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RESEARCH ARTICLE

Techno-economic feasibility of biomass briquetting system for sustainable waste-to-energy generation

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Abstract

Biomass has gained attention as a renewable energy source capable of achieving net-zero carbon dioxide emissions during its production and use. Biomass, particularly agro-residues and forestry waste, is a promising energy source for developing countries facing fossil fuel shortages and environmental challenges. However, these materials are difficult to handle due to their bulky nature and inefficient combustion. Briquetting, a compaction technology, addresses these challenges by converting biomass into compact, high-density, low-moisture briquettes with improved combustion properties and reduced smoke emissions. The study evaluates various combinations of biomass, finding that briquettes made from sawdust and plywood residues exhibit higher bulk density, increased fixed carbon content, and calorific values ranging from 4200 to 4814.4 kcal/kg, comparable to fuel wood. Additionally, the briquettes demonstrate favorable ash fusion and deformation temperatures and perform well in impact resistance and compression tests. Economically, the briquetting model, tested at the Forest College and Research Institute, has a payback period of two years due to the low cost of raw materials. This technology is an eco-friendly and cost-effective solution for biomass utilization, offering a sustainable alternative to traditional fuels and contributing to forest conservation efforts. The results suggest that briquetting using forest and industrial wood residues will remain profitable even with potential increases in raw material costs.

Keywords: biomass briquettes; economic feasibility; physical and thermal characteristics; quality parameters

Introduction

Solid biofuels have become an alternative energy source in recent years due to the global depletion of fossil fuels. Researchers increasingly focus on renewable sources, particularly non-food agricultural products, as potential alternatives. The growing recognition of deforestation and wood fuel shortages in many countries has shifted attention toward other forms of biomass energy (1). Biomass is India's primary fuel energy source, accounting for over 85 % of the total energy consumed. Annually, India produces approximately 600 million tons of agricultural residues, including rice husks, coconut shells, groundnut shells, cotton stalks, and sawdust. Biomass energy plays a significant role in meeting the energy demands of developing countries, with around 46 % of India's energy consumption coming from biomass resources (2). However, the traditional disposal method of burning surplus biomass in situ leads to severe environmental pollution. Converting these residues into high-density briquettes offers a cleaner, more efficient alternative. Briquettes, with a 1.2 g/cm^3 density, are more manageable and eco-friendlier than loose biomass, which has a bulk density of 0.1-0.2 g/cm^3. The process of briquetting also contributes to conserving forest resources (3). However, certain disadvantages remain, such as briquettes' sensitivity to moisture and their emission of smoke due to high volatile matter content during combustion. Addressing these challenges is crucial for the commercial success of this technology (4).

Materials and Methods

In this study, biomass briquettes were prepared using various combinations of forest plantation residues and wood-based industrial residues. The biomass materials used in the experiment include matchwood residues, bark residues, plywood residues, and sawdust. Each type of biomass was tested individually and in different mixture ratios of 25 % + 75 %, 50 % + 50 %, and 75 % + 25 %. The materials were air-dried to reduce the moisture content below 10 %, followed by grinding to achieve a uniform particle size of approximately 3 mm. The briquetting process involved using a hydraulic briquetting press with a die size of 60 mm. The pressure applied during the briquetting process ranged from 5 to 7 MPa, and the temperature was controlled between 120°C and 150°C. Briquettes were formed without any additional binder, relying solely on the natural lignin present in the biomass for binding. The physical properties of the briquettes, such as bulk density and moisture content, were measured following the International Standard ISO 18134. The mechanical properties, including impact resistance and compression strength, were assessed using a universal testing machine.

Additionally, the calorific value of the briquettes was determined using a bomb calorimeter, following ASTM D5865. Thermo-gravimetric analysis, including ash fusion temperature, was measured using an ash fusion tester under controlled conditions, and the ash deformation temperature was recorded for each sample. Proximate analysis was conducted to determine the briquettes' fixed carbon, volatile matter, and ash content. The quality parameters, such as water resistance and lignin content (Klason method), have also been tested. The produced briquettes were stored in ambient conditions for 30 days, and their swelling behavior was evaluated by immersing them in water to study moisture absorption and dimensional changes. Each experiment was repeated three times, and the results were averaged to ensure accuracy and reliability. An economic feasibility study was also conducted to assess the profitability of briquette production. The collected data were analyzed statistically to explore potential relationships between different parameters, and an analysis of variance was performed using the Completely Randomized Design method (5).

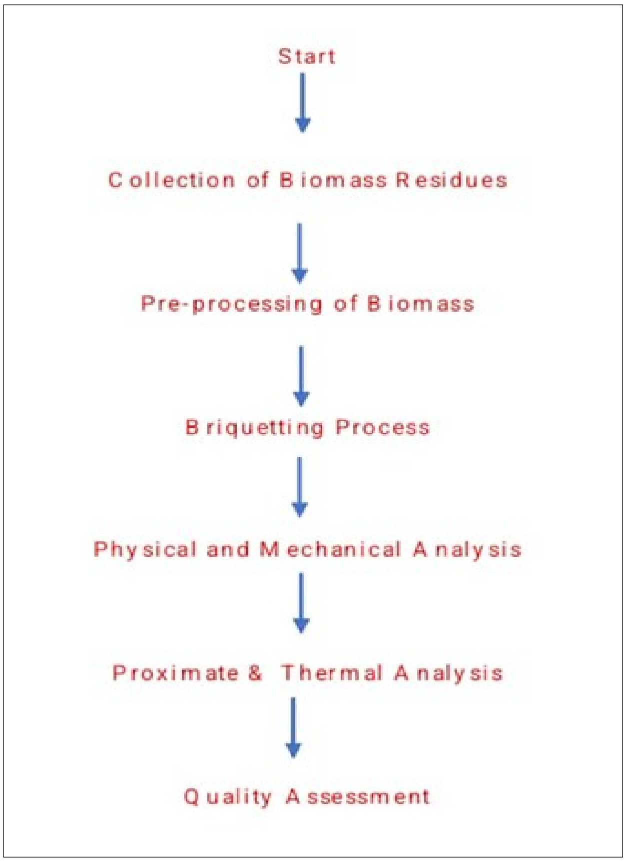

Fig. 1. Flowchart of briquette manufacturing process.

