
OPTIMIZATION OF ORGANOSOLV LIGNIN EXTRACTION FROM GROUNDNUT SHELL FOR ADHESIVE PRECURSOR APPLICATIONS

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DOI: <https://doi.org/10.67203/sp.ICESID.2026>

ABSTRACT

The increasing demand for sustainable materials has intensified research into lignin-based adhesives derived from agricultural biomass. This study presents an integrated approach for optimizing organosolv extraction of lignin from groundnut shell waste for potential adhesive applications. Groundnut shell lignin was extracted via an organosolv process. A three-factor central composite design (CCD) of response surface method (RSM) was applied to optimize extraction variables using design expert 13.0.1 including ethanol concentration, temperature, and reaction time considering % yield and lignin reactivity index (LRI). The model was tested with its adequacy fit statistics, where R^2 -value is 0.9941 which has 0.90 % and 4.4 % difference from the adjusted R^2 and predicted R^2 values. The theoretical optimal parameters obtained were 55 % ethanol concentration, 120 °C temperature, and 45 minutes reaction time which yielded a lignin recovery of 87.55 % and 5.17 LRI. These were validated having a close value of the responses 86.24 % yield and 5.25 LRI having a 1.45 % and 1.52 % error for yield and LRI respectively, as compared with the theoretical values. FTIR and compositional analysis confirmed successful isolation of a lignin-rich fraction from groundnut shell. The extracted lignin retained characteristic hydroxyl, aliphatic C-H, aromatic skeletal and C-O/ether functionalities, with prominent absorptions observed around 3404, 2928, 1508 – 1529, 1410 – 1412 and 1044 – 1119 cm^{-1} . The novelty of this work lies in consideration of quantity and quality of lignin in optimization of organosolv extraction method of groundnut shell lignin, an underutilized agricultural waste, to produce a functionally improved adhesive precursor. Conclusively, the optimized extraction conditions produced high lignin yield and enhanced lignin reactivity, demonstrating that groundnut shell is a sustainable and promising source of reactive lignin for the development of bio-based adhesive precursors. These findings provide a reliable foundation for the subsequent modification and functionalization of high-performance and environmentally friendly bio-adhesives synthesis.

Keywords: Lignin; Organosolv; Adhesive Precursor; Lignin Reactivity Index; Central Composite Design; Compositional Analysis; FTIR

1. INTRODUCTION

The increasing global emphasis on environmental sustainability and the depletion of fossil-based resources have intensified research into renewable and eco-friendly alternatives for industrial materials. Conventional adhesives, largely derived from petroleum-based polymers such as epoxy, polyurethane, and phenol–formaldehyde resins, are associated with significant environmental concerns, particularly the emission of volatile organic compounds (VOCs) during their production and application (Paez & Fatehi, 2025). In response, bio-based polymers derived from lignocellulosic biomass have gained increasing attention as sustainable substitutes. Among these, lignin has emerged as a promising renewable resource due to its aromatic structure, high availability, and compatibility with phenolic resin systems (Mateo *et al.*, 2025; Ait Benhamou *et al.*, 2025).

Lignin is a complex, three-dimensional amorphous polymer composed of phenylpropanoid units, namely p-coumaryl, coniferyl, and sinapyl alcohols, which give rise to hydroxyphenyl (H), guaiacyl (G), and syringyl (S) structural units (Liu *et al.*, 2023). It functions as a natural adhesive within

plant cell walls, imparting rigidity, hydrophobicity, and resistance to biological degradation (Zhang *et al.*, 2024). Although it is the second most abundant biopolymer after cellulose, lignin remains largely underutilized, with the majority being combusted for energy recovery in pulp and biorefinery industries rather than converted into value-added products (Mateo *et al.*, 2025). This presents a significant opportunity for its valorization in the development of sustainable materials, particularly bio-adhesives.

Groundnut (*Arachis hypogaea*) shell (Figure 1) is an abundant agricultural residue generated in large quantities in many developing countries, including Nigeria. Global groundnut processing produces millions of tonnes of shell waste annually, which is often disposed of through open burning or landfilling, thereby contributing to environmental pollution (Ogunkunle *et al.*, 2024). However, groundnut shell is rich in lignocellulosic components, typically comprising cellulose, hemicellulose, and lignin, making it a viable raw material for lignin extraction (Adebayo & Adeola, 2023). Its utilization for lignin recovery therefore supports sustainable waste management and the development of renewable bio-based products (Gerber & Roberts, 2024).



