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Production and characteristic analysis of thick solid biomass fuel from the waste of watermelon-muskmelon using ceramic powder and cassava starch as binder – ceramics in energy application

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Despite their status as non-renewable energy sources, fossil fuels are widely utilized across industries, resulting in substantial harmful emissions upon combustion. This poses severe environmental consequences and disrupts natural ecosystems. To tackle this challenge, our research focused on replacing fossil fuels with biomass briquettes derived from watermelon and muskmelon waste blends in varying ratios (100:0, 75:25, 50:50, 25:75, and 0:100). Utilizing a mixture of ceramic powder and cassava starch as binding agents, we aimed to improve the briquetting process. The briquettes underwent comprehensive testing to evaluate proximate parameters like ash content and volatile matter, alongside ultimate parameters such as chemical composition and calorific value. Advanced analyses including SEM/EDAX and TGA were employed to thoroughly assess the briquettes. The findings suggest that these briquettes, being renewable, emit minimal pollutants, and produce reduced residue, hold potential as a feasible alternative to traditional non-renewable energy sources.

Keywords: Biomass briquettes, Ceramic powder – cassava starch binder, Watermelon – muskmelon fruit waste, Thermo gravimetric analysis, Proximate parameter.

Introduction

The current lack in non-renewable energy resources highlights a pressing global challenge. Non-renewable sources like fossil fuels (coal, oil, and natural gas) have fueled modern society for decades, but their finite nature poses significant concerns. As demand continues to rise, these resources become scarcer and more expensive to extract [1, 2]. Additionally, their combustion releases greenhouse gases, contributing to climate change and environmental degradation [3]. The lack of sustainable alternatives has led to energy security issues and geopolitical tensions. Transitioning to renewable energy sources like biomass energy is essential to address these shortcomings, reduce environmental impact, and ensure a stable and resilient energy future [4]. Solid biomass briquettes represent a transformative stride towards addressing our environmental challenges while meeting energy demands sustainably [5]. These briquettes, which condense organic matter into compact forms, span a spectrum of sources from agricultural residues, like stalks and husks, to wood waste—forging a promising departure from traditional fossil fuels. Through this shift, we carve a path toward an eco-conscious energy matrix.

This innovation derives its strength from the very heart of sustainability—renewable resources. By leveraging materials such as crop residues and sawdust, we redirect waste from landfills and repurpose it into valuable energy carriers [6]. Even fruit waste, previously considered mere byproducts, gain new significance in this context, fostering a circular economy that mitigates waste's environmental impact [7]. Central to this metamorphosis is the process of compaction. By compressing these materials into dense briquettes, we achieve energy-dense fuel that is convenient to store and transport, thus reducing logistical complexities [8]. The shift towards these briquettes concurrently quells two key environmental concerns: the release of greenhouse gases from fossil fuel combustion and the destructive impact of deforestation for fuel sources [9].

The far-reaching impact of these briquettes extends beyond emissions reduction. Beyond their eco-friendly combustion, they take a prominent role in waste management, effectively addressing the burgeoning

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waste crisis by transforming organic waste into an asset [10]. In regions where traditional fuels may be scarce or unaffordable, these briquettes offer an accessible energy source for cooking and heating, simultaneously addressing energy poverty. Moreover, these briquettes march in lockstep with industrial requirements. Their application in industries replaces fossil fuels, further curbing emissions while fostering economic growth [11]. This dual benefit underscores their role not just as an environmental boon, but also as a driver of sustainable development [12]. Biomass briquettes in place of loose biomass feeding offers advantages such as improved energy efficiency, reduced air pollution, and simplified handling and storage, making them an attractive solution for sustainable energy production.

