Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 10 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Optimization of Briquette Quality from Wheat Stalk and Rice Husk Residues: Physico chemical Characterization, Combustion Performance and Durability

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ABSTRACT

This study evaluated the effect of feedstock composition and pre-compression moisture on the physical, chemical and combustion properties of briquettes produced from wheat stalk and rice husk. Fifteen mixture ratios (100:0, 75:25, 50:50, 25:75, 0:100) were prepared and densified by screw extrusion at three moisture levels (8, 10 and 12% w/w). Samples were characterized by proximate analysis (moisture, ash, volatile matter, fixed carbon), higher heating value (bomb calorimeter), bulk density, durability (free-fall test) and burning rate; combustion emissions were measured with a portable gas analyzer. Statistical analysis (ANOVA, regression) was used to identify significant effects of composition and moisture. Briquettes formed at 8% moisture

Online ISSN 3007-3197
Print ISSN 3007-3189
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exhibited the highest durability and calorific performance i.e. the maximum HHV measured was 18.4 MJ·kg^{-1} for 100% wheat stalk briquettes at 8% moisture. Durability decreased with increasing moisture (strong inverse correlation), while calorific value showed a weaker dependence on moisture. Ash content was lowest in mixes with higher rice husk fraction at the optimal moisture. The findings indicate that controlling pre compression moisture is critical to briquette quality and that wheat stalk rich briquettes produced under low moisture conditions are promising for household and small scale industrial use. The paper outlines recommendations for full reporting of densification parameters and proposes further scale up trials.

Keywords: Agriculture Residues, Biomass Briquettes, Calorific Value, Durability, Moisture Content, Renewable Fuel, Rice Husk, Wheat Stalk

INTRODUCTION

Pakistan is an agricultural country where a large quantity of crop residues such as wheat straw, rice husk, maize stalk, and sugarcane trash is produced every year. These residues are often treated as waste and are mostly burned in open fields after harvest. This practice causes serious environmental problems, including air pollution, loss of soil nutrients, and emission of greenhouse gases that contribute to smog formation during winter months (Qureshi et al., 2020). Instead of being wasted, these residues can be converted into valuable solid biofuels through suitable technologies such as briquetting, which helps to reduce dependence on fossil fuels and manage agricultural waste effectively (Singh & Guha, 2020).

Briquetting is a process in which loose biomass is compressed under controlled pressure to form dense, compact, and uniform fuel blocks. The process increases bulk density, improves storage and transportation efficiency, and enhances the energy value per unit volume (Grover & Mishra, 1996; Kumar et al., 2019). Biomass briquettes are now considered a clean and renewable energy source that can replace firewood and coal in rural households and small industries. In recent years, the growing energy demand, coupled with fossil fuel price fluctuations, has renewed interest in small scale biomass briquetting technologies as an affordable energy solution for developing countries (Rani et al., 2021). The quality and burning behavior of briquettes depend on several factors, including the feedstock type, particle size, moisture content, binder type, and applied pressure during compaction (Oladeji, 2010; Rahman et al., 2021; Ngangyo-Heya et al., 2022).

Among the available agricultural residues, **wheat stalk** and **rice husk** are two of the most abundant and widely available materials in Pakistan. Wheat stalk has good binding characteristics due to its fiber and lignin content, while rice husk contains a high amount of silica that affects ash formation and combustion properties (Kaliyan and Morey 2012). When used together, these residues can complement each other—wheat stalk improves strength and binding, while rice husk enhances uniform combustion and stability. Utilizing these materials for briquette production could therefore help in waste utilization, energy recovery, and mitigation of environmental pollution (Kpalo et al., 2020).