Fig. 1 shows the process of briquette manufacturing process.

Results and Discussion

Physical characteristics

Fig. 2 shows the density of briquettes is influenced by the initial bulk density of the biomass, the briquetting process, and the pressure applied during manufacturing, according to studies at PAU Ludhiana (6). Among the five biomass types studied, plywood residues, having the highest bulk density (0.196 gm/cm^3) as raw biomass, also exhibited the highest bulk density in their briquette form. Conversely, sawdust, which had the lowest bulk density (0.172 gm/cm^3) among the raw biomass, also produced briquettes with lower bulk density. Fig. 3 explained briquette combinations, it was observed that those including a higher proportion of biomass with greater bulk density, such as the 25 % sawdust + 75 % plywood residues combination, also resulted in higher overall briquette bulk density.

Proximate analysis

Fig. 4 & 5 shows the proximate analysis done individually and in combinations in which the moisture content plays a crucial role in determining the burning characteristics of biomass (7). Among the different briquette samples analyzed for moisture content, the values ranged from 6.87 % (plywood residues) to 9.89 % (sawdust). Sawdust recorded the highest and most significant moisture content of 9.89 %, higher than the general mean of 8.23 %, while plywood residues had the lowest moisture content at 6.87 %. In terms of combination briquettes, sawdust 50 % + plantation residues 50 % (9.44 %) and sawdust 75 % + plantation residues 25 % (9.61 %) recorded the highest and most significant moisture content values, surpassing the general mean of 7.83 % at a 5 % significance level. The lowest moisture content was observed in sawdust 50 % + plywood residues 50 %, with a value of 5.97 %. Biomass generally contains 70-86 % volatile matter on a dry weight basis (8), whereas coal contains about 35 %. The volatile matter content of the biomass and briquettes ranged from 71.04 % (plywood residues) to 73.59 % (matchwood residues). Among the combination briquettes, sawdust 25 % + matchwood residues 75 % (73.89 %) and sawdust 75 % + matchwood residues 25 % (74.35 %) recorded the highest volatile matter values, which were significantly higher than the general mean of 72.13 % at the 5 % level. The lowest volatile matter content was observed in sawdust 50 % + bark residues 50 % (70.75 %). Ash content, a non-combustible component of biomass, negatively affects calorific value; the higher the ash content, the lower the fuel's energy output (8, 9). A study noted that increased ash content in fuelwood adversely affects the heat of combustion, explaining variations in combustion values (10). The ash content values of the various biomass samples analyzed ranged from 4.90 % for bark residues to 6.08 % for sawdust. In contrast, the ash content of the briquettes varied from 4.06 % for plywood residues to 5.76 % for sawdust. For the combination briquettes, ash content values ranged from 2.92 % for a mixture of 25 % sawdust and 75 % plywood residues to 5.23 % for a

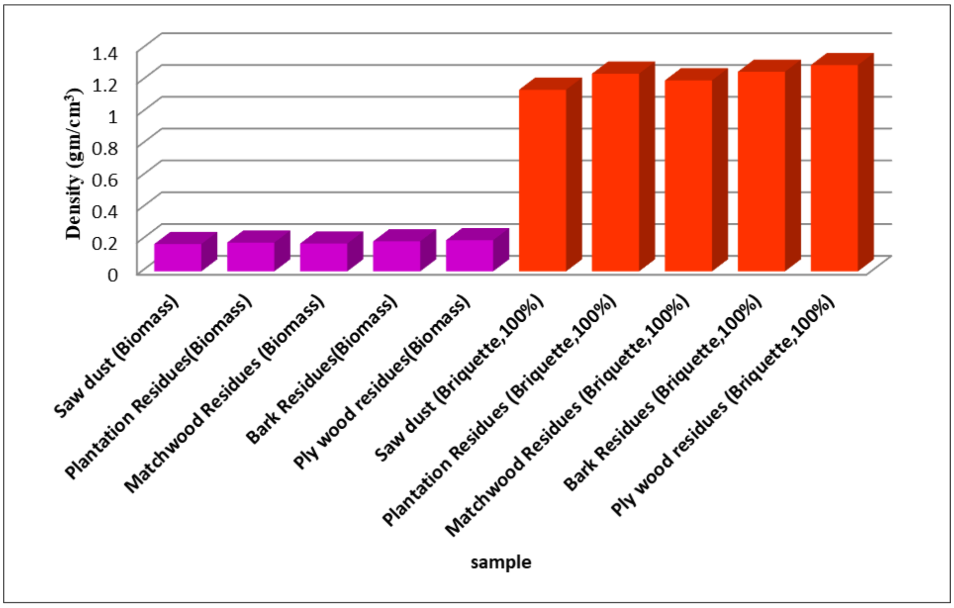

Fig. 2. Bulk density of biomass and 100 % briquettes.

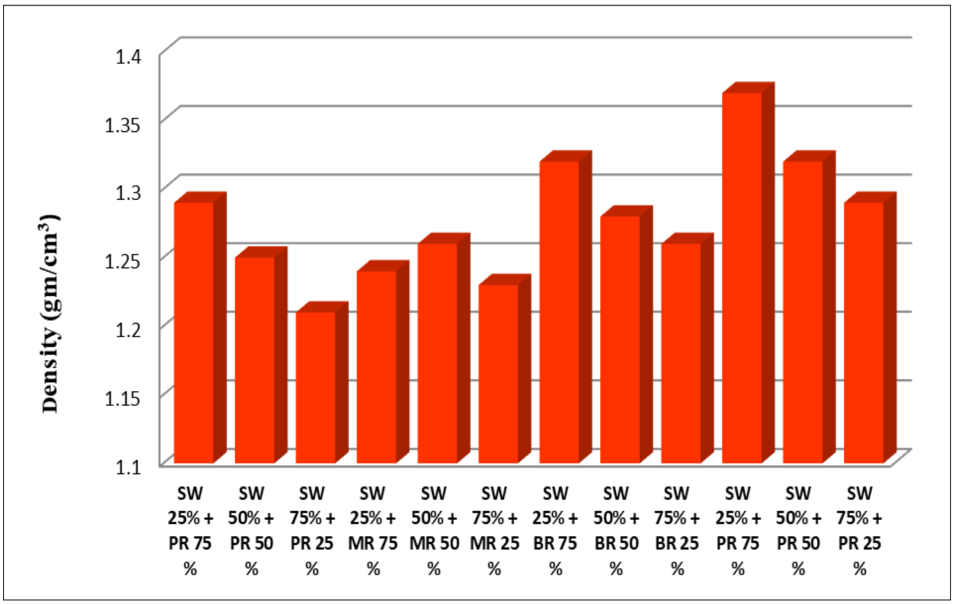

Fig. 3. Bulk density of combination briquettes.