As journey towards a more sustainable future, solid biomass briquettes shine brightly as symbols of hope. They illuminate our trajectory toward a world less dependent on finite resources and more attuned to the rhythm of nature. These briquettes symbolize the amalgamation of innovation, resourcefulness, and responsible stewardship of the planet—a triumphant step in the journey of environmental conservation and the pursuit of sustainable energy practices. The research utilizes a combination of ceramic powder and cassava starch as binders in the production of biomass fuel. Ceramic powders, known for its thermal properties, and cassava starch, a biodegradable and renewable binder, have not been widely studied together in biomass fuel production. This combination could enhance the structural integrity and combustion characteristics of the biomass fuel. The inclusion of ceramic binder in biomass briquettes offers several advantages. Firstly, it enhances the thermal stability of the briquettes, enabling them to withstand high temperatures during combustion without disintegration. Secondly, ceramic binders contribute to reducing the ash content of the briquettes, resulting in cleaner burning and less residue. Additionally, the mechanical strength of the briquettes is improved, making them more durable and resistant to breakage during handling and transportation. Lastly, biomass briquettes with ceramic binders tend to exhibit lower emission levels, contributing to reduced air pollution and environmental impact compared to conventional biomass fuels.

The objectives of the research is to develop a sustainable and efficient biomass fuel by utilizing agricultural waste, to explore the synergistic effects of using ceramic powder and cassava starch as binders on the structural and combustion properties of the biomass briquettes, and to evaluate the environmental and energy performance of the resulting fuel. The hypotheses are that the incorporation of ceramic powder will enhance the thermal stability and combustion efficiency of the biomass fuel, while cassava starch will provide adequate binding and mechanical strength, resulting in a high-quality, eco-friendly solid fuel with improved energy output and reduced emissions compared to traditional biomass fuels.

Materials and Methods

Materials

The fruit wastes are collected from various parts of Erode district. Approximately 22 kg of watermelon wastes and 17 kg of muskmelon wastes are gathered all around. The wastes were separately dried under the sun for about two weeks until the waste becomes completely dried and breakable. After the drying process they are taken for grinding. The grounds are sieved to receive particle size <2.36 mm. The watermelon and muskmelon wastes are represented in Fig. 1.

Binder Preparation

A proper proportion of cassava starch and ceramic powder is measured. In this study the cassava starch and the ceramic powder is taken in a proportion of 2:1 respectively. Adequate amount of water is added and mixed thoroughly such that no lumps are formed [13]. The mixture is heated at 100°C for nearly ten minutes. This process gives a thick product which can be readily used as an effective binder and this ensures efficient briquetting by mixing it manually with the fruit waste.

Ceramic Powder in Biomass Briquette Production

The experimental procedure for using ceramic powder


(a) (b)

Fig. 1. Representation of (a) Watermelon waste and (b) Muskmelon waste.

(a) (b)

Fig. 2. (a) Cassava starch and Ceramic powder, (b) Combined Binder.

in biomass briquette production involves collecting and cleaning watermelon and muskmelon waste, followed by drying and grinding to achieve a fine particle size. Ceramic powder (with particle size less than 100 μm) and cassava starch (prepared as a paste with water) are used as binders. These components are mixed in varying proportions, typically starting with 70% biomass waste, 20% ceramic powder, and 10% cassava starch by weight. The mixture is then molded and compressed using a hydraulic press at 1000-2000 psi to form briquettes, which are air-dried initially and then oven-dried at 60-80°C to reduce moisture content below 10%. The briquettes are characterized for physical properties (density, porosity, compressive strength), chemical composition (proximate and ultimate analysis), and combustion properties (calorific value, burning rate, thermal efficiency), along with emissions analysis. Data from these tests help optimize the formulation and processing conditions to improve briquette quality and performance.

Briquetting Process

The cylindrical mould and a compression shaft are primarily employed in briquetting process [14]. The mould has the physical dimensions of height, diameter and weight as 200 mm, 60 mm and 5 kg respectively. The shaft has physical dimensions of height, diameter and weight as 240 mm, 56 mm and 8 kg respectively. The equipments are represented in Fig. 3.

The watermelon and muskmelon wastes are combined in various proportions for the following samples: (S1)100:0, (S2)75:25, (S3)50:50, (S4)25:75 and (S5)0:100. The samples are illustrated in Fig. 4. Then the mixture is combined with required amount of binder and mixed properly [15]. This mixture is kept in the mould and Briquettes are formed using a piston press. This process involves applying a constant load of 150 kN on the mixture within the mould. The peak load for each sample varied and the variations are listed in Table 1.

