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Research Article

Mechanical and Thermal Behaviour of Rice Bran Green Composite Using RSM and Design of Experiment Techniques

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The aim of this research is to synthesise a cost-effective biodegradable green composite for various low- and medium-load applications. The tensile and flexural results reveal that the rice bran composition in green composite enhances the stiffness of composite, while strength and hardness decrease. The highest values of tensile strength 27 MPa and flexural strength 25 MPa were obtained for 15/85 treated rice bran composites, while the highest value of young modulus 2958 MPa was obtained for the 35/65 composite combination. The highest value of hardness, i.e., 11 HRF was obtained for 15/85 treated rice bran composite. The water absorption test reveals the hydrophilic nature of rice bran and the hydrophobic nature of PLA. Results also reveal better water-absorbing properties of the green composite due to the surface treatment of rice bran. The lowest density of 1.001 g/cm^3 found for the 50/50 composite combination means the addition of rice bran makes the composite light in weight. The thermogravimetric analysis performed on the composite to analyse its thermal behaviour shows that major weight loss occurs approximately in the temperature range of 80–350° Celsius. The response surface methodology (RSM) and design of experiment (DOE) optimization model were developed to find that the optimum condition for maximum weight loss reveals two desirable conditions, i.e., 500° Celsius and 424.85° Celsius. ANOVA analysis reveals that the obtained results are significant.

1. Introduction

There is widespread awareness that the world's petrochemical resources are not only limited but also expensive to manufacture, contribute to climate change, raise carbon footprint, and pose waste management issues [1]. All of these lead to a rise in demand for polymeric composites made from sustainable and environmentally friendly raw materials rather than petrochemicals. An environmental burden and high demand for lightweight, high-strength materials incite researchers to search for new biodegradable composite materials to fulfil today's needs. Polylactic acid (PLA) is the best known biodegradable biopolymer extracted from natural resources such as sugarcane and corn that may be used as matrix materials with reinforcement of various natural fibres to manufacture a number of biodegradable green composite materials. Natural fibres can be added in different forms like powder, particulate, flakes, or in fibrous form. PLA at present is considered one of the most promising biodegradable polymer materials that have been subjected to an abundance of literature over the last few decades [2, 3]. PLA can be processed using various processing techniques such as injection moulding, hand layup, compression moulding, extrusion, and additive manufacturing. PLA also has a wide range of application in the field of packaging. At present, PLA-based composite materials are mainly used in three different fields, namely, medical applications, packaging, and textile industry [4]. When PLA get mixed with natural fibres, it forms a green composite that has a wide range of applications in aircraft, automotive, electrical, sports, construction, medical, and various other fields, with a prime focus on environmental protection. Green composites have the ability to replace plastics and petrochemicals in the future by enhancing their properties and may be used as structural materials in the future [5, 6]. Surface treatment of natural fibres enhances their mechanical properties and makes them suitable for automotive applications. In many natural fibres, surface treatment affects their colour and thickness [7, 8]. With increase in fibre volume fraction in composite, mechanical properties of composite gets improved up to certain limit; after that, it starts degradation in mechanical properties like mechanical properties with 13.6% hemp fibre found more superior than 7.9% and 17.6% [9]. With fibre treatment, mechanical properties get enhanced because the untreated portion of the fibre does not carry load in composite rather increase its fibre volume ratio [10]. Thermogravimetric analysis of PLA shows that PLA is more thermally stable as compared to PLA composites, but composites are prepared to meet the society requirements. Composite fibre and matrix adhesion gets improved with treatment of fibres with NaOH and enhances water absorption [11]. Date palm wood powder as filler in PLA can be used as a thermal insulating material [12].