Figure 1: Groundnut Shell (*Arachis hypogaea*)

Several extraction techniques have been reported for lignin recovery from biomass, including Kraft pulping, soda pulping, organosolv processes, and deep eutectic solvent (DES) systems. Among these, the organosolv process has attracted considerable interest due to its ability to produce high-purity lignin with relatively low structural degradation compared to conventional alkaline methods (Xu *et al.*, 2024). Although emerging fractionation technologies such as DES extraction have demonstrated considerable potential for lignin recovery, organosolv extraction was selected in this study because its established ability to selectively fractionate lignocellulosic biomass and recover sulfur-free lignin with relatively high purity and useful hydroxyl functionalities. These characteristics are particularly relevant to the intended functionalization of lignin for adhesive precursor development (Alam *et al.*, 2024; Tanis *et al.*, 2024). Among organic solvents used in organosolv processing, ethanol is attractive for its lignin-solubilizing capacity, relatively low toxicity, miscibility with water and potential for recovery and reuse (Brienza *et al.*, 2024). However, the efficiency of lignin extraction and the quality of the resulting product are strongly influenced by operational parameters such as solvent composition, reaction temperature, and extraction time (Ruwoldt *et al.*, 2024). Consequently, optimisation of these parameters is essential to obtain lignin with desirable physicochemical properties suitable for adhesive applications.

Despite growing interest in lignin valorisation, limited studies have systematically optimised organosolv extraction conditions for lignin recovery from groundnut shell and evaluated its reactivity to suit adhesive synthesis precursor. In particular, the relationship between extraction parameters, and lignin structural characteristics remains insufficiently understood.

Therefore, this study aims to optimise the organosolv extraction of lignin from groundnut shell and evaluate its suitability for adhesive synthesis. Specifically, the study focuses on optimisation of extraction parameters of lignin from groundnut shell using the organosolv method for improved quantity and quality, and characterisation of the extracted lignin for possible adhesive applications.

This work contributes to the sustainable utilisation of agricultural waste and supports the development of environmentally benign bio-based adhesives as alternatives to petroleum derived products.

2. MATERIALS AND METHODS

The details of reagents used are presented in Table 1, and experimental setup is shown in Figure 2, showing all methods used.

Table 1: Chemicals and reagents used

S/N	Chemical	Purity/Grade	Supplier
1	Ethanol	≥99.5%	Sigma-Aldrich
2	Sulfuric acid	95%	Sigma-Aldrich
3	Distilled water	Laboratory grade	Laboratory supply