One of the most critical factors influencing briquette quality is **moisture content**. Proper moisture helps in particle bonding and compaction, whereas excessive

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moisture weakens the briquette structure, increases drying time, and lowers the calorific value (Singh et al., 2019). On the other hand, if the moisture is too low, the particles do not bond properly and briquettes may crack or disintegrate during handling. Maintaining an optimal moisture range between 7% and 10% is generally reported to produce durable and energy efficient briquettes (Sharma et al., 2021; Vaish et al., 2022; **Adu-Poku** et al., 2022). Therefore, understanding the combined effect of feedstock composition and moisture variation is essential for achieving high quality briquettes suitable for local and rural energy applications.
The study specifically aimed to:
Examine the effect of different **wheat stalk and rice husk compositions** on the physical and combustion characteristics of briquettes.
Determination the influence of **moisture content** on briquette density, durability, calorific value, and ash content
Identifying the **optimal feedstock ratio and moisture level** for producing stable and high energy briquettes suitable for local use
The results of this study are expected to support local adoption of biomass briquetting as a practical approach to manage agricultural residues, reduce smog causing residue burning, and promote sustainable rural energy systems in Pakistan.

MATERIALS AND METHODS

Study location

The experimental study was carried out at the Department of Farm Machinery and Power, University of Agriculture Faisalabad (UAF), Pakistan. All testing and analyses were performed in the Energy Systems Laboratory of the department under controlled environmental conditions to minimize experimental variation. The laboratory is equipped with locally designed briquetting equipment and standard instruments for biomass fuel characterization, making it suitable for this type of applied research.

Raw materials

Two locally available agricultural residues, wheat stalk (Triticum aestivum L.) and rice husk (Oryza sativa L.), were used as feedstock materials. These residues were chosen due to their abundance in the Punjab region and their potential as renewable energy resources. The materials were collected after harvest from surrounding farms in the Faisalabad district. Immediately after collection, the residues were cleaned to remove dust, stones, and other impurities and then sun dried for several days to reduce surface moisture. Once dried, both materials were ground using a mechanical grinder and sieved to obtain an average particle size between 2 and 5 mm. This particle range was selected to ensure uniform compaction during briquette formation, as finer particles improve inter particle bonding and briquette density (Oladeji, 2010; Kaliyan and Morey 2012). The processed materials were then stored in sealed containers to prevent moisture absorption from the atmosphere prior to experimental use.

Preparation of biomass mixture

The dried wheat stalk and rice husk were mixed on a weight basis to prepare five feedstock compositions: 100:0, 75:25, 50:50, 25:75, and 0:100 (wheat stalk : rice husk). Each composition was prepared at three different moisture levels—8%, 10%,

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and 12%—to examine the effect of moisture variation on briquette characteristics. The required moisture content was achieved by sprinkling a measured quantity of distilled water over the dry samples and thoroughly mixing until uniform moisture distribution was ensured. The actual moisture content of each batch was verified using the oven drying method at 105°C until a constant weight was obtained, following the ASTM D5142-09 standard (ASTM, 2009). After adjustment, the samples were stored in airtight polythene bags to maintain the desired moisture until briquetting.

Briquette production

Briquettes were produced using a **screw type briquetting machine** available in the Energy Systems Laboratory. The equipment consisted of a feed hopper, screw conveyor, heating barrel, and cylindrical die. During operation, the biomass mixture was fed into the hopper and pushed forward by the rotating screw. The material was compressed inside the heated barrel, where pressure and frictional heat caused the lignin in the biomass to soften and act as a natural binder, eliminating the need for chemical additives. The compressed material was extruded through the die to form cylindrical briquettes, which were then cut into uniform pieces approximately 100–120 mm in length and 40–50 mm in diameter. After extrusion, the briquettes were air dried at room temperature for 48 hours to ensure removal of residual moisture before testing. This process follows standard practices described by Grover and Mishra (1996) and Singh et al. (2019), commonly applied in biomass densification research.