A review of the literature shows that silane treatment of natural fibre raises the surface energy of rice husk and reduces its moisture sensitivity. Due to the alkaline treatment of fibres, hemicellulose, lignin, and wax get dissolved [13]. Addition of rice husk as reinforcement in composite enhances its wear properties as well as thermal conductivity decreases with addition of rice husk into PLA composite, but brittleness and high cost of PLA hinder its application in broad variety [14–16]. The mechanical properties of rice hull PLA composites are strongly affected by the types of rice husks used as well as affected by the poor interfacial bonds between the rice hulls and matrix [17]. PLA-based green composite materials have the ability to not only replace steel and wood but also challenge many nonbiodegradable polymer composites [18]. The addition of sisal fibre to the PLA matrix improves the mechanical and thermal properties of green composites. With increase in fibre content, mechanical properties enhance. The treated sisal fibres have a lower thermal degradation temperature than untreated sisal fibres. The rate of degradation of composites increased in an enzymatic environment [19]. The soil burial of rice straw powder improves its thermal stability, but the mechanical properties of the composite get depressed [20]. With the addition of food and agricultural wastes such as *Citrus limetta* (mosambi), tea mill waste, wood flour, and rice husk to suitable matrix materials such as epoxy, PLA, and polyester, they can be converted into useful materials. The addition of untreated mosambi powder to epoxy resin reduces its mechanical properties due to weak interfacial adhesion. Similarly, many agroindustrial wastes can be converted into useful materials [21, 22]. Thermal, mechanical, and chemical properties of sugarcane bagasse may be improved by surface modification with NaOH treatment [23]. Fibre content plays a major role than fibre length in composite properties. The experimental results reveal the application of bagasse/basalt fibre PLA composites in low- and medium-load applications due to their high availability and low cost. The water absorption rate of composite enhances with increases in fibre volume [24].

From the above literature work, it has been seen that researchers mostly focus on the mechanical characterization of various natural fibre composites and the work related to the optimization of properties has received less attention. Therefore, in this study, we prepare a green composite and find out the optimum conditions for better use of it using modern optimization techniques such as response surface methodology (RSM) and design of experiment (DOE). The addition of rice bran to PLA matrix has been done to prepare a cost-effective biodegradable composite that can be used in various low- and medium-load applications such as three-dimensional printer fluid, packaging, and thermal insulating material. Mechanical testing has been done to see the behaviour of composites under different loading conditions. Thermal behaviour of composite has been analysed to examine its thermal behaviour. A hardness test has been carried out for the calculation of the surface hardness of composites.

2. Materials

In the present study, 100 g of sieved rice bran powder purchased from the local market in Lalganj, Azamgarh, Uttar Pradesh, India (276202), has been taken as the reinforcement material, and polylactic acid obtained from the Chemistry Lab of Rajkiya Engineering College, Azamgarh, Uttar Pradesh, India (276201), has been considered as the matrix material. Initially, PLA pallets were kept in steel mould of size 300 mm × 300 mm × 3 mm in one layer followed by rice bran and then upper part of mould cavity was again filled with rest amount of PLA pallets. After filling, the mould was closed using steel plates. Then, rice bran PLA-filled mould was kept in the compression moulding machine and a pressure of 150 bar and temperature 110 degrees Celsius (Deg C/^{0}C) were applied on it for curing time of 3-4 hours. After preparation of lamina, the specimens were cut further with the help of hacksaw for various testing. The surface treatment of rice bran was performed with the help of 1M NaOH for 30 min by soaking in it.

3. Testing Standard

After preparation of green composite laminates, the tensile test specimens in different combinations were cut using a hacksaw as per the ASTM D638 standard with dimensions 165 mm length, 19 mm width, 3 mm thickness, and gauge length 57 mm, as shown in Figure 1. The rice bran has been selected in five different combinations, namely, 15/85, 20/80, 30/70, 35/65, and 50/50, respectively, with gauge length of 50 mm and thickness of 3 mm for all specimens. In the combination, first shows the weight percentage of rice bran and second the respective PLA amount. Based on results, 15/85 (15% rice bran and 85% PLA) combination has been washed with NaOH treatment to analyse the effect of surface treatment on mechanical properties with adhesion of rice bran with PLA. The tensile test was performed using the universal testing machine with modal number SOM-556 provided by Neelam Engineering Company, Agra, Uttar Pradesh, India, with testing speed of 2 mm/min, and the experiment was performed at room temperature.

Flexural testing, also known as three-point bending testing, is performed on composite materials to see the behaviour of composite-like force required to bend it or its flexural resistance. Specimen was prepared as per ASTM D790 standard, and the length (l), breadth (b), and the thickness (l) of specimen were considered 140 mm, 15 mm, and 5 mm, respectively, as shown in Figure 2.