Physical Properties

Diameter of Briquette

The diameter of the briquettes was determined by the dimensions of the mould utilized in their production. Alternatively, vernier calipers could be employed to gauge the diameter of the briquettes [16]. It was established that the inner diameter of the mould utilized in the briquette production process measured 56 mm.

Volume of Briquette

The radius and height of the briquettes were determined using a vernier caliper. The volume of the briquettes was then computed using the formula $\pi r^2 h$, where r represents the radius and h stands for the height [17]. The sample with the proportion of 100:0 has the highest volume of 184.75 m^3.

(a) (b)

Fig. 3. Representation of (a) Mould and Shaft and (b) Controlled universal testing machine.

Fig. 4. Briquette samples of various proportions.

Density

A weighing balance was utilized to determine the density of the manufactured briquettes [18]. The dimensions of the briquettes were assessed using a vernier caliper, while their weight was measured employing a weighing machine. Subsequently, the density of the briquettes was computed using the following equation:

$$D = M / V \tag{1}$$

D - Density of the briquettes (kg/m^3)
M - Mass of the briquettes in kg
V - Volume of the briquettes in m^3

Relaxed Density

The density of the briquettes achieved once they reach a stable state, termed as relaxed density, is determined using the formula:

$$RD = Md / V \tag{2}$$

RD - Relaxed density (kg/m^3)
Md - Mass of dried briquette (kg)
V - Volume (m^3)

Density Ratio

The Density Ratio of briquettes, represents the ratio between the relaxed density and the maximum density of the briquettes.

$$DR = RD / MD \tag{3}$$

DR - Density ratio of the briquettes
RD - Relaxed density of the briquettes
MD - Maximum density of the briquettes

Proximate Parameters

Ash Content

The ash content in a briquette serves as a pivotal parameter when evaluating the briquette's quality and its suitability as a biomass fuel. It signifies the portion of the briquette that is inorganic and non-combustible, remaining as residue after the combustion process. Typically, determining the ash content within a briquette involves laboratory analysis, with the results expressed as a percentage relative to the total mass of the briquette. Recognizing and comprehending the ash content's significance is of utmost importance due to its direct influence on the combustion efficiency and emissions produced during the briquette's combustion [19]. Higher ash content can lead to an increased accumulation of ash within the combustion system, potentially resulting in operational challenges and a reduction in the overall energy output.

$$A_C = M_A / M_B \times 100 \quad (4)$$

Here, A_C refers to the percentage of ash content, M_A refers to the mass of ash residue and M_B refers the mass of briquette before combustion.

Volatile Matter

Volatile matter serves as a vital parameter in the assessment of a briquette's composition as a biomass fuel. It signifies the fraction of the briquette that has the potential to undergo vaporization or conversion into gas during the initial stages of combustion [20]. The determination of volatile matter content within a briquette is typically conducted through laboratory analysis and is expressed as a percentage relative to the total mass. Recognizing the significance of volatile matter content is of paramount importance due to its direct influence on the briquette's ignition and combustion characteristics. Briquettes featuring a higher volatile matter content are more prone to rapid ignition and the swift release of energy during combustion. Hence, the careful control and ongoing monitoring of volatile matter content are imperative for evaluating ignition behavior and the overall combustion performance of biomass briquettes, thus ensuring their optimal utility as a sustainable energy source.

$$V_M = (M_B - M_1) / M_B \times 100 \quad (5)$$

V_M refers to the percentage of volatile matter and M1 indicates the mass of sample after oven drying.

Moisture Content

The moisture content within a briquette is a pivotal factor in evaluating its appropriateness and quality as a biomass fuel. It denotes the ratio of water contained within the briquette, a component that directly affects its combustion efficiency and the overall energy it yields. Typically, moisture content in a briquette is determined through laboratory analysis, and the findings are expressed as a percentage in relation to the briquette's total mass. Recognizing and effectively managing moisture content is of paramount significance, as excessive moisture can lead to detrimental consequences, including diminished combustion efficiency, increased emissions, and a reduction in calorific value [21]. Moreover, elevated moisture levels can also impede the storage and handling characteristics of the briquette. Therefore, precise measurement and control of moisture content are essential to ensure the quality and performance of biomass briquettes across a diverse range of applications, encompassing heating, electricity generation, and bioenergy production.

$$M_C = M_W / M_B \times 100 \quad (6)$$

Here, M_C represents moisture content and M_W represents determined mass of water.