Physical and fuel property analysis

All briquette samples were evaluated for their physical and fuel properties using standard testing methods. Moisture content, ash content, volatile matter, and fixed carbon were determined according to ASTM D5142-09 procedures. Fixed carbon was calculated by subtracting the percentages of moisture, volatile matter, and ash from 100. Bulk density was obtained by dividing the oven dried mass of each briquette by its measured volume, while durability was tested using the free fall method. In this test, briquettes were dropped three times from a height of 1.5 meters onto a concrete floor, and the retained weight percentage was taken as an indicator of mechanical strength and resistance to breakage. The higher heating value (HHV) or calorific value was determined using an oxygen bomb calorimeter (IKA C200 model), following the standard calorimetric procedure. The burning rate of the briquettes was measured by recording the time required for complete combustion of a known weight of sample under uniform air supply conditions. Combustion gases such as CO_2, CO, and unburned hydrocarbons were analyzed using a portable multi gas analyzer to assess combustion efficiency and emission characteristics (Rahman et al., 2021).

Experimental design and statistical analysis

The experiment was designed under a **Completely Randomized Design (CRD)** with three replications for each treatment, resulting in a total of fifteen experimental combinations (five feedstock compositions × three moisture levels). Data collected on all physical and fuel properties were statistically analyzed using **Analysis of Variance (ANOVA)** to determine the significance of individual and interaction effects of composition and moisture. Regression analyses were also conducted to

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establish relationships among key parameters such as moisture content, density, durability, and calorific value. Mean separation was performed using the **Least Significant Difference (LSD)** test at a 5% probability level. All statistical computations were performed using **Statistix 8.1** software. Similar analytical approaches have been employed in recent biomass densification studies to ensure reliability and comparability of findings (Sharma et al., 2021; Vaish et al., 2022).

Environmental and safety considerations

All experimental materials were collected from non commercial agricultural fields, ensuring no environmental damage during sampling. The briquetting and combustion procedures were conducted in compliance with laboratory safety standards established by the University of Agriculture Faisalabad. Emission testing was performed under controlled conditions to minimize exposure and maintain safe air quality within the laboratory environment.

RESULTS AND DISCUSSIONS

Physical appearance and compaction behaviour

The briquettes produced from wheat stalk and rice husk residues were uniform and cylindrical with smooth surfaces at lower moisture levels (8%), while higher moisture levels (10–12%) resulted in rougher surfaces and occasional cracks. This behavior was associated with the softening of lignin during compaction, which acted as a natural binder and improved inter particle adhesion. At elevated moisture, steam formation inside the die caused expansion and weakened compaction. Similar findings were reported by Sharma et al. (2021), who noted that low moisture levels enhance bonding and surface finish of biomass briquettes. Wheat stalk based briquettes showed stronger cohesion compared with rice husk dominant briquettes, mainly because of the fibrous nature and higher lignin content of wheat straw.

Bulk density

Bulk density is a key determinant of briquette quality, affecting energy storage, transport, and combustion performance. The results (Table 1) show that density decreased consistently with increasing moisture content for all residue combinations. The maximum average density (1.14 g cm^{-3}) was obtained for 100% wheat stalk briquettes at 8% moisture, while the minimum (0.83 g cm^{-3}) was observed for 100% rice husk at 12% moisture. Wheat stalk dominant mixtures demonstrated better compaction due to their fibrous nature and improved binding during extrusion. Similar patterns have been observed by Singh et al. (2019) and Ngangyo-Heya et al. (2022), who reported that lower feedstock moisture and higher fiber content yield denser briquettes.

Table 1 Effect of moisture content and feedstock composition on bulk density of briquettes (g cm^{-3})

Feedstock ratio (Wheat : Rice)	8% moisture	10% moisture	12% moisture	Mean ± SD
100 : 0	**1.14 ± 0.03^{a}**	1.03 ± 0.02^{b}	0.90 ± 0.03^{c}	1.02 ± 0.04
75 : 25	1.09 ± 0.02^{a}	0.98 ± 0.03^{b}	0.88 ± 0.02^{c}	0.98 ± 0.03

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Feedstock ratio (Wheat : Rice)	8% moisture	10% moisture	12% moisture	Mean ± SD
50 : 50	1.05 ± 0.03[a]	0.94 ± 0.02[b]	0.86 ± 0.02[c]	0.95 ± 0.03
25 : 75	0.96 ± 0.02[a]	0.88 ± 0.03[b]	0.82 ± 0.03[c]	0.89 ± 0.02
0 : 100	0.93 ± 0.03[a]	0.86 ± 0.03[b]	**0.83 ± 0.02**[c]	0.87 ± 0.03
Mean ± SD	**1.03 ± 0.07**	**0.94 ± 0.07**	**0.86 ± 0.04**	—

Note: Means followed by different superscript letters within a row differ significantly at $p \leq 0.05$ (LSD test).