The Rockwell hardness test was performed using the hardness testing machine provided by Neelam Engineering Company on composite specimens as shown in Figure 3 to calculate the surface hardness. A standard specimen is placed on the surface of the Rockwell hardness testing machine. A minor load of 10 kg is applied, and the gauge is set to zero. After 10 seconds, the load is removed, the specimen is allowed to recover for 10 seconds, and the hardness is read off the dial with the minor load. The size of the test specimen made from the composition of PLA and rice bran is taken according to the ASTM D785 standard with a 6.4 mm thickness in a round shape. The figure of the specimen is shown in Figure 3.

Apart from the above tests, to see the compatibility of rice bran PLA composite as three-dimensional printer fluid, a water absorption test, density test, and thermogravimetric analysis were done. The thermogravimetric analysis (TGA) is done to determine the thermal stability of composites, which is needed in the designing and manufacturing of goods whose thermal stability is required.

4. Experimental Results

4.1. Tensile Test. The tensile test was performed on various combinations of rice bran and PLA composite, and the results are shown in Table 1. From Table 1, it is clearly visible that the addition of rice bran to PLA has a negative effect on its tensile properties. It happens due to poor interfacial bonding between the matrix and reinforcement due to the untreated rice bran powder used. The maximum tensile properties, i.e., tensile stress at break 18.2 MPa and corresponding young modulus 3500 MPa were found for 15/85 weight percentage combination. One more reason for the negative result may be due to the hydrophobic nature of PLA and hydrophilic nature of rice bran, but due to the surface treatment of rice bran, the stress increased by 48.35% and the elastic modulus by 6.85%. This is due to an increase in interfacial bonding between rice bran and PLA due to the removal of undesirable content like lignin from rice bran. The stress values decreased with an increase in rice bran weight percentage, and the modulus of elasticity was found maximum for the 35/65 combination. The lowest values of peak stress and young modulus were found to be 8.5 MPa and 2650 MPa, respectively, for 50/50 combination, and young modulus is 6.85% higher than the 15/85 composite combination. It means the addition of rice bran into composite enhances the stiffness of composite. The peak stress of 50/50 combination decreased 53.29% as compared with 15/85 composite combination. The highest value of young modulus is found at 2958 MPa for the 30/70 composite combination, which is 19.27% higher than the 15/85 composite combination. From the tensile test results, it is clearly visible that with an increase in rice bran percentage, the value of young modulus also increases up to 30/70 combination and decreases for 50/50 combination suddenly.

4.2. Flexural Test. The three-point bending test was performed on the same machine as the tensile test and results are shown in Table 2. The length, breadth, and thickness of the specimen were taken as 140 mm, 15 mm, and 5 mm, respectively, to perform the three-point bending test as per the ASTM D790 standard. From Table 3, similar variation results are obtained. With the mixing of untreated rice bran with PLA, due to weak adhesion between rice bran powder and PLA, the flexural properties are decreasing with an increase in rice bran percentage. The maximum stress was 18.5 MPa with 15/85 composite combination, and due to surface treatment of 15/85 combination composite, the flexural properties of flexural modulus and stress improved by 4.16% and 35.13%, respectively, as compared with 15/85 composite combination of untreated rice bran. For 20/80 composites, the stress diminishes by 15.13% as compared with 15/85 combination, but flexural modulus increases by 4.58% as compared with 15/85 combination, and it happens because the addition of rice bran to composite increases the stiffness of composites. The maximum value for flexural modulus 3091 MPa was found maximum for 50/50 combination and increased by 7.32% as compared with 15/85 composite combination. The lowest stress value 16.5 MPa was found for 50/50 composite combination. The surface treatment of rice bran powder enhances the mechanical properties of composite because it removes the undesired part from rice bran such as dust and lignin.

4.3. Hardness Test. The Rockwell hardness test has been performed, and the obtained results are shown in Table 2. From Table 4, it is clearly visible that the hardness values are decreasing with an increase in rice bran powder percentage. Due to the addition of untreated rice bran powder to composites, the hardness of the composite decreases due to poor interfacial bonding between rice bran and PLA, but on the other hand, due to the surface treatment of rice bran, the hardness increased by 22.22% with the same rice bran combination, i.e., 15/85 combination. It means surface treatment enhances interfacial bonding between rice bran and PLA due to the removal of undesirable contents from raw rice bran. In combination, the maximum value of hardness is found to be 9 HRF for 15/85 composite combination and the lowest hardness value was found to be 5.7 HRF for 50/50 composite combination, that is, 36.67% less as compared with 15/85 composite combination. The harness of other composite combinations for 20/80, 30/70, and 35/65 was found to be 13.33%, 20%, and 28.89%, respectively.

