International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(10): 1859-1863
www.biochemjournal.com
Received: 15-08-2025
Accepted: 19-09-2025

Vishal Choudhary
(1) ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India
(2) The Graduate School, IARI, New Delhi, India

Sandip Gangil
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Sandip Mandal
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Corresponding Author:
Vishal Choudhary
(1) ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India
(2) The Graduate School, IARI, New Delhi, India

Physicochemical and thermal characterization of rice straw and rice husk biomass

Vishal Choudhary, Sandip Gangil and Sandip Mandal

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i10Sw.6107

Abstract
This study investigates the physicochemical and structural properties of rice straw and rice husk to understand their suitability as potential bioenergy feedstocks. Proximate and compositional analyses were conducted to determine their basic chemical composition. Thermogravimetric analysis (TGA) was performed to evaluate their thermal degradation behavior, while bulk density, true density, and higher heating value (HHV) were measured to assess fuel quality. The results highlight distinct differences between rice straw and rice husk in terms of ash content, volatile matter, cellulose, hemicellulose, lignin, and energy potential. These findings provide useful insights for the development of biomass-based energy applications.

Keywords: Rice straw, rice husk, bioenergy, physicochemical properties, thermal analysis, fuel quality

1. Introduction

The rapid depletion of fossil fuels and their harmful effects on the environment have compelled humanity to seek alternative, renewable sources of energy. Biomass is an important renewable energy source that can be used to produce liquid fuels, bio-based materials for industries, as well as heat and power (Özsin & Pütün, 2017; R. K. Sahu & Gangil, 2025) [7, 12, 13]. Agricultural residues are among the most abundant renewable resources available for energy generation (P. Sahu *et al.*, 2022a) [9]. In India, around 611 million tonnes of agricultural residues are generated each year, out of which approximately 158 million tonnes (about 25%) are available for energy production (P. Sahu *et al.*, 2022b) [10]. India ranks as the second-largest producer of rice in the world, with an annual production of approximately 165 million tonnes (Mt) (Durga *et al.*, 2022) [3]. Rice straw and rice husk are the byproducts produced in large quantities during rice cultivation and milling. These biomass resources are often underutilized and disposed of in ways that cause environmental issues such as open-field burning and waste accumulation (Durga *et al.*, 2022) [3]. However, their organic composition makes them promising candidates for conversion into biofuels, biochar, and other value-added products. Biomass can be converted into various value-added products using different methods such as thermochemical, biological, or physical processes (P. Sahu & Gangil, 2023) [8]. The choice of method to apply on biomass for energy generation is based on physical and chemical properties of biomass material.

Characterizing the physicochemical and thermal behavior of these residues is essential to evaluate their energy potential and to design suitable conversion processes (P. Sahu *et al.*, 2023) [8, 11]. Proximate and compositional analyses reveal the distribution of moisture, ash, volatile matter, and fixed carbon, while structural components such as cellulose, hemicellulose, and lignin influence thermal decomposition pathways. The thermal behavior of biomass depends on its intrinsic components (Jagadale *et al.*, 2024) [4]. Thermogravimetric analysis provides insight into pyrolysis and combustion behavior measures the loss of biomass weight with respect to time or temperature (P. Sahu *et al.*, 2022a) [9]. Properties such as bulk density, true density, and higher heating value (HHV) indicate practical aspects of storage, handling, and energy efficiency. The higher heating value (HHV) is commonly used to measure the energy content of a fuel (Mythili *et al.*, 2013).

This study aims to present a detailed comparison of two byproducts of rice cultivation, i.e., rice straw and rice husk through systematic physicochemical and thermal characterization.

2. Materials and Methods

2.1 Selection of biomass materials

Rice straw samples were collected from the field of ICAR-Central institute of Agricultural Engineering, Bhopal (M.P.) while the rice husk samples were collected after milling of rice, from farm section of ICAR-CIAE, Bhopal. The samples were cleaned, sun dried, and ground to uniform particle size for further analysis.