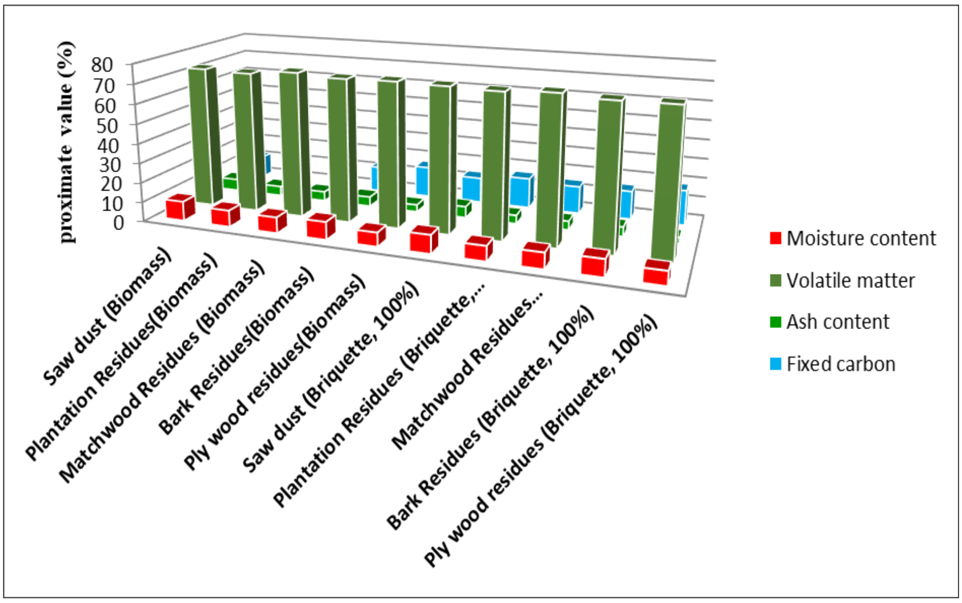

Fig. 4. Proximate analysis of biomass and 100 % briquettes.

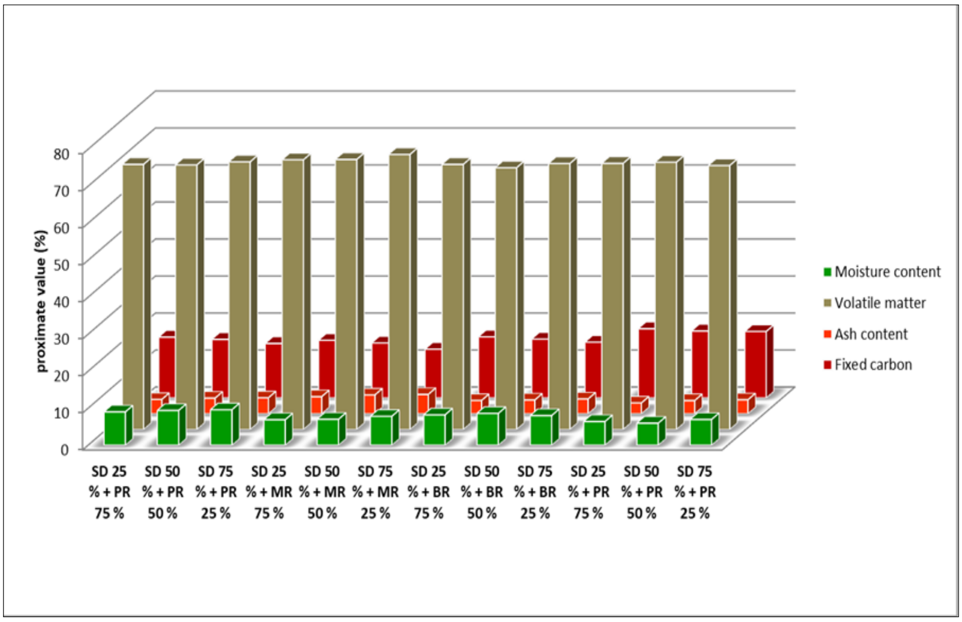

Fig. 5. Proximate analysis of combination briquettes.

combination of 75 % sawdust and 25 % matchwood residues. The fixed carbon content of the biomass and briquettes varied significantly, ranging from 11.45 % for sawdust to 17.87 % for plywood residues. Among the biomass samples, plywood residues demonstrated the highest fixed carbon content at 16.98 %, significantly greater than the general mean of 14.36 % at a 5 % significance level. The fixed carbon content for various combination briquettes ranged from 13.20 % for the mix of 75 % sawdust and 25 % matchwood residues to 18.73 % for the combination of 25 % sawdust and 75 % plywood residues. The combinations of sawdust 25 % + plywood residues 75% (18.73 %), sawdust 50 % + plywood residues 50 % (18.11 %), and sawdust 25 % + plywood residues 75 % (17.98 %) all had significantly higher fixed carbon content compared to the general mean of 16.08 % at 5 % significance level. In contrast, the combination of sawdust 75 % + matchwood residues 25 % yielded the lowest fixed carbon value of 13.20 %.