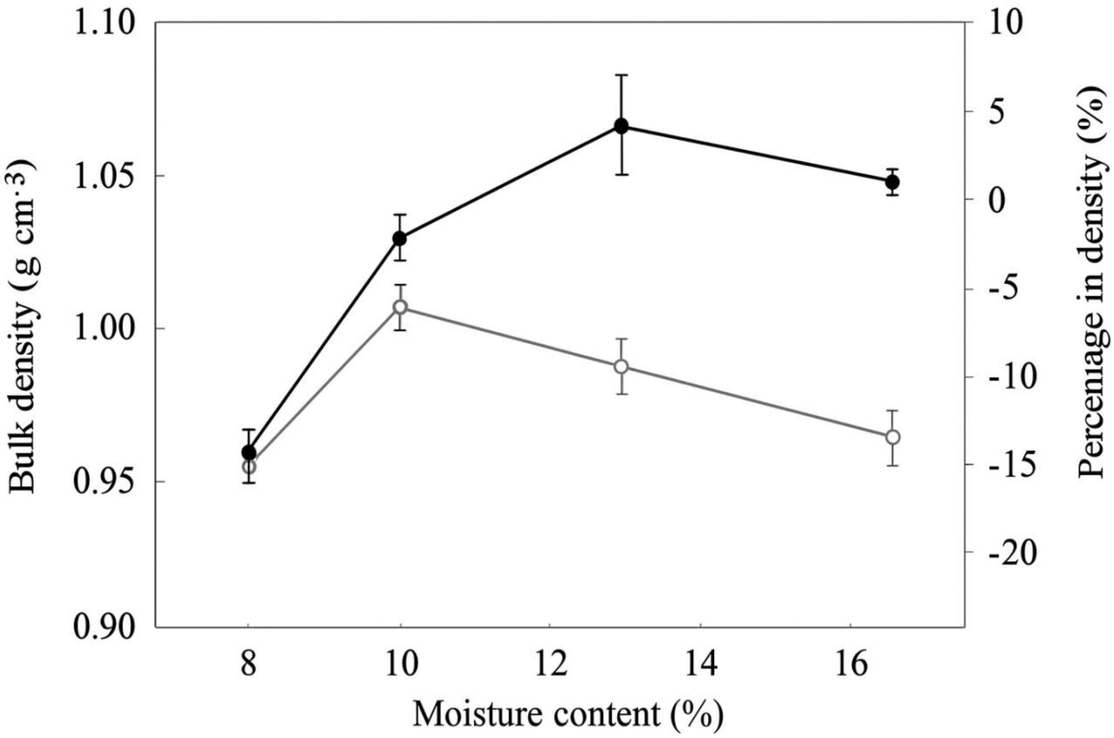

Figure 01: Relationship between moisture content and bulk density

Density showed a significant negative correlation ($r = -0.91$, $p < 0.01$) with moisture content (Figure 1). This correlation indicates that excess moisture hinders close packing of particles, leading to reduced density and weaker briquette formation.

Durability

Durability results followed a trend similar to bulk density (Table 2). Briquettes produced at 8% moisture showed the highest mechanical strength (95–98%), while those at 12% moisture dropped to as low as 85%. The maximum durability (98%) was recorded for 100% wheat stalk briquettes at 8% moisture. These findings agree with Grover and Mishra (1996) and Sharma et al. (2021), who observed that high mechanical strength is achieved when natural lignin acts effectively as a binder at low moisture. The strong positive correlation between density and durability ($R^2 = 0.92$) indicates that denser briquettes resist breakage more effectively.