2.2 Physiochemical characterization of biomass

2.2.1 Proximate analysis

Proximate analysis provides details about moisture, volatile matter, fixed carbon and ash content in biomass material. Standard methods (ASTM procedures) were followed to determine moisture, volatile matter, ash, and fixed carbon content. The proximate analysis of biomass was done using the following standards, moisture content (ASTM E1756-08), volatile matter (ASTM E872-82), ash content (ASTM E1755-01), and fixed carbon content (by difference).

2.2.2 Compositional analysis

The main biopolymeric compositions of lignocellulosic feedstock or residues of agricultural crops are lignin, hemicellulose, and, cellulose (R. kumar Sahu & Gangil, 2025) [12, 13]. The thermal degradation behavior of whole biomass depends on thermal behavior of its bioconstituenents. The structural composition of biomass, i.e., cellulose, hemicellulose, and lignin were determined using Van Soest method. The values were calculated on a dry weight basis.

2.2.3 Determination of bulk density, true density, and HHV

Bulk density and true density are important biomass properties concerned with handling and storage of biomass materials. The higher heating value is important as it provides knowledge about energy content of biomass materials. The material having high bulk density is suitable in easy handling and transportation while high HHV is desirable to generate more energy per unit mass Bulk density was measured using a graduated cylinder method, while true density was determined using toluene displacement method. The higher heating value (HHV) was measured using a bomb calorimeter according to ASTM standards.

2.3 Thermo gravimetric analysis

Thermal degradation behavior was studied using a thermogravimetric analyzer. Samples of 10 ± 5 mg were heated from ambient temperature to 1000 °C at heating rate of 10 °C/min under nitrogen atmosphere. Weight loss curves (TG) and derivative thermogravimetric curves (DTG) were recorded.

3. Results and Discussion

3.1 Physicochemical characterization of biomass materials

Table 1 represents the physiochemical characterization of two biomass materials. The proximate analysis results showed differences in ash, volatile matter, and fixed carbon between rice straw and rice husk. Rice straw exhibited lower ash and higher volatile matter, while rice husk contained lower moisture and higher fixed carbon. Rice straw contain higher amount of volatile (64.50%) than rice husk (63.58%), while the quantity of fixed carbon was higher in rice husk (15.06%) than rice straw (13.39%).Volatile matter is important in the thermal decomposition of biomass because it causes the material to break down quickly at lower temperatures, leading to increased production of gases and bio-oil (Kirti *et al.*, 2022) [5]. The moisture content in rice husk (4.99%) was lower than rice straw (6.58%). Materials with low moisture content allow heat to be transferred evenly during pyrolysis while additional energy is required for pyrolysis if moisture content is more than 10% (Jagadale *et al.*, 2024; R. K. Singh *et al.*, 2020) [4, 14]. The ash content was found higher (>10%) for both the biomass. High ash content leads to a lower yield of volatile matter. The fixed carbon content was higher in rice husk which promotes the increased char yield and reduced liquid product yield (Balasundram *et al.*, 2017) [1].

Compositional analysis indicated that cellulose, hemicellulose, and lignin contents varied significantly. Rice straw contains hemicellulose (21.48%), cellulose (33.70%), and lignin (8.48%) while rice husk contain hemicellulose (14.41%), cellulose (29.9%), and lignin (16.53%). Rice husk demonstrated higher lignin content, contributing to its higher resistance to thermal degradation. In contrast, rice straw exhibited higher cellulose and hemicellulose content, which are more reactive during thermal conversion. A higher amount of fibrous components, i.e., cellulose and hemicellulose, together with volatile matter in biomass, has a strong impact on bio-oil production (Mythili *et al.*, 2013) [6].

Bulk and true density values suggested that rice husk is denser and may provide advantages in storage and transportation. Various densification methods such as briquetting, palleting etc. are used to densify the biomass material for easy handling and storage. The HHV values were 15.75, and 15.91 MJ/kg for rice straw and rice husk, respectively, confirmed their potential as energy sources, though rice husk generally showed higher value. There was little difference in HHV was observed between rice husk and rice straw. The higher heating value of both the material was higher than other biomass material such as garlic stalk (14.24 MJ/kg) (S. Singh & Sawarkar, 2020) [15], and cotton stalk (13.68 MJ/kg) (Balsora *et al.*, 2023) [2].

