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Biofuel Pellet Production and Characterization from Rice Production Waste

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ABSTRACT

Biofuel pellet materials are a key renewable alternative to fossil fuels. Evaluating biomass quality is essential for both operational efficiency and environmental impact. This study aimed to produce and characterize biofuel pellets made from rice husks and straw. The pellets were analyzed using ASTM methods and compared against the ISO 17225-6 standard. The results indicated a low moisture content (2.53 ± 0.04 %) and a relatively high ash content (11.96 ± 0.05%). Thermally, the net calorific value was 3,951 ± 7.21 Cal/g. In terms of elemental composition, nitrogen (0.29 ± 0.02%), sulfur (0.15 ± 0.02%), and chlorine (0.34 ± 0.04%) contents were in line with the ISO 17225-6 standard. Additionally, the pellets made from both biomass met durability, length, and diameter specifications. The results indicate that mixing these rice-based biomass improves pellet quality and combustion performance. Lastly, this research supports SDG 7 (ensuring access to affordable, reliable, sustainable, and modern energy for all), SDG 12.2 (promoting the sustainable management and efficient utilization of natural resources), and SDG 12.5 (minimizing waste generation through prevention, reduction, recycling, and reuse).

INTRODUCTION

Rice is one of the most widely grown and consumed cereal grains globally. During 2023-2024, the total rice production in Thailand reached 26,933,808 tons (Office of Agricultural Economics 2024), ranking the country sixth among world rice exporters (Sowcharoensuk 2024). While high rice production contributes to economic growth, it also poses significant environmental challenges due to the associated rise in energy demand (Cetinkaya et al. 2024). One of the main contributors to global greenhouse gas emissions (GHG) is rice cultivation and the unsustainable disposal of rice straw. Approximately 30 million tons of methane (CH_4) are released annually worldwide from rice cultivation, accounting for 8% of all CH_4 emissions (Roder et al. 2024). Rice husk, a by-product generated in large volumes at rice mills, is often underutilized (Phonphuak & Chindaprasirt 2015). Therefore, effective management methods are essential for substantial quantities of rice straw and husk produced (Jyothsna et al. 2024).

Rice husks and rice straws are classified as lignocellulosic materials. Rice husk is composed of approximately 50% cellulose, 25–30% lignin, and 15–20% silica (Fathurahman & Surjosatyo 2021). In comparison, rice straw contains 36.5% cellulose, 33.8% hemicellulose, and 12.3% lignin (Nie et al. 2013). The presence of cellulose, hemicellulose, and lignin in these materials enables them to function as natural binders in biofuel pellets, enhancing heat resistance and combustion efficiency (Gil et al. 2010; Rios-Badarn et al. 2020).

In terms of calorific value, rice straw has a higher heating value (HHV) ranging between 14.08 and 15.09 MJ.kg⁻¹, while rice husks exhibit an HHV of

Fig. 1: (A) Rice husks and (B) Rice straws.

approximately 14.2 MJ.kg^{-1} (Gummert et al. 2019). Rice straw contains a high proportion of volatile matter (VOM), approximately 60.55-69.70%, comparable to other biomass sources such as sugar cane bagasse and corn straw. In terms of volatiles, rice husk is around 73.41% (Biswas et al. 2017). High VOM content in bioenergy materials offers advantages such as easier ignition and better combustibility; however, it may also result in rapid and difficult-to-control combustion (Liu et al. 2011; Gummert et al. 2019). Moisture content is important for biofuel production. Rice straw typically contains around 11.4% moisture, whereas rice husk moisture content ranges between 6–10% (Jusoh et al. 2013, Hezam Saeed et al. 2021).

Globally, the biomass pellet market is projected to grow at a compound annual growth rate (CAGR) of 5.4% from 2024 to 2033, rising from an estimated $9.5 billion in 2023 to approximately $16.0 billion by 2033. Biofuels pellets offer a more environmentally friendly and cleaner substitute to traditional fossil fuels. They are cost-effective, reduce pollution, and provide clean-burning, sustainable energy. Moreover, biofuel pellets are easy to transport, produce low carbon emissions, and are dependable and efficient energy sources (Singh & Brar 2021, Kumari & Prasad 2024).