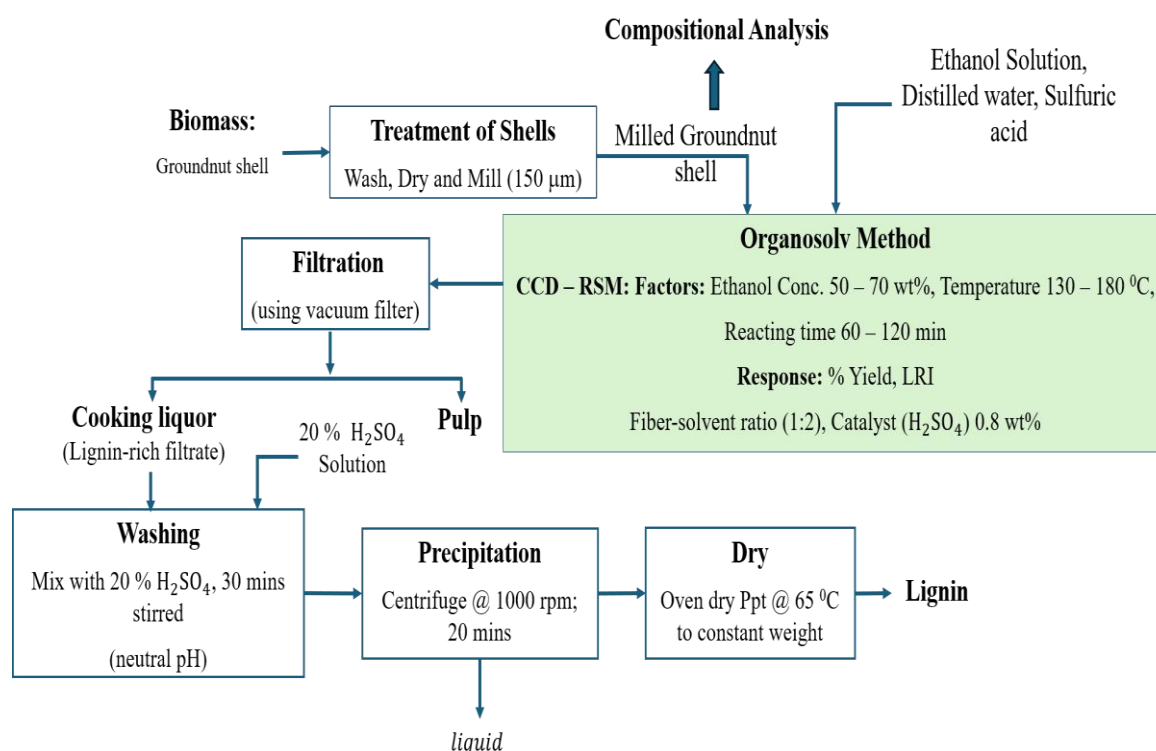


Figure 2: Experimental Setup of the extraction process

Groundnut shells (*Arachis hypogaea*) were collected from local oil processing mills in Zaria, Kaduna State, Nigeria. The shells were thoroughly washed with distilled water to remove adhering dirt and impurities, sun dried, and further oven dried at 65 °C (Mettler UN55 Oven, Germany) for 6 h to reduce moisture content. The dried shells were milled using a hammer mill (SIEBTECHNIK GmbH) and sieved to a particle size of 150 µm. All chemicals and reagents as presented in Table 1 were of analytical grade and were used as received without further purification. Ethanol was selected as the extraction solvent based on its reported efficiency in producing high purity organosolv lignin. Sulfuric acid (0.8 wt%) was employed as a mild catalyst in line with previous studies (Farid *et al.*, 2023).

2.1 Experimental Design

The experimental design was developed using Design-Expert software (Version 13.0.1, Stat-Ease Inc., USA) based on three-factor Central Composite Design (CCD). The coded factorial levels (-1 and +1) corresponded to ethanol concentration (50 – 70% v/v), reaction temperature (130 – 180 °C), and reaction time (60 – 120 min). The CCD axial points extended the actual experimental design space to 43 – 77 % ethanol concentration, 113 – 198 °C, and 39 – 141 min reaction time. The response variables were lignin yield (%), and reactivity index. A total of 16 randomized experimental runs were

generated with two-center points, allowing evaluation of linear, interaction, and quadratic effects of the process variables. All experiments were conducted in triplicate, and the average values were reported.

2.2 Extraction of Lignin from Groundnut Shell

Prior to extraction, compositional analysis was carried out on the groundnut shell to ascertain and compare with the existing literature, the percentage of lignin, cellulose, and hemicellulose present in the shell. 100 g of groundnut shell powder of a particle size 150 μ m was pretreated by washing in hot distilled water at 80 °C to remove soluble extractives and then oven-dried at 65 °C to a constant weight and then transferred into the reactor. Organosolv extraction was carried out using ethanol – water solution (50 – 70% v/v) at a solid-to-liquid ratio of 1:2 (w/v). The solution was added into the batch reactor, and sulfuric acid (0.8 wt%) was then added as a catalyst to enhance cleavage of ether linkages (Farid *et al.*, 2023). The lignin extraction was carried out using a closed-sealed, mechanically stirred and temperature-controlled pressure reactor. The reactor head was mechanically secured to the vessel prior to operation to provide a closed reaction environment, then purged with nitrogen for 3 min to minimize oxidative degradation and heated to the desired temperature range (130 – 180 °C) for 60 – 120 min continuously stirred at 800 rpm, in accordance with the CCD matrix. At the end of the reaction time, heating was automatically stopped and the reactor was cooled to below 45 °C before pressure was released through the release valve. The resulting slurry was recovered for lignin separation, vacuum filtered to separate the solid residue from the black liquor. A photograph of the experimental reactor and control system is presented in Figure 3