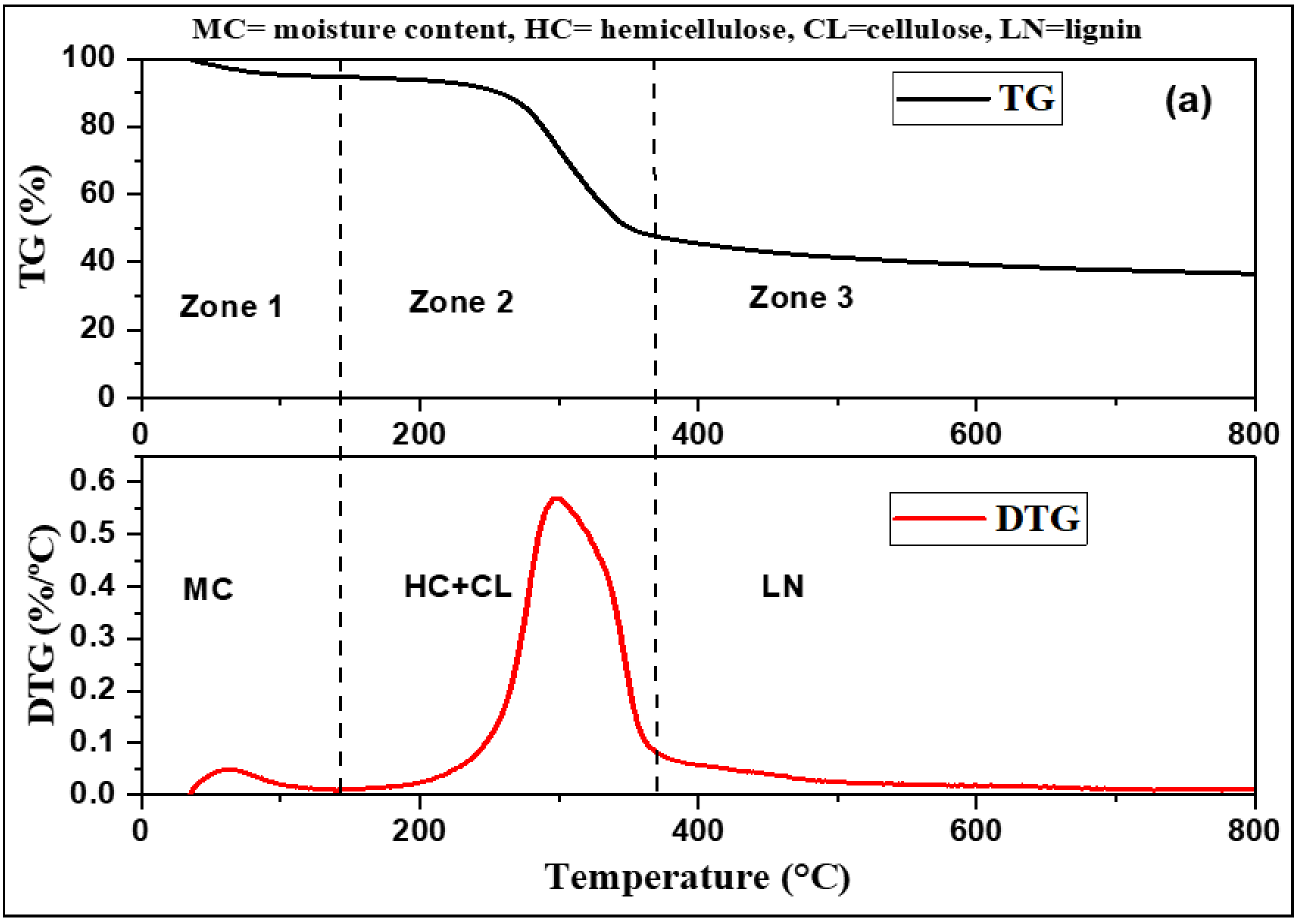
Table 1: Physiochemical characterization of rice straw and rice husk