Therefore, the objective of this research is to produce and characterize biofuel pellets using rice husk (a by-product of rice milling) and rice straw (a by-product of rice harvesting). Biofuel pellet production offers a potential solution to reduce open-field burning of agricultural residues and the large volumes of waste generated from rice production. This can help in reducing carbon dioxide (CO_2) emissions and encouraging more sustainable waste management strategies.

MATERIALS AND METHODS

Biomass Collection and Preparation

Rice husks (Fig. 1A) were collected from Thanyakit Nakhonpathom (2521) Co., Ltd., located in Nakhon Pathom Province, Thailand. Rice straws (Fig. 1B) were collected from paddy fields within the same province. After mashing and removing the damaged rice straws and rice husks, samples were homogenized using a 3 mm mesh screen to ensure uniform particle size (Rios-Badran et al. 2020).

Used cooking oil was obtained from a collection station in Nakhon Pathom Province. Its heating value was reported as 3.99×10^4 kJ/kg (Saniso et al. 2008).

Biofuel Pellet Production

Rice husks and straws were chopped using a 7.5 HP hammer mill equipped with a 3 mm mesh screen. The processed biomass materials were then mixed with water and used cooking oil in appropriate proportions, maintaining a 1:1 ratio of rice husk to rice straw. The mixture was compressed into biofuel pellets (Fig. 2) using a pellet press, with each sample undergoing two pressing cycles before the analysis of pellet properties.

Biofuel Pellet Characterization Analysis

1. Physical Analysis

The physical properties of biofuel pellets were evaluated

Fig. 2: Rice husk and rice straw pellets.

by measuring their diameter and length using a vernier caliper. Bulk density was determined by three replicates and calculated using Equation 1.

$$Bulk\ density = \frac{M}{V} \qquad \qquad ...(1)$$

Where: Bulk density = Bulk density of pellets (kg/m^3)

M = Total mass of pellets (kg)

V = Volume of the container (m^3)

2. Proximate Analysis

The proximate analysis was conducted to determine the average moisture content, volatile matter, and ash content of the biofuel pellets. Each parameter was measured in triplicate, following the procedures specified in the ASTM D7582-15 (2015) standard.

Moisture Content: The moisture content was determined by weighing the sample before and after oven drying. A biofuel pellet sample was weighed and then dried in an oven at 105 °C for 2 hours. After cooling in a desiccator, the sample was reweighed. The moisture content was calculated using Equation 2.

$$\text{Moisture content} = \left(\frac{A-B}{A}\right) \times 100 \qquad ...(2)$$

Where: A = Weight of the sample before oven drying(g)

B = Weight of the sample after oven drying (g)

Volatile Matter: To determine volatile matter, a 2 g sample was ground, placed in a crucible, and oven-dried for 2 hours. The dried sample was then transferred to a furnace at 550°C for 10 minutes. After cooling in a desiccator, the sample was weighed. The volatile matter was calculated using Equation 3:

$$\text{Volatile matter} = \left(\frac{B-C}{B}\right) \times 100 \qquad ...(3)$$

Where: B = Weight of the sample after drying in the oven (g)

C = Weight of the sample after furnace treatment for 10 minutes (g)

Ash Content: The ash content was determined by placing a 2 g sample in a furnace at 550°C for 4 hours. After cooling in a desiccator, the sample was weighed. The ash content was calculated using Equation 4:

$$\text{Ash content} = \frac{D}{B} \times 100 \qquad ...(4)$$

Where: B = Weight of the sample after drying in the oven (g)

D = Weight of the sample after furnace treatment for four hours (g)

Fixed Carbon: The fixed carbon content was calculated by subtracting the sum of ash content and volatile matter from the total mass, as represented in Equation 5:

Fixed carbon=100% − (Ash content + Volatile matter)

$$...(5)$$

3. Elemental and Thermal Analysis

The elemental composition of the biofuel pellets including carbon, hydrogen, nitrogen, sulfur, and chlorine were determined in accordance with ASTM standards: ASTM D5373-16 (2016) for carbon, hydrogen, and nitrogen; ASTM D4239-17 (2017) for sulfur; and ASTM D6721-01 (2015) for chlorine. For thermal analysis, the net and gross calorific values were determined using the ASTM D 5865-13:2013 standard.