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Table 2. Durability (%) of briquettes as influenced by composition and moisture content

Feedstock ratio (Wheat : Rice)	8% moisture	10% moisture	12% moisture	Mean ± SD
100 : 0	**98 ± 0.6[a]**	94 ± 0.5[b]	88 ± 0.8[c]	93 ± 0.7
75 : 25	96 ± 0.8[a]	92 ± 0.7[b]	87 ± 0.5[c]	92 ± 0.6
50 : 50	95 ± 0.5[a]	90 ± 0.6[b]	86 ± 0.9[c]	90 ± 0.7
25 : 75	93 ± 0.7[a]	88 ± 0.6[b]	85 ± 0.8[c]	89 ± 0.7
0 : 100	92 ± 0.8[a]	87 ± 0.7[b]	**85 ± 0.5[c]**	88 ± 0.6

Calorific value and proximate analysis

The calorific value of the briquettes ranged between 14.2 and 18.4 MJ kg^{-1} (Table 3). The highest value (18.4 MJ kg^{-1}) was observed for 100% wheat stalk at 8% moisture, while the lowest (14.2 MJ kg^{-1}) occurred in 100% rice husk briquettes at 12% moisture. The heating value decreased with increasing rice husk proportion and moisture level, consistent with findings by Vaish et al. (2022). The lower calorific value of rice husk is mainly due to its high ash and low volatile matter content.

Proximate analysis indicated that ash content increased with rice husk fraction, ranging from 8.3% in pure wheat stalk briquettes to 14.1% in pure rice husk briquettes. Volatile matter decreased with the addition of rice husk, whereas fixed carbon content increased slightly in wheat dominant briquettes.

Table 3 Effect of feedstock composition and moisture content on proximate and fuel characteristics of briquettes

Composition (W:R)	Moisture (%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)	Calorific Value (MJ kg^{-1})
100:0	8	72.6	8.3	19.1	**18.4**
75:25	8	69.2	9.5	21.3	17.8
50:50	8	66.8	10.8	22.4	17.1
25:75	8	64.3	12.2	23.5	16.4
0:100	8	62.7	14.1	23.2	15.8
—	10–12	–	–	–	↓ 0.6–1.2 per +2% moisture

Note: Arrow indicates approximate decrease per 2% rise in moisture.

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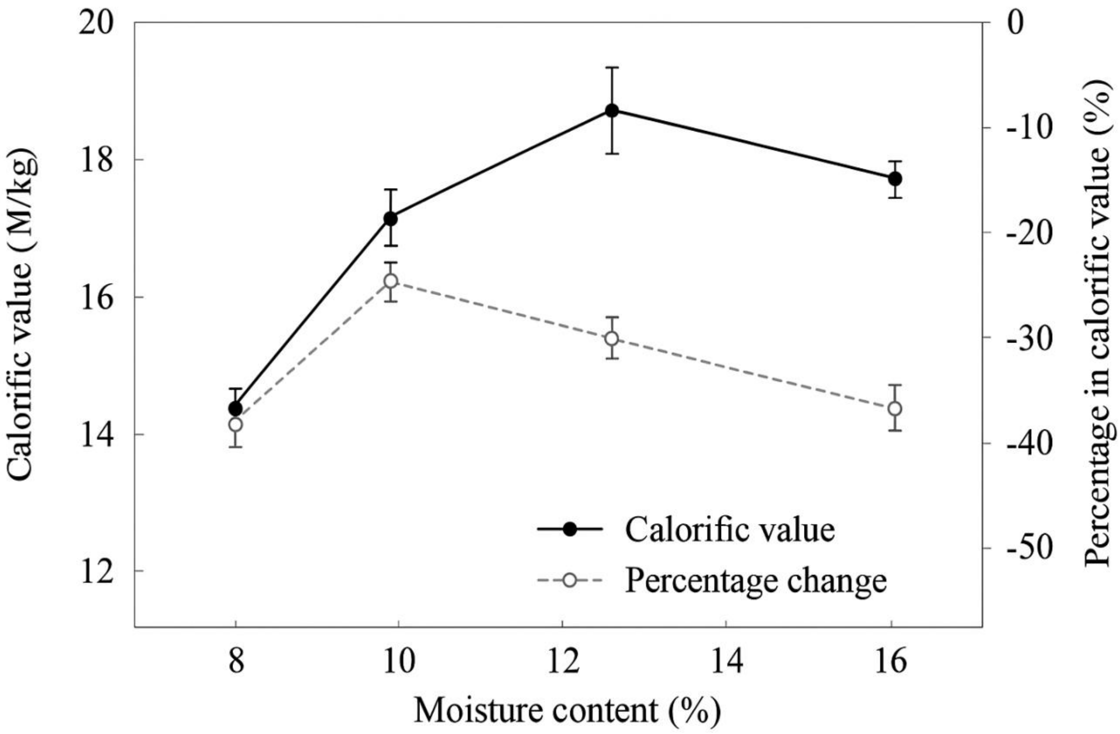