4.4. Water Absorption Test. A water absorption test was carried out on rice bran PLA composites to investigate the swelling behaviour of distilled water. The specimen opted for

(a) (b) (c) (d) (e) (f)

Figure 1: Specimen of PLA and rice bran composite with different ratios in wt. %: (a) 15/85. (b) 20/80. (c) 30/70. (d) 35/65. (e) 50/50. (f) Neat PLA.

Figure 2: Flexural test specimen.

Figure 3: Hardness test setup.

Table 1: Tensile test result of rice bran PLA composite.

Sr. no.	Rice bran/PLA in wt%	Young's modulus (E) in MPa	Stress at break (σ) in MPa	Strain at break (%)
1	Neat PLA	3500	59	7
2	15/85	2480	18.2	1.45
3	20/80	2590	17.5	1.34
4	30/70	2765	10.2	1.02
5	35/65	2958	9.7	1.00
6	50/50	2650	8.5	1.15
7	Treated 15/85	2650	27	2.5

the water absorption test is as per ASTM D570 standard size 60 mm × 60 mm × 1 mm. The size of the test specimen has been considered 60 mm × 60 mm × 1 mm in length, width, and height, respectively. The cutting of test samples has been done with the help of hack saw at atmospheric conditions. After cutting the test samples, the samples were dried for 24 hours in a hot oven at a temperature of 60° Celsius (Deg C) overnight. After the cooling and drying processes, samples were weighted using a weighing machine. After that, samples were dipped in distilled water for 25 days at room temperature. The water absorption percentage is calculated by the following equation [25–27].

Table 2: Hardness results of rice bran PLA composite.

Specimen	Rice bran/PLA in wt. %	Hardness (HRF)
1	15/85	9.0
2	20/80	7.8
3	30/70	7.2
4	35/65	6.4
5	50/50	5.7
6	Treated 15/85	11

Table 3: Flexural test results for rice bran PLA composite.

Sr. no.	Rice bran/ PLA	Flexural modulus (MPa)	Stress at peak (MPa)
1	Neat PLA	2700	32
2	15/85	2880	18.5
3	20/80	3012	15.7
4	30/70	3035	13.6
5	35/65	3045	10.8
6	50/50	3091	16.5
7	Treated 15/85	3000	25

Table 4: Density test of rice bran PLA composite.

Specimen	Rice bran/PLA in wt. %	Density (g/cm^3)
1	15/85	1.023
2	20/80	1.019
3	30/70	1.018
4	35/65	1.015
5	50/50	1.001
6	Treated 15/85	1.031

$$\text{Water absorption percentage}\left(W_{\mathrm{g}}\right) = \frac{W_{\mathrm{ws}} - W_{\mathrm{Ds}}}{W_{\mathrm{DS}}} * 100, \quad (1)$$

where W_{g} denotes the percentage weight gain of specimen, W_{WS} denotes the weight of wet specimen, and W_{DS} denotes the weight of dry specimen or baseline weight of specimen.

To perform the water absorption test, the weight of test samples was considered and recorded at 0, 10, 15, 20, and 25 days. The outcome is shown in Figure 4. From the graph, it is clearly visible that with an increase in rice bran percentage, the amount of water absorption also increases. It reveals the hydrophilic nature of rice bran. The highest water absorption rate has been reported for the 50/50 composite combination, while the lowest value has been reported for the 15/15 composite combination. Due to the surface treatment of rice bran, its water absorption properties also get improved and are found to be the best in all combinations. Most of the components in rice bran, including lignin, hemicellulose, cellulose, and other soluble contents, contain polar groups that make rice bran hydrophilic by nature. When these constituents react with water, they form hydrogen bonds. Therefore, the higher the rice bran content in the composite, the higher the percentage of water absorption, and this makes the composite weaker in its mechanical properties.

4.5. Density Test. The density test of rice bran PLA composite has been performed in air, water, petrol, and diesel using the Archimedes principal, and the average values of density are shown in Table 4. From Table 4, it can be concluded that with the addition of rice bran to PLA, density decreases due to the light weight of rice bran powder. The highest value of density, 1.023 g/cm^3, was found for the 15/85 composite combination, while the lowest value of density, 1.001 g/cm^3, was found for the 50/50 composite combination. After surface treatment with NaOH, the value of density increases to 1.031 g/cm^3 due to the removal of light-weight constituents from rice bran.