4. Statistical Analysis

All experimental measurements were conducted in triplicate. The results were analyzed statistically by calculating the mean values and standard deviations to ensure the reliability and consistency of the data.

Results and Discussion

Physical and Proximal Analysis

The physical and proximate characteristics of biofuel pellets (Fig. 3), produced from rice husk and rice straw, are presented in Table 1. The results were compared to the ISO 17225-6 standard for non-woody biomass.

The biofuel pellet in this study exhibited a higher volatile matter (68.20 ± 0.40%) and fixed carbon content (15.70 ± 0.30%) compared to previous findings by Efomah & Gbabo (2015). Combining different biomass types can improve the biomass energy properties of solid biofuels (Liu et al. 2013). Due to their high cellulose and lignin content, rice husks and straws have a high calorific power attributed to

Fig. 3: Length of biofuel pellet.

Table 1: Physical and proximal analysis.

Parameters of Biofuel pellet analysis	Biofuel pellet	ISO 17225-6	
		Class A	Class B
Diameter	8.16 ± 0.03 mm	6-10 mm	6-10 mm
Length	24.69 ± 0.27 mm	3.15-40 mm	3.15-40 mm
Bulk Density	600.64 ± 0.43 kg/m^3	≥ 600 kg/m^3	≥ 550 kg/m^3
Moisture content	2.53 ± 0.04 %	≤ 12%	≤ 15%
Ash content	11.96 ± 0.05%	≤ 6	≤ 10

Table 2: Elemental and thermal analysis.

Parameters of Biofuel pellet analysis	Biofuel pellet	ISO 17225-6	
		Class A	Class B
Nitrogen	0.29 ± 0.02%	≤ 1.5%	≤ 2.0%
Sulfur	0.15 ± 0.02%	≤ 0.20%	≤ 0.30%
Chlorine	0.34 ± 0.04%	≤ 0.10%	≤ 0.40%

depolymerization reactions that occur when these chemical components are exposed to high temperatures (Bridgeman & Jones 2008).

Moisture content of the pellets in this study was notably low (2.53%), in comparison to earlier research by Rios-Badran et al. (2020), which reported a moisture content of 15.95%. Moisture content is a critical parameter affecting the combustion efficiency of biofuels, with lower moisture levels generally enhancing combustion performance.

All evaluated parameters of the biofuel pellets, i.e., diameter, length, bulk density, and moisture content, met the ISO 17225-6 standard for non-woody biomass, with the exception of ash content. The ash content was higher than Class A and B pellets, primarily due to the inclusion of rice husk, which typically contains high ash levels (approximately 16.0 wt%) (Puri et al. 2024, Islam et al. 2021). High ash content can lead to machinery problems such as fouling and slag deposition. Therefore, pretreatment methods to reduce ash content may be necessary prior to thermochemical processes like pyrolysis (Puri et al. 2024, Islam et al. 2021).

Although the bio-pellet from rice husk and straw had high ash content, the other parameters contribute to making it an effective biofuel pellet. These results show that bio-pellet production not only utilizes wastes from rice harvest and production but also enables more efficient use of biomass, all of which align with the biomass densification process.

Elemental and Thermal Analysis

The elemental and thermal properties of biofuel pellets produced from rice husk and rice straw are presented in Table 2. The results were compared to the ISO 17225-6 standard for non-woody biomass. Among the parameters, nitrogen,

sulfur, and chlorine contents in the biofuel pellets conformed to the ISO 17225-6 standard.

Chlorine is a critical element in fuel as it contributes to machinery corrosion, accelerates oxidation, and leads to metal wastage (Nielsen et al. 2000). Although the chlorine content in the bio-pellets met the Class B ISO 17225-6 standard, it may still cause operational issues in machinery over time.