Fixed Carbon

Fixed carbon content is a fundamental parameter when evaluating the suitability of a briquette as a biomass fuel. It denotes the percentage of the briquette's solid, non-volatile carbonaceous material that remains after the volatile components have been removed during combustion. Typically determined through laboratory analysis, this value is expressed as a percentage of the total briquette mass. Understanding and quantifying fixed carbon content is crucial because it directly affects the briquette's energy content and how it behaves during combustion. A higher fixed carbon content generally leads to a briquette with a higher calorific value, making it a more efficient and valuable biomass fuel [22]. Consequently, a thorough assessment and precise control of the fixed carbon content are essential for evaluating the quality and performance of biomass briquettes across a range of applications, including heating, electricity generation, and bioenergy production.

$$C_F = 100 - (A_C + V_M + M_C) \quad (7)$$

C_F denotes the amount of fixed carbon in the briquette.

Ultimate Analysis

SEM/EDAX

The combination of Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analysis (EDAX) has proven to be a powerful tool for the thorough examination of biomass briquettes. These analytical techniques offer a detailed and informative view of the microstructure and chemical composition of these densely compacted biomass materials.

SEM provides researchers with the capability to closely inspect the surface morphology of biomass briquettes at high levels of magnification [23]. This methodology allows for the visualization of the physical structure of the briquette, unveiling intricate details such as particle arrangement and the presence of voids or pores. Such insights are indispensable for evaluating the quality of briquette compaction and its ability to withstand mechanical stresses during various phases, including handling, storage, and transportation. In conjunction with SEM, EDAX takes the analysis a step further by identifying and quantifying the elemental composition of the briquette. It accomplishes this by emitting X-rays when exposed to electrons. Analyzing the energy and intensity of these X-rays empowers researchers to identify the presence and concentration of different elements within the briquette, encompassing critical elements like carbon, oxygen, hydrogen, and trace elements [24]. This data is invaluable for gaining an in-depth understanding of the chemical composition of the briquette and can play a pivotal role in optimizing its performance during combustion or gasification processes. The utilization of SEM/EDAX analysis on biomass briquettes serves a multitude of purposes, including quality control, research and development, and assessing the impact of diverse processing techniques on the microstructure and composition of the briquette. This combined approach furnishes a holistic comprehension of the physical and chemical attributes of biomass briquettes, ultimately facilitating their continuous enhancement and adaptation for a broad spectrum of applications, ranging from energy generation to environmental sustainability.

TGA

The utilization of TGA and DSC analyses is of great value in comprehending the thermal characteristics of briquettes. TGA is focused on monitoring variations in weight as temperature fluctuations occur, providing valuable information regarding mass loss and the initiation of decomposition [25]. In contrast, DSC concentrates on tracking heat flow throughout temperature changes, facilitating the detection of phase transitions and the elucidation of associated energy alterations. TGA equipment comprises a precision balance and a furnace, while DSC necessitates a calorimeter equipped with a sample holder and a reference material. These analytical methods supply crucial insights, enabling the enhancement of briquette performance in combustion and gasification, thus playing a pivotal role in improving efficiency and promoting environmental sustainability within the biomass energy sector.

Results and Discussions

Physical Properties

The study conducted a detailed analysis of the physical characteristics of briquettes, adhering to ASTM standards. Parameters such as diameter, thickness, mass, volume, density, mass in relaxed state, relaxed density, density ratio, relaxation ratio, and shattered index were meticulously examined and documented for comprehensive evaluation in Table 1. Regarding diameter, all briquette samples showed a consistent measurement of 56 mm, ensuring uniformity.