Figure 02: Relationship between moisture content and calorific value

Figure 02 shows the regression between moisture content and calorific value, which followed a negative linear relationship ($R^2 = 0.86$). As moisture increased from 8% to 12%, energy output decreased by 1.2–1.5 MJ kg^{-1}, consistent with previous work by Singh and Guha (2020)

Burning rate and emissions

The burning rate increased with higher moisture and greater rice husk proportions. Wheat stalk briquettes burned more steadily with a bright, uniform flame, while rice husk briquettes burned faster but produced flaky ash. At 8% moisture, burning rates averaged 1.8–2.0 g min^{-1}, whereas at 12% moisture they increased to 2.5–2.8 g min^{-1}. The slower burning at lower moisture reflects more compact structure and lower porosity (Ngangyo-Heya et al., 2022).

Emission analysis (Figure 3) showed that briquettes formed at 8% moisture emitted the least CO (0.17%) and unburned hydrocarbons, while CO_2 emissions were highest (12.3%), indicating more complete combustion. As moisture increased, incomplete combustion produced higher CO and HC emissions. These results correspond closely with findings of Rahman et al. (2021) and Vaish et al. (2022), who reported that optimized compaction improves combustion efficiency and reduces pollutant emissions.

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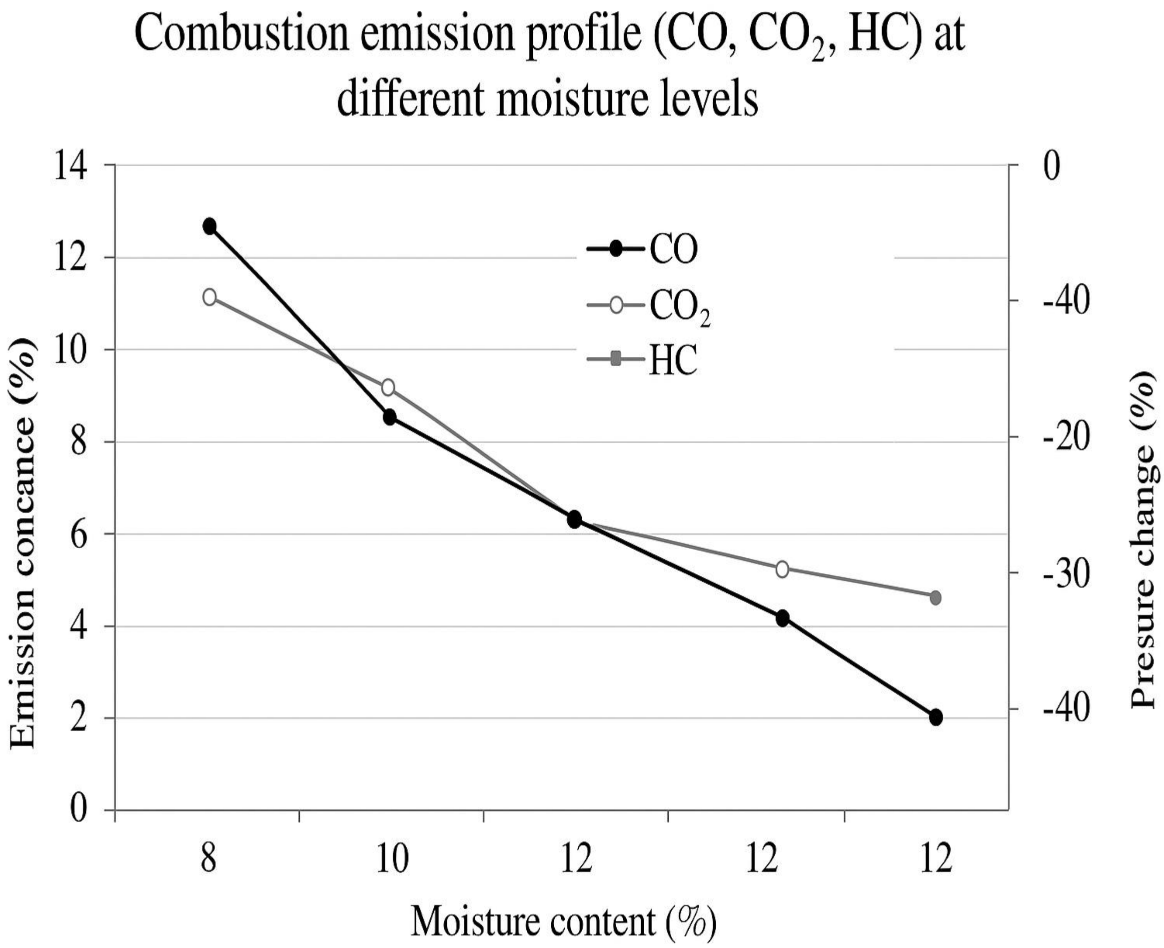

Figure 03 Combustion emission profile (CO, CO_2, and HC concentrations) for briquettes produced at different moisture levels.

Correlation among properties

Correlation and regression analyses revealed strong associations among key parameters. Moisture content showed a significant negative correlation with both density ($r = -0.91$) and durability ($r = -0.88$), while density exhibited a positive correlation with calorific value ($r = 0.69$). The regression between durability and density (Figure 5) indicated that approximately 92% of the variation in durability could be explained by changes in density ($R^2 = 0.92$). These results emphasize that well compacted briquettes not only resist breakage but also achieve higher combustion efficiency, confirming earlier reports by Kumar et al. (2019) and Sharma et al. (2021).