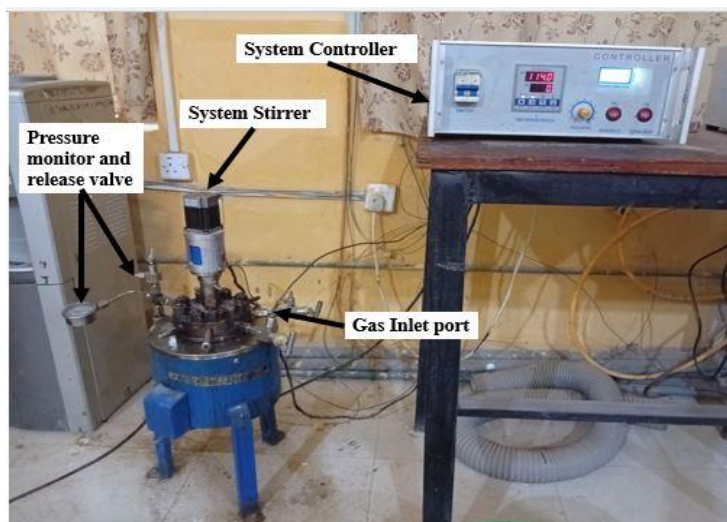


Figure 3: Reactor and control system setup

Lignin was recovered from the liquor by dilution with sulfuric acid solution, followed by centrifugation at 1000 rpm to precipitate the lignin fraction. To quench the reaction, the precipitate was washed repeatedly with distilled water until neutral pH (6.5 – 7.5) was achieved and subsequently dried under vacuum at 65 °C to constant mass.

Lignin yield, an important response signifying extraction efficiency which is usually expressed in percentage for the lignin recovered from the biomass (Mao *et al.*, 2025; Sandner *et al.*, 2025). This was calculated using equation 1:

$$\text{Yield (\%)} = \frac{W_L}{W_S} \times 100 \quad (1)$$

where W_L is the dry mass of extracted lignin and W_S is the dry mass of raw groundnut shell.

Lignin reactivity index (LRI) is a measure of chemical reactivity of extracted lignin, revealing the availability of reactive functional groups (Karlsson *et al.*, 2023). LRI was calculated using equation 2.

$$\text{Lignin Reactivity index (LRI)} = \frac{A_{\sim 3400}}{A_{\sim 1510}} \quad (2)$$

$$\text{Abundance (A)} = \log \left(\frac{100}{(\%T)} \right) \quad (3)$$

2.3 Functional Group Analysis

The extracted lignin using the optimum extraction parameters was characterized to evaluate the functional groups of both the groundnut shell and lignin through Fourier Transform Infrared Spectroscopy (FTIR).

3. RESULTS AND DISCUSSIONS

3.1 Constituents of Groundnut Shell and Extract

Comparison of the major lignocellulosic components measured for both milled groundnut shell and the extracted lignin are presented in Table 2

Table 2: *Constituents of groundnut shell and extract Lignin*

Component	Groundnut shell (%)	Extract (Lignin)
Lignin	26.97	78.49
Hemicellulose	12.88	2.53
Cellulose	55.24	15.06
Moisture	4.67	3.92
Ash	0.24	0.163

As shown in Table 2, the composition of lignin, hemicellulose, cellulose contained in the groundnut shell are 26.97 %, 12.88 %, and 55.24 % respectively, these are in line with various report on groundnut shell studies. Recent studies confirm that groundnut shell composition varies considerably according to cultivar, geographical origin, maturity, processing and method adopted for analysis. From the work of Almeida-Naranjo *et al.*, (2024), reported 36.2 % lignin, 26.1 % hemicellulose and 19.4 % cellulose, similar trend of 28.4 % lignin, 14.5 % hemicellulose and 47.86 % cellulose was also reported recently by Mousa *et al.*, (2026). In another study, identification was reported for peanut shell to be broadly composed of about 48 % cellulose, 3 % hemicellulose, and 28 % lignin (Zhang *et al.*, 2025). Therefore, 26.97 % lignin, 55. 24 % cellulose, and 12.88 % hemicellulose recorded are within the reported compositional range with a close agreement for lignin and cellulose.

Also, the 78.49 % lignin contained in the extract demonstrates substantial purification but not fully chemically pure lignin due to some fractions of other constituents present, this could be because of the process efficiency. Recent studies also show that groundnut shell is agreeable to effective fractionation, a microwave-assisted diol-deep eutectic solvent (DES) system was reported to have 86.39 % delignification and 91.17 % hemicellulose removal (Xie *et al.*, 2025), while another recent peanut-shell DES study reported 73.22 % lignin removal and 93.05 % hemicellulose removal (Lu *et al.*, 2023). The low ash content in lignin (0.163 %) indicates a low level of inorganic impurities, which makes it a good precursor for adhesive applications because a low inorganic fraction means fewer mineral impurities interfering with subsequent lignin functionalization. Recent studies have similarly associated low-ash, high-purity lignin with greater chemical activity and suitability for lignin-based resin and adhesive synthesis (Ren *et al.*, 2025; Sapenti *et al.*, 2025).