Thermal characteristics

Fig. 6 depicts the calorific value of biomass and 100 % briquettes. Among the analyzed biomass samples, the calorific values ranged from 3900 Kcal/kg for sawdust to 4685 Kcal/kg for plywood residues, with plywood showing a significant value above the grand mean of 4033.21 Kcal/kg. The briquettes demonstrated similar trends, with the highest calorific value of 4814 Kcal/kg for the combination of 25 % sawdust and 75 % plywood residues. This pattern indicates that higher biomass percentages contribute to increased calorific values, emphasizing the relationship between biomass quality and calorific content. Fig. 7 clearly shows the calorific value of combinations briquettes, which concluded that the calorific values of the analyzed briquette combinations ranged from 4273 Kcal/kg for sawdust 75 % and matchwood residues 25 % to 4802 Kcal/kg for sawdust 25 % and plywood residues 75 %. Higher biomass percentages corresponded to increased calorific values, indicating a positive relationship between biomass content and energy output. From Table 1, the analysis of ash fusion and deformation temperatures for various 100 % briquette samples revealed that ash

Table 1. Ash fusion and deformation temperature

Sample	Ash Deformation Temperature (°c)	Ash Fusion Temperature (°c)
Saw dust (Briquette, 100%)	1050-1080	1100-1110
Plantation residues (Briquette, 100%)	1080-1100	1100-1120
Matchwood residues (Briquette, 100%)	1050-1100	1100-1120
Bark residues (Briquette, 100%)	1100-1120	1115-1125
Plywood residues (Briquette, 100%)	1100-1120	1125-1150
Sawdust + Plantation residues		
25 % + 75 %	1080-1100	1100-1150
50 % + 50 %	1050-1100	1100-1110
75 % + 25 %	1030-1080	1100-1120
Saw dust + Matchwood residues		
25 % + 75 %	1050-1180	1110-1130
50 % + 50 %	1030-1080	1050-1180
75 % + 25 %	1020-1050	1050-1080
Saw dust + Bark residues		
25 % + 75 %	1080-1100	1110-1125
50 % + 50 %	1050-1100	1100-1120
75 % + 25 %	1050-1100	1100-1110
Saw dust + Plywood residues		
25 % + 75 %	1080-1110	1125-1150
50 % + 50 %	1080-1100	1100-1130
75 % + 25 %	1050-1100	1100-1125

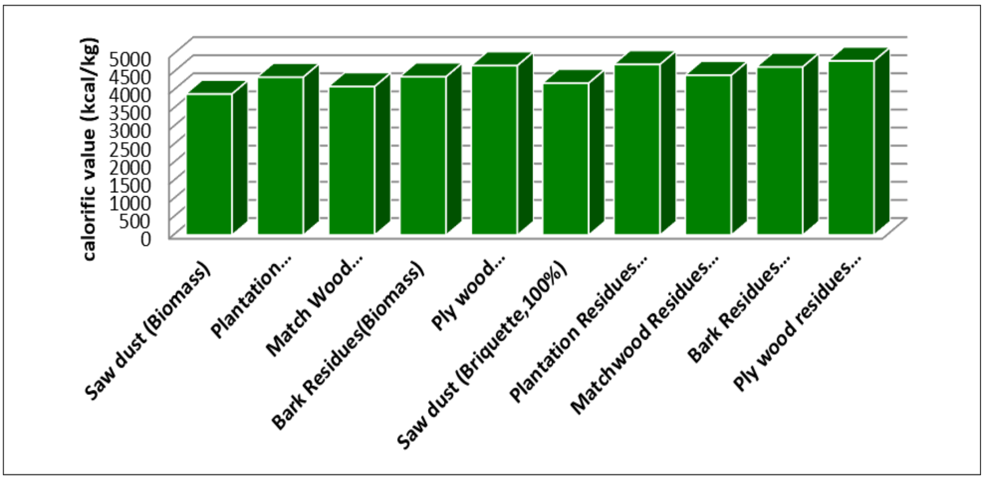

Fig. 6. Calorific value of biomass and 100 % briquettes.

deformation temperatures ranged from 1050-1080°C for sawdust to 1100-1120°C for plywood residues. Plywood and bark residues exhibited the highest deformation temperatures, while sawdust recorded the lowest. The ash fusion temperature varied from 1100-1110°C for sawdust to 1125-1150°C for plywood residues, indicating a maximum difference of 50-80°C between the two materials. For combination briquettes, ash deformation temperatures ranged from 1020-1050°C for sawdust 75 % and matchwood residues 25 % to 1080-1110°C for sawdust 25 % and plywood residues 75 %. The highest ash deformation temperature was noted in the sawdust 25 % and plywood residues 75 % combination, while the lowest was observed in the sawdust 75 % and matchwood residues 25 % combination. Correspondingly, the ash fusion temperatures for the combinations ranged from 1050-1080°C (sawdust 75 % + matchwood residues 25 %) to 1125-1150°C (sawdust 25 % + plywood residues 75 %). A study highlighted that biomass ashes consistently contain high-temperature molten materials regardless of ash temperature (11). Therefore, evaluating biomass ash fusion characteristics should focus on the initial deformation temperature and the presence of high-temperature molten materials rather than solely on elemental proportions. Thermo-gravimetric analysis (TGA) of briquettes made from sawdust, plantation residues, matchwood residues, bark residues, and plywood residues revealed a similar thermal degradation pattern across all samples when heated from 0 to 800°C. Table 2 shows that the residue content was lower in sawdust and bark residues (6.013 % each) than in matchwood residues (22.31 %). During thermal degradation, significant weight loss occurred between 200-350°C (5-8 % due to moisture) and 350-400°C (62-75 % due to volatiles), providing insights into the combustion behavior of these biomass samples. This analysis highlights different briquettes' thermal characteristics and suitability for energy applications (12).

Quality parameters

Tables 3 & 4 show the impact resistance of 100 % briquettes and different combinations, where the impact resistance of various briquette samples was assessed by measuring weight loss after dropping from heights of 1.8 m, 1.5 m and 1 m onto steel and concrete surfaces. Weight loss for 100 % briquettes ranged from 0.26 % (plywood residues) to 2.83 % (sawdust) on concrete, indicating that sawdust had the highest vulnerability to impact. Combination briquettes exhibited weight loss of 0.39-1.92 % on steel and 0.73-2.49 % on concrete for sawdust and plantation residues. Results suggest that briquettes dropped on concrete sustained greater weight loss than