Property	Rice straw	Rice husk
Proximate data		
Moisture content	6.58	4.99
Volatile matter	64.50	63.58
Ash content	15.53	16.36
Fixed Carbon	13.39	15.06
Compositional analysis		
Hemicellulose	21.48	14.41
Cellulose	33.70	29.90
Lignin	8.48	16.53
HHV (MJ/kg)	15.75	15.91
Bulk density (kg/m^3)	123.72	314.07
True density (kg/m^3)	919.00	909.00

3.2 Thermal behavior of biomass materials

Thermogravimetric analysis (TGA) is a widely used technique to study the thermal stability and decomposition behavior of biomass materials. A thermogravimetric analysis (TGA) is used to determine the thermal behavior of biomass by determining its mass loss (%) over time or temperature called thermogram. Differential thermogram i.e. the first order derivative of thermogram is a plot of decomposition rate (%/min) with time or temperature (P. Sahu & Gangil, 2023) [8]. Thermal degradation of lignocellulosic biomass can be explained in three zones based on degradation temperature. The first zone is called dehydration zone where moisture escape from biomass, second zone is active pyrolysis zone where holocellulose (hemicellulose+cellulose) degrade and the last zone is lignin degradation zone. The TG and DTG curves Fig. 1 revealed three main stages of weight loss: moisture evaporation, hemicellulose/cellulose decomposition, and lignin degradation. Table 2 shows the weight loss observed in different thermal degradation zone obtained through TG profile. In first zone about 5% weight losses was observed for both the material, which was related to moisture degradation. Rice straw exhibited a sharper weight loss in zone 2 corresponding to its higher hemicellulose and cellulose content. A weight loss of 50.53% was observed for rice straw, and 47.19% for rice husk in this zone. In the third zone the weight loss was 15.61 and 10.96%, respectively for rice straw and rice husk.

The derivative curves showed distinct peaks, indicating maximum decomposition rates. The peak observed in first zone related to moisture degradation; observe between ambient to 150 °C. The peaks related to hemicellulose and cellulose was observed in the temperature range of 150 to 380 °C. The highest peak corresponding to maximum rate of degradation is related to cellulose degradation. A shouldered peak, observed in Fig. 1b between 200 and 300 °C, is related to hemicellulose degradation. The hemicellulose peak was not clearly observed in rice husk. The lignin degradation zone ranged from 380 to 800 °C, which shows the complex nature of lignin.