3.2 Lignin Yield from CCD-RSM Optimization

The experimental lignin yields and reactivity obtained under different combinations of ethanol concentration, reaction temperature, and reaction time, as designed by the Central Composite Design (CCD), are presented in Table 3.

Table 3: *Effect of extraction parameters on lignin yield and reactivity index*

Run	Ethanol Conc. (%)	Temperature (°C)	Reaction Time (min)	Yield (%)	LRI
1	60	198	90	63.55	4.11
2	50	180	120	61.06	6.26
3	50	130	60	50.45	5.19
4	50	180	60	61.45	3.98
5	60	155	141	55.23	7.24
6	70	180	120	60.64	6.13
7	60	155	90	54.99	4.45
8	50	130	120	51.24	6.87
9	43	155	90	56.43	5.79
10	77	155	90	53.66	7.14
11	70	130	120	49.78	7.46
12	60	155	39	55.02	4.76
13	70	180	60	58.96	4.47
14	60	155	90	55.2	4.81
15	70	130	60	50.11	6.88
16	60	113	90	47.06	5.96

Lignin yield varied from 47.06 % to 63.55 %, indicating strong dependence on process conditions. The highest experimental yield (63.55 %) was obtained at 60% ethanol, 198 °C, and 90 min. This suggests that moderate solvent polarity combined with elevated temperature enhances lignin solubilisation and cleavage of lignin carbohydrate linkages. A decline in yield at higher temperature (180 °C) and shorter residence time (60 min) indicates possible lignin degradation or condensation reactions under harsh conditions. Conversely, insufficient reaction time reduced extraction efficiency due to incomplete biomass delignification. Similar behaviour has been reported in organosolv systems where temperature and residence time strongly govern lignin depolymerisation kinetics (Xu *et al.*, 2024). Although the maximum experimental yield (63.55 %) was slightly higher than other runs, the amount of ethanol concentration of 60 % may have prevented the excessive lignin degradation effects, as compared to the 50 % concentration used in runs 2 and 4, similar experience was also reported in the work of Sun *et al.* (2023).

More so, the lignin reactivity index (LRI) was also influenced by the extraction temperature, solvent concentration and the extraction time, but the effects were observed to vary with respect to their operating conditions, which is also consistent with the findings reported by Li *et al.* (2024). LRI was considered independently of lignin yield, which represents the quality of lignin recovered. As presented in Table 3, relatively low lignin reactive index of 4.11 was obtained in experimental run 1 at high temperature of 198 °C, 90 minutes extraction time and 60 % ethanol concentration, indicating that; despite maximizing the lignin recovery, the structural arrangements may have been disrupted by the

severe extraction temperature, thereby reducing the availability of reactive functional groups. Additionally, the influence of reaction time can be observed by comparing Runs 2 and 4, that were investigated under a similar concentration, extraction temperature but different reaction time (120 and 60 min, respectively). This indicates that, the increase in LRI from 3.98 to 6.26, suggests that extending the extraction time beyond 60 minutes did not substantially improve lignin reactivity. Kim *et al.* (2023) also reported similar trends, indicating that prolonged residence time may have altered the chemical structure of the extracted lignin through partial depolymerization and exposure of additional reactive sites, resulting in a higher lignin reactivity index without significantly increasing extraction efficiency.

3.3 Analysis of Variance (ANOVA) and Model Significance

The ANOVA results for the quadratic response surface model of lignin yield are presented in Table 4. The model was statistically significant ($p = 0.0001$), indicating that the selected variables adequately describe lignin yield behaviour within the studied range.

Table 4: ANOVA results of the independent variable effects on the yield of lignin

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	348.36	9	38.71	111.72	0.0001	significant
A-% Ethanol	6.44	1	6.44	18.58	0.0050	
B-Temperature	340.62	1	340.62	983.09	0.0001	
C-Reacting Time	0.3222	1	0.3222	0.9298	0.3721	
AB	0.1540	1	0.1540	0.4445	0.5297	
AC	0.1128	1	0.1128	0.3256	0.5890	
BC	0.0861	1	0.0861	0.2485	0.6359	
A ²	0.0280	1	0.0280	0.0807	0.7859	
B ²	0.1109	1	0.1109	0.3200	0.5921	
C ²	0.0638	1	0.0638	0.1841	0.6829	
Residual	2.08	6	0.3465			
Lack of Fit	2.06	5	0.4114	18.66	0.1739	not significant
Pure Error	0.0221	1	0.0221			
Cor Total	350.44	15				

Nevertheless, their inclusion improved overall model predictability and stability, which is consistent with response surface methodology practices (Weremfo *et al.*, 2023).