Table 3. Impact resistance of 100 % briquettes

Sample briquettes 100 %	Steel surface				Concrete surface			
	Initial wt (gm)	1.8 m (%)	1.5m (%)	1 m (%)	Initial wt (gm)	1.8 m (%)	1.5 (%)	1 m (%)
Saw dust	56.86				67.40			
	49.69	2.79	2.21		60.39	2.83	2.39	
	58.48			1.68	51.43			1.81
Plantation residues	83.59				56.97			
	78.93	1.05	0.89		59.36	1.19	0.90	
	69.22			0.87	66.01			0.53
Matchwood residues	95.60				45.85			
	89.21	1.31	1.11		49.55	1.18	1.17	
	72.38			0.83	53.11			0.93
Bark residues	83.75				67.40			
	74.86	0.97	0.81		74.62	1.23	0.91	
	82.33			0.39	60.00			0.41
Plywood residues	45.84				59.58			
	42.13	0.46	0.31		54.17	0.51	0.35	
	51.47			0.26	49.60			0.29
Standard Deviation	20.84	0.88	0.70	0.56	8.91	0.86	0.76	0.62
Confidence interval (95%)	47.26, 98.99	0.22, 2.41	0.19, 1.94	0.11, 1.50	48.38, 70.50	0.32, 2.46	0.20, 2.09	0.03, 1.56

Table 4. Impact resistance of combination briquettes

Briquette combination	Steel surface				Concrete surface			
	Initial wt (gm)	1.8 m (%)	1.5 (%)	1 m (%)	Initial wt (gm)	1.8 m (%)	1.5 (%)	1 m (%)
Saw Dust % + Plantation residues %								
25 + 75	78.54	1.92	1.31	0.89	89.33	2.49	1.98	1.70
50 + 50	76.44	1.41	0.93	0.85	68.80	2.03	1.46	0.99
75 + 25	71.69	0.93	0.51	0.39	78.63	1.45	0.94	0.73
Saw Dust % + Match residues %								
25 + 75	70.86	1.71	1.32	0.91	82.84	2.21	1.75	1.32
50 + 50	67.86	1.39	1.04	0.62	85.74	2.01	1.63	1.04
75 + 25	81.67	1.17	0.86	0.81	78.99	1.46	1.13	0.52
Saw Dust % + Bark residues %								
25 + 75	59.76	1.32	0.93	0.56	65.57	1.36	0.75	0.44
50 + 50	63.75	1.12	0.76	0.42	74.79	0.87	0.56	0.41
75 + 25	60.23	0.87	0.43	0.39	68.22	0.61	0.42	0.39
Saw Dust % + Plywood residues %								
25 + 75	71.74	1.01	0.63	0.41	87.42	1.21	0.89	0.37
50 + 50	67.58	0.44	0.31	0.19	80.24	0.77	0.51	0.31
75 + 25	68.24	0.35	0.26	0.13	67.60	0.69	0.39	0.27

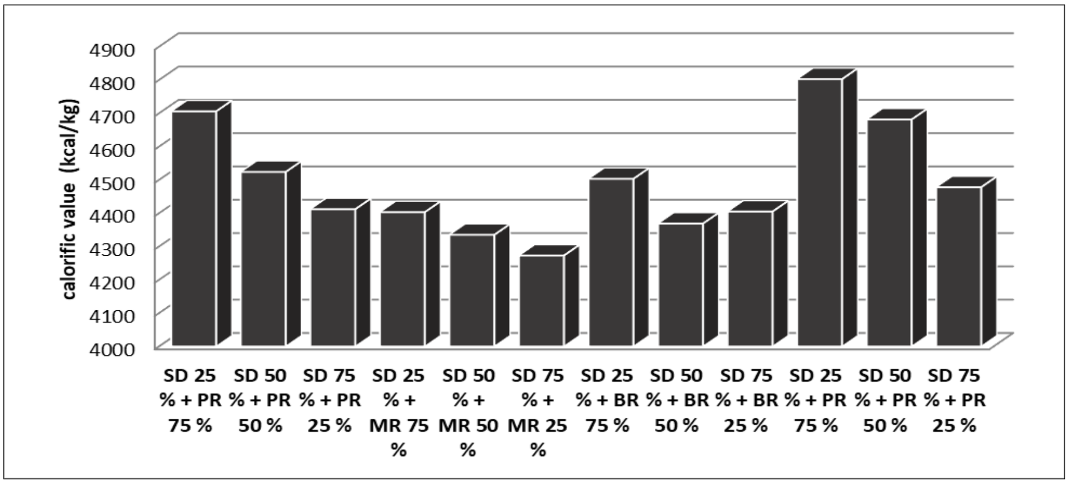

Fig. 7. Calorific value of combination briquettes.

steel, attributed to the latter's limited rebound effect (13). Thus, plywood briquettes were more durable than sawdust, supporting their use in practical applications.

Water resistance of 100 % briquettes and different combinations was recorded in Tables 5 & 6, which evaluated the briquette durability after 15 min in water. Sawdust, plantation residues, and matchwood residues exhibited poor water resistance, losing shape and particles rapidly, while bark and plywood residues demonstrated good water resistance. Among combination briquettes, sawdust of 25 % with plantation, bark, and plywood residues showed better resistance, whereas combinations with higher sawdust content were less durable. The lower porosity of plywood and bark residues limited water absorption, unlike the more porous sawdust and plantation residues, which absorbed more water, causing particle detachment (14, 15). The compressive strength of various briquette combinations shows the relationship between the pressure plate displacement and the compression load. The graphs reveal the ultimate load values at which the briquettes failed; for instance, matchwood residue briquettes withstood a maximum load of 7.9 kN before breaking, whereas sawdust briquettes failed at 3.9 kN. The compression load increased with the displacement of the plate, indicating that briquettes maintained structural integrity until reaching their breaking point. Notably, briquettes made from plywood and bark residues demonstrated lower porosity, resulting in greater rigidity and strength than those made from sawdust and plantation residues, which exhibited higher porosity and, thus, weaker structural integrity (16). This study emphasizes the importance of material composition in enhancing the compressive resistance of briquettes, which is crucial for ensuring durability during storage and handling (17, 18).