4.6. Thermogravimetric Analysis. The thermogravimetric analysis has been carried out in an inert nitrogen atmosphere with a heating rate of 10°C per minute using a thermogravimetric analyser. The thermogravimetric study has been conducted with a nitrogen flow rate of 18 ml/min to avoid unwanted oxidation. Form Table 5, it can be stated that the initial mass loss reported in rice bran and rice bran PLA composite is due to moisture absorption up to temperature 80°C and the second mass loss approximately 80°C–350°C is due to the decomposition of major constituent present in natural rice bran, i.e., decomposition of lignin, hemicellulose, and cellulose present in rice bran. The higher the cellulose content in rice bran, the thermal degradation rate and the initial degradation temperature will be higher, and also, it will produce higher ash content with higher residual weight [28]. The results reveal the application of rice bran composite to work as fluid in three-dimensional printing application.

4.7. Response Surface Method (RSM) Design and Design of Experiment (DOE) Analysis. Using the response surface method (RSM) design with one element, a totally random design is taken into consideration. All randomized designs with a single primary component are distinguished by three factors, k, L, and n, which, respectively, define the number of factors, levels, and replications.

$$\text{Total sample size (number of runs)}, N = k\,L\,n. \quad (2)$$

The response model is given by

$$Z_{ij} = \mu + P_i + \text{random error}\,(\varepsilon), \quad (3)$$

where Z_{ij} is the observation with respect to $X_1 = i$. Replication within the level of the factor is indicated by the letters I and j, respectively.

P_i is a result of receiving treatment level I, while μ considered as a general location parameter. The Design Expert 8.0.6 software is used for experimental design and statistical analysis of data. The coefficients of determination (R^2) and analysis of variance (ANOVA) are considered to examine the good fit and to estimate the regression model.

The optimal value of T, which is considered a one-factor design model, is calculated. For producing ten primary values for three response units (i.e., rice bran weight loss, rice bran PLA composite weight loss, and neat PLA weight loss), this component is assigned the values 0 and 1 as low and high values, respectively. Table 6 shows the results of these

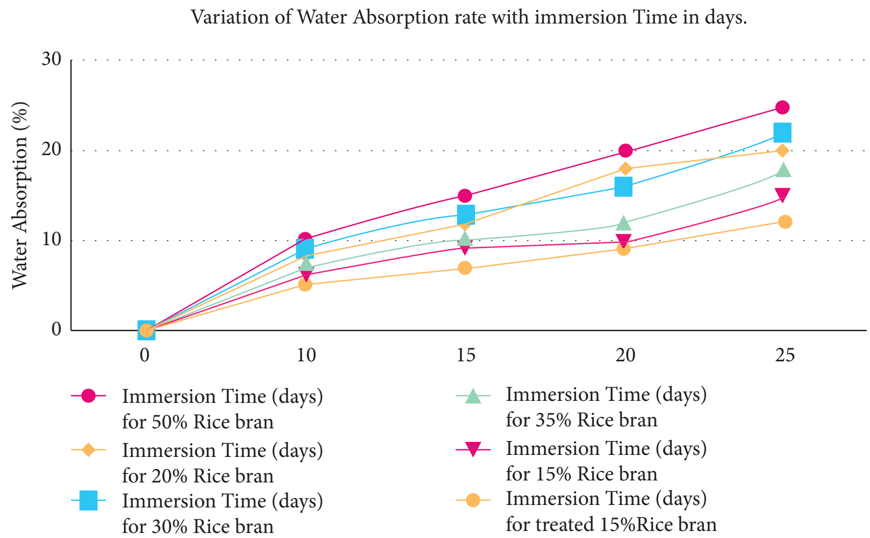

Figure 4: Water absorption test result for rice bran PLA composite.

Table 5: Thermogravimetric analysis of rice bran PLA composite.

T (Deg C)	Rice bran (weight loss %)	Rice bran/PLA (15/85 wt. %) weight loss %	Neat PLA weight loss %
50	2.5	0.7	0
80	5.2	1.2	0
200	15.6	10.5	0.5
350	18.9	80.4	9.5
500	50.7	92.3	100

Table 6: Optimum model results using DOE.