The carbon-to-nitrogen (C/N) mass ratio serves as both a qualitative and environmental indicator, reflecting the combustion potential of biomass. High content can lead to increased NOx emissions during combustion (Toscano et al. 2023). However, the nitrogen content observed in this study (0.29%) was lower than in various types of biomass reported in earlier research: herbaceous (0.9%), fruit (1.5%), and woody biomass (0.3%), indicating reduced NOx emission potential and minimal environmental impact.

The carbon (44.50 ± 0.44%) and hydrogen (6.54 ± 0.13%) contents were similar to those reported by Efomah & Gbabo (2015), where carbon and hydrogen contents were 45.20% and 5.80%, respectively. Thermal analysis revealed that the biofuel pellets had a net calorific value of 3,951 ± 7.21 Cal/g and a gross calorific value of 4,274 ± 5.29 Cal/g; the calorific value was higher than previous research (Nipa Palm 4092.7 kcal/kg) (Harun et al. 2020), confirming their energy potential as a viable biofuel source.

CONCLUSIONS

This study successfully produced and characterized biofuel pellets from rice husks and rice straws. The results indicate that a 1:1 blend of rice husks and rice straws, combined with water and used cooking oil, meets the ISO 17225-6 standard for non-woody biomass. Additionally, the resulting pellets

also fulfilled the standard requirements for durability, length, and diameter.

Our findings suggest that blending these two types of agricultural waste enhances the quality and combustion properties of the resulting bio-pellets, making them a viable source of renewable energy and a sustainable alternative to fossil fuels. This work contributes directly to Sustainable Development Goals (SDGs), particularly SDG 7 (ensuring access to affordable, reliable, sustainable, and modern energy for all), SDG 12.2 (promoting the sustainable management and efficient use of natural resources), and SDG 12.5 (reducing waste generation through prevention, reduction, recycling, and reuse).

Additionally, biofuel pellet production helps reduce open-field burning of paddy residues, supporting efforts to lower greenhouse gas (GHG) emissions and contributing to climate change mitigation and adaptation. Future work will focus on evaluating combustion efficiency, long-term storage stability, and emissions analysis to address the remaining challenges associated with biofuel pellet utilization.

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REFERENCES

Biswas, B., Pandey, N., Bisht, Y., Singh, R., Kumar, J. and Bhaskar, T. 2017. Pyrolysis of agricultural biomass residues: comparative study of corn cob, wheat straw, rice straw, and rice husk. *Bioresource Technology*, 237, pp. 57–63. [DOI]

Bridgeman, T.G. and Jones, J.M. 2008. Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties. *Fuel*, 87, pp. 844–856. [DOI]

Cetinkaya, B., Erkent, S., Jkinci, K., Civan, M., Bilgili, M.E. and Yurdakul, S. 2024. Effect of torrefaction on fuel properties of biopellets. *Heliyon*, 10, 23989. [DOI]

Efomah, A.N. and Gbabo, A. 2015. The physical, proximate and ultimate analysis of rice husk briquettes produced from a vibratory block mould briquetting machine. *International Journal of Innovative Science, Engineering & Technology*, 2 (5), pp. 814–822.

Fathurahman, R. and Surjosatyo, A. 2021. Utilization of rice husks as a fuel for gasification – a review. *IOP Conference Series: Earth and Environmental Science*, 1034, 012065. [DOI]

Gil, M.V., Oulego, P., Casal, M.D., Pevida, C., Pis, J.J. and Rubiera, F. 2010. Mechanical durability and combustion characteristics of pellets from biomass blends. *Bioresource Technology*, 101, pp. 8859–8867. [DOI]

Gummert, M., Quilty, J., Hung, N.V. and Vial, L. 2019. Engineering and management of rice harvesting. In: Pan, Z. and Khir, R. (eds) *Advances in science and engineering of rice*. Lancaster: DEStech Publications, Inc., pp. 67–102.