The analysis of lignin content in various biomass samples, shown in Fig 8 revealed values ranging from 19.64 % in bark residues to 25.90 % in sawdust. The sawdust

Table 5. Water resistance of 100 % briquettes

Briquettes, 100%	Time range in which shape dispersed		
	0-5 min	5-10 min	10-15 min
Saw dust	Bad	-	-
Plantation residues	Bad	-	-
Matchwood residues	Bad	-	-
Bark residues	-	Good	-
Plywood residues	-	Good	-

Table 6. Water resistance of combination briquettes

Briquette combinations	Time range in which shape dispersed		
	0-5 min	5-10 min	10-15 min
Saw dust % + Plantation residues %			
25 + 75		Good	
50 + 50	Bad		
75 + 25	Bad		
Saw dust % + Matchwood residues %			
25 + 75	Bad		
50 + 50	Bad		
75 + 25	Bad		
Saw dust % + Bark residues %			
25 + 75		Good	
50 + 50	Bad		
75 + 25	Bad		
Saw dust % + Plywood residues %			
25 + 75		Good	
50 + 50	Bad		
75 + 25	Bad		

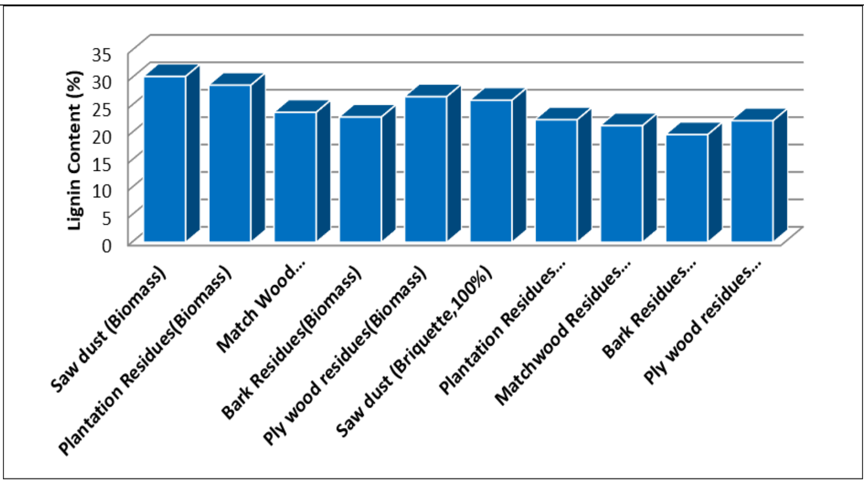

Fig. 8. Lignin content of briquettes.

exhibited the highest lignin content, significantly above the general mean of 23.33 %. Notably, after briquetting, a slight reduction in lignin content was observed: sawdust decreased from 30.24 % to 25.90 % and plantation residues from 27.65 % to 22.35 %. This decrease can be attributed to lignin melting during the densification process, where it acts as a natural binder due to increased temperatures (150-220°C). Lignin content is crucial in determining calorific value, as higher lignin levels correlate with improved energy content (16). Fig. 9 depicts the water absorption characteristics of various briquette samples, showing values ranging from 17 mL in plywood residues to 83 mL in sawdust, indicating significant differences in water absorption. The investigation revealed that briquettes made from plywood and plantation residues absorbed less water due to their lower porosity.

In contrast, sawdust, matchwood, and bark residues exhibited higher water absorption due to their increased pore structure, allowing more water to penetrate (14, 15). This difference in water absorption is crucial, as excessive moisture can negatively impact the durability and strength of briquettes. Fig. 10 shows the diameter study aimed to evaluate the atmospheric moisture absorbed by fresh briquettes over six months. The diameter values ranged from 40.5 mm for plywood residues to 44.2 mm for

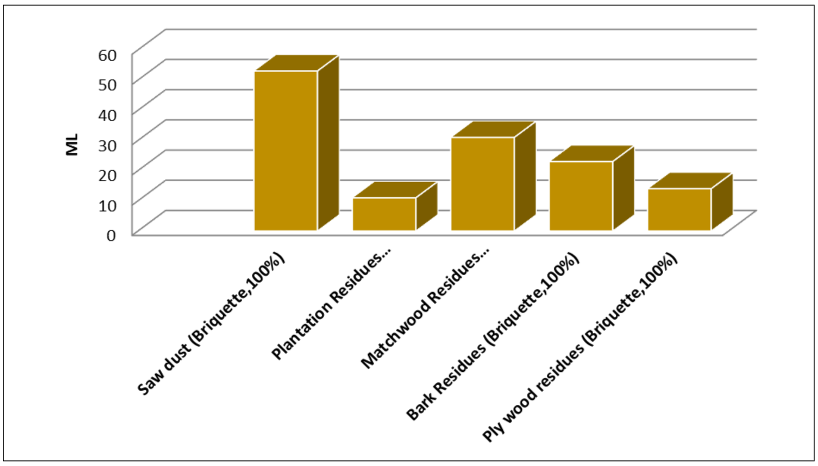

Fig. 9. Water absorption study of briquettes.

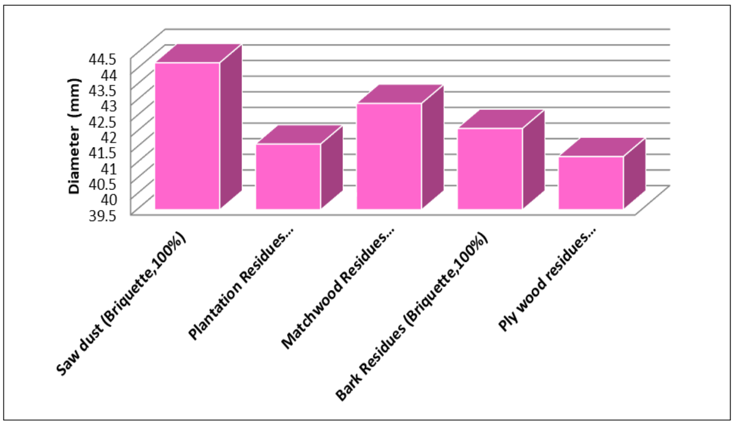

Fig. 10. Diameter study of six months stored briquettes.

sawdust, with sawdust exhibiting the largest diameter increase due to moisture absorption. The results indicated that plywood and bark residues had fewer pores, leading to reduced moisture absorption compared to sawdust, plantation residues, and matchwood residues, which had a more porous structure that allowed greater air and moisture ingress (14, 15). This swelling can negatively impact the briquettes' structural integrity and durability. Fig. 11 shows the swelling study that evaluated the diameter increase of fresh briquettes after soaking them in water for one minute. The results indicated that plywood and plantation residues exhibited lower swelling, making them more suitable for commercial briquettes. Conversely, sawdust briquettes displayed the highest swelling, indicating a greater capacity to absorb water. This behavior can be attributed to the porous structure of sawdust, matchwood, and bark residues, allowing more water ingress than plywood and plantation residues (14, 15). Excessive swelling can compromise briquettes' mechanical integrity and durability, highlighting the importance of selecting appropriate raw materials for briquette production to ensure long-term performance and stability under varying moisture conditions.