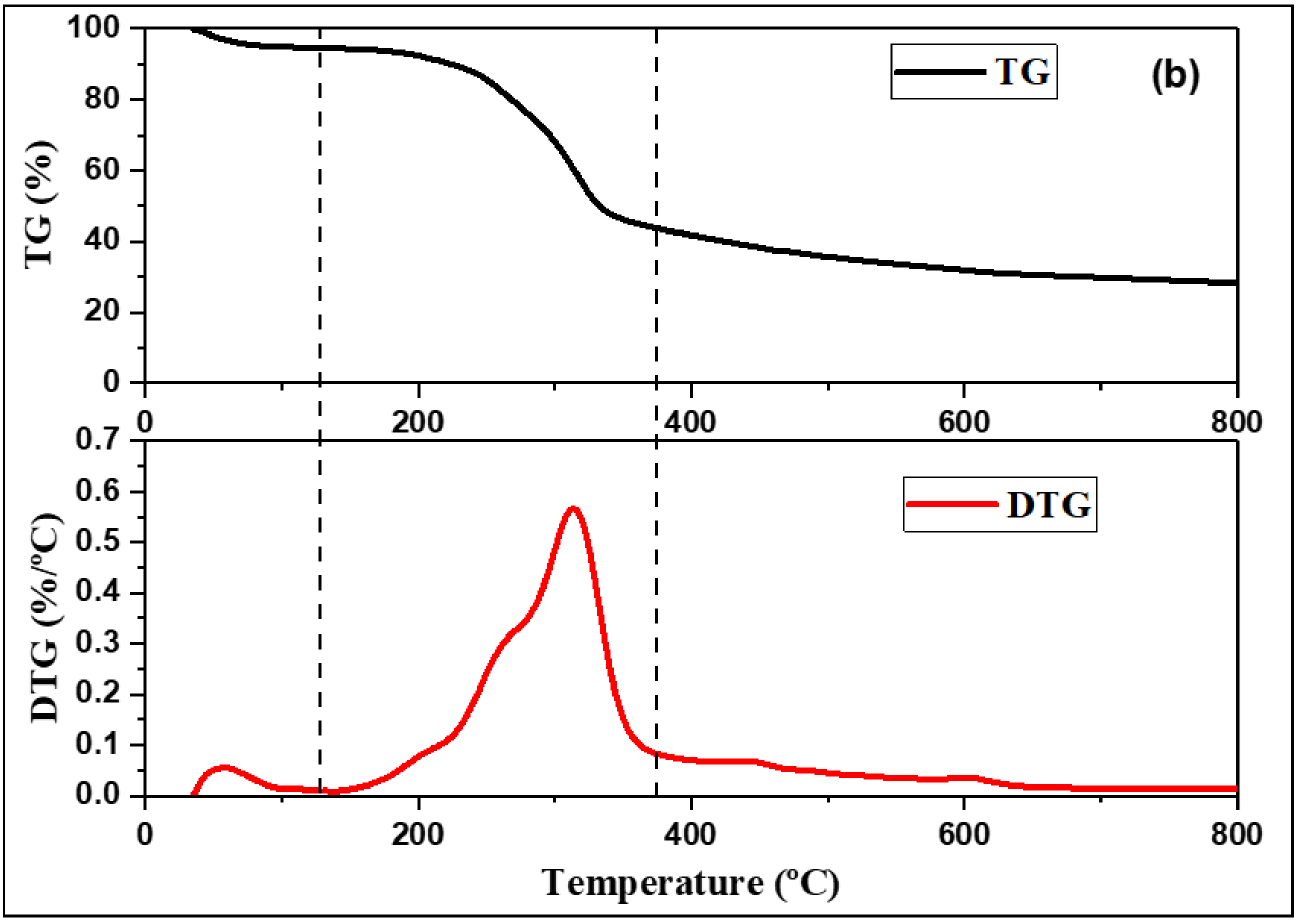


Fig 1: TG and DTG graph of (a) rice husk, and (b) rice straw at heating rate of 10 ºC/min.

Table 2: Weight loss in different thermal degradation zone

Biomass	Weight loss%		
	Zone 1	Zone 2	Zone 3
Rice straw	5.52	50.53	15.61
Rice husk	5.3	47.19	10.96

4. Conclusion

This study presented a comparative characterization of rice straw and rice husk. The results demonstrated clear differences in their physicochemical composition and thermal behavior. Rice straw contained higher volatile matter and cellulose, making it more reactive, while rice husk exhibited higher lignin and fixed carbon, leading to slower thermal degradation and greater density. These findings highlight the importance of material-specific characterization for optimizing biomass utilization in energy applications.

Future work may focus on developing pretreatment and conversion strategies tailored to the unique properties of rice straw and rice husk.

5. Acknowledgement

The author is thankful to the Director (CIAE, Bhopal), Head (AEP), Dean (IARI, New Delhi) for providing facilities and resources. We thank staff members of the AEP division of ICAR-CIAE Bhopal for their support during research work. This work forms a part of the corresponding author's Ph.D. research conducted at ICAR-CIAE, Bhopal.