However, thickness varied among compositions, with sample 100:0 at 75 mm, while compositions like 75:25, 50:50, 25:75, and 0:100 measured 72 mm, 74 mm, 72 mm, and 73 mm respectively. Notably, researches indicated potential thicknesses ranging from 25 mm to 280 mm, highlighting versatility [26]. Volume differences were significant, with sample 100:0 0having the maximum volume at 184.72 m^3, while samples 75:25 and 25:75 had the lowest volumes, both at 177.33 m3. Briquette density ranged from 1161.67 kg/m^3 to 1134.65 kg/m^3, aligning with the recommended range of 900 kg/m^3 to 1300 kg/m^3, indicating compliance with standards [27]. Mass in the relaxed state varied across samples, with sample 100:0 having the highest mass at 206.09 g and sample 0:100 the lowest at 198.02 g, indicating differences in compactness and composition.

Experimental results showed relaxed density between 1133.47 kg/m^3 and 1101.28 kg/m^3, increasing with higher compaction pressure and smaller feedstock particles. Olive cake briquettes exhibited a durable density range of 1100 kg/m^3 to 1300 kg/m^3. Density ratio ranged from 0.976 to 0.966, indicating high compactness. Despite minor differences, relaxation ratio and shattered index remained consistent across all compositions, indicating high quality suitable for transportation and storage.

Proximate Analysis

The analysis included determining moisture content, ash content, volatile matter, and fixed carbon content of biomass briquette samples following ASTM standards, with results presented in Table 2. Moisture content ranged from a maximum of 7.83% in sample 100:0 to a minimum of 6.72% in the sample composed of 25% watermelon and 75% muskmelon [29]. Ash content ranged from 12.03% in sample 100:0 to 10.86% in sample 0:100, demonstrating satisfactory levels that did not impact combustion. Volatile matter percentage varied from 72.34% to 68.90% among biomass briquette samples, a crucial indicator of spontaneous ignition and thus a desirable property for fuel.

The proximate analysis of thick solid biomass fuel produced from watermelon-muskmelon waste using ceramic powder and cassava starch as binders provides crucial insights into its fuel quality and combustion characteristics. This analysis includes the determination of moisture content, volatile matter, fixed carbon, and ash content. The expected low moisture content (<10%) achieved through controlled drying processes enhances combustion efficiency and energy output. The presence of ceramic powder is hypothesized to reduce the ash content due to its thermal stability, potentially resulting in cleaner combustion with less residue. The volatile

Table 1. Physical Properties of Briquettes.

S.No	Sample	Diameter (mm)	Thickness (mm)	Mass (g)	Volume (m^3)	Density (kg/m^3)	Mass in relaxed stage (g)	Relaxed Density (kg/m^3)	Density Ratio	Relaxation Ratio	Shattered Index (%)
1.	100:0	56	75	211.06	184.72	1142.26	206.09	1115.20	0.976	1.024	97.64
2.	75:25	56	72	206.43	177.33	1161.67	201.03	1133.47	0.975	1.024	97.38
3.	50:50	56	74	209.43	182.26	1146.71	202.65	1108.30	0.966	1.034	96.56
4.	25:75	56	72	205.48	177.33	1156.03	199.89	1127.22	0.975	1.025	97.27
5.	0:100	56	73	204.09	179.79	1134.65	198.06	1101.28	0.970	1.030	97.04

Table 2. Proximate Characteristics of Briquette.

S.No	Sample	Ash Content (%)	Volatile Matter (%)	Moisture Content (%)	Fixed Carbon (%)
1.	100:0	12.03	69.63	7.83	14.07
2.	75:25	11.85	68.90	7.52	12.43
3.	50:50	11.63	72.34	6.96	14.14
4.	25:75	12.02	71.48	6.72	13.29
5.	0:100	10.86	69.74	7.01	13.85

matter, representing the components that vaporize upon heating, is anticipated to be moderate, ensuring a balance between quick ignition and sustained burning. The fixed carbon content, indicative of the fuel's calorific value, is expected to be significant due to the inclusion of carbon-rich agricultural waste. Overall, the proximate analysis will demonstrate how the innovative use of ceramic powder and cassava starch improves the fuel's combustion properties, making it a viable alternative to traditional biomass fuels.