Economic analysis

Table 7 shows the economic analysis of briquette production, indicating a promising opportunity for sustainable energy generation. The machine's production capacity is 250 kg/hr, allowing for a total output of 2.5 tons per day, equating to approximately 75 tons per month and 900 tons annually. The calculated total net benefit per year is estimated at Rs. 1,573,200. This substantial return suggests that the initial expenditure on setting up the production facility can be recovered within two years. The break-even point is determined at 719 tons per year, indicating a safety margin of 181 tons, which ensures operational viability and profitability. The customs hire charge for the machine is Rs. 2140. This cost structure enables a net profit of approximately Rs. 1748 per ton, leading to an output-input ratio (OIR) of 1.75, signifying a healthy return on investment.

Such favorable economic indicators are crucial for promoting the adoption of biomass briquettes as a renewable energy source, particularly in regions where reliance on non-renewable fuels is prevalent (19). In light of the global energy crisis and the depletion of fossil fuels, there is an urgent need for alternative energy resources that are renewable, cost-effective, and environmentally friendly (20). Renewable energy technologies (RETs), including biomass, offer promising solutions to address energy demands while enhancing energy security and sustainability in developing countries (21). The profitability associated with the Forest College and Research Institute (FC & RI) briquetting unit underscores the importance of utilizing locally available raw materials, which are relatively cheaper than conventional fuels. While the initial establishment cost of a briquetting plant can be significant, the potential for rapid recovery of the investment makes it an attractive venture. The findings indicate that banks are increasingly supportive of funding such projects, with the government of Tamil Nadu offering

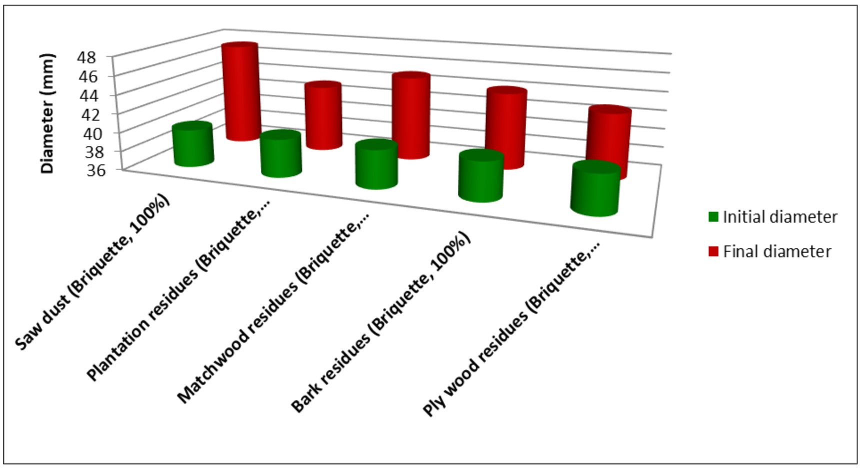

Fig. 11. Swelling study of briquettes.

Table 7. Cost factors of the established briquetting unit in Forest College and Research Institute, Mettupalayam

Sl.No	Particulars	Fixed Cost (Rs/tonne)
1	Machinery cost	7,50,000.00
2	Land and construction cost of unit	4,00,000.00
3	Electricity power connection cost	1,00,000.00
4	Spares	7,700.00
5	Total fixed cost	12,57,700.00
		Variable cost (Rs/tonne)
7	Raw material cost (saw dust, plantation & match wood waste, bark & plywood residues)	800.00
8	Transport cost	200.00
9	Labour Cost	300.00
10	Electricity Cost Rs. 4.25/ Unit	200.00
11	Spares	75.00
12	Lubricating oil	50.00
13	Packing	200.00
14	Miscellaneous	50.00
15	Interest on working capital (14%)	263.00
16	Total Variable cost	2138.00
17	Rental of building	100.00
18	Machinery items- Depreciation (@11.3 percent)	85.00
19	Electricity (power connection)	15.00
20	Depreciation on buildings (@3.34 percent)	14.82
21	Input cost	2352.82
22	Selling price (Output cost)	4100.00
23	Net Profit	1748.00
24	OIR	1.75

a 20 % subsidy on the total investment cost, further enhancing financial viability. This aligns with (22) assertion that utilizing a mixture of various biomass materials can optimize production capacity while maintaining economic efficiency. Moreover, studies have shown that wood waste is a superior raw material for briquette production compared to agricultural residues, resulting in higher economic returns due to lower material costs and minimal production expenses. This supports the findings from Coimbatore and the Department of Bioenergy at TNAU, where the production capacities of briquette machines range from 500 kg/h to 750 kg/h. The efficient use of plantation residues and wood-based industrial by-products reduces costs. It enhances the competitiveness of briquettes in the local market, with prices falling between 30000 and 33000 forints per ton, ensuring sufficient returns for manufacturers. The Forest College and Research Institute's model of using plantations and industrial residues has been particularly effective, with reported reductions in production costs from 1.1 to 0.9 times the price of traditional fuel wood. Such data confirm that briquettes can effectively compete with fuel wood, further emphasizing the need for widespread adoption of this alternative energy source. The economic feasibility of briquette production is robust, driven by favorable production costs, supportive government policies, and increasing market demand for renewable energy solutions. The FC & RI briquetting unit exemplifies a successful model that could be replicated in other regions, contributing to sustainable energy practices while offering economic benefits.