The lack of fit was not significant ($p > 0.05$), confirming that the model adequately fits the experimental data.

The model exhibited strong predictive capability with $R^2 = 0.9941$, indicating that 99.4% of the variability in lignin yield was explained by the model. The adjusted R^2 (0.9852) and predicted R^2 (0.9499) were in reasonable agreement, confirming acceptable model reliability. The adequate precision value of 36.37 further justified the significance of the model, because it is greater than 4. A good correlation between predicted and experimental values was observed (Figure 4), with data points closely distributed along the regression line, confirming that the model reliably predicts lignin yield within the experimental domain

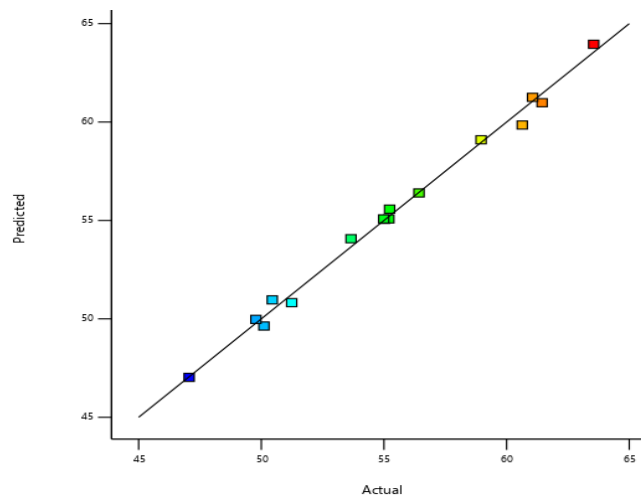


Figure 4: Relationship between experimental (actual) and predicted data

Equation 4 depicts the coded model equation generated for the yield which shows the interactions between the independent variables (reaction time and temperature and ethanol concentration) that were investigated.

$$\text{Yield} = 55.08 - 0.6835A + 4.97B + 0.1529C - 0.1387AB + 0.1188AC + 0.1038BC + 0.0543A^2 + 0.1080B^2 + 0.0819C^2 \quad (4)$$

Table 5 presents the ANOVA results of the reactivity index of lignin extraction. As shown in Table 5, the model is significant as the p-value obtained is less than 0.05. The model terms-A, B and C as shown in the Table are also significant as their p-values are less than 0.05.

Table 5: ANOVA results of the independent variable effects on the lignin RI

Source	Sum Squares	of df	Mean Square	F-value	p-value	
Model	21.18	9	2.35	75.27	0.0001	significant
A	1.77	1	1.77	56.52	0.0003	
B	5.54	1	5.54	177.21	0.0001	
C	7.87	1	7.87	251.80	0.0001	
AB	0.4608	1	0.4608	14.74	0.0086	
AC	0.3698	1	0.3698	11.83	0.0138	
BC	0.3528	1	0.3528	11.28	0.0152	
A ²	3.90	1	3.90	124.65	0.0001	
B ²	0.2174	1	0.2174	6.95	0.0387	
C ²	2.19	1	2.19	69.89	0.0002	
Residual	0.1876	6	0.0313			
Lack of Fit	0.1228	5	0.0246	0.3790	0.8348	not significant
Pure Error	0.0648	1	0.0648			
Cor Total	21.37	15				

Moreso, the lack of fit with p-value obtained as 0.8387 is not significant as it is greater than 0.05. The model was further subjected to the adequacy test where the R² was obtained as 0.9912, with the adjusted R² of 0.9781 and predicted R² of 0.9424, which 1.0 % and 4.9 % percentage error differences from the R² respectively. This was further justified by the value of adequate precision of 25.0126. Figure 5 shows the parity plot of the predicted and experimental variables of the reactivity index. As observed in the Figure, the experimental variables are in close agreement with the predicted variables, which was further justified by the low error difference obtained from the R² and the R² adjusted values.