Ultimate Analysis

SEM/EDAX

Figure 5 offers an intricate examination of the sample's microstructure, providing detailed insights into its composition and morphology at a magnification scale of up to 100 micrometers.

In Fig. 5(a), the image showcases a magnified view of the briquette composed entirely of watermelon waste. The surface of this sample appears to be characterized by irregular bumps and protuberances. These features contribute to a surface topology with fewer voids, which is significant as it implies a reduced permeability to gases like oxygen [30]. The presence of fewer voids suggests that oxygen penetration into the briquette may be limited, potentially affecting processes such as combustion or decomposition. Moving on to Fig. 5(b), it focuses on the sample consisting entirely of muskmelon. In contrast to the watermelon waste briquette, this sample exhibits numerous nodule-like structures across its surface. These nodules are accompanied by relatively fewer ligamentous stretches. Such a configuration indicates a distinct microstructure compared to the watermelon waste briquette. The presence of these nodules and ligamentous stretches may influence various properties of the briquette, such as its mechanical strength, porosity,

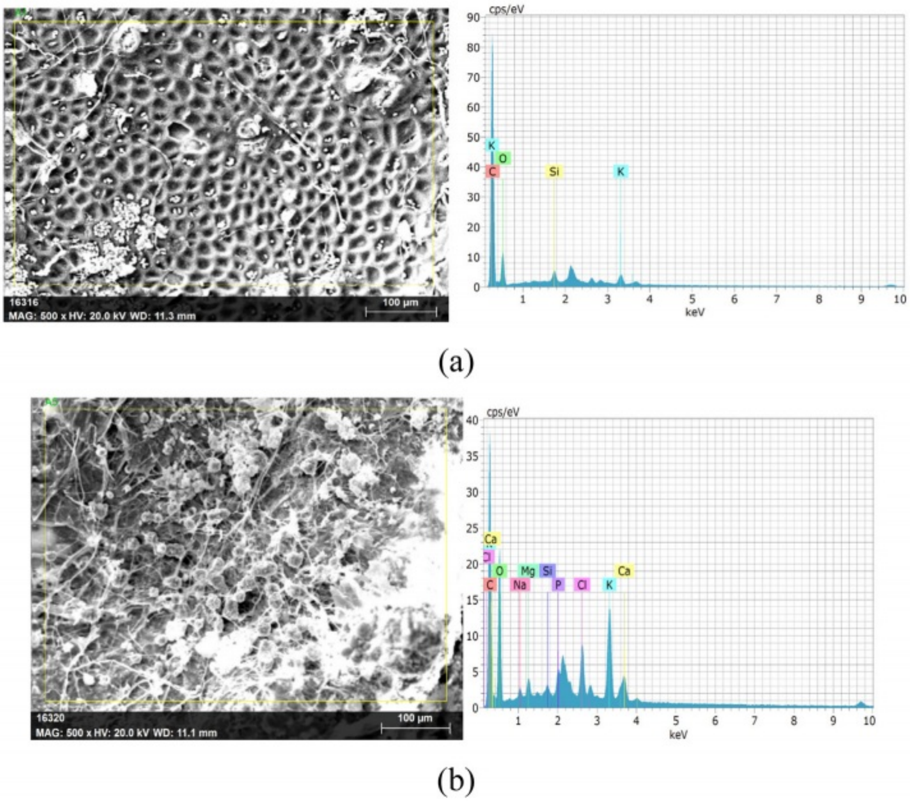

Fig. 5. Elemental composition of briquette sample (a) High carbon and (b) Low carbon.

Table 3 Elemental Composition.