Conclusion

In conclusion, this study underscores the significant potential of briquetting technology as an effective means of upgrading forest plantations and wood-based industrial residues into high-quality biomass briquettes. The research demonstrated that the briquettes produced from various combinations of sawdust, plywood residues, matchwood, and bark exhibited enhanced physical and thermal properties, including increased bulk density, calorific value, and fixed carbon content, all of which are comparable to traditional fuels. Notably, the economic analysis revealed that the briquetting process is both environmentally friendly and financially viable, with a promising payback period of two years. This profitability is attributed to utilizing locally sourced, low-cost raw materials and supportive government policies, significantly lowering production costs. The study also highlighted the importance of moisture control and selecting appropriate biomass types to enhance briquettes' durability and combustion efficiency. The findings also indicated that briquettes made from a higher proportion of plywood residues demonstrated superior mechanical strength and water resistance, confirming their suitability for commercial applications. Integrating briquetting technology in biomass utilization presents a sustainable alternative to conventional fuels, contributing to energy security and environmental conservation. As the global demand for renewable energy sources grows, successfully implementing briquetting can be pivotal in addressing fossil fuel shortages, reducing waste, and promoting forest conservation efforts. Future research should focus on optimizing production processes and exploring additional biomass combinations to maximize the benefits of this innovative technology. The novelty of the studies compared to other studies is, unlike many studies that focus on a single biomass type (e.g., sawdust, rice husk, or agricultural residues), this research compares multiple wood-based biomass residues, including matchwood, bark, plywood, and sawdust. Many previous works use binders like starch or clay to improve briquette strength, but this study achieves high durability using only lignin-based self-binding mechanisms. The study includes ash fusion and deformation temperature analysis, which is often missing in traditional biomass briquetting research. These factors are crucial for industrial applications. Unlike many research papers focusing only on technical performance, this study conducts a cost-benefit analysis.

Most briquetting studies focus on dry performance, but this research evaluates water resistance and moisture absorption, which are critical for storage and transportation.

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Authors' contributions

HBR and IS carried out the research work. MS participated in the sequence alignment. PR contributed to the statistical analysis.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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References

1. Suarez JA, Luengo CA, Felfli FF, Bezzon G, BeatÓn PA. Thermochemical properties of Cuban biomass. Energy Sources. 2000;22(10):851–57. https://doi.org/10.1080/00908310051128156
2. Bhattacharya SC. Carbonized and uncarbonized briquettes from waste. In: Workshop on Biomass Thermal Processing. London Shell. 1990;1:1–9
3. Felfli FF, Luengo CA, Bezzon G, Soler PB. Bench unit for biomass residues torrefaction. In: Proceedings of the 10th European Conference on Biomass for Energy and Industry, Würzburg, Germany; 1998.
4. Tripathi AK, Iyer PV, Kandpal TC. A techno-economic evaluation of biomass briquetting in India. Biomass Bioenergy. 1998;14(5-6):479–88. https://doi.org/10.1016/S0961-9534(97)10023-X
5. Snedecor GW, Cochran WG. Statistical methods. 6th ed. Bombay/New Delhi: Oxford and IBH Co; 1967
6. Singh A, Singh Y. Briquetting of wheat straw. J Res Punjab Agric Univ. 1983;20(2):154–59.
7. Yang YB, Ryu C, Khor A, Yates NE, Sharifi VN, Swithenbank J. Effect of fuel properties on biomass combustion. Part II. Modelling approach-identification of the controlling factors. Fuel. 2005;84(16):2116–30. https://doi.org/10.1016/j.fuel.2005.04.023
8. Koppejan J, Van LS. The handbook of biomass combustion and co-firing. Routledge; 2012 https://doi.org/10.4324/9781849773041
9. Ragland KW, Aerts DJ, Baker AJ. Properties of wood for combustion analysis. Biores Technol. 1991;37(2):161–68. https://doi.org/10.1016/0960-8524(91)90205-X
10. Shanavas A, Mohan Kumar B. Fuelwood characteristics of tree species in home gardens of Kerala, India. Agrofor Syst. 2003;58:11–24. https://doi.org/10.1023/A:1025450407545
11. Niu Y, Tan H, Wang X, Liu Z, Liu H, Liu Y, Xu T. Study on fusion characteristics of biomass ash. Biores Technol. 2010;101(23):9373–81. https://doi.org/10.1016/j.biortech.2010.06.144
12. Richards SR. Physical testing of fuel briquettes. Fuel Process Technol. 1990;25(2):89–100. https://doi.org/10.1016/0378-3820(90)90098-D
13. Pietsch W. Granulate dry particulate solids by compaction and retain key powder particle properties. Chem Eng Prog. 1997;93(4):24–46.
14. Fasina O, Sokhansanj S. Estimation of moisture diffusivity coefficient and thermal properties of alfalfa pellets. J Agric Eng Res. 1996;63(4):333–43. https://doi.org/10.1006/jaer.1996.0036
15. Lindley JA, Vossoughi M. Physical properties of biomass briquets. Trans ASAE. 1989;32(2):361–66. https://doi:10.13031/2013.31010
16. Kaliyan N, Morey RV. Factors affecting strength and durability of densified biomass products. Biomass Bioenergy. 2009;33(3):337–59. https://doi.org/10.1016/j.biombioe.2008.08.005
17. Tumuluru JS. Biomass preprocessing and pretreatments for production of biofuels. Mechan Chem Therm Method. 2018 . https://doi.org/10.1201/9781315153735
18. Law HC, Gan LM, Gan HL. Experimental study on the mechanical properties of biomass briquettes from different agricultural residues combination. In: UTP-UMP-VIT Symposium on Energy Systems; 2018. https://doi.org/10.1051/matecconf/201822504026
19. Davies M, Steadman P, Oreszczyn T. Strategies for the modification of the urban climate and the consequent impact on building energy use. Energy Policy. 2008;36(12):4548–51. https://doi.org/10.1016/j.enpol.2008.09.013
20. Kour D, Rana KL, Yadav N, Yadav AN, Rastegari AA, Singh C, et al. Technologies for biofuel production: current development, challenges and future prospects. In: Rastegari A, Yadav A, Gupta A, editors. Prospects of Renewable Bioprocessing in Future Energy Systems. Biofuel Bioref Technol Cham: Springer. 2020;10:1–50. https://doi.org/10.1007/978-3-030-14463-0_1
21. Mulugetta Y. Human capacity and institutional development towards a sustainable energy future in Ethiopia. Renew Sustain Energy Rev. 2008;12(5):1435–50. https://doi.org/10.1016/j.rser.2007.01.007
22. Wu MH, Hwang CS, Chang CL, Tsai CH, Yang SF, Fu CY. The effects of oxide sintering aid on the solid electrolyte $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$–δ of SOFCs prepared by atmosphere plasma spray method. In: International Research Conference on Sustainable Energy, Engineering, Materials and Environment. Northumbria University City Campus; 2018. p. 30.

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