction and operational costs of the vertical system are comparatively lower, as it utilises locally sourced components and a modular design. In contrast, horizontal pelletisers typically require higher initial capital investment and more complex maintenance procedures (Furuhashi et

al., 2024). For instance, the vertical pelletizer used in this study consumes approximately 2.0–2.5 litres of diesel per hour, whereas horizontal-type systems generally demand 3.5–4.0 litres per hour to operate efficiently (González et al., 2006). Consequently, the estimated return on investment (ROI) for the vertical system is around 2 to 3 years, compared to 4 to 5 years for horizontal systems. This economic profile renders the vertical roller-type pelletiser highly suitable for community-based energy systems in rural and agricultural regions, where budgetary constraints and logistical simplicity are critical factors for adoption of technology (Pimentel et al., 2017).

In terms of thermal behaviour, the TG/DTG analysis performed in this study indicates that sorghum, as the primary biomass feedstock, exhibits a major thermal decomposition peak at approximately 301 °C, suggesting efficient energy release from its lignocellulosic components. This confirms that the resulting biopellets possess favourable combustion properties for solid fuel applications. When compared to horizontal pelletising or briquetting systems, the vertical pelletiser generates pellets with low moisture content (6–9%) and high density, which align with established industrial standards for combustion efficiency (García-Maraver et al., 2011). Moreover, the use of blended materials – such as rice husk, sawdust, starch, and cassava flour – demonstrated that the system maintained consistent pellet quality without compromising structural integrity or thermal performance. This further highlights the vertical system's capacity to process heterogeneous biomass mixtures while ensuring energy-efficient outcomes.

Overall, the vertical roller-type pelletiser offers distinct advantages in terms of affordability, operational efficiency in localised contexts, and its capacity to accommodate diverse biomass blends such as rice husk, sawdust, starch, and cassava flour. These features make it particularly well-suited for decentralised, small- to medium-scale energy systems, especially in rural or agricultural settings where flexibility and cost-effectiveness are essential (Mostafa et al., 2021; González et al., 2006). Conversely, the horizontal roller-type pelletiser remains highly relevant for large-scale industrial applications, where standardised input materials and maximum production throughput are critical (Li et al., 2014).

Therefore, the selection of pelletising technology should be context-driven: vertical systems are more appropriate for sustainable, community-based energy strategies with diverse raw material availability, while horizontal systems are better suited for centralised facilities with consistent feedstock supply and higher capital capacity. These complementary roles affirm the importance of aligning technological design with socioeconomic and environmental objectives in the broader pursuit of renewable energy deployment.

Conclusion

The working capacity of the sorghum biopellet moulding machine is influenced by the initial moisture content of the raw material, the particle size of the raw material, the rotating speed of the moulding cylinder, and the rotating speed of the drive motor. The raw material was first dried to a moisture content of 6–9% in order to be processed

in a machine with a size of less than 300 µm. The pelletising work capacity ranges from 100 to 130 kg·h⁻¹. An increase in the rotational speed of the drive motor results in improved working capacity and enhanced efficiency of the moulding machine.

The pyrolysis process of biomass samples, including sorghum (SO), rice husk (RH), and their blends (BB-1, BB-2, BB-3), was analysed through TG and DTG curves, revealing three distinct temperature zones. Blended samples showed pyrolysis profiles that reflected the composition of their individual components, with peak temperatures shifting based on the proportion of SO and RH. For instance, BB-1 resembled SO, while BB-3 was similar to RH. No significant synergy effect was observed in the blends, with the solid residue at the end of pyrolysis being a combination of individual residue values. The residue from SO was notably lower than that from RH, likely due to the catalytic effects of the metal content in the ash of both biomass types. Overall, the study highlights that blending SO with RH does not produce a synergistic effect but rather reflects the individual behaviours of each component.

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