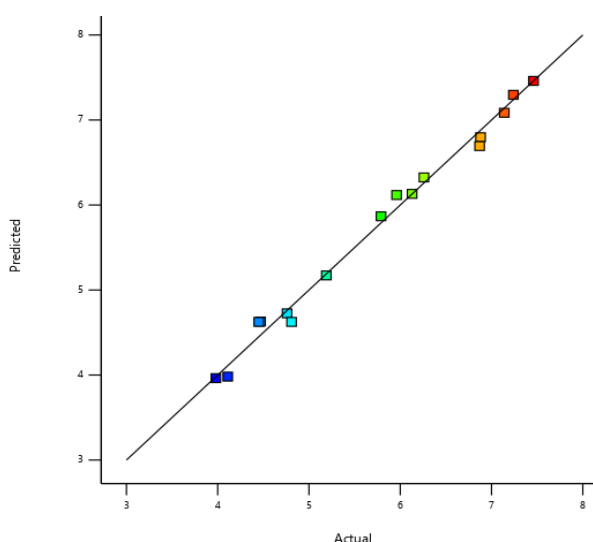


Figure 5: Parity plot of the predicted and experimental data

Equation 5 shows the model generated from the statistical analysis carried out. As highlighted in the model, the quadratic regression equation explained the relationship between the reacting time, ethanol concentration, extraction temperature and the lignin reactivity index.

$$\text{LRI Model} = 4.63 + 0.3581A - 0.6343B + 0.7559C - 0.2400AB - 0.2150AC + 0.2100BC + 0.6405A^2 + 0.1512B^2 + 0.4796C^2 \quad (5)$$

3.4 Model Validation and Multi-Response Optimization

The multi-response optimization approach was employed to identify the extraction conditions that simultaneously maximize lignin yield and its reactivity index. The desirability function combines the individual desirability of each response into an overall desirability value ranging from 0 to 1. The optimum condition obtained theoretically are 55 % ethanol concentration, 120 °C extraction temperature and 45 min reaction time, with overall desirability of 0.963. This high desirability indicates that the selected operating condition provides favourable response predicted at 87.55 % lignin yield and 5.17 LRI as presented in Table 6.

Table 6: The predicted and validated of the yield and lignin reactivity index

	Ethanol Conc	Temperature	Reaction Time	Yield	LRI
Theoretical values	55	120	45	87.55	5.17
Validated values	55	120	45	86.28	5.25
% Error				1.45	1.52

As shown in Table 6, the validated values at the same operating conditions produced a lignin yield of 86.28 % and an LRI of 5.25, which are in close agreement with the predicted values with their respective error differences of 1.45 % and 1.52 %. These indicate a high level of accuracy in the prediction model, suggesting that the optimization model used to predict the extraction yield and the lignin refractive index values are quite reliable, with minimal deviations observed between the predicted and validated values. These trends, when compared with the works of Li *et al.* (2024); Samson *et al.* (2022); Lannucci and Willows, (2022); Higuchi *et al.* (2021) follow similar percentage deviation.