S.No	Sample Ratio	C	O	Na	Mg	P	Cl	K	Ca	Si
1.	100:0	72.22 ± 24.92	21.06 ± 10.71	-	-	-	-	1.25 ± 0.20	-	0.64 ± 0.17
2.	75:25	71.74 ± 24.78	26.04 ± 10.87	-	-	-	-	2.23 ± 0.29	-	-
3.	50:50	56.70 ± 20.26	37.75 ± 14.82	-	0.36 ± 0.15	-	-	4.86 ± 0.53	-	0.33 ± 0.13
4.	25:75	68.75 ± 23.71	29.61 ± 11.87	-	-	-	-	1.41 ± 0.22	-	0.22 ± 0.11
5.	0:100	47.70 ± 8.81	41.33 ± 7.91	0.44 ± 0.13	0.56 ± 0.13	0.76 ± 0.12	2.16 ± 0.19	5.31 ± 0.32	1.66 ± 0.16	0.08 ± 0.08

and thermal conductivity. Understanding these structural differences is crucial for assessing the suitability of muskmelon waste as a material for various applications, including biofuel production or agricultural waste utilization.

Fig. 5 offers a close-up depiction of the sample's structure, magnified to a scale of up to 100 micrometers, and provides insights into its elemental composition. Fig. 5(a) Shows the magnified view of the briquette made of 100% watermelon waste, the surface has irregular bumps with less amount of voids which will allow oxygen to penetrate. Fig. 5(b) Specifies the sample made of 100% of muskmelon, and it has lots of nodule like structures with few ligamentous stretches.

According to the analysis, the sample primarily consists of carbon, oxygen, and potassium. The composition of elements in various briquette sample is depicted in Table 3. This indicates the pivotal roles these elements play in shaping the composition and properties of the material under investigation. Such findings are crucial for comprehending the characteristics and possible uses of the studied material. Across all samples, carbon content ranged from 47.70 ± 8.81% to 72.22 ± 24.92%, constituting the highest weight percentage. High carbon content is crucial for maximizing burning efficiency, indicating good briquette quality [28]. Oxygen content ranged from 21.06 ± 10.71% to 41.33 ± 7.91%, forming the second major element in the briquette samples. Carbon, oxygen, and potassium emerged as the primary components in all samples, while trace quantities of elements such as calcium, chlorine, silicon, magnesium, sodium, and phosphorus constituted the minor elements in biomass briquette samples [31].

TGA

The mass loss curve for each sample was derived from the thermo-gravimetric analysis. Fig. 6(a) specifically illustrates the thermogravimetric curve representing a biomass briquette exclusively composed of watermelon (100%) and devoid of muskmelon. Upon examination of Fig. 6(a), it becomes evident that a significant decline in moisture content and volatile molecular weight occurs around the temperature of approximately 195°C, leading to an observed mass loss of around 8%.

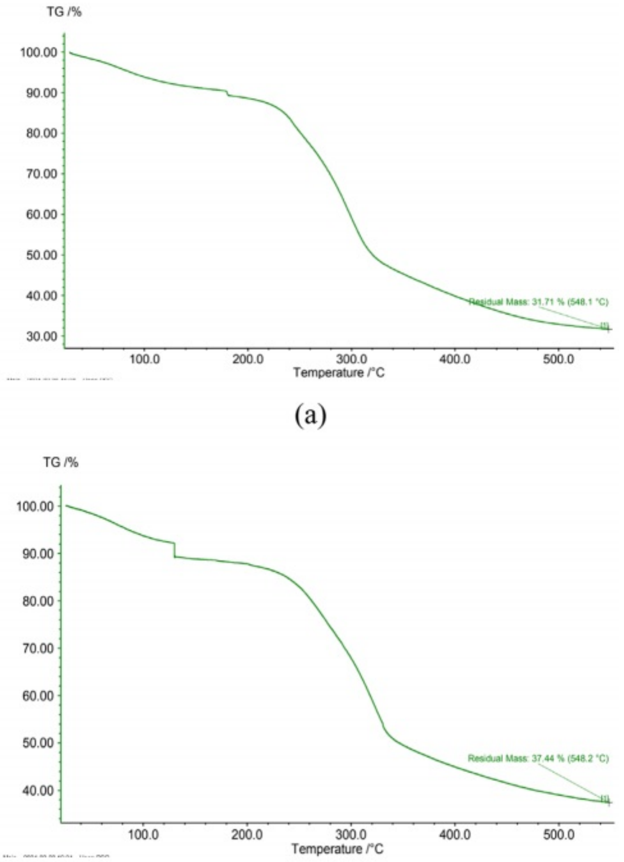

Fig. 6. Temperature Vs Weight loss % (a) High loss and (b) Low loss.