Gummert, M., Van Hung, N., Chivenge, P. and Douthwaite, B. 2020. *Sustainable rice straw management*. Springer Open. [DOI]

Hezam Saeed, A.A., Yub Harun, N., Roil Bilad, M., Afzal, M.T., Parvez, A.M., Shahirah Roslan, F.A., Abdul Rahim, S., Vinayagam, V.D.

and Afolabi, H.K. 2021. Moisture content impact on properties of briquette produced from rice husk waste. *Sustainability*, 13 (6), 3069, pp. 1–14. [DOI]

Harun, N.Y., Hezam Saeed, A.A. and Ramachandran, V. A/L. A. 2020. Abundant nipa palm waste as Bio-pellet fuel. *Material Today*, 42 (2) pp.436-443. [DOI]

International Organization for Standardization. 2014. *Solid biofuels. Fuel specifications and classes. Part 6: Graded non-woody pellets (ISO 17225-6)*. Geneva: ISO.

Islam, M.K., Khatun, M.S., Arefin, M.A., Islam, M.R. and Hassan, M. 2021. Waste to energy: an experimental study of utilizing the agricultural residue, MSW, and e-waste available in Bangladesh for pyrolysis conversion. *Heliyon*, 7 (12), e08530. [DOI]

Jusoh, M.L., Manaf, C.L.A. and Latiff, P.A. 2013. Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. *Iranian Journal of Environmental Health Science & Engineering*, 10 (1), 17. [DOI]

Jyothsna, G., Bahurudeen, A. and Sahu, P.K. 2024. Sustainable utilization of rice husk for cleaner energy: a circular economy between agricultural, energy and construction sectors. *Materials Today Sustainability*, 25, 100667. [DOI]

Kumari, A. and Prasad, E. 2024. *Biomass pellets market size, share, competitive landscape and trend analysis report, by source, by application: global opportunity analysis and industry forecast, 2024–2033*. Page 290. Available at: https://www.alliedmarketresearch.com/biomass-pellets-market

Liu, Z., Xu, A. and Long, B. 2011. Energy from combustion of rice straw: status and challenges to China. *Energy and Power Engineering*, 3, pp. 325–331. [DOI]

Nie, X.N., Liu, J., She, D., Sun, R.C. and Xu, F. 2013. Physicochemical and structural characterization of hemicelluloses isolated by different alcohols from rice straw. *BioResources*, 8, pp. 3817–3832. [DOI]

Office of Agricultural Economics 2024. *Agricultural Statistics of Thailand 2023 Report*. Available at: https://www.agrithai.org/wp-content/uploads/2024/03/statistic2566.pdf

Phonphuak, N. and Chindaprasirt, P. 2015. Types of waste, properties, and durability of pore-forming waste-based fired masonry bricks. In: *Eco-efficient Masonry Bricks and Blocks*, pp. 103–126. [DOI]

Puri, L., Hu, Y. and Naterer, G. 2024. Critical review of the role of ash content and composition in biomass pyrolysis. *Frontiers in Fuels*, 2, 1378361, pp. 1–19. [DOI]

Rios-Badarn, I., Luzardo-Ocampo, I., Garcia-Trejo, J.F., Santos-Cruz, J. and Gutierrez-Antonio, C. 2020. Production and characterization of fuel pellets from rice husk and wheat straw. *Renewable Energy*, 145, pp. 500–507. [DOI]

Roder, M., Thornley, P. and Jamieson, C. 2024. The greenhouse gas performance and climate change mitigation potential from rice straw biogas as a pathway to the UN sustainable development goals. *Biomass and Bioenergy*, 182, 107072. [DOI]

Sawasdee, A., Haosagul, S. and Pisutpaisal, N. 2023. Biogas production from co-digestion between rice Sataw and food waste with pilot scale. *International Journal of Environmental Research*, 17 (31), pp. 1–9. [DOI]

Singh, L. and Brar, B.S. 2021. A review on rice straw management strategies. *Nature Environment and Pollution Technology*, 20 (4), pp. 1485–1493. [DOI]

Sowcharoensuk, C. 2024. *Thailand Industry Outlook 2024-26 Rice Industry*. Krungsri Research, pp. 1–22. Available at: https://www.krungsri.com/en/research/industry/summary-outlook/industry-outlook-2024-2026

Toscano, G., Francesco, C.D., Gasperini, T., Fabrizi, S., Duca, D. and Ilari, A. 2023. Quality assessment and classification of feedstock for bioenergy applications considering ISO 17225 standard on solid biofuels. *Resources*, 12 (69), pp. 1–23. [DOI]