3.5 FTIR Analysis

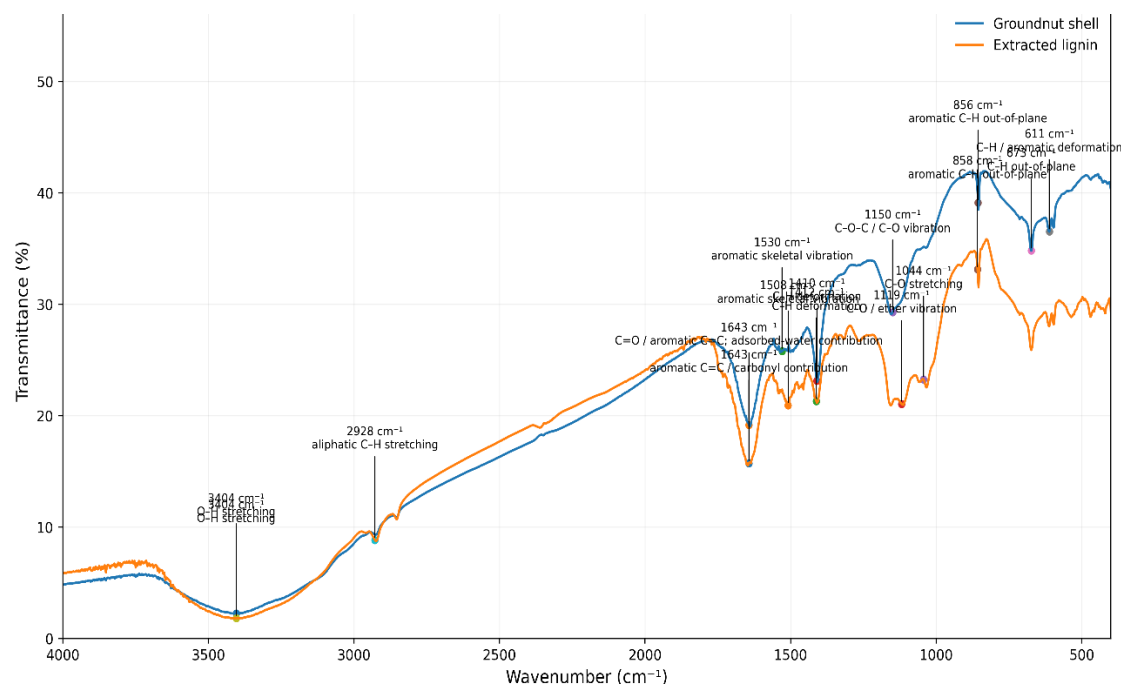


Figure 6: The FTIR spectra of Groundnut Shell and Lignin

The FTIR spectra (Figure 6) provide comparison on functional groups of both groundnut shell and lignin at an optimum extraction condition as presented in Table 6. Both spectra exhibit a broad absorption centred around 3404 cm^{-1} , attributable primarily to O-H stretching of phenolic and aliphatic hydroxyl groups. The presence of this band in the extracted lignin is highly significance because hydroxyl groups are abundant in lignin. Its presence indicates that a substantial proportion of lignin hydroxyl functionalities was retained after undergoing the extraction process, suggesting that the organosolv extraction conditions did not cause extensive degradation of the functional groups. This preservation is important because the hydroxyl groups contribute to the chemical reactivity of lignin and provide active sites for subsequent functionalization. Recent work on peanut/groundnut shell also reported similar trends with bands around 3426 cm^{-1} and 3335 cm^{-1} , these were also attributed to hydroxyl groups associated with lignin, cellulose and moisture (Mousa *et al.*, 2026; Arizpe-Diaz *et al.*, 2025; Almeida-Naranjo-Diaz *et al.*, 2024)

Other functional groups aliphatic C-H with band 2928 cm^{-1} , Bands around 1530 cm^{-1} and $1508 - 1529\text{ cm}^{-1}$ reflects oxygen containing and aromatic skeletal vibrations characteristic of lignin. Similar aromatic bands around 1620 , 1509 and 1422 cm^{-1} have been reported for peanut shells (Petraglia, *et al.*, 2024) C-O/ether vibrations represent band $1044 - 1119\text{ cm}^{-1}$. This pattern agrees with recent groundnut shell FTIR studies which identifies hydroxyl, C-H, aromatic lignin and C-O containing bands as characteristic components of the shell (Mousa *et al.*, 2026; Almeida-Naranjo-Diaz *et al.*, 2024)

The lower wavenumber bands at $856 - 858$, 673 and 611 cm^{-1} occur in the aromatic region and are consistent with aromatic C-H ring deformation vibrations. Comparable low-wavenumber bands have been reported for lignocellulosic and peanut shell materials (Arizpe-Diaz *et al.*, 2025; Jadhav, *et al.*, 2022). These distinctive peaks provide strong evidence of lignin enrichment and preservation of characteristic functional groups after extraction process.

4. CONCLUSIONS

This study demonstrated the successful extraction of lignin from groundnut shell using an organosolv process integrated with response surface methodology (CCD-RSM). The optimized predicted conditions were 55 % ethanol concentration, $120\text{ }^{\circ}\text{C}$, and 45 min, having lignin recovery of 87.55 % and 5.17 LRI with a desirability value of 0.963. Experimental validation confirmed the reliability of the model, indicating strong agreement between predicted and observed responses.

The novelty of this work lies in the combined optimisation of organosolv extraction of groundnut shell lignin, considering the quality and quantity as a leading tool to determine the best extraction parameters. FTIR spectral changes relative to the raw groundnut shell confirmed the fractionation of the lignocellulosic matrix and recovery of a lignin-rich fraction.

Overall, the study establishes groundnut shell as a viable low-cost lignocellulosic feedstock for sustainable lignin-based material development and highlights its potential in eco-friendly adhesive formulations. Future work should focus on modification of the structural property and evaluating of the mechanical bonding performance adhesive system.

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