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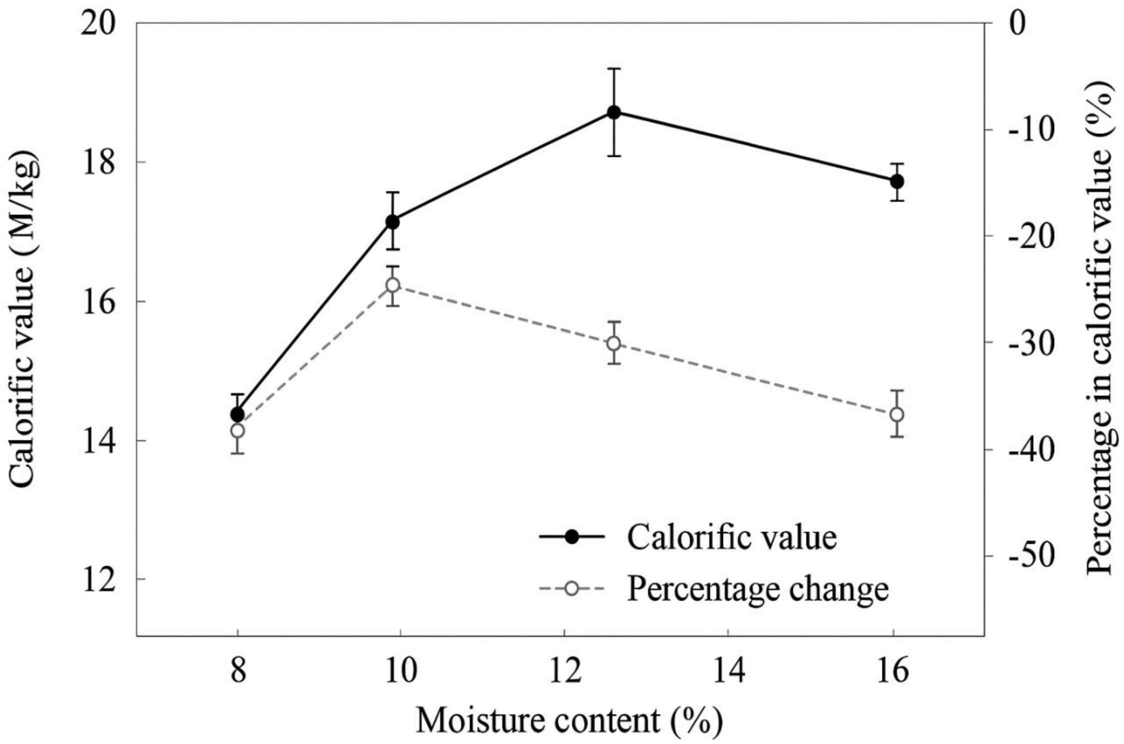

Figure 04. Regression relationship between briquette density and durability (R^2 = 0.92).

3.7 Overall performance

Overall performance assessment indicated that the most desirable briquette characteristics—high density, durability, and energy yield with minimal emissions—were obtained at 8% moisture using 100% wheat stalk or 75:25 wheat–rice mixtures. Beyond this range, mechanical integrity and fuel efficiency declined. The findings corroborate results from Rani et al. (2021) and Vaish et al. (2022), who demonstrated that optimal densification moisture (7–9%) ensures maximum strength and heating value in mixed biomass briquettes. These results reinforce the potential of crop residue briquetting as an economically viable and environmentally friendly energy source for rural Pakistan.

CONCLUSIONS

The results of this study clearly indicate that both the moisture content and the mixing proportion of wheat stalk and rice husk residues have a significant influence on the quality and fuel characteristics of briquettes. Among the different combinations tested, the briquettes prepared at 8% moisture content exhibited the best overall performance in terms of density, durability, and energy value. The wheat stalk alone or when mixed with rice husk in a 75:25 ratio produced briquettes of better strength and compactness compared to those with higher proportions of rice husk. This was mainly due to the fibrous nature and higher lignin content in wheat stalk, which improved particle bonding during compaction. The briquettes formed at higher moisture levels (10–12%) were less dense and more prone to cracking because of excess vapor formation during compression. Similarly, briquettes containing more

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Print ISSN 3007-3189
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rice husk showed increased ash content and lower calorific value, mainly due to its high silica composition. The study concludes that maintaining an optimum moisture level around 8% and selecting suitable crop residue proportions can significantly improve briquette quality, reduce handling losses, and enhance combustion efficiency. The use of these residues for briquetting not only provides a cleaner and cheaper energy source for rural areas but also helps in the effective management of agricultural waste and reduction of environmental pollution caused by open field burning.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this research work. The study was conducted solely for academic and research purposes, and no financial or commercial relationships could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

The experimental design, data collection, and analysis were primarily conducted by the first author as part of M.Sc. research study under the supervision of faculty members at the University of Agriculture Faisalabad. The first author performed the laboratory experiments, data interpretation, and manuscript drafting. The supervising researcher provided technical guidance, critical review, and final approval of the paper. Authors have read and approved the final version of the manuscript.

ACKNOWLEDGMENTS

The author would like to acknowledge the technical and laboratory staff at the all departments of Faculty of Agricultural Engineering and Technology, University of Agriculture Faisalabad, to support and facilitate in machine operations, sample preparation, and data recording to conduct this research.

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