Number desirability	A	R1	R2	R3		
1	500	50.7	92.3	100	1	Selected
2	424.85	50	92	100	0.994	
3	110.84	4.58994	—	—	0.351	
4	207.28	16.241	9.78314	0.52678	0.053	

calculations. The values of the ten fundamental variables of T are randomly assigned to the three responses in a totally randomized design using equation (2). Now, the expression defined in equation (3) is used to predict the optimum temperature for a complete weight loss response.

$$Y(\varphi) = \alpha_o + \sum_{i=1}^{N} \sum_{j=1}^{q} \alpha_i \varphi_{ij} + \varepsilon, \tag{4}$$

where T is the predicted response, α_o is the intercept, N is the runs, and q is the number of design variables.

4.8. Response Surface Model Fitting. The regression model developed with equation (3) using simulated values of rice bran weight loss, rice bran PLA composite weight loss, and neat PLA weight loss gives a good match with the collected findings, which is relevant for different values of P (probability that the null hypothesis is true) and adequate fit R^2 values. The coefficients R^2, Adj. R^2, and adequate precision are adopted for testing the model. The model is considered adequate for $P < 0.05$, lack of fit for P value >0.05, $R^2 > 0.9$, and adequate precision >4.

Using ANOVA, the model is optimized for maximization of rice bran weight loss, rice bran PLA composite weight loss, and neat PLA weight loss.

A six-degree equation for rice bran weight loss (Y_1) with $P < 0.0001$, $R^2 = 1$, and Adj. $R^2 = 1$ is represented as

$$\begin{aligned} \mathrm{Y1} = &+4.12 - 0.91\mathrm{A} - 0.49\mathrm{A}^2 + 14.8\mathrm{A3} \\ &+ 7.25\mathrm{A}^4 - 11.13\mathrm{A}^5 - 6.52\mathrm{A}^6. \end{aligned} \tag{5}$$

Similarly, a six-degree equation for rice bran PLA composite (Y_2) with $P < 0.0001$, $R^2 = 1$, and Adj. $R^2 = 1$ is represented as

$$\begin{aligned} \mathrm{Y2} = &+3.46 + 9.57\mathrm{A} + 33.24\mathrm{A}^2 - 9.18\mathrm{A}^3 \\ &- 91.83\mathrm{A}^4 + 4.00\mathrm{A}^5 + 60.35\mathrm{A}^6. \end{aligned} \tag{6}$$

Similarly, a six-degree equation for Neat PLA (Y_3) with $P < 0.0001$, $R^2 = 1$, and Adj. $R^2 = 1$ is represented as

$$\begin{aligned} \mathrm{Y3} = &+0.77 + 1.35\mathrm{A} + 9.86\mathrm{A}^2 + 22.05\mathrm{A}^3 \\ &+ 3.14\mathrm{A}^4 - 18.39\mathrm{A}^5 - 8.77\mathrm{A}^6. \end{aligned} \tag{7}$$

The weight loss numbers for rice bran, rice bran PLA composite weight loss, and neat PLA weight loss are based on the 10 primary T factor values shown in Table 7.

After running the above objectives and constraints, the obtained fit results are shown in Table 8. From Table 7, it can be concluded that the best-suited model came up at a

TABLE 7: Values of weight loss for rice bran weight loss, rice bran PLA composite weight loss, and neat PLA weight loss as per the 10 primary values of the T factor.

Run	Temperature (T)	Rice bran (weight loss %) (R1)	Rice bran/PLA (15/85 wt %) weight loss % (R2)	Neat PLA weight loss % (R3)
1	424.85	50	92	100
2	50	2.5	0.7	0
3	275	17	12	0.6
4	50	2.5	0.7	0
5	200.07	15.6	10.5	0.5
6	349.93	18.9	80.4	9.5
7	500	50.7	92.3	100
8	275	17	12	0.6
9	500	50.7	92.3	100
10	125.15	6	1.5	0

Objective: maximize R1, R2, and R3. Constraints: $50 < T < 500$.

TABLE 8: ANOVA analysis of rice bran.