Subsequently, within the temperature range of 195°C to 395°C, the breakdown of chemical constituents such as cellulose and hemicelluloses takes place, resulting in a substantial 54% reduction in mass. The degradation of lignin and carbonaceous solids ensues at temperatures surpassing 395°C. Notably, at 547.44°C, the residual

Table 4. TGA Residual Mass of Various Sample.

S.No	Sample	Temperature (°C)	Residual Mass (%)
1.	100:0	547.44	31.70
2.	75:25	547.95	31.37
3.	50:50	495.87	33.00
4.	25:75	547.56	30.66
5.	0:100	547.47	37.46

mass of the sample (100:0) is determined to be 31.70%.

The thermogravimetric (TG) analysis of thick solid biomass fuel produced from watermelon-muskmelon waste using ceramic powder and cassava starch as binders offers valuable information on the thermal stability and decomposition behavior of the fuel [32]. TG analysis measures the weight loss of the biomass briquettes as they are heated, providing insights into moisture content, volatile release, and the stability of fixed carbon. The initial weight loss observed at lower temperatures corresponds to the evaporation of residual moisture, while subsequent weight losses indicate the release of volatile compounds. The presence of ceramic powder is expected to enhance the thermal stability, resulting in a higher decomposition temperature for the fixed carbon and potentially leading to a slower and more controlled combustion process [33]. The cassava starch binder, being organic, will contribute to the early stages of decomposition, while the ceramic powder will remain thermally stable, influencing the overall weight loss profile. This balance between organic and inorganic components in the briquette formulation will be reflected in a TG curve that demonstrates a well-defined multi-step degradation process, showcasing the improved performance and stability of the biomass fuel compared to conventional biomass without ceramic additives.

Conclusion

Understanding various factors and analytical techniques is crucial for advancing biomass briquette development. Investigating blends of watermelon and muskmelon waste helps assess their impact on moisture content, calorific value, and mechanical strength. With precise pressure control of 150 kN during compression, consistent density and durability of resulting briquettes are ensured. A crosshead mechanism maintains uniformity, and real-time monitoring allows immediate adjustments. Analysis techniques EDAX and TGA provide insights into internal structure and composition, aiding in performance assessment. Graphical representation of results facilitates comparison of different waste blends. The maximum carbon content ranges from 72.22% to 47.70% and the mass of the sample declines up to 31% of the original mass on heating. This comprehensive approach combines experimentation with advanced analysis to optimize biomass briquettes, promoting sustainable use of agricultural waste. The production of biomass fuel from watermelon-muskmelon waste using ceramic powder and cassava starch reduces agricultural waste and greenhouse gas emissions, promoting sustainable energy. The ceramic powder enhances combustion efficiency and reduces ash content, further lowering environmental pollution. Potential drawbacks include the energy and resources required for drying and processing the biomass, which must be managed to ensure overall sustainability.

Practical Applications of the Research

The development of biomass briquettes from agricultural waste offers an eco-friendly alternative to fossil fuels. These briquettes can be used in residential heating, cooking, and industrial applications, reducing dependence on non-renewable energy sources and lowering carbon emissions.

This research provides an innovative solution for managing agricultural waste, particularly watermelon and muskmelon residues. Converting these wastes into valuable biomass fuel not only addresses waste disposal issues but also promotes resource efficiency and sustainability.

The inclusion of ceramic powder and cassava starch as binders improves the structural integrity, thermal stability, and combustion efficiency of the biomass briquettes. These enhanced properties make the briquettes more competitive with traditional biomass fuels, offering higher energy output and more efficient burning.

The production of biomass briquettes can create new economic opportunities in rural areas, providing jobs and income for farmers and local communities. This can stimulate rural economies and support sustainable agricultural practices.

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