References

1. Balasundram V, Ibrahim N, Kamaruddin M, Hamid A, Isha R, Hasbullah H. Thermogravimetric catalytic pyrolysis and kinetic studies of coconut copra and rice husk for possible maximum production of pyrolysis oil. J Clean Prod. 2017;167:218-228. https://doi.org/10.1016/j.jclepro.2017.08.173
2. Balsora HK, Kartik S, Rainey TJ, Abbas A, Joshi JB, Sharma A, Chakinala AG. Kinetic modelling for thermal decomposition of agricultural residues at different heating rates. Biomass Convers Biorefin. 2023;13(4):3281-3295. https://doi.org/10.1007/s13399-021-01382-4
3. Durga ML, Gangil S, Bhargav VK. Thermal influx induced biopolymeric transitions in paddy straw. Renew Energy. 2022;199:1024-1032. https://doi.org/10.1016/j.renene.2022.09.054
4. Jagadale M, Gangil S, Jadhav M, Sahu P, Durga L. Biopolymeric degradation of jute sticks under pyrolytic thermal stresses. Process Saf Environ Prot. 2024;189:517-529. https://doi.org/10.1016/j.psep.2024.06.096
5. Kirti N, Tekade SP, Tagade A, Sawarkar AN. Pyrolysis of pigeon pea (*Cajanus cajan*) stalk: Kinetics and thermodynamic analysis of degradation stages via isoconversional and master plot methods. Bioresour Technol. 2022;347:126440. https://doi.org/10.1016/j.biortech.2021.126440
6. Mythili R, Venkatachalam P, Subramanian P, Uma D. Characterization of bioresidues for biooil production through pyrolysis. Bioresour Technol. 2013;138:71-78. https://doi.org/10.1016/j.biortech.2013.03.161
7. Özsin G, Pütün E. Kinetics and evolved gas analysis for pyrolysis of food processing wastes using TGA/MS/FT-IR. Waste Manag. 2017;64:315-326. https://doi.org/10.1016/j.wasman.2017.03.020
8. Sahu P, Gangil S. Stepped pyrolysis: A novel approach for enhanced adsorbency and carbon in pigeon pea stalk char. Renew Energy. 2023;219. https://doi.org/10.1016/j.renene.2023.119596

9. Sahu P, Gangil S, Bhargav VK. Overriding investigation on strengthening of thermal stability of torrefied pigeon pea stalk and kinetic compensation. Int J Environ Climate Change. 2022;12(12):662-673. https://doi.org/10.9734/ijecc/2022/v12i121503
10. Sahu P, Gangil S, Bhargav VK. Pyrolytic thermal degradation kinetics of pigeon pea stalk (*Cajanus cajan*): Determination of kinetic and thermodynamic parameters. Mater Today Proc. 2022;56:1542-1550. https://doi.org/10.1016/j.matpr.2022.01.274
11. Sahu P, Gangil S, Bhargav VK. Biopolymeric transitions under pyrolytic thermal degradation of pigeon pea stalk. Renew Energy. 2023;206:157-167. https://doi.org/10.1016/j.renene.2023.02.012
12. Sahu RK, Gangil S. Thermo-kinetic analysis of pyrolysis of chickpea stalk using thermogravimetric analysis and artificial neural network. Biomass Bioenergy. 2025;198:107860. https://doi.org/10.1016/j.biombioe.2025.107860
13. Sahu R Kumar, Gangil S. Insights into biopolymeric transitions during thermal degradation and kinetic parameters for chickpea stalk (*Cicer arietinum*). Process Saf Environ Prot. 2025;195:106766. https://doi.org/10.1016/j.psep.2025.01.020
14. Singh RK, Patil T, Sawarkar AN. Pyrolysis of garlic husk biomass: Physico-chemical characterization, thermodynamic and kinetic analyses. Bioresour Technol Rep. 2020;12:100558. https://doi.org/10.1016/j.biteb.2020.100558
15. Singh S, Sawarkar AN. Thermal decomposition aspects and kinetics of pyrolysis of garlic stalk. Energy Sources Part A Recover Util Environ Eff. 2020;46(1):4914-4924. https://doi.org/10.1080/15567036.2020.1716891