Source	Sum of squares	df	Mean square	F value	P value, prob > F	Result
Model	41.9626	6	6.993767	63660000	<0.0001	Significant
A-A	0.078093	1	0.078093	63660000	<0.0001	
A^2	0.001454	1	0.001454	63660000	<0.0001	
A^3	1.477591	1	1.477591	63660000	<0.0001	
A^4	0.03366	1	0.03366	63660000	<0.0001	
A^5	1.448628	1	1.448628	63660000	<0.0001	
A^6	0.057011	1	0.057011	63660000	<0.0001	
Pure error	0	3	0			
Cor total	41.9626	9				

TABLE 9: ANOVA analysis of rice bran PLA composite.

Source	Sum of squares	df	Mean square	F value	P value, prob > F	
Model	135.9347	6	22.65578	63660000	<0.0001	Significant
A-A	8.677553	1	8.677553	63660000	<0.0001	
A^2	6.591164	1	6.591164	63660000	<0.0001	
A^3	0.568285	1	0.568285	63660000	<0.0001	
A^4	5.406708	1	5.406708	63660000	<0.0001	
A^5	0.187148	1	0.187148	63660000	<0.0001	
A^6	4.877571	1	4.877571	63660000	<0.0001	
Pure error	0	3	0			
Cor total	135.9347	9				

TABLE 10: ANOVA analysis of neat PLA composite.

Source	Sum of squares	df	Mean square	F value	P value, prob > F	
Model	186.319	6	31.05317	63660000	<0.0001	Significant
A-A	0.172222	1	0.172222	63660000	<0.0001	
A^2	0.579932	1	0.579932	63660000	<0.0001	
A^3	3.276912	1	3.276912	63660000	<0.0001	
A^4	0.006307	1	0.006307	63660000	<0.0001	
A^5	3.958855	1	3.958855	63660000	<0.0001	
A^6	0.103052	1	0.103052	63660000	<0.0001	
Pure error	0	3	0			
Cor total	186.319	9				

temperature of 500 C for maximum weight loss. The second-best prediction for maximum weight loss is found at 424.85 C with a prediction value of 0.994. The third and fourth best values for maximizing of R1, R2, and R3 are not very significant.

4.9. ANOVA Analysis. ANOVA is a statistical analysis technique that separates systematic components from random factors to account for the observed aggregate variability within a dataset. The presented dataset is statistically affected by the systematic factors but not by the random ones. The

ANOVA test is used by analysts to evaluate the impact of independent factors on the dependent variable in a regression analysis. The ANOVA results for rice bran weight loss, rice bran PLA composite weight loss, and neat PLA weight loss are shown in Tables 8–10, respectively. The alpha value was considered 0.5 while performing the ANOVA analysis. From the obtained results, the *P* value was found below 0.5, so it can be concluded that the obtained results are statistically significant.

5. Conclusion

From this study, it can be concluded that cost-effective rice bran PLA composite may be produced to fulfil the need of biodegradable material nowadays. The addition of rice bran makes composites eco-friendly for the environment, and rice bran can be used as a biodegradable, eco-friendly filler to minimize pollution, and it can save the cost of composites. As the result shows, with increase in rice bran contents in composite, the stiffness of composite enhances but strength gets decreased. Due to the surface treatment of rice bran, its mechanical properties are enhanced due to the removal of unwanted contents from rice bran, and it increases the adhesion between the matrix and reinforcement. With increase in rice bran content, the density of composite gets diminished, and the maximum density was reported for 15/85 composite combination. The other mechanical properties were also found to be better for the 15/85 composite combination as compared with other combinations. The water absorption test reveals the hydrophilic nature of rice bran, and as a result, it shows an adverse effect on the mechanical properties of composite. The hardness test performed on composites reveals that the hardness value decreases with an increase in rice bran content. Thermogravimetric analysis reveals that the thermal stability of neat PLA is better than the thermal stability of rice bran PLA composite, but the thermal stability of rice bran PLA composite is better than rice bran. After optimizing the model of thermogravimetric analysis of rice bran, rice bran, rice bran composites, and neat PLA using response surface methodology and design of experiment, a six-degree equation is generated with the objective of maximum weight loss of rice bran, rice bran composite, and neat PLA. An optimized model is evaluated. So, as per the generated model, the maximum weight loss of rice bran composite and neat PLA was found at 500°C. A future scope of checking its validity as 3D printer fluid may be performed and found suitable around 